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Environmental and anthropogenic drivers of watercress (*Nasturtium officinale*) communities in char-lands and water channels across the Swat River Basin: implication for conservation planning

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Recent anthropogenic sources and excess usage have immensely threatened the communities and habitat ecology of this region's medicinally and economically significant crops. Therefore, our study aims to evaluate the community structure and related environmental characteristics sustaining *Nasturtium officinale* communities along the river basin (RB) in Northwest Pakistan, using the clustering procedure (Ward's method) and Redundancy analysis (RDA). From 340 phytosociological plots (34 × 10 = 340), we identified four ecologically distinct assemblages of *N. officinale* governed by different environmental and anthropogenic factors for the first time. The floristic structure shows the dominance of herbaceous (100%), native (77%), and annual (58.09%) species indicating relatively stable communities; however, the existence of the invasive plants (14%) is perturbing and may cause instability in the future, resulting in the replacement of herbaceous plant species. Likewise, we noticed apparent variations in the environmental factors, i.e., clay percentage ($p = 3.1 \times 10^{-5}$), silt and sand percentage ($p < 0.05$), organic matter ($p < 0.001$), phosphorus and potassium ($p < 0.05$), and heavy metals, i.e., Pb, Zn, and Cd ($p < 0.05$), indicating their dynamic role in maintaining the structure and composition of these ecologically distinct communities. RDA has also demonstrated the fundamental role of these factors in species–environment correlations and explained the geospatial variability and plants' ecological amplitudes in the Swat River wetland ecosystem. We concluded from this study that *N. officinale* communities are relatively stable due to their rapid colonization; however, most recent high anthropogenic interventions especially overharvesting and sand mining activities, apart from natural enemies, water deficit, mega-droughts, and recent flood intensification due to climate change scenario, are robust future threats to these communities. Our research highlights the dire need for the sustainable uses and conservation of these critical communities for aesthetics, as food for aquatic macrobiota and humans, enhancing water quality, breeding habitat, fodder crop, and its most promising medicinal properties in the region.

KEYWORDS

physical environment, vegetation structure, anthropogenic factors, charland, *Nasturtium officinale*

1 Introduction

Biodiversity regulates the ecosystem functioning and stability and is essential for human survival and economic wellbeing (Singh, 2002; Htun et al., 2011; Biplab et al., 2017; Baboo et al., 2017). The loss of biodiversity is a major challenge faced by humans in maintaining the stability and functional sustainability of ecosystems (Hua et al., 2022; Bisht et al., 2023). Wetland ecosystems are threatened by anthropogenic activities (Bisht et al., 2022). Among these, poverty, human population, agricultural expansion and intensification, and infrastructure development have been suggested as major threats to biodiversity in the tropics (Davidar et al., 2010; Bargali et al., 2019; Bargali et al., 2022; Bisht et al., 2023). Wetland ecosystem and its vegetation provide a wide range of ecosystem goods and services to the inhabitants (Gosain et al., 2015; Fartyal et al., 2022). Overexploitation of natural resources has created a big gap between the demand and supply of the natural goods (Manral et al., 2020; Pandey et al., 2023).

The biodiversity patterns along environmental gradients are one of the fundamental questions and are the synthetic reflection of all different types of ecological research (Khan S. et al., 2011; Raduła et al., 2020; Yu et al., 2021). The foundation of biodiversity research is based on the patterns of plant species diversity and the ecological variables affecting these patterns (Nogués-Bravo et al., 2008; Johnson et al., 2015; Li et al., 2018). Because of its importance in predicting future community composition and species performance, plant species diversity has received significant attention (Ullah et al., 2022; Khan et al., 2020; Wang et al., 2008; Subedi et al., 2020). The preservation of ecosystem biodiversity is significantly aided by habitat diversity, where topographical factors have multidimensional and multiscale effects on the pattern of species diversity (De Leo et al., 2014). These factors are interconnected and indicators of several abiotic parameters, including geographic, topographic and soil nutrient flow (Twilley and Rivera-Monroy, 2005).

The spatial scale will likely determine how an organism affects its surroundings, including ecosystem services (Ze-Hao and Xin-Shi, 2000; Kremen et al., 2007). In recent research using worldwide field survey data, organism–environment linkages may change with geography (Grace and Anderson, 2016). Abiotic factors at the regional scale determines the species distribution, as the effects of biotic factors (species types) on their environment are typically more localized (van de Koppel et al., 2012). However, direct and indirect interaction of these factors ultimately constitute organism–environment relationship (Grace and Anderson, 2016). The influence of biota may have been overstated in most studies due to the prevalence of statistical techniques (Alsterberg et al., 2013; Grace and Anderson, 2016).

The edaphic and geographical elements are also important for the variety of plant species and their distribution in aquatic emergent (char-land and water channels) plant communities (Schlaepfer et al., 2012). According to Chao et al. (2006), the soil's physicochemical characteristics and parent materials may impact the plants growing there and the species diversity. Various direct ecological factors at large scales, including soil texture, nutrient level, and soil hydraulic and metal concentration, influence the distribution and structure of plant communities and species biodiversity in emergent plant communities (Stella et al., 2013). However, the altitudinal gradient is the primary factor forming different mountain habitats and is one of the key elements determining the spatial patterns of species diversity in many regions (Bhattarai and Vetaas, 2003; Wang et al., 2003; Zhao et al., 2005; Jiang et al., 2007; Bhattarai et al., 2014; Subedi et al., 2020).

According to Mitsch and Gosselink (1993), the main factor affecting the distribution of plant species at the land–water interface in wetlands is the water regime. In addition, wetland vegetation's spatial heterogeneity is influenced by several variables, such as soil composition, microclimate, and topography since it controls the water regime (Naiman et al., 2005; Rybicki and Landwehr, 2007; Watt et al., 2007). The ranges of aquatic plants have been estimated using a variety of methods (Mcfarland and Shafer, 2011; Santos et al., 2011; Orellana et al., 2012; Singh et al., 2020). Field observations and large-scale analyses may now be combined with advances in spatial technology like aerial photography and other remote sensing techniques (Vis et al., 2003) and potent geo-statistical tools like plant cover/density estimators (Pepe et al., 2018). However, owing to the biophysical limitations in the environment, it is important to accurately assess aquatic plant species' spatial distribution and plant community composition and comprehend their interactions.

The recent anthropogenic activities and rapid urbanization have deliberately changed the natural wetland communities in many areas of the world, particularly in developing countries like Pakistan. These activities threatened the communities' lies at the junction of terrestrial and aquatic ecosystems or on wetlands. For example, recently, Ali et al. (2022) reported different mining operations along the riparian vegetation that adversely affect the community composition and structure. Therefore, this study evaluated *Nasturtium officinale* (R. Br. In Aiton) communities' floristic composition and structure along the River Swat using quantitative ecological parameters. The study aims to assess plant communities dominated by *N. officinale* and associated species, and to provide scientific basis on the following questions: (i) How do these natural bog-plant communities and species diversity at char-land and channels along the Swat River Basin (SRB) respond to ecological factors? (ii) How do different degrees of anthropogenic factors act in the instability perspective of *N. officinale* at the community-level? By analyzing the ecological data of community composition and structure, we anticipated specifying a valid scientific basis for species assemblage's distribution and characterization besides its protection and management in the region.

2 Materials and methods

2.1 Study area

The bogs of River Swat were selected for sampling because of rich *Nasturtium officinale* communities, from where the residents and local sellers often collect vegetables for edible purposes. The study area is located at 35.22271134 North and 72.42581572 East, in the northern region of Khyber Pakhtunkhwa, Pakistan, spreading over 14,737 square kilometres area covered by hilly glaciers having snowfall and rain (Figure 1) (Farooq et al., 2018). River Swat flows through the districts of Swat, Malakand, and Dir Lower (Ahmad et al., 2015), having subtropical and temperate climates (Barinova et al., 2013). The average higher temperature in the summer may reach 41.9°C, while the average low in the winter can reach 0.8°C. The Pakistan Meteorological Department reported an annual average rainfall of 1,003 mm; the highest rainfall was recorded in February and March (162 mm). According to Nafees et al. (2008), relative humidity may drop as low as 40% in April and rise as high as 85% in July.

Ali et al. (2018) report that the average monthly temperature in the study area is between 34.96°C and 1.36°C, and the average annual rainfall is between 384 to 639 mm (Figure 2). These factors maintain the local climate to comprehend the structure and composition of the vegetation that ultimately affects economic, social, and agricultural activities and hydrological characteristics (Deo and Şahin, 2015).

2.2 Field sampling protocols

In our field research, we randomly selected *N. officiale*-dominated stands at 34 distinct locations throughout five districts as part of routine trips to gather vegetation data (Figure 1). The entire area was represented by taking 340 phytosociological plots (34 × 10 = 340 plots) and carefully selected according to the structural and floristic homogeneity. The variations in plot size were considered following Morsdorf et al. (2010), where the plot sizes of 3–5 m^2 were taken as standard for herb and shrub communities. The standard procedure for computing plant species densities, frequencies, covers, relative densities, relative frequencies, relative covers, and important values in each plot and sites was adopted following Curtis and Mcintosh (1950). To reduce edge effects, a 10-m buffer zone was removed from the stand's

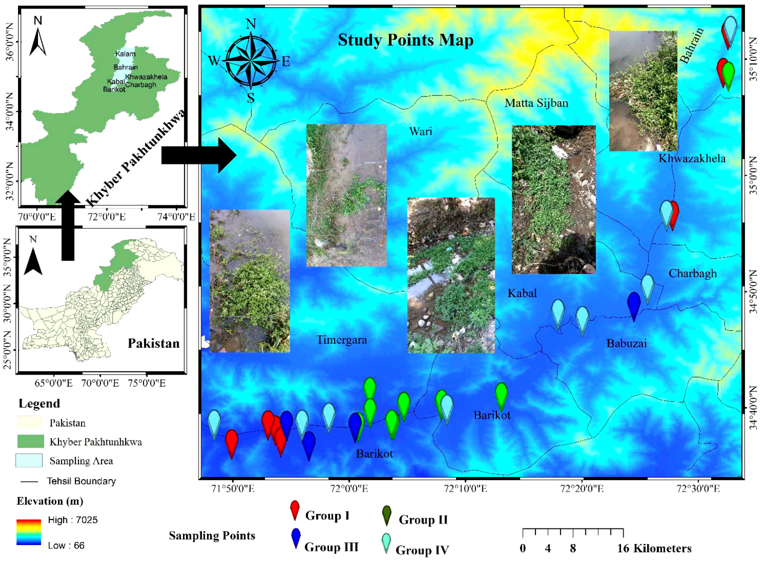

FIGURE 1
Map showing sampling points of the research area.

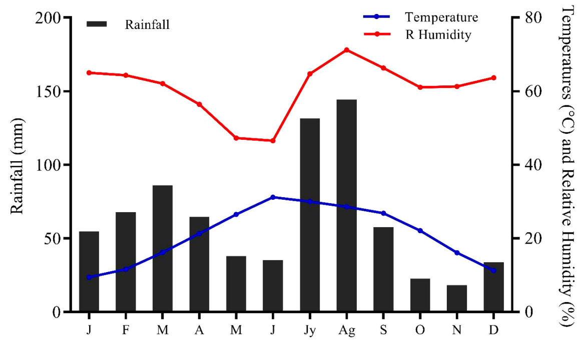

FIGURE 2
Important climate variables of the sampling sites. J, January; F, February; M, March; A, April; M, May; J, June; Jy, July; Ag, August; S, September; O, October; N, November; D, December.

boundaries following Martínez-Falcón et al. (2018). Nomenclature for plant taxa was taken from Flora of Pakistan (Ali, 2008), and binomials were given accordingly.

2.3 Soil data acquisition and analysis

In each stand, a soil sample of 3 kg was collected randomly from each stand's middle and two opposing corners to characterize soil parameters. Since topsoil is often the most nutrient-rich part of the soil, soil samples were collected at a depth of 0–30 cm bulked and fully mixed (Bargali et al., 2018) to reduce heterogeneity (Morsdorf et al., 2010; Kamrani et al., 2011). The electrical conductivity and pH of a soil–water suspension (1:5) were measured in the field using a digital pH meter and an EC meter, respectively. The soil samples were allowed to air dry at room temperature and then passed through a sieve set at 2 mm. The samples were homogenized and packed in transparent polythene bags for subsequent processing (Chawla et al., 2008).

The soil's physiochemical composition and textural parameters were determined by air-drying the samples and passing them through a 2-mm sieve per USDA recommendations (Taubner et al., 2009). Organic matter was assessed using the Walkley-Black method, while total and organic carbon was computed utilizing moist burning with chromic acid digestion after dry combustion (Nelson and Sommers, 1996). Total nitrogen was determined using the micro-Kjeldahl method, and soluble phosphorus (P^{2+}) and exchangeable potassium (K^{+}) were determined using the methods described by Yadav et al. (2002). Lime (calcium carbonate; %) was calculated geometrically, and CO_2 evolution was tracked geometrically, following Gómez-Díaz et al. (2006). Following the methodology established by Saxton et al. (1986), we used an online calculator (https://www.nrcs.usda.gov) to determine the soil's field capacity (FC), available water (AW), bulk density (BD), and wilting and saturation point (WSP). The distribution of soil textural characteristics, i.e., sand, silt, and clay percentage, was assessed using the hydrometer approach (Gangwar and Baskar, 2019).

2.4 Anthropogenic variables assessment and quantification of diversity indices

Semi-structured interviews were conducted with 200 respondents to identify the anthropogenic factors threatening the diversity of *N. officinale* communities. The respondents were selected based on their connection with the collection and sale of plant species. Following Kefalew et al. (2015), the respondents were categorized into two groups; i.e., category "A" includes 100 respondents selected randomly, and category B has 100 respondents that were chosen purposefully having past and present knowledge of the site where the plant species grows naturally. These respondents identified factors, i.e., mining factor, agricultural field disturbance (cultivation factors), grazing intensity, and over-harvesting that disturbed these communities severely. Of the respondents, 12 respondents, i.e., 5 from Category A and 7 from Category B, were excluded from the analysis as they do not respond to the questionnaire.

A six-point scale (0–5) was used to evaluate whether these anthropogenic factors are affected quantitatively. A plot was considered undisturbed if it obtained a score of 0, while a score of 5 was considered severely disturbed (Mligo, 2011). Accordingly, 0 denotes no disturbance, 1 represents a disruption of 0%–20% of the plot, 2 denotes a disruption of 21%–40% of the plot, 3 denotes a disruption of 41%–60% of the plot, 4 denotes a disruption of 61%–80% of the plot, and 5 denotes a disruption of 81–100% of the plot. Each type of disturbance was assessed separately in this semi-quantitative evaluation. The degrees of disturbance were evaluated based on the percentage of the given parameter persisting in a disturbing plot of 10 × 10 m. The point scale values were assessed according to Barry (2006) and Lewis et al. (2017) to describe various forms of anthropogenic disturbance.

In addition, the species richness and diversity indices, i.e., Shannon index *H'* and Evenness index *E*, were used to describe group diversity (Maan et al., 2021).

$$H' = \sum_{(i=1)}^{S} \left[pi\ Inpi \right] \qquad (1)$$

$$E = H'/InS \qquad (2)$$

where Σ = summation, S = species richness, pi = proportion of the species (i) to total number of species, In = natural logarithm.

2.5 Community data analysis and ordination

The species' phytosociological data and relevant environmental parameters for the 34 stands were collected and compiled for statistical analysis. An important value index (IVI) based on comparative phytosociological features was calculated following Khan et al. (2013). Ward's agglomerative technique (McCune, 1997) was used to evaluate the classification of vegetative communities by choosing Euclidean distance. Each species in the stand was then assigned a phytosociological group based on the numbers assigned to them. We examined recent studies to see whether a particular species might be taken as illustrative of a stand or group (Biondi et al., 2015; Rahman et al., 2022). The converted relative phytosociological values were used for numerical classification to determine the diagnostic species of a particular group. The Redundancy analysis (RDA) was used to determine the relationship between species IVI and environmental variables (20 soil and 4 topographic) of the *N. officinale*-dominated vegetation. The statistical *post-hoc* interpretation of the RDA ordination axes was analyzed using the Monte Carlo permutation test. The ordination bi-plot displayed the essential variables as vectors that determined the community structure and composition. Microsoft Excel 2010 and PC-ORD version 6.0 were used to conduct the statistical analysis of the quantitative vegetation and environmental data (Barua et al., 2020).

3 Results

3.1 Floristic characteristics

The floristics of vegetation consists of 22 species dominated by *N. officinale*, where all the species were either emergent or floating aquatic habitats indicating a wetland community. The species belongs to 16 families; Poaceae and Asteraceae were represented by three species each, followed by Polygonaceae and Fabaceae (two species each). The remaining 12 families were monospecific (Figure 3), where herbaceous plants were evident (100%) in the floristic composition, with 13 species having annual life cycles, 8 perennials, and 1 having both (Table A1). Similarly, based on status, 17 species were classified as native to Pakistan, 3 as invasive, and 1 each for cosmopolitan and naturalized. In addition, based on aquatic habitat, 18 species were emergent, and 4 were emergent/floating (Figure 3).

3.2 Vegetation classification and structural attributes

The two-way cluster dendrogram indicates four vegetation groups showing stands on one side and species distributed in these groups on the other (Figure 4). Similarly, the red dots indicated the intensity of the species' IVI, i.e., its increase or decrease in the studied stands. Based on the number of stands, Group II was the largest, including 13 stands in the middle of the dendrogram. Group III was the smallest, having five stands of *N.*

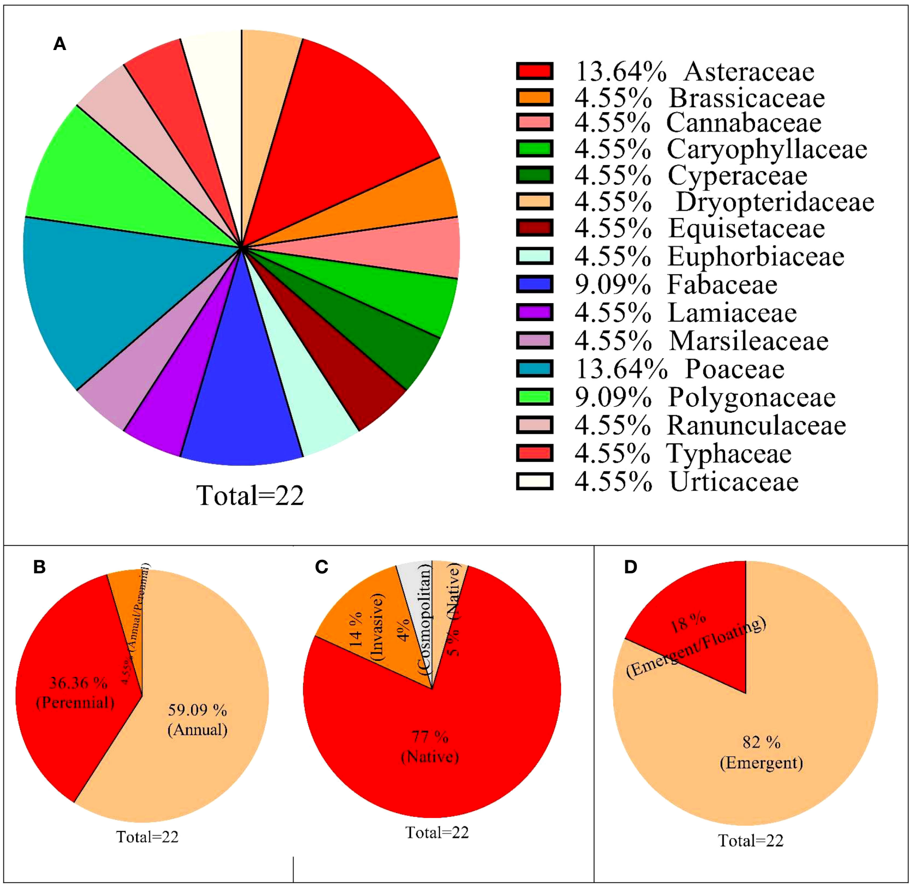

FIGURE 3
Floristic structure of *Nasturtium officinale* and associated species found in communities. **(A)** (family base distribution); **(B)** (life cycle), **(C)** (taxon), **(D)** (status in Pakistan), and **(E)** (aquatic habitat).

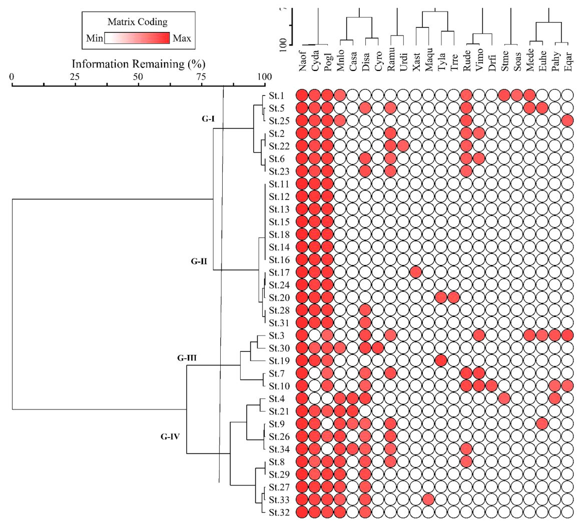

FIGURE 4
Two-way cluster dendrogram of *Nasturtium officinale* communities along the Swat River catchments. Plant species acronyms are the same as that in Table 1.

officinale-dominated vegetation. Group I has seven stands with 14 species and is considered the third largest community of vegetation dominated by *N. officinale* (42.9 ± 1.0), followed by *Polygonum glabrum* (19.4 ± 0.5) and *Cynodon dactylon* (13.4 ± 0.5). In comparison, the remaining 11 species of this group have a mean IVI of less than 10 as presented in Table 1. Group II has 13 stands with seven species and was considered the largest group with low species richness. The dominant species of the group was *N. officinale* (53.4 ± 0.4), having co-dominance of *Cynodon dactylon* (31.8 ± 2.5).

Group III consists of five stands with 16 species dominated by *N. officinale* (42.5 ± 1.4) while the co-dominant species was *Digitaria sanguinalis* (11.8 ± 2.7). The important associated species of the group include *Vicia monantha* (7.8 ± 3.65), *Rumex dentatus* (6.4 ± 3.9), and *Polygonum glabrum* (5.4 ± 1.7). Similarly, Group IV consisted of 9 stands with 10 species and was considered the second largest community dominated by *N officinale* (45.0 ± 0.5), with *Mentha longfolia* (16.9 ± 0.9) being the co-dominant species. The other important species of the group are *Ranunculus muricatus* (10.3 ± 2.5) and *Cynodon dactylon* (6.26 ± 1.1).

Density/hectare and cover/hectare of *N. officinale*, and associated species (Table A2), revealed that, in Group I, the density of *N. officinale* is 46,243 ± 4,119 individuals/hectare. At the same time, the co-dominant species was *C. dactylon* (18,730 ± 2,316). In Group II, *N. officinale* has a density/ha of 57,094 ± 2,469 followed by *C. dactylon* (13,162 ± 1,939). Similarly, Group III is the largest community by the number of species, including *N. officinale*, with a density/hectare of 47,555 ± 7,702. However, the co-dominant species was *D. sanguinalis* (10,222 ± 3,723) while Group IV included 10 species having *C. dactylon* (11,851 ± 2,051) as the co-dominant species. Similarly, the same patterns have been followed by cover/hectare of *N. officinale* and the remaining co-dominant species.

3.3 Analysis of environmental and anthropogenic variables

The results of associated soil variables showed a sandy or silty loamy soil having significant variation in sand and clay particles ($p< 0.05$). In contrast, Groups II and IV have high contents of silt and sand (Table 2). The soil pH was basic, showing non-significant variation, while the electrical conductivity of Group III was higher (0.3 ± 0.05) than others. Similarly, total dissolved solids were high in Groups III and II, i.e., 0.09 ± 0.005 and 0.09 ± 0.01, respectively, complementing the electrical conductivity results. The soil nutrients, Group IV, had higher contents of organic matter (0.97 ± 0.02), and varied significantly ($p< 0.05$) within the vegetation groups, while the nitrogen content of all the community groups was

TABLE 1 Importance values index (IVI) of different plant species associated with *Nasturtium officinale* in different vegetation groups along the Swat River catchments.

Species Binomial	Acronyms	Group I	Group II	Group III	Group IV
		M ± SE	M ± SE	M ± SE	M ± SE
Nasturtium officinale W.T. Aiton	Naof	42.9 ± 1.0	53.4 ± 0.4	42.5 ± 1.4	45.0 ± 0.5
Cannabis sativa L.	Casa	*-	*-	3.4 ± 3.4	3.6 ± 2.1
Cynodon dactylon (L.) Pers	Cyda	13.4 ± 0.5	31.8 ± 2.5	1.1 ± 1.1	6.26 ± 1.1
Cyperus rotundus L.	Cyro	*-	*-	3.4 ± 3.4	*-
Digitaria sanguinalis (L.) scop.	Disa	3.4 ± 1.7	1.03 ± 0.7	11.8 ± 2.7	5.7 ± 0.9
Dryopteris filix-mas (L.) Schott	Drfi	*-	*-	1.5 ± 1.5	*-
Equisetum arvense L.	Eqar	0.80 ± 0.8	*-	3.6 ± 2.7	*-
Euphorbia helioscopia L.	Euhe	0.99 ± 0.9	*-	0.90 ± 0.9	0.5 ± 0.5
Marsilea quadrifolia L.	Maqu	*-	*-	*-	0.52 ± 0.5

(Continued)

TABLE 1 Continued

Species Binomial	Acronyms	Group I	Group II	Group III	Group IV
		M ± SE	M ± SE	M ± SE	M ± SE
Medicago denticulata Willd.	Mede	2.0 ± 1.3	*-	1.5 ± 1.5	*-
Mentha longfolia (L.) Huds.	Melo	1.2 ± 0.81	*-	2.9 ± 1.9	16.9 ± 0.9
Parthenium hysterophorus L.	Pahy	*-	*-	3.2 ± 1.4	*-
Polygonum glabrum Willd.	Poba	19.4 ± 0.5	14.6 ± 1.3	5.4 ± 1.7	3.2 ± 1.4
Ranunculus muricatus L.,	Ramu	4.8 ± 1.5	*-	2.7 ± 1.9	10.3 ± 2.5
Rumex dentatus L.	Rude	6.2 ± 0.7	*-	6.4 ± 3.9	1.03 ± 0.6
Sonchus asper (L.) Hill	Soas	0.62 ± 0.6	*-	*-	*-
Stellaria media (L.) Vill.	Stme	1.2 ± 1.2	*-	0.95 ± 0.9	*-
Trifolium repens L.	Trre	*-	0.51 ± 0.51	*-	*-
Typha latifolia L.,	Tyla	*-	2.13 ± 1.65	*-	*-
Urtica dioica L.	Utdi	0.67 ± 0.6	*-	*-	*-
Vicia monantha Retz.	Vimo	1.3 ± 0.8	*-	7.8 ± 3.6	*-
Xanthium strumarium L.	Xast	*-	0.51 ± 0.51	*-	*-
Σ		14	7	16	10

Σ, summation; M, mean; SE, standard error; *species absence in group.

TABLE 2 Soil characteristics of different *N. officinale* dominated vegetation in the Swat River tributaries.

Factors	Groups				ANOVA	
	I	II	III	IV		
	M ± SE	M ± SE	M ± SE	M ± SE	*F*-value	*p*-value
Alt	915.28 ± 139	763.5 ± 50	629 ± 19.7	919 ± 83.4	2.178	0.11
Lat.	34.82 ± 0.099	34.7 ± 0.06	34.5 ± 0.1	34.8 ± 0.05	1.749	0.17
Long	72.15 ± 0.12	72.1 ± 0.04	71.9 ± 0.1	72.2 ± 0.07	1.589	0.21
AD	111.2 ± 32.1 ^{d}	239.6 ± 10 ^{a}	167.4 ± 41 ^{bc}	192.6 ± 27 ^{ab}	5.279	0.004
Clay	7.14 ± 0.5	14.6 ± 0.8	10 ± 2.28	8.22 ± 0.5	11.66	3.1×10^{-5}
Silt	39.14 ± 1.8	50.07 ± 1.6	42 ± 3.94	51.5 ± 4.0	4.229	0.013
Sand	39.14 ± 3.6	43.2 ± 2.5	30.4 ± 2.7	50.6 ± 2.8	6.122	0.002
pH	7.9 ± 0.037	7.9 ± 0.04	7.72 ± 0.09	7.9 ± 0.04	3.919	0.017
EC	0.26 ± 0.02	0.25 ± 0.02	0.3 ± 0.05	0.26 ± 0.02	0.472	0.703
TDS	0.06 ± 0.003	0.09 ± 0.005	0.09 ± 0.01	0.08 ± 0.007	3.008	0.045
CC	6.71 ± 0.03	6.75 ± 0.0	6.75 ± 0.0	6.75 ± 0.00	1.323	0.285
OM	0.92 ± 0.02	0.93 ± 0.02	0.926 ± 0.07	0.97 ± 0.02	7.747	0.0005
N	0.046 ± 0.001	0.04 ± 0.002	0.04 ± 0.004	0.04 ± 0.003	0.252	0.858
P	22.941 ± 2	35.0 ± 3.21	28.03 ± 4.0	34.9 ± 3.15	4.440	0.010
K	74 ± 4.6	118.3 ± 17	126.8 ± 21	124.1 ± 16	2.945	0.048
WP	0.096 ± 0.005	0.09 ± 0.003	0.09 ± 0.008	0.08 ± 0.001	1.487	0.237
FC	0.25 ± 0.008	0.24 ± 0.005	0.25 ± 0.01	0.23 ± 0.006	0.951	0.428

(Continued)

TABLE 2 Continued

Factors	Groups				ANOVA	
	I	II	III	IV		
	M ± SE	M ± SE	M ± SE	M ± SE	*F*-value	*p*-value
BD	1.50 ± 0.03	1.49 ± 0.01	1.53 ± 0.06	1.55 ± 0.01	0.978	0.415
SP	0.43 ± 0.01	0.43 ± 0.006	0.42 ± 0.02	0.41 ± 0.004	0.988	0.411
AW	0.15 ± 0.005	0.14 ± 0.004	0.15 ± 0.01	0.14 ± 0.005	1.202	0.325
Cd	1.71 ± 0.32	3.22 ± 0.52	1.88 ± 0.5	3.7 ± 0.5	3.10	0.04
Pb	36.92 ± 6.3	70.88 ± 6.7	39.18 ± 7.5	68.35 ± 11	4.15	0.01
Cu	1.52 ± 0.17	5.04 ± 1.14	2.16 ± 0.12	3.16 ± 0.2	3.19	0.04
Zn	8.02 ± 0.86	6.59 ± 1.07	6.94 ± 0.89	6.56 ± 0.6	0.43	0.74

Alt, altitude; Lat, latitude; AD, aspect degree; pH, power of hydrogen; EC, electrical conductivity; M, Mean; SE, Standard error; ANOVA, Analysis of variance. Note: Different superscript indicate significant difference at P < 0.05. TDS, total dissolved salts; CC, calcium carbonate; OM, organic matter; N, nitrogen; P, phosphorus; K, potassium; WP, wilting point; FC, field capacity; SP, saturation point; BD, bulk density; AW, available water; Cd, cadmium; Pb, lead; Cu, copper; Zn, zinc.

the same, i.e., 0.04 ± 0.002. In addition, the essential nutrients, i.e., phosphorus and potassium contents (mg kg^{-1}) of Group II (35.0 ± 3.21) and Group III (126 ± 21), were higher, respectively, compared to the other groups. Moreover, the heavy metals, i.e., cadmium, lead, and copper, showed significant variation among the communities ($p < 0.05$), revealing their prominent role in maintaining communities' structure and composition.

The anthropogenic factors identified by respondents during the semi-structure interview showed non-significant χ^2 results between the Category "A" and Category "B" population, revealing that both the categories of factors affect the vegetation of *N. officinale*-dominated communities (Table 3). In addition, the lower cumulative variance percentage indicated that these anthropogenic factors equally contributed in disturbing vegetation groups. The quantitative anthropogenic factors (Table 4) vary across the communities coupled with IVI gradients; i.e., mining factor, cultivated fields percentage, and grazing intensity were higher in Group II and progressively decrease towards Group I via Groups III and IV (F = 3.56 and 7.61, respectively at $p < 0.05$). However, the reverse was true for over-harvesting and varied significantly, having F = 9.21 ($p < 0.001$). The diversity indices show increasing trends with increase in elevation. Similarly, the diversity indices were in reverse trends with *N. officinale* IVI; i.e., Group II has low species richness (3.33 ± 0.49) and higher IVI, while Group III with high species richness has low IVI. The Shannon–Wiener diversity index ranges from 0.97 ± 0.20 to 1.16 ± 0.24 and varies significantly ($p < 0.05$). Similarly, the species evenness index ranges from 0.62 ± 0.07 to 0.69 ± 0.05, showing significant variation ($p > 0.05$), indicating that the anthropogenic factors disturbed the group's diversity.

3.4 Response of communities' composition to environmental and anthropogenic factors

In the RDA ordination (Table 5), the species–environment association was higher on the first two axes, contributing 44.8% of the overall variation (50.6%). Each of the 24 soil variables separately contributed to the overall ordination since none of the inflation factors had a score higher than 20.0. The Inter-set correlations, soil variables, like organic matter, clay, and pH, showed a significant positive correlation with the first axis (r = 0.51, 0.56, and 0.49, respectively). Similarly, silt, sand, and organic matter were significantly positively correlated on axis 2 (r = 0.32, 0.31, and 0.31 respectively). In contrast, sand percentage had a negative correlation (r = −0.25) on axis 3. Similarly, in anthropogenic variables, mining factor, cultivation factor, and grazing intensity showed positive correlation on axis 1 (r = 0.46, 0.57, and 0.67 respectively), while overexploitation showed negative correlation on axis 1 (r = −0.61). An unconstrained Monte Carlo permutation test (499 permutations) revealed that the F-ratio for the eigenvalue of axis 1 was significant (p = 0.05). The RDA

TABLE 3 Anthropogenic disturbance semi-structure interview qualitative factor citation identified by respondents.

Factor	MF	CF	GI	OH	CV %
Category A	47 (49.4%)	33 (34.7%)	45 (47.3%)	70 (73.6%)	21.14
Category B	75 (81.5%)	30 (31.5%)	72 (78.25)	85 (92.35%)	10.65
χ^2-value	3.35	P-value	0.33	Non-significant	

Category A, random selected respondents; Category B, non-random selected respondents; MF, mining factor; CF, cultivation factor; GI, grazing intensity; OH, over-harvesting; CV, cumulative variance percentage.

TABLE 4 Anthropogenic factors affecting *Nasturtium officinale* communities.

Group	I	II	III	IV	*F*-value	*p*-value
Factor	M ± SE	M ± SE	M ± SE	M ± SE		
MF	15.72 ± 5.3^{d}	42.08 ± 15.73^{ab}	34 ± 24^{bc}	40 ± 22^{a}	3.56	0.02
CF	12.71 ± 20.70^{b}	43.33 ± 17.62^{a}	17 ± 8.36^{c}	16 ± 3.94^{c}	7.61	0.0006
GI	21.43 ± 6.26^{d}	68.75 ± 12.63^{a}	42 ± 25.8^{c}	54.5 ± 19.5^{b}	12.88	0.000014
OH	59.29 ± 14.26^{a}	25.42 ± 9.15^{d}	44 ± 21.9^{b}	31.5 ± 15^{c}	9.21	0.00019
S	6.71 ± 0.95^{ab}	3.33 ± 0.49^{d}	7 ± 2^{a}	5.9 ± 0.87^{bc}	25.3	0.0000021
H	1.04 ± 0.35^{a}	1.16 ± 0.24^{a}	1 ± 0.40^{a}	0.97 ± 0.20^{ab}	0.95	0.03
J	0.69 ± 0.05^{a}	0.65 ± 0.13^{bc}	0.67 ± 0.08^{ab}	0.62 ± 0.07^{cd}	3.89	0.03

MF, mining factor; CF, cultivation factor; GI, grazing intensity; OH, over-harvesting; S, species richness; H', Shannon–Wiener diversity index; J, evenness index; different superscripts represent significant differences of the mean values.

ordination bi-plot demonstrated the correlation between the stands occupied on the right side and several soil characteristics, including organic matter, clay, sand, clay, phosphorus, pH, and aspect degree (Figure 5). On the other hand, electrical conductivity and calcium carbonate were associated with the remaining plant groups that filled the bi-plot's left side. These factors also show higher biplot scores (Table A3).

4 Discussion

The floristic composition shows a narrow spectrum of vegetation in the aquatic plant communities of *N. officinale* across the River Swat having 22 species, which are dominated by native species (77%) and non-native species (invasive, naturalized, and cultivated). Similarly, the range of life forms comprises annual herbaceous plants representative of 16 plant families. These spectrums show the physiognomy of the flora and vegetation, which is the result of all living activities combined with the environment, making it vital to comprehend the ecological foundation of vegetation of *N. officinale* (Amjad et al., 2016). The dominance of annual plant species in communities can bring community homogeneity that favors the invasion of foreign species (Milchunas et al., 1988; Tappeiner et al., 1991; Qian and Guo, 2010). The vegetative reproductive potential of *N. officinale* may also contribute to community homogenization, resulting in the formation of less diverse vegetation. Similarly, smaller herb species like *Xanthium strumarium, Mentha longifolia, Cynodon dactylon*, and *Cannabis sativa* may be advantageous over native species since they can more easily spread across the communities (Timsina et al., 2011). The future vegetation diversity will be at risk, due to this relocation, which ultimately brings communities' disturbance. These results were contrary to what has been observed in other aquatic ecosystems; non-native species comprise a significant and substantially greater component of submerged aquatic plant communities (Santos et al., 2011; Du Toit et al., 2021), while in this case, *N. officinale*, a native invasive species, dominated the communities.

The cluster analysis segregated four unique vegetation groups, each dominated by *N. officinale* and have different co-dominant species. *Polygonum glabrum* was the co-dominant species in Group I, *Cynodon dactylon* in Group II, *Digitaria sanguinalis* in Group III, and *Mentha longfolia* in Group IV. Similarly, a study was conducted on the phytosociology of *Sedum brevifolium* and found six plant groups (Nabi et al., 2012), while Ali et al. (2022) reported two plant communities across the wetlands of Panjkora River in district Dir Lower. At the sample sites, *N. officinale* was often found with several associated species, including *Polygonum glabrum*, *Cynodon dactylon*, and *Digitaria sanguinalis*. The same environmental factors and nutritional requirements might cause their communities' association, as reported by Khan (2012); Khan et al. (2014); Muhammad et al. (2016); Nasrullah et al. (2015), and Shah and Hussain (2009).

The soil characteristics revealed that the calcareous nature accounted for roughly 99% of the growth of *N. officinale*. The

TABLE 5 Axis summary statistics (number of canonical axes: 3 of a possible 22; total variance in the species data: 43.8).

Axis	Axis 1	Axis 2	Axis 3
Eigenvalue	4.892	2.395	2.358
Variance in species data			
% of variance explained	22.2	10.9	10.7
Cumulative % explained	22.2	33.1	43.8
Pearson Corr., Response-Pred.*	0.999	0.987	0.992
Kendall Corr., Response-Pred.	0.936	0.817	0.799

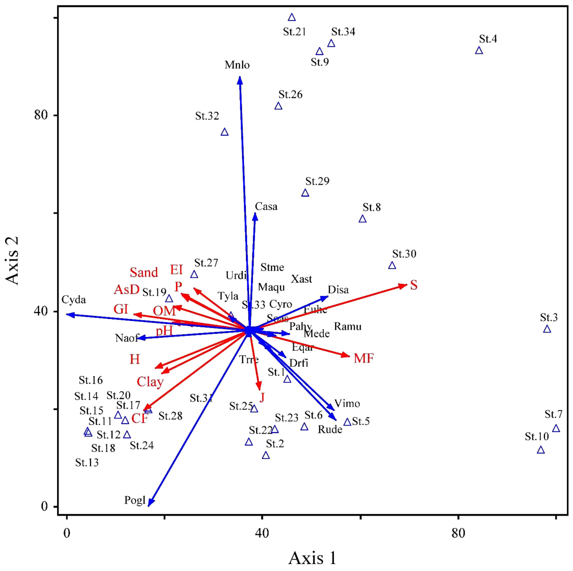

FIGURE 5
Projection of 22 species distributed in 34 stands with corresponding environmental variables on the 2D-RDA axis along the Swat River catchments and small tributaries. Importance values of species and 24 environmental variables were used in the analysis (for details, see Tables 2, 5, Table A1). Plant species, and environmental and anthropogenic factors' acronyms are the same as that in Tables 1–4.

calcareous soils with high potassium, nitrogen, and low phosphorus concentrations range from sandy loam to loamy silty texture, resulting in gregarious communities, as that reported in the region by Ullah et al. (2021) and Ullah et al. (2022). The smaller communities having high density and cover in terms of species composition may be attributed to two factors, i.e., the communities are new to the region and the potential of *N. officinale* to regenerate (Ali et al., 2022). Our results were contrasted to that reported by Khan et al. (2020), who reported that seedlings and juvenile plants grow quicker than mature plants, resulting in a decreased density. However, these results complied with Hitimana et al. (2004), where the high density is linked to the plant species' capacity for regeneration. The community structure and composition may change due to man-made activities, intra- and inter-specific competition, and the pattern of regeneration (Faridah-Hanum et al., 2012). These soils also allow water and air to move through them, letting roots penetrate more readily, providing nutrients and clay aggregation stability (Zimmermann, 1991). Certain invasive generalist species, such as *C. sativa*, *X. strumarium, and C. dactylon*, pioneer species of disturbed vegetation, were dominant in the communities (Iqbal et al., 2021). *N. officinale* probably establishes itself as the dominant species in wetlands in Khyber Pakhtunkhwa due to these environmental factors that favor their propagation and growth. In addition, the vegetation decomposition and microbial activities in the root zone may further add soil nutrients that add to the fertility of soil and resulting in the establishment and propagation of a particular community in an area (Bargali et al., 2018).

As expected, the anthropogenic variables substantially disrupted the communities' structure, favoring non-native species invasion (Geiger and McPherson, 2005; Bhattarai et al., 2014). The study assessed mining factor, grazing pressure, cultivated fields, and over-harvesting to determine how these factors relate to the disturbance of *N. officinale* communities. However, these factors vary significantly along IVI gradients, showing that they are linked to invasive species and community disturbance. The sites of Group II had greater grazing intensity, agricultural activities or areas occupied by cultivated fields, and mining factors, making the populations more susceptible to invasion, as reported by Chhogyel et al. (2021) and Pretto et al. (2010). This could be due to the easy transportation of the alien species propagules in such areas. According to McDougall et al. (2005) and Sjödin et al. (2008), grazing pressure and mining factor disturbed communities by generating unoccupied niches for alien propagules, enabling the plant to invade the vacant habitats. Similarly, sand extraction from aquatic environments, like rivers and coasts, provides an ecosystem service (Grizzetti et al., 2019). Sand is primarily used in construction because concrete contains 75% sand (Jnr et al., 2018). All this equates to approximately 200 tons of sand for a home, 30,000 tons for every kilometer of roadway, and an astounding 12 million tons of sand for a nuclear power station (Ludacer, 2018; Rentier, and Cammeraat, 2022). This tremendous sand demand has made mining a global environmental concern that disturbed community structure (Asabonga et al., 2017). This mining operation caused habitat fragmentation that continuously disturbed these communities in the river bed and char-land areas.

RDA of vegetation–soil interactions revealed that organic matter, silt, sand, clay, phosphorus, potassium, pH, latitude, longitude, aspect degree, wilting point, field capacity, and available water were the key factors controlling the distribution of vegetation in the region. The role of organic carbon in soil fertility is well known and reported by many authors like Kononova (2013) and Rao et al. (2017). Similarly, increase in soil organic matter content results from the breakdown of plant residues, lower salt toxicity from dissolved potassium and calcium brought by rainwater (Taiz and Zeiger, 2002), and increasing vegetation diversity (Lyons et al., 2005). Moreover, many studies like Ali et al. (2022); Ullah et al. (2022), and Ullah et al. (2021) in the same region reported the significance of soil organic matter, nitrogen, and soil texture in sustaining plant communities. Similar research on the influence of surface sediment percentages of various size classes on the geographical distribution of soil moisture was reported by Dasti and Agnew (1994). In addition, many other factors, such as precipitation, rain, and flood, increase the percentages of silt and clay in the soil texture that play an important role in shaping plant communities (Duniway et al., 2010). The most significant factors closely related to the dispersion of vegetation communities are nutritional status, electrical conductivity, soil texture, slope, and aspect (Tavili and Jafari, 2009). Our results were also in agreement with those of Zare et al. (2011), who reported that the distribution of plants is influenced by slope, aspect elevation, soil texture, lime content, soil moisture, available nitrogen, potassium, and organic matter, and Bargali et al. (2018), revealing the importance of soil organic matter and nitrogen in maintaining plant communities.

5 Conclusions

The study concluded that topography and spatial variability influenced the *N. officinale* vegetation's distribution in the area. In addition, the anthropogenic factors qualitative and quantitative intensity have the most prominent role in disturbing the communities. In addition, it has been shown that the spread of *N. officinale* vegetation is more strongly correlated with physical environmental factors and substrate characteristics that affect water availability. The disturbance in communities can be minimized by land use to change the water conditions in wetlands directly or indirectly by draining them to make the surface drier and by introducing plant species like *N. officinale* that are tolerant to flooding and produce more crops and feed. In addition, non-wetland species swiftly builds up peaty soils in the wetlands, elevating the surface above the water building diverse communities. However, the presence of non-native species may subject the communities to unexpected changes in vegetation; therefore, proper management of non-native invasive species should be considered for future perspective.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

NK and RU conceptualized this research, conducted the field and laboratory experiments, and compiled and analyzed the data; NK and RU wrote the original draft of the manuscript; MO and MA-M supervised the experiments; IS, H-AH, and TA contributed to data analysis; and HA helped in the review and edited the initial draft of the manuscript; all authors read and approved the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpls.2023.1225030/full#supplementary-material.

References

Ahmad, L., Semotiuk, A., Zafar, M., Ahmad, M., Sultana, S., Liu, Q.-R., et al. (2015). Ethnopharmacological documentation of medicinal plants used for hypertension among the local communities of DIR Lower, Pakistan. *J. Ethnopharmacol.* 175, 138–146. doi: 10.1016/j.jep.2015.09.014

Ali, S. (2008). Significance of flora with special reference to Pakistan. *Pak. J. Bot.* 40 (3), 967–971.

Ali, A., Khan, T. A., and Ahmad, S. (2018). Analysis of climate data of Khyber Pakhtunkhwa, Pakistan. *Int. Res. J. Eng. Technol.* 5 (5), 4266–4282.

Ali, K., Khan, N., Ullah, R., Shah, M., Khan, M. E. H., Jones, D. A., et al. (2022). Spatial Pattern and Key Environmental Determinants of Vegetation in Sand Mining and Non-Mining Sites along the Panjkora River Basin. *Land* 11 (10), 1801. doi: 10.3390/land11101801

Alsterberg, C., Eklöf, J. S., Gamfeldt, L., Havenhand, J. N., and Sundbäck, K. (2013). Consumers mediate the effects of experimental ocean acidification and warming on primary producers. *Proc. Natl. Acad. Sci.* 110 (21), 8603–8608. doi: 10.1073/pnas.1303797110

Amjad, M. S., Arshad, M., Sadaf, H. M., Akrim, F., and Arshad, A. (2016). Floristic composition, biological spectrum and conservation status of the vegetation in Nikyal valley, Azad Jammu and Kashmir. *Asian Pac. J. Trop. Dis.* 6 (1), 63–69. doi: 10.1016/S2222-1808(15)60986-0

Asabonga, M., Cecilia, B., Mpundu, M. C., and Vincent, N. M. D. (2017). The physical and environmental impacts of sand mining. *Trans. R. Soc. S. Afr.* 72 (1), 1–5.

Baboo, B., Sagar, R., Bargali, S. S., and Verma, H. (2017). Tree species composition, regeneration and diversity of an Indian dry tropical forest protected area. *Trop. Ecol.* 58 (2), 409–423.

Bargali, K., Manral, V., Padalia, K., Bargali, S. S., and Upadhyay, V. P. (2018). Effect of vegetation type and season on microbial biomass carbon in Central Himalayan Forest soils, India. *Catena* 171, 125–135. doi: 10.1016/j.catena.2018.07.001

Bargali, S. S., Padalia, K., and Bargali, K. (2019). Effects of tree fostering on soil health and microbial biomass under different land use systems in the Central Himalayas. *Land. Degradation. Dev.* 30 (16), 1984–1998. doi: 10.1002/ldr.3394

Bargali, S. S., Shahi, C., Bargali, K., Negi, B., and Khatri, K. (2022). Energy and monetary efficiencies at the different altitudinal agroecosystems in central Himalaya, India. *Heliyon* 8 (11), 1–16. doi: 10.1016/j.heliyon.2022.e11500

Barinova, S., Ali, N., and Barkatullah, S. F. (2013). Ecological adaptation to altitude of algal communities in the Swat Valley (Hindu Cush Mountains, Pakistan). *Expert Opin. Environ. Biol.* 2), 2. doi: 10.4172/2325-9655.1000104

Barry, S. (2006). *Understanding Livestock Grazing Impacts: Strategies for the California Annual Grassland and Oak Woodland Vegetation Series: University of*

California, Division of Agriculture and Natural Resources. Berger Drive, San Jose, CA 95112

Barua, N., Aziz, M. A. I., Tareq, A. M., Sayeed, M. A., Alam, N., ul Alam, N., et al. (2020). In vivo and *in vitro* evaluation of pharmacological activities of Adenia trilobata (Roxb.). *Biochem. Biophys. Rep.* 23, 100772. doi: 10.1016/j.bbrep.2020.100772

Bhattarai, K. R., Måren, I. E., and Subedi, S. C. (2014). Biodiversity and invasibility: Distribution patterns of invasive plant species in the Himalayas, Nepal. *J. Mountain. Sci.* 11, 688–696. doi: 10.1007/s11629-013-2821-3

Bhattarai, K. R., and Vetaas, O. R. (2003). Variation in plant species richness of different life forms along a subtropical elevation gradient in the Himalayas, east Nepal. *Global Ecol. Biogeogr.* 12 (4), 327–340. doi: 10.1046/j.1466-822X.2003.00044.x

Biondi, E., Allegrezza, M., Casavecchia, S., Galdenzi, D., Gasparri, R., Pesaresi, S., et al. (2015). New insight on Mediterranean and sub-Mediterranean syntaxa included in the Vegetation Prodrome of Italy. *Flora. Mediterr.* 25 (Special Issue), 77–102. doi: 10.7320/FlMedit25SI.077

Biplab, B., Sagar, R., Bargali, S. S., and Hariom, V. (2017). Tree species composition, regeneration and diversity of an Indian dry tropical forest protected area. *Trop. Ecol.* 58 (2), 409–423.

Bisht, S., Bargali, S. S., Bargali, K., Rawat, G. S., Rawat, Y. S., and Fartyal, A. (2022). Influence of anthropogenic activities on forest carbon stocks—a case study from Gori Valley, Western Himalaya. *Sustainability* 14 (24), 16918. doi: 10.3390/su142416918

Bisht, S., Rawat, G. S., Bargali, S. S., Rawat, Y. S., and Mehta, A. (2023). Forest vegetation response to anthropogenic pressures: a case study from Askot Wildlife Sanctuary, Western Himalaya. *Environment. Dev. Sustainabil.* 1–25. doi: 10.1007/s10668-023-03130-2

Chao, W., Xiaoan, W., Hua, G., Weiyi, F., and Zhihong, Z. (2006). Species diversities of major communities in Malan forest region of the Loess Plateau. *Acta Botanica Boreali-Occidentalia. Sin.* 26 (4), 791–797.

Chawla, A., Rajkumar, S., Singh, K., Lal, B., Singh, R., and Thukral, A. (2008). Plant species diversity along an altitudinal gradient of Bhabha Valley in western Himalaya. *J. Mountain. Sci.* 5, 157–177. doi: 10.1007/s11629-008-0079-y

Chhogyel, N., Kumar, L., and Bajgai, Y. (2021). Invasion status and impacts of parthenium weed (Parthenium hysterophorus) in West-Central region of Bhutan. *Biol. Invasions.* 23 (9), 2763–2779. doi: 10.1007/s10530-021-02534-3

Curtis, J. T., and Mcintosh, R. P. (1950). The interrelations of certain analytic and synthetic phytosociological characters. *Ecology* 31 (3), 434–455. doi: 10.2307/1931497

Dasti, A., and Agnew, A. (1994). The vegetation of Cholistan and Thai deserts, Pakistan. *J. Arid. Environments.* 27 (3), 193–208. doi: 10.1006/jare.1994.1058

Davidar, P., Sahoo, S., Mammen, P. C., Acharya, P., Puyravaud, J. P., Arjunan, M., et al. (2010). Assessing the extent and causes of forest degradation in India: where do we stand? *Biol. Conserv.* 143 (12), 2937–2944. doi: 10.1016/j.biocon.2010.04.032

De Leo, F. C., Vetter, E. W., Smith, C. R., Rowden, A. A., and McGranaghan, M. (2014). Spatial scale-dependent habitat heterogeneity influences submarine canyon macrofaunal abundance and diversity off the Main and Northwest Hawaiian Islands. *Deep. Sea. Res. Part II.: Topical. Stud. Oceanogr.* 104, 267–290. doi: 10.1016/j.dsr2.2013.06.015

Deo, R. C., and Şahin, M. (2015). Application of the artificial neural network model for prediction of monthly standardized precipitation and evapotranspiration index using hydrometeorological parameters and climate indices in eastern Australia. *Atmospheric. Res.* 161, 65–81. doi: 10.1016/j.atmosres.2015.03.018

Duniway, M. C., Bestelmeyer, B. T., and Tugel, A. (2010). Soil processes and properties that distinguish ecological sites and states. *Rangelands* 32 (6), 9–15. doi: 10.2111/Rangelands-D-10-00090.1

Du Toit, M. J., Du Preez, C., and Cilliers, S. S. (2021). Plant diversity and conservation value of wetlands along a rural–urban gradient. *Bothalia-African. Biodivers. Conserv.* 51 (1), 1–18.

Faridah-Hanum, I., Kudus, K., and Saari, N. S. (2012). Plant diversity and biomass of Marudu Bay mangroves in Malaysia. *Pakistan J. Bot.* 44 (Suppl 2), 151–156.

Farooq, M., Shafique, M., and Khattak, M. S. (2018). Flood frequency analysis of river swat using Log Pearson type 3, Generalized Extreme Value, Normal, and Gumbel Max distribution methods. *Arabian. J. Geosci.* 11, 1–10. doi: 10.1007/s12517-018-3553-z

Fartyal, A., Khatri, K., Bargali, K., and Bargali, S. S. (2022). Altitudinal variation in plant community, population structure and carbon stock of Quercus semecarpifolia Sm. forest in Kumaun Himalaya. *J. Environ. Biol.* 43 (1), 133–146. doi: jeb/43/1/MRN-2003

Gangwar, D., and Baskar, M. (2019). *Texture determination of soil by hydrometer method for forensic purpose* (Chandigarh, India: Central Forensic Science Laboratory).

Geiger, E. L., and McPherson, G. R. (2005). Response of semi-desert grasslands invaded by non-native grasses to altered disturbance regimes. *J. Biogeogr.* 32 (5), 895–902. doi: 10.1111/j.1365-2699.2004.01235.x

Gómez-Díaz, D., Navaza, J. M., and Sanjurjo, B. (2006). Analysis of mass transfer in the precipitation process of calcium carbonate using a gas/liquid reaction. *Chem. Eng. J.* 116 (3), 203–209. doi: 10.1016/j.cej.2005.12.004

Gosain, B. G., Negi, G. C. S., Dhyani, P. P., Bargali, S. S., and Saxena, R. (2015). Ecosystem services of forests: Carbon Stock in vegetation and soil components in a watershed of Kumaun Himalaya, India. *Int. J. Ecol. Environ. Sci.* 41 (3-4), 177–188.

Grace, J., and Anderson, T. (2016). Seabloom EWet al. Integrative modelling reveals mechanisms linking productivity and plant species richness. *Nature* 529, 390–393.310. doi: 10.1038/nature16524

Grizzetti, B., Liquete, C., Pistocchi, A., Vigiak, O., Zulian, G., Bouraoui, F., et al. (2019). Relationship between ecological condition and ecosystem services in European rivers, lakes and coastal waters. *Sci. Total. Environ.* 671, 452–465. doi: 10.1016/j.scitotenv.2019.03.155

Hitimana, J., Kiyiapi, J. L., and Njunge, J. T. (2004). Forest structure characteristics in disturbed and undisturbed sites of Mt. Elgon Moist Lower Montane Forest, western Kenya. *For. Ecol. Manage.* 194 (1-3), 269–291. doi: 10.1016/j.foreco.2004.02.025

Htun, N. Z., Mizoue, N., and Yoshida, S. (2011). Tree species composition and diversity at different levels of disturbance in Popa Mountain Park, Myanmar. *Biotropica* 43 (5), 597–603. doi: 10.1111/j.1744-7429.2011.00753.x

Hua, F., Bruijnzeel, L. A., Meli, P., Martin, P. A., Zhang, J., Nakagawa, S., et al. (2022). The biodiversity and ecosystem service contributions and trade-offs of forest restoration approaches. *Science* 376 (6595), 839–844. doi: 10.1126/science.abl4649

Iqbal, M. F., Feng, Y.-L., Feng, W.-W., Liu, M.-C., and Lu, X.-R. (2021). Ecological impacts of the invasive plant Xanthium strumarium and the impacts of three aboveground herbivores on the invader. *Ecol. Indic.* 131, 108140. doi: 10.1016/j.ecolind.2021.108140

Jiang, Y., Kang, M., Zhu, Y., and Xu, G. (2007). Plant biodiversity patterns on Helan mountain, China. *Acta Oecol.* 32 (2), 125–133. doi: 10.1016/j.actao.2006.12.003

Jnr, A. K. L., Yunana, D., Kamsouloum, P., Webster, M., Wilson, D. C., and Cheeseman, C. (2018). Recycling waste plastics in developing countries: Use of low-density polyethylene water sachets to form plastic bonded sand blocks. *Waste. Manage.* 80, 112–118. doi: 10.1016/j.wasman.2018.09.003

Johnson, P. T., Ostfeld, R. S., and Keesing, F. (2015). Frontiers in research on biodiversity and disease. *Ecol. Lett.* 18 (10), 1119–1133. doi: 10.1111/ele.12479

Kamrani, A., Jalili, A., Naqinezhad, A., Attar, F., Maassoumi, A. A., and Shaw, S. C. (2011). Relationships between environmental variables and vegetation across mountain wetland sites, N. Iran. *Biologia* 66, 76–87. doi: 10.2478/s11756-010-0127-2

Kefalew, A., Asfaw, Z., and Kelbessa, E. (2015). Ethnobotany of medicinal plants in Ada'a District, East Shewa Zone of Oromia regional state, Ethiopia. *J. Ethnobiol. Ethnomed.* 11 (1), 1–28.

Khan, N. (2012). A community analysis of Quercus baloot Griff, forest District Dir, Upper Pakistan. *Afr. J. Plant Sci.* 6 (1), 21–31. doi: 10.5897/AJPS11.231

Khan, N., Ali, K., and Shaukat, S. (2014). Phytosociology, structure and dynamics of Pinus roxburghii associations from Northern Pakistan. *J. Forestry. Res.* 25, 511–521. doi: 10.1007/s11676-014-0490-x

Khan, S. M., Harper, D. M., Page, S., and Ahmad, H. (2011). Species and community diversity of vascular flora along environmental gradient in Naran Valley: A multivariate approach through indicator species analysis. *Pak. J. Bot.* 43 (5), 2337–2346.

Khan, S. A., Khan, S. M., Ullah, Z., Ahmad, Z., Alam, N., Shah, S. N., et al. (2020). Phytogeographic classification using multivariate approach; a case study from the Jambil Valley Swat, Pakistan. *Pak. J. Bot.* 52, 279–290. doi: 10.30848/PJB2020-1(11)

Khan, N., Shaukat, S. S., Ahmed, M., and Siddiqui, M. F. (2013). Vegetation-environment relationships in the forests of Chitral district Hindukush range of Pakistan. *J. Forestry. Res.* 24 (2), 205–216. doi: 10.1007/s11676-013-0346-9

Kononova, M. (2013). *Soil organic matter: its nature, its role in soil formation and in soil fertility* (Oxford London: Pergamon Press).

Kremen, C., Williams, N. M., Aizen, M. A., Gemmill-Herren, B., LeBuhn, G., Minckley, R., et al. (2007). Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. *Ecol. Lett.* 10 (4), 299–314. doi: 10.1111/j.1461-0248.2007.01018.x

Lewis, J. S., Farnsworth, M. L., Burdett, C. L., Theobald, D. M., Gray, M., and Miller, R. S. (2017). Biotic and abiotic factors predicting the global distribution and population density of an invasive large mammal. *Sci. Rep.* 7 (1), 1–12. doi: 10.1038/srep44152

Li, S., Su, P., Zhang, H., Zhou, Z., Xie, T., Shi, R., et al. (2018). Distribution patterns of desert plant diversity and relationship to soil properties in the Heihe River Basin, China. *Ecosphere* 9 (7), e02355. doi: 10.1002/ecs2.2355

Rentier, E. S., and Cammeraat, L. H. (2022). The environmental impacts of river sand mining. *Sci. Total Environ.* 838, 155877. doi: 10.1016/j.scitotenv.2022.155877

Lyons, K. G., Brigham, C., Traut, B., and Schwartz, M. W. (2005). Rare species and ecosystem functioning. *Conserv. Biol.* 19 (4), 1019–1024. doi: 10.1111/j.1523-1739.2005.00106.x

Maan, I., Kaur, A., Singh, H. P., Batish, D. R., and Kohli, R. K. (2021). Exotic avenue plantations turning foe: Invasive potential, distribution and impact of Broussonetia papyrifera in Chandigarh, India. *Urban. Forestry. Urban. Greening.* 59, 127010. doi: 10.1016/j.ufug.2021.127010

Manral, V., Bargali, K., Bargali, S. S., and Shahi, C. (2020). Changes in soil biochemical properties following replacement of Banj oak forest with Chir pine in Central Himalaya, India. *Ecol. Processes.* 9, 1–9. doi: 10.1186/s13717-020-00235-8

Martínez-Falcón, A. P., Zurita, G. A., Ortega-Martínez, I. J., and Moreno, C. E. (2018). Populations and assemblages living on the edge: dung beetles responses to forests-pasture ecotones. *PeerJ* 6, e6148. doi: 10.7717/peerj.6148

McCune, B. (1997). Influence of noisy environmental data on canonical correspondence analysis. *Ecology* 78 (8), 2617–2623. doi: 10.1890/0012-9658(1997)078[2617:IONEDO]2.0.CO;2

McDougall, K. L., Morgan, J. W., Walsh, N. G., and Williams, R. J. (2005). Plant invasions in treeless vegetation of the Australian Alps. *Perspect. Plant Ecol. Evol. Syst.* 7 (3), 159–171. doi: 10.1016/j.ppees.2005.09.001

Mcfarland, D. G., and Shafer, D. (2011). Protocol considerations for aquatic plant seed bank assessment. *J. Aquat. Plant Manage.* 49 (9), 9–19.

Milchunas, D. G., Sala, O. E., and Lauenroth, W. K. (1988). A generalized model of the effects of grazing by large herbivores on grassland community structure. *Am. Nat.* 132 (1), 87–106. doi: 10.1086/284839

Mitsch, W., and Gosselink, J. (1993). *Wetlands Van Nostrand Reinhold* 5th Edn. (John Wiley & Sons, Inc. New York), 722.

Mligo, C. (2011). Anthropogenic disturbance on the vegetation in Makurunge woodland, Bagamoyo district, Tanzania. *Tanzania. J. Sci.* 37, 94–108.

Morsdorf, F., Mårell, A., Koetz, B., Cassagne, N., Pimont, F., Rigolot, E., et al. (2010). Discrimination of vegetation strata in a multi-layered Mediterranean forest ecosystem using height and intensity information derived from airborne laser scanning. *Remote Sens. Environ.* 114 (7), 1403–1415. doi: 10.1016/j.rse.2010.01.023

Muhammad, Z., Khan, N., Ali, S., Ullah, A., and Khan, S. M. (2016). Density and taxonomic diversity of understory vegetation in relation to site conditions in natural stands of Acacia modesta in Malakand Division, Khyber Pakhtunkhwa, Pakistan. *Science* 35 (1), 26–34. doi: 10.3923/std.2016.26.34

Nabi, G., Ali, I., Tahir, T., and Ahmed, M. (2012). Growth and yield of Kinnow (Citrus reticulata Blanco) and soil physical properties as affected by orchard floor management practices in Punjab, Pakistan. *Soil Environ.* 31 (2), 163–170.

Nafees, M., Jan, M. R., Khan, H., and Ali, A. (2008). Status of soil texture and required associated soil conservation measure of river swat catchments area, NWFP, Pakistan. *Sarhad. J. Agric.* 24 (2), 251–259.

Naiman, R. J., Bechtold, J. S., Drake, D. C., Latterell, J. J., O'Keefe, T. C., and Balian, E. V. (2005). Origins, patterns, and importance of heterogeneity in riparian systems. *Ecosyst. Funct. Heterogeneous. Landscapes.* 279–309. doi: 10.1007/0-387-24091-8_14

Nasrullah, K., Fayaz, A., Kishwar, A., and Shahid, S. (2015). Composition, structure and regeneration dynamics of *Olea ferruginea* Royle forests from Hindukush range of Pakistan. *J. Mountain. Sci.* 12, 647–658. doi: 10.1007/s11629-013-2831-1

Nelson, D. W., and Sommers, L. E. (1996). Total carbon, organic carbon, and organic matter. *Methods Soil Analysis.: Part 3. Chem. Methods* 5, 961–1010. doi: 10.2134/agronmonogr9.2.2ed.c29

Nogués-Bravo, D., Araújo, M. B., Romdal, T., and Rahbek, C. (2008). Scale effects and human impact on the elevational species richness gradients. *Nature* 453 (7192), 216–219.

Orellana, F., Verma, P., Loheide, S. P., and Daly, E. (2012). Monitoring and modeling water-vegetation interactions in groundwater-dependent ecosystems. *Rev. Geophys.* 50 (3), 1–24. doi: 10.1029/2011RG000383

Pandey, R., Bargali, S. S., Bargali, K., and Pandey, V. C. (2023). Temporal variability in fine root dynamics in relation to tree girth size in sub-tropical sal (Shorea robusta) forests. *Land. Degradation. Dev.* 34 (5), 1522–1537. doi: 10.1002/ldr.4550

Pepe, M., Fregonese, L., and Scaioni, M. (2018). Planning airborne photogrammetry and remote-sensing missions with modern platforms and sensors. *Eur. J. Remote Sens.* 51 (1), 412–436. doi: 10.1080/22797254.2018.1444945

Pretto, F., Celesti-Grapow, L., Carli, E., and Blasi, C. (2010). Influence of past land use and current human disturbance on non-native plant species on small Italian islands. *Plant Ecol.* 210, 225–239. doi: 10.1007/s11258-010-9751-8

Qian, H., and Guo, Q. (2010). Linking biotic homogenization to habitat type, invasiveness and growth form of naturalized alien plants in North America. *Diversity Distributions.* 16 (1), 119–125. doi: 10.1111/j.1472-4642.2009.00627.x

Raduła, M. W., Szymura, T. H., Szymura, M., Swacha, G., and Kącki, Z. (2020). Effect of environmental gradients, habitat continuity and spatial structure on vascular plant species richness in semi-natural grasslands. *Agricult. Ecosyst. Environ.* 300, 106974. doi: 10.1016/j.agee.2020.106974

Rahman, A., Khan, N., Bräuning, A., Ullah, R., and Rahman, I. U. (2022). Effects of environmental and spatial gradients on Quercus-dominated Mountain forest communities in the Hindu-Kush ranges of Pakistan. *Saudi. J. Biol. Sci.* 29 (4), 2867–2877. doi: 10.1016/j.sjbs.2022.01.013

Rao, C. S., Indoria, A., and Sharma, K. (2017). Effective management practices for improving soil organic matter for increasing crop productivity in rainfed agroecology of India. *Curr. Sci.* 112, 1497–1504. doi: 10.18520/cs/v112/i07/1497-1504

Rybicki, N. B., and Landwehr, J. M. (2007). Long-term changes in abundance and diversity of macrophyte and waterfowl populations in an estuary with exotic macrophytes and improving water quality. *Limnol. Oceanogr.* 52 (3), 1195–1207. doi: 10.4319/lo.2007.52.3.1195

Santos, M. J., Anderson, L. W., and Ustin, S. L. (2011). Effects of invasive species on plant communities: an example using submersed aquatic plants at the regional scale. *Biol. Invasions.* 13, 443–457. doi: 10.1007/s10530-010-9840-6

Saxton, K., Rawls, W. J., Romberger, J. S., and Papendick, R. (1986). Estimating generalized soil-water characteristics from texture. *Soil Sci. Soc. America J.* 50 (4), 1031–1036. doi: 10.2136/sssaj1986.03615995005000040039x

Schlaepfer, D. R., Lauenroth, W. K., and Bradford, J. B. (2012). Ecohydrological niche of sagebrush ecosystems. *Ecohydrology* 5 (4), 453–466. doi: 10.1002/eco.238

Shah, M., and Hussain, F. (2009). Phytosociological Study of the Vegetation of Hayat Abadpeshawar, Pakistan. *Pakistan J. Plant Sci.* 15 (2), 1–12.

Singh, J. S. (2002). The biodiversity crisis: a multifaceted review. *Curr. Sci.* 82, 638–647.

Singh, G., Reynolds, C., Byrne, M., and Rosman, B. (2020). A remote sensing method to monitor water, aquatic vegetation, and invasive water hyacinth at national extents. *Remote Sens.* 12 (24), 4021. doi: 10.3390/rs12244021

Sjödin, N. E., Bengtsson, J., and Ekbom, B. (2008). The influence of grazing intensity and landscape composition on the diversity and abundance of flower-visiting insects. *J. Appl. Ecol.* 45, 763–772.

Stella, J. C., Rodríguez-González, P. M., Dufour, S., and Bendix, J. (2013). Riparian vegetation research in Mediterranean-climate regions: common patterns, ecological processes, and considerations for management. *Hydrobiologia* 719, 291–315. doi: 10.1007/s10750-012-1304-9

Subedi, S. C., Bhattarai, K. R., Perez, T. M., and Sah, J. P. (2020). Gymnosperm species richness patterns along the elevational gradient and its comparison with other plant taxonomic groups in the Himalayas. *Front. Biogeogr.* 12 (1). doi: 10.21425/F5FBG44232

Taiz, L., and Zeiger, E. (2002). Photosynthesis: physiological and ecological considerations. *Plant Physiol.* 9, 172–174.

Tappeiner, J., Zasada, J., Ryan, P., and Newton, M. (1991). Salmonberry clonal and population structure: the basis for a persistent cover. *Ecology* 72 (2), 609–618. doi: 10.2307/2937201

Taubner, H., Roth, B., and Tippkötter, R. (2009). Determination of soil texture: Comparison of the sedimentation method and the laser-diffraction analysis. *J. Plant Nutr. Soil Sci.* 172 (2), 161–171. doi: 10.1002/jpln.200800085

Tavili, A., and Jafari, M. (2009). Interrelations between plants and environmental variables. *Int. J. Environ. Res.* 3 (2), 239–246.

Timsina, B., Shrestha, B. B., Rokaya, M. B., and Münzbergová, Z. (2011). Impact of Parthenium hysterophorus L. invasion on plant species composition and soil properties of grassland communities in Nepal. *Flora-Morphol. Distribution. Funct. Ecol. Plants* 206 (3), 233–240. doi: 10.1016/j.flora.2010.09.004

Twilley, R. R., and Rivera-Monroy, V. H. (2005). Developing performance measures of mangrove wetlands using simulation models of hydrology, nutrient biogeochemistry, and community dynamics. *J. Coast. Res.* 79–93.

Ullah, R., Khan, N., Hewitt, N., Ali, K., Jones, D. A., and Khan, M. E. H. (2022). Invasive Species as Rivals: Invasive Potential and Distribution Pattern of *Xanthium strumarium* L. *Sustainability* 14 (12), 7141. doi: 10.3390/su14127141

Ullah, R., Khan, N., and Rahman, A. (2021). Comparison of Invaded And Non-Invaded Sites: A Case Study Of Rough Cocklebur (*Xanthium strumarium* L.) An Alien Invasive Species. *Appl. Ecol. Environ. Res.* 19 (2), 1533–1548. doi: 10.15666/aeer/1902_15331548

van de Koppel, J., Bouma, T. J., and Herman, P. M. (2012). The influence of local-and landscape-scale processes on spatial self-organization in estuarine ecosystems. *J. Exp. Biol.* 215 (6), 962–967. doi: 10.1242/jeb.060467

Vis, C., Hudon, C., and Carignan, R. (2003). An evaluation of approaches used to determine the distribution and biomass of emergent and submerged aquatic macrophytes over large spatial scales. *Aquat. Bot.* 77 (3), 187–201. doi: 10.1016/S0304-3770(03)00105-0

Wang, X., Hao, Z., Ye, J., Zhang, J., Li, B., and Yao, X. (2008). Spatial pattern of diversity in an old-growth temperate forest in Northeastern China. *Acta Oecol.* 33 (3), 345–354. doi: 10.1016/j.actao.2008.01.005

Wang, G., Zhou, G., Yang, L., and Li, Z. (2003). Distribution, species diversity and life-form spectra of plant communities along an altitudinal gradient in the northern slopes of Qilianshan Mountains, Gansu, China. *Plant Ecol.* 165, 169–181. doi: 10.1023/A:1022236115186

Watt, S., García-Berthou, E., and Vilar, L. (2007). The influence of water level and salinity on plant assemblages of a seasonally flooded Mediterranean wetland. *Plant Ecol.* 189, 71–85. doi: 10.1007/s11258-006-9167-7

Yadav, R., Tomar, S., and Sharma, U. (2002). Output: Input ratios and apparent balances of N, P and K inputs in a rice-wheat system in North-West India. *Exp. Agric.* 38 (4), 457–468. doi: 10.1017/S0014479702000479

Yu, Y., Li, J., Zhou, Z., Ma, X., and Zhang, X. (2021). Response of multiple mountain ecosystem services on environmental gradients: How to respond, and where should be priority conservation? *J. Cleaner. Production.* 278, 123264. doi: 10.1016/j.jclepro.2020.123264

Zare, S., Jafari, M., Tavili, A., Abbasi, H., and Rostampour, M. (2011). Relationship between environmental factors and plant distribution in arid and semiarid area (Case Study: Shahriyar Rangelands, Iran). *American-Eurasian. J. Agric. Environ. Sci.* 10 (1), 97–105.

Ze-Hao, S., and Xin-Shi, Z. (2000). Spatial pattern analysis and topographical interpretation of species diversity in the forests of Dalaoling in the region of the Three Gorges. *J. Integr. Plant Biol.* 42 (6), 620.

Zhao, C. M., Chen, W. L., Tian, Z. Q., and Xie, Z. Q. (2005). Altitudinal pattern of plant species diversity in Shennongjia Mountains, Central China. *J. Integr. Plant Biol.* 47 (12), 1431–1449. doi: 10.1111/j.1744-7909.2005.00164.x

Zimmermann, H. (1991). Biological control of mesquite, Prosopis spp. (Fabaceae), in South Africa. *Agricult. Ecosyst. Environ.* 37 (1-3), 175–186. doi: 10.1016/0167-8809(91)90145-N