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Vegetation communities and identification of indicator species in the riparian areas of Zabarwan mountain range in the Kashmir Himalaya

Shiekh Marifatul Haq [a], Muhammad Shoaib Amjad [b,c,**], Muhammad Waheed [d], Rainer W. Bussmann [a,e], Kishwar Ali [f,*], David Aaron Jones [g]

[a] Department of Ethnobotany, Institute of Botany, Ilia State University, Tbilisi, Georgia
[b] Department of Botany, Women University of Azad Jammu & Kashmir, Bagh, 12500, Pakistan
[c] Birmingham Institute of Forest Research, University of Birmingham, Birmingham, B15 2TT, UK
[d] Department of Botany, University of Okara, Okara, 56300, Pakistan
[e] Department of Botany, Institute of Life Sciences, State Museum of Natural History, Karlsruhe, Germany
[f] College of General Education, University of Doha for Science and Technology, Al Tarafa, Jelaiah Street, Duhail North, PO Box 24449, Doha, Qatar
[g] College of Health Sciences, University of Doha for Science and Technology, Al Tarafa, Jelaiah Street, Duhail North, PO Box 24449, Doha, Qatar

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ABSTRACT

Plant communities that occur along water corridors are termed riparian vegetation. Although relatively narrow and long, riparian zones do provide an extensive spatially linear network of connectivity between existing habitats, allowing species to move more easily in response to changing microclimate conditions. Knowledge of riparian ecosystems in the Himalayan Region of Kashmir has not been explored, even though this region is unique and comprises some of the most important hotspots for Himalayan biodiversity. The current study characterizes the vegetation community along a riparian ecosystem in the Zabarwan Range, where there is no information on community characterization. After preliminary surveys, the three sites representing the study area were selected for detailed field sampling (Community-1 at the lower end of the stream; Community-2 at the middle of the stream, and Community-3 at the upper end of the stream). Data on the communities were gathered using the T-transect vegetation sampling method, and indicator plant species along the riparian zones were identified using Analysis of Indicator Species (AIS). A total of 71 plant species were collected, which were divided into 64 genera and 38 families. With nine species, the Rosaceae family was the largest, followed by the Asteraceae with six species. Three community associations, *Ulmus-Parrotiopsis-Oplismenus, Salix-Rosa-Oplismenus, Celtis-Viburnum-Fragaria*, were identified on the basis of an important value index. Diversity indices show significant differences in riparian vegetation between the types of plant communities. Shannon Diversity was also found to be higher in communities 2 and 3, indicating that the vegetation there was more diverse. *Ulmus villosa* is a common indicator species in Community-1 and Community-2, while *Prunus tomentosa* is a common indicator species in Community-3 and Community-1. *Rosa webbiana* was found as an indicator species in Community-2 and Community-3 while *Celtis australis* and *Viburnum grandiflorum* were restricted to Community-3. The identified indicator species in the vegetation associations can be employed for restoring riparian zones because of their excellent ecological performance and capacity for regrowth in these environments.

1. Introduction

Riparian temperate forests play a crucial role in biodiversity preservation and ecological connectivity (Giraldo et al. 2022) as well as the provision of essential ecosystem services such as the maintenance of water flows (Nunes et al. 2019). Riparian areas are rare habitats with disproportionately high biodiversity that occupy transition zones between terrestrial (dry) and aquatic (wet) ecosystems (Olson et al. 2007; Assal et al. 2021). Although riparian zones are relatively narrow and long (George et al. 2011), they do offer extensive spatially linear

* Corresponding author. College of General Education, University of Doha for Science and Technology, Al Tarafa, Jelaiah Street, Duhail North, PO Box 24449, Doha, Qatar.
** Corresponding author. Department of Botany, Women University of Azad Jammu & Kashmir, Bagh, 12500, Pakistan.
E-mail addresses: malikshoaib1165@yahoo.com, m.mjad.1@bham.ac.uk (M.S. Amjad), kishwar.ali@udst.edu.qa (K. Ali).

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network connectivity between existing habitats, enabling species to move more readily in response to changing microclimatic conditions (Rouquette et al. 2013). The riparian ecosystem is vital to the delivery of many ecosystem services, including those which are cultural (recreational activities), provisional (fresh drinking water), and ecological (water purification) (Pastor et al. 2022), as well as those which support nutrient cycling and wildlife habitat (La Notte et al. 2017). Furthermore, the riparian ecosystem provides a landscape for forests, helps in carbon sequestration, and reduces flood intensity (Zhu et al. 2022).

Riparian plant communities are typically home to hydrophilic organism assemblages and are distinguished by the influence of periodic water inundation, as well as material and energy exchange with surrounding ecosystems (Majumdar et al. 2020). Patterns of species richness along the riparian corridor have been considered a product of natural and anthropogenic disturbances, competition, and habitat niche diversification (Liu et al. 2022), which is manifested in the diversity of floodplain forest habitats (Mekotová et al., 2006). The response of riparian vegetation to flood disturbance dynamics (Del Tánago et al. 2021) with regular moderate flooding is required to sustain rich species diversity in riparian ecosystems (Naiman and Decamps 1997). The microhabitats of the transition zone are created by overbank deposition, which alters the frequency of flooding and the composition of the plant species (Graziano et al. 2022).

The type of plant community and the spatial distribution pattern of the riparian vegetation serve as an indicator of the healthy environment of a region (Del Tánago et al. 2021; Khan et al. 2022; Haq et al. 2023). Predictable changes in species abundance, community composition, and other properties of the ecosystem have been experienced due to a shift in environmental conditions such as hydrological alterations, nutrient enrichment, sediment loading, and turbidity (Lin et al. 2021). The dynamic vegetation pattern indicates a response from a community that integrates the effects of a wide range of existing environmental conditions, that is, hydrological changes, turbidity and sediment loading, nutrient enrichment, and operative phylogenetic processes (O'Hare et al. 2018; Haq et al. 2021a; Jamil et al., 2022). The structure of the riparian corridor, the quality of the water, and the biotic integrity of the aquatic ecosystem are all directly impacted by the quality of the riparian vegetation (Bertora et al. 2022). The accurate assessment of plant diversity, the use of ecological traits in resource management, and how resource management actions affect riparian vegetation are all important components of management (Ramaano, 2022).

Despite its significance, riparian vegetation has historically received little attention, especially in the Himalayas (Haq et al. 2019a). The Himalayas of Kashmir are among the most important hotspots for Himalayan biodiversity in the world. Located at the northwest boundary of the great Indian Himalayan range, it is well known for its unique and endemic phytodiversity. However, until now, knowledge of the riparian ecosystems of this biologically important region has not been explored. One such area is the riparian ecosystem in the Zabarwan Range, for which no information on the characterization of the community is available. Keeping these facts in mind, the current effort was designed to address the following objectives: (i) to analyze the vegetation distribution pattern in plant communities along the riparian zones in this region; (ii) to understand the emergent functional traits of the vegetation; and finally, (iii) to identify the indicator species which determine the patterns in each plant community. By addressing these objectives, we will identify indicator species which may be suitable options for the restoration of riparian ecosystems in this Himalayan region and elsewhere in the world.

2. Materials and methods

2.1. Study area

The Zabarwan Range is situated in the Indian Union Territory of Jammu and Kashmir, is a short (32 km) submountain range between the Pir Panjal and Great Himalayan Ranges. On its eastern side, the Zabarwan Range borders the Kashmir Valley. It literally refers to the mountain range that divides the Jehlum Valley from the Zanskar Range on the east and west, as well as the Zanskar Range from the north and south sides of the Sind Valley and the Lidder Valley, respectively. The Zabarwan mountain range is renowned for its abundant wildlife and Himalayan features. The most notable feature of the range is Dachigam National Park, occupying a territory of 141 km^2 and is located between 34°05′ and 34°11′ N and 74°54′ and 75°09' E (Fig. 1).

Protected Since 1910, Dachigam was initially created to ensure clean drinking water supply for the city of Srinagar, the summer capital of J&K. In 1981, Dachigam was upgraded and made a national park. The climate of Dachigam can be used to summarize the climate of the Zabarwans. It is located in the sub-Mediterranean region and has two dry seasons, April to June and September to November. The amount of precipitation varies greatly across the range, as does the weather. Snow is the main source of precipitation and does not melt until June in some areas. The Zabarwan receives an annual rainfall ranging from 32 to 546 mm (Haq et al. 2021a). The dominant vegetation of the park is coniferous forest followed by alpine meadow, scrub vegetation, and waterfalls with deep gullies known locally as 'Nars'. The Dagwan stream begins at Marsar Lake (a high-altitude lake) and flows down into the lower Dachigam along the only road in the park (Haq et al. 2021a). These areas can be viewed as a transitional zone between the aquatic ecosystem and the dry upland area. A number of species use this area between land and water as a passageway. Riparian plant communities attract a wide variety of species, and as a result, riparian environments are home to high biological diversity. Riparian zones serve a crucial role in preserving water quality. They harbor vegetation that filters and buffers water. All of the plant life that grows in the areas aids in the absorption and trapping of sediment, excess nutrients, and pollutants before they enter the water. Thus, natural riparian vegetation contributes to biodiversity conservation by acting as a corridor and preserving excellent water quality in streams.

2.2. Sampling design and measurements

Field reconnaissance surveys were initially carried out in 2019 in order to understand the terrain, vegetation composition, and accessibility of the study area. Following the preliminary surveys, three study sites were chosen to represent the study area based on vegetation types. Community-1 at the lower end of the stream, Community-2 in the middle, and Community-3 at the upper end of the stream. Four transects were established at each sampling site, two of which ran parallel to the stream and the other two perpendiculars to it, forming a 'T' (Fig. 1) (Haq et al. 2019). Two square-shaped, 0.1 ha-sized quadrats made up the head of the "T," and the remaining two square-shaped quadrats of the same size (referred to as Mainland 1 & Mainland 2) were situated perpendicular to the stream. In each sampling quadrat (0.1 ha), two square shaped plots of size (5 m^2) were used to record shrubs. For herbaceous diversity, 5 square shaped plots of size (1 m^2) (4 in each corner 0.1 ha plot, and one at the center) were laid. Sixteen (5 m^2) plots for shrubs and forty (1 m^2) plots for herbs were randomly placed to ascertain diversity of the understory at each site. A total of 36 quadrats (12 quadrats per site) for tree diversity, one hundred twenty (40 × 3 = 120) (1 m^2) plots for herbs and forty-eight (16 × 3 = 48) (5 m^2) plots for shrubs were sampled in the present study. Field collection of plant specimens was carried out to obtain herbarium voucher specimens, which were then identified using available taxonomic literature (Haq et al. 2019a, 2019b). To ensure accuracy, the identification process included comparing the collected plant specimens with vouchers at the University of Kashmir Herbarium (KASH) herbarium. Conventional herbarium procedures were followed to preserve the collected plant specimens (Bridson and Forman 1999). The nomenclature of the plants was updated using the Plants of the World Online (POWO) taxonomic database, accessible at https://powo.science.kew.org. To make the

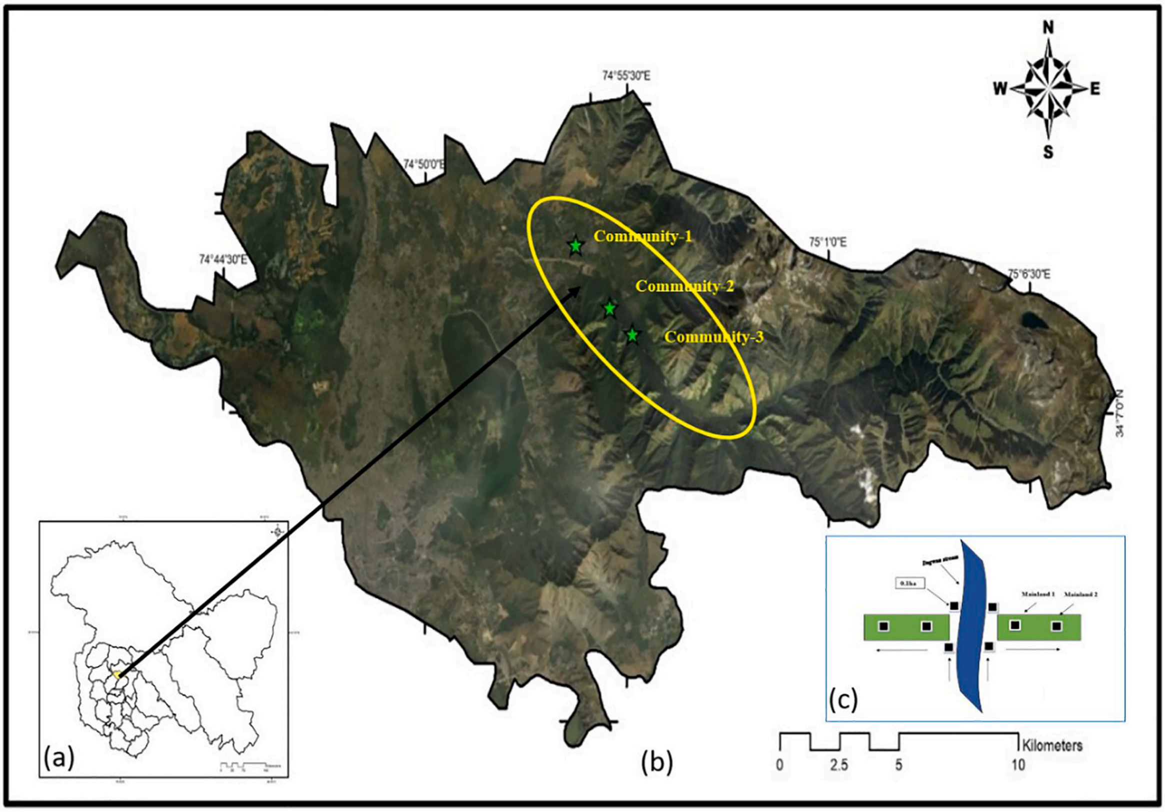

Fig. 1. Map of the study area. (a) Jammu and Kashmir (b) The study area in Dachigam National Park (DNP) (c) Experimental design and sampling scheme with plot layouts used for vegetation data collection.

specimens readily available for future reference, the voucher specimens were deposited in the University of Kashmir Herbarium (KASH). The field data associated with each specimen were carefully annotated onto the corresponding herbarium labels**.** Various physiographic parameters (i.e., aspect and altitude), were measured at the forest sites using a GPS device (Garmin, GPS map76cs). The plant species' dominance was determined using the Importance Value Index (IVI) for each species. Phytosociological attributes such as frequency, abundance, and density were calculated using the Importance Value Index (IVI) for each species. The IVI was chosen since it is a widely used ecological technique for determining the dominance of plant species in a given habitat (Haq et al. 2019c; Waheed et al., 2023). Following the Whitford (1949)**,** the Abundance-to-Frequency (A/F) Ratio was determined for various species. The ratio value was then classified into various types based on distribution, ie. regular (<0.025), random (0.025–0.050), and contagious (>0.050).

2.3. Data analysis

Data organisation and processing were done using Microsoft Excel 2016. Software programmes CANOCO and PAST were used to analyze the phytosociological data for plants that had been gathered. To illustrate the relation between plant growth forms and recorded plant species, a chord diagram was prepared in Origin Pro software (version 10). Data from the three plant communities were analysed using a detrended correspondence analysis (DCA), which was supported by reciprocal averaging. DCA, an Eigen vector ordination technique, was used to determine the length of the gradient and the relationship between vegetation types (Ter Braak and Smilauer, 2002). Using PAST software 4.10, the Shannon-Wiener, Equitability, and Dominance diversity indices were calculated following Haq et al. (2022a). The diversity indices of various riparian communities were compared using the nonparametric Kruskal-Wallis test, followed by the Tukey HSD, and a ridgeline graph with significant difference letters was created using the Origin Pro software (Rahman et al. 2022).

2.4. Indicator species analysis

To determine indicators for each community along the riparian zone, an Analysis of Indicator Species (AIS) was conducted. AIS revealed details on the fidelity of species to a particular ecosystem. A Monte Carlo evaluation was carried out to check statistical significance after each species indicator values had been determined using the method of Dufrêne and Legendre (1997). The indicator species were identified using a threshold level of 25% indication and 95% significance ($p \leq 0.05$). The indicator species with the value ($p \leq 0.05$) were additionally graphically represented using the PAST software (version 4.10) (Haq et al., 2022a).

3. Results

3.1. Vegetation composition and distribution

71 plant species were identified in the current study, and divided into 64 genera and 38 families (Table 1). Perennials with 60 species (85%) was the dominant category of life span, followed by 9 annuals (13%) and 2 biennials (3%) (Table 1). The number of species that all families contributed was disproportionate; half of the species were contributed by 9 families and the other half by 29 families, and 23 families were monotypic. With 9 species, Rosaceae is the largest family (13%), followed by the Asteraceae (6%) and Poaceae (4%) families (Table 1). Of these 71-plant species, 47 (66%) are herbs, 6 (9%) shrubs, and 18 (25%) are trees (Fig. 2). According to the abundance-to-frequency ratio values, 86% of the species have contagious distribution patterns, while the

Table 1
The indicator p-values of the communities sampled along the riparian ecosystem in the Zabarwan Range of the Kashmir Himalayas.

Family	Name of species	Species Code	Community-1	A/F ratio	Community-2	A/F ratio	Community-3	A/F ratio	Life span
Acanthaceae	*Strobilanthes urticifolia* Wall. ex Kuntze	Str.urt	0.233	0.08	0.133	0.21	0.140	0.15	Perennial
Amaranthaceae	*Achyranthes bidentata* Blume	Ach.bid	1.000	–	0.220	0.09	1.000	–	Perennial
Apiaceae	*Daucus carota*L.	Dac.car	0.395	0.45	0.384	0.06	0.685	0.09	Annual
Asteraceae	*Arctium lappa* L.	Art.lap	0.426	0.27	0.448	0.11	0.365	0.05	Biennial
	Artemisia vulgaris L.	Art.vul	1.000	–	1.000	–	0.691	0.09	Perennial
	Conyza canadensis (L.) Cronquist	Con.can	0.368	0.04	0.580	0.045	1.000	–	Annual
	Taraxacum officinale (L.) Weber ex F.H. Wigg.	Tax.off	1.000	–	0.539	0.06	0.626	0.04	Perennial
	Erigeron multiradiatus(Lindl. ex DC.) Benth. &Hook.f.	Eri.mul	1.000	–	1.000	–	0.524	0.72	Perennial
	Leucanthemum vulgare(Vaill.) Lam.	Leu.vul	1.000	–	0.377	0.12	1.000	–	Perennial
Asparagaceae	*Asparagus filicinus* Buch.-Ham. ex D.Don	Asp.fil	0.422	0.27	0.149	0.28	1.000	–	Perennial
	Asparagus officinalis L.	Asp.off	1.000	–	1.000	–	0.417	1.26	Perennial
	Polygonatum verticillatum(L.) All.	Pol.ver	1.000	–	1.000	–	0.602	0.36	Perennial
	Polygonatum acuminatifolium Kom.	Pol.acu	0.374	0.15	1.000	–	1.000	–	Perennial
Araliaceae	*Hedera nepalensis*K.Koch	Hed.nep	0.308	0.16	0.279	0.04	0.320	0.23	Perennial
Balsaminaceae	*Impatiens glandulifera*Royle	Imp.gra	0.135	0.43	0.190	0.13	0.429	0.18	Annual
Berberidaceae	*Berberis lycium* Royle	Ber.lyc	1.000	–	0.038	0.02	1.000	–	Perennial
	*Epimedium elatum*C. Morren & Decne.	Epi.ela	1.000	–	0.335	0.36	1.000	–	Perennial
Campanulaceae	*Asyneuma thomsonii* (C.B.Clarke) Bornm.	Asy.tho	1.000	–	0.514	0.36	1.000	–	Perennial
Cannabaceae	*Celtis australis*L.	Cel.aus	0.097	0.115	0.116	0.36	0.052	0.13	Perennial
Caryophyllaceae	*Silene vulgaris*(Moench) Garcke	Sil.vul	1.000	–	1.000	–	0.516	0.1	Perennial
	Stellaria media(L.) Vill.	Ste.med	1.000	–	0.346	0.17	1.000	–	Annual
Dioscoreaceae	*Dioscorea deltoidea*Wall. ex Griseb.	Dio.del	0.318	0.16	0.445	0.11	1.000	–	Perennial
Dryopteridaceae	*Dryopteris barbigera*(T. Moore ex Hook.) Kuntze	Dry.bar	0.419	0.27	0.586	0.04	0.475	0.33	Perennial
Equisetiaceae	*Equisetum arvense*L.	Equ.arv	1.000	–	1.000	–	0.153	0.18	Perennial
Fagaceae	*Quercus robur*L.	Que.rob	0.189	0.1	1.000	–	0.409	0.02	Perennial
Fabaceae	*Robinia pseudoacacia*L.	Rob.pse	1.000	–	1.000	–	0.290	0.1	Perennial
	*Trifolium pratense*L.	Tri.pra	1.000	–	0.292	0.12	0.332	0.78	Perennial
	*Trifolium repens*L.	Tri.rep	0.208	0.32	0.381	0.12	0.462	0.36	Perennial
Geraniaceae	*Geranium nepalense*Sweet	Ger.nep	1.000	–	0.415	0.05	1.000	–	Perennial
	*Geranium wallichianum*D.Don ex Sweet	Ger.wal	1.000	–	0.497	0.11	0.380	0.6	Perennial
Hamamelidaceae	*Parrotiopsis jacquemontiana* (Decne.) Rehder	Par.jac	0.001	0.02	1.000	–	1.000	–	Perennial
Iridaceae	*Iris kashmiriana*Baker	Iri.kas	0.142	0.25	0.217	0.16	0.277	0.11	Perennial
Juglandaceae	*Juglans regia*L.	Jug.reg	1.000	–	0.194	0.02	0.068	0.02	Perennial
Lamiaceae	*Clinopodium vulgare*L.	Cli.vul	1.000	–	0.612	0.09	1.000	–	Perennial
	*Prunella vulgaris*L.	Pru.vul	1.000	–	0.537	0.06	1.000	–	Perennial
Moraceae	*Morus alba*L.	Mor.alb	0.172	0.12	0.103	0.04	0.106	0.1	Perennial
	*Morus nigra*L.	Mor.nig	1.000	–	1.000	–	0.373	0.04	Perennial
Plantaginaceae	*Digitalis purpurea*L.	Dig.pur	1.000	–	1.000	–	0.689	0.09	Biennial
	*Plantago major*L.	Pla.maj	0.337	0.06	0.362	0.04	0.499	0.13	Perennial
Platanaceae	*Platanus orientalis*L.	Pla.ori	0.075	0.1	1.000	–	1.000	–	Perennial
Pinaceae	*Pinus wallichiana*A.B.Jacks.	Pin.wal	0.165	0.04	0.081	0.22	1.000	–	Perennial
Polygonaceae	*Fagopyrum esculentum*Moench	Fag.esc	1.000	–	1.000	–	0.265	0.14	Annual
	Polygonum amplexicaule D.Don	Pol.amp	1.000	–	1.000	–	0.572	0.45	Perennial
	*Rumex nepalensis*Spreng.	Rum.nep	1.000	–	0.531		0.499		Perennial
Poaceae	*Oplismenus undulatifolius* (Ard.) Roem. &Schult.	Opl.und	0.030	–	0.089	0.27	0.241	0.03	Perennial
	*Poa bulbosa*L.	Poa.bul	1.000	–	1.000	–	0.446	1.08	Annual
	Setaria viridis (L.) P.Beauv.	Sat.vir	1.000	–	1.000	–	0.625	0.04	Annual
	Stipa sibirica(L.) Lam.	Sti.sib	0.085	0.76	0.158	0.09	0.167	0.33	Perennial
Pteridaceae	*Adiantum capillus-veneris* L.	Adi.cap	1.000	–	0.451	0.63	1.000	–	Perennial
Ranunculaceae	*Delphinium roylei*Munz	Del.roy	1.000	–	1.000	–	0.586	0.09	Perennial
	*Ranunculus laetus*Wall. ex Hook. f. & J.W. Thomson	Ran.lae	0.348	0.06	1.000	–	1.000	–	Perennial
Rosaceae	*Crataegus songarica*K. Koch	Cra.son	0.268	0.08	0.248	0.12	1.000	–	Perennial
	Fragaria nubicola(Lindl. ex Hook.f.) Lacaita	Fra.nub	1.000	–	1.000	–	0.093	1.03	Perennial
	*Geum roylei*Wall.	Geu.roy	0.263	0.07	0.508	0.11	0.570	0.11	Perennial
	Potentilla multifida L.	Pot.mul	1.000	–	1.000	–	0.344	0.21	Perennial
	Prunus cerasus L.	Pru.cer	0.288	0.04	1.000	–	1.000	–	Perennial
	Prunus persica(L.) Batsch	Pru.per	0.119	0.09	0.320	0.02	0.199	0.24	Perennial
	Prunus tomentosa Thunb.	Pru.tom	0.015	0.01	1.000	–	0.037	0.02	Perennial
	*Rosa webbiana*Wall. ex Royle	Ros.web	0.061	0.02	0.006	0.04	0.023	0.01	Perennial
	Rubus ellipticus Sm.	Rub.ell	1.000	–	0.019	0.03	1.000	–	Perennial
Sapindaceae	*Acer caesium* Wall. ex Brandis	Ace.cae	1.000	–	1.000	–	0.222	0.2	Perennial
	Acer cappadocicum Gled.	Ace.cap	0.303	0.04	0.253	0.06	1.000	–	Perennial
	Aesculus indica (Wall. ex Cambess.) Hook.	Aes.ind	1.000	–	1.000	–	0.206	0.22	Perennial
Saliaceae	*Populus alba*L.	Pop.alb	1.000	–	0.238	0.06	0.121	0.02	Perennial
	*Salix alba*L.	Sal.alb	1.000	–	0.060	0.74	0.182	0.2	Perennial
Scrophulariaceae	*Verbascum thapsus*L.	Ver.tha	1.000	–	1.000	–	0.642	0.18	Perennial

(*continued on next page*)

Table 1 (*continued*)

Family	Name of species	Species Code	Community-1	A/F ratio	Community-2	A/F ratio	Community-3	A/F ratio	Life span
Simaroubaceae	*Ailanthus altissima* (Mill.) Swingle	Ail.alt	0.199	0.06	0.305	0.04	0.257	0.14	Perennial
Ulmaceae	*Ulmus villosa*Brandis ex Gamble	Ulm.vil	0.046	0.16	0.056	0.03	0.082	0.24	Perennial
Viburnaceae	*Viburnum grandiflorum*Wall. ex DC.	Vib.gra	1.000	–	1.000	–	0.012	0.01	Perennial
Violaceae	*Viola odorata*L.	Vio.ord	0.247	0.07	0.470	0.06	0.319	0.09	Annual
Urticaceae	*Urtica dioica* L.	Urt.dio	1.000	–	0.600	0.18	0.547	0.54	Annual

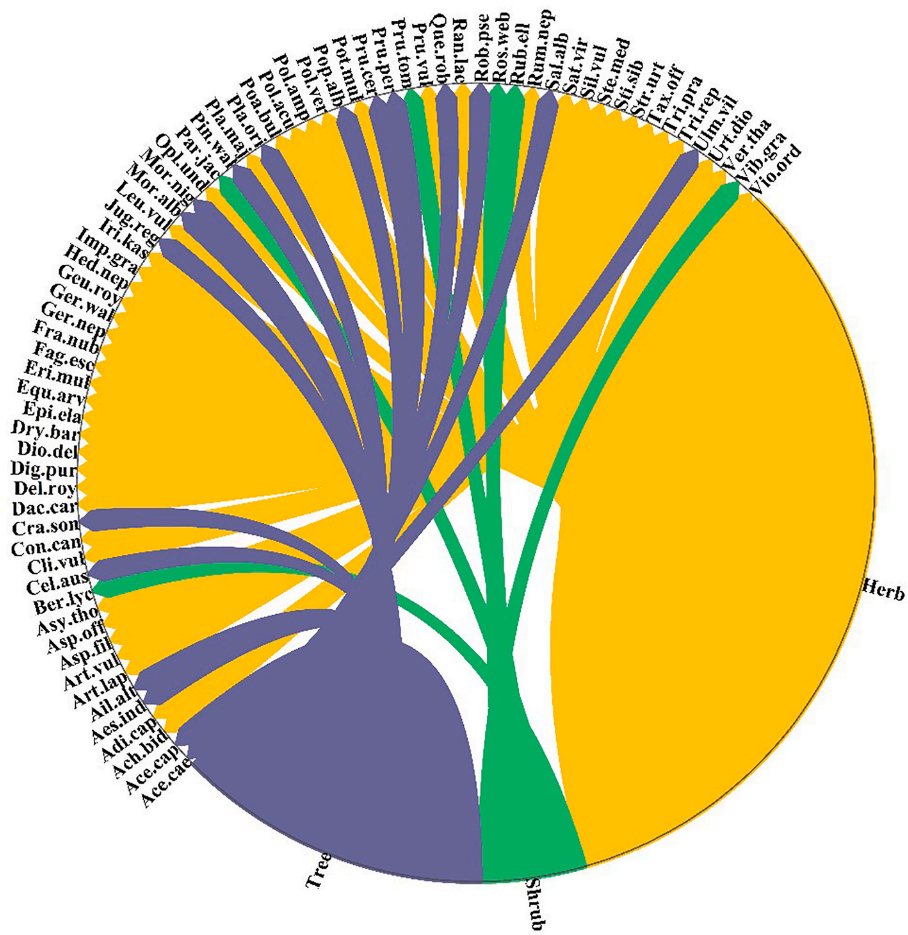

Fig. 2. Chord diagram showing contribution of various life forms in vegetation along the riparian zones in the Zabarwan Range of the Kashmir Himalaya. Full species names can be found in Table 1.

remaining 14% have regular and random distribution patterns (Table 1).

3.2. Diversity attributes

The diversity indices show significant differences in the riparian vegetation of different types of plant communities. With 49 species, the total number of species recorded from Community-3 was higher followed by Community-2 (44 species) and Community-1 (32). Community-1 and Community-3 had the highest dominance index. Compared to Community-2, these two communities were very different. Similar to how riparian community types differ, species evenness also reveals significant differences, with the highest species evenness recorded from Community-1 sampling sites (Fig. 3). Maximum Shannon and Simpson diversity was also observed at Community-2 and Community-3, demonstrating that they are more diverse in vegetation composition.

3.3. Ulmus villosa, Parrotiopsis jacquemontiana and Oplismenus undulatifolius community

The *Ulmus-Parrotiopsis-Oplismenus* community occurred at the lower end of the stream located at an altitude of ca. 16500 m. The tree layer contained 11 species, with *Ulmus villosa* dominating the layer and having the highest IVI value of 70.52. The codominant species in terms of decreasing IVI values were *Platanus orientalis* (57.51), *Celtis australis* (39.45), and *Prunus persica* (32.54). In the shrub layer, three species were discovered. The highest IVI value was 133.65 for *Parrotiopsis jacquemontiana*, followed by *Prunus tomentosa* (101.60) and *Rosa webbiana* (101.60). There were 18 species in the herbaceous layer, and *Oplismenus undulatifolius* had the highest IVI of 87.33. *Stipa sibirica* (47.80), *Impatiens glandulifera* (30.98), and *Iris kashmiriana* (27.49) were among the co-dominant species, while *Daucus carota* (3.30) and *Asparagus filicinus* (4.41) were relatively rare (Fig. 4**)**.

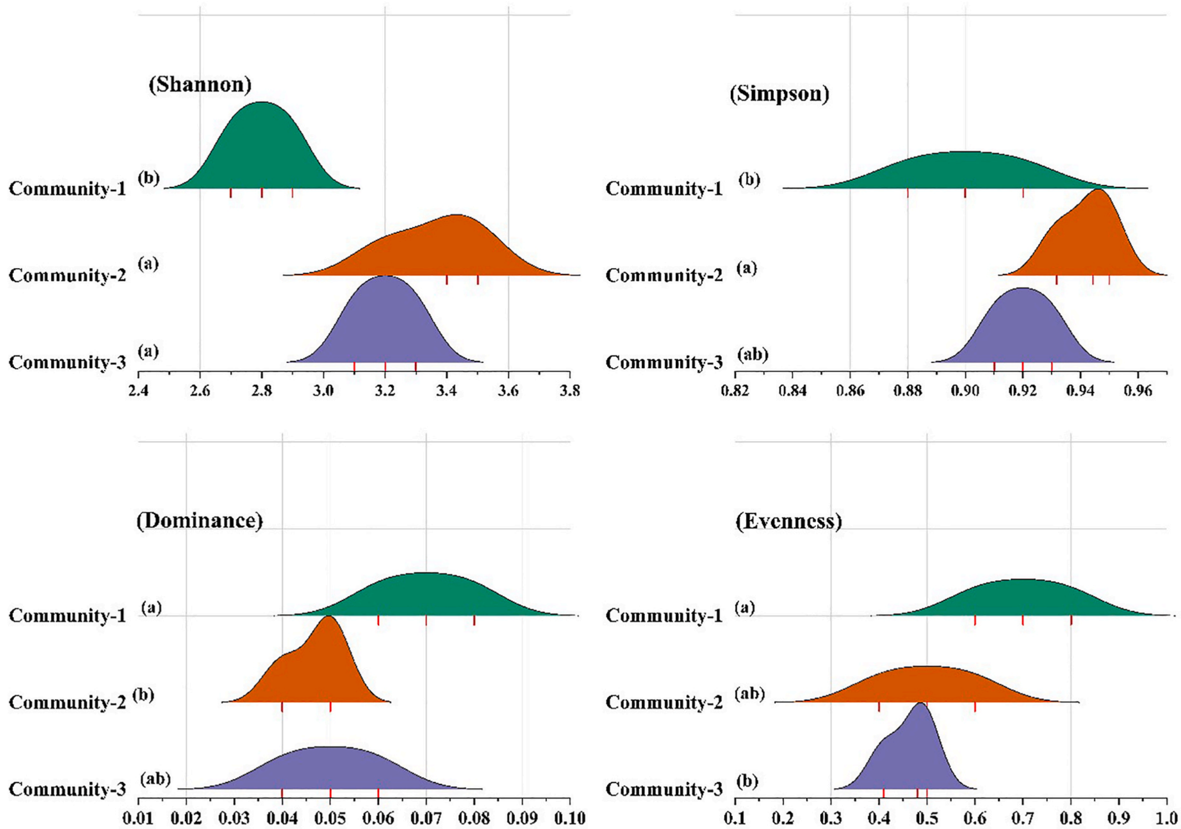

Fig. 3. Diversity profiles of the vegetation community along riparian zones in the Zabarwan Range of the Kashmir Himalayas. The ridgeline diagram depicts the diversity of sampling sites, (lower case letters (a,b) indicate significant difference between different riparian communities determined by the Tukey test.

3.4. *Salix alba, Rosa webbiana and Oplismenus undulatifolius community*

The *Salix-Rosa-Oplismenus* community occurred in the middle of the stream at an altitude of ca. 1750 m. *Salix alba*, the dominant tree with the highest IVI value of 62.75, was among the 11 species that made up the tree layer. *Ulmus villosa* (52.09), *Pinus wallichiana* (42.35), and *Morus alba* (30.28) were the codominant species in terms of decreasing IVI values. Three species were identified in the shrub layer. *Rosa webbiana* had the highest IVI value (122.22), followed by *Rubus ellipticus* (100) and *Berberis lycium* (77.77). *Oplismenus undulatifolius,* the dominant species with the highest IVI of 31.28, was among the 30 species that made up the herbaceous layer. *Strobilanthes urticifolia* (27.20), *Asparagus filicinus* (26.39), and *Stipa sibirica* (23.20) were some of the codominant species, while *Conyza canadensis* (2.86) and *Clinopodium vulgare* (1.75) were relatively rare herbaceous species (Fig. 4).

3.5. *Celtis australis, Viburnum grandiflorum and Fragaria nubicola community*

The *Celtis-Viburnum-Fragaria* community occurred at the higher end of the stream at an altitude of ca. 1850 m. With a total of 13 species in the tree layer, *Celtis australis* was the dominant species and had the highest IVI score (54.90). In terms of declining IVI values, *Juglans regia* (35.93), *Ulmus villosa* (31.52) and *Morus alba* were the codominant species (26.53). The shrub layer contained three species, with *Rosa webbiana* (100.83) and *Prunus tomentosa* having the highest IVI values and *Viburnum grandiflorum* having the lowest 121.94 IVI. The herbaceous layer consisted of 33 species, with *Fragaria nubicola* being the dominant species due to its high IVI of 26.91. Some of the codominant species included *Strobilanthes urticifolia* (24.91), *Equisetum arvense* (22.88), Other species, such as *Setaria viridis* (2.58), *Verbascum thapsus* (1.96), and *Taraxacum officinale* (1.48), were relatively uncommon (Fig. 4).

3.6. DCA ordination of riparian communities

The distribution of various species along the two axes and their relationship to the gradients are shown in a DCA dispersed diagram of species (based on the species score) (Fig. 5). On the extreme top left side of the DCA diagram, the species *Leucanthemum vulgare*, *Stellaria media*, *Clinopodium vulgare*, *Geranium nepalense*, *Asyneuma thomsonii*, *Epimedium elatum, Prunella vulgaris, Rubus ellipticus, Achyranthes bidentate, Berberis lyceum, Adiantum capillus-veneris* and *Asparagus filicinus* suggest a low score on axis 1 and a high score on axis 2. The top right side position in the diagram suggests that *Acer caesium*, *Robinia pseudoacacia*, *Silene vulgaris*, *Digitalis purpurea*, *Asparagus officinalis, Polygonatum verticillatum, Fragaria nubicola, Poa bulbosa, Erigeron multiradiatus, Potentilla multifida, Verbascum thapsus* and *Aesculus indica* have high scores on axes 1 and 2. The close proximity of these species reveals microclimatic variations. *Prunus cerasus, Parrotiopsis jacquemontiana, Geum roylei, Iris kashmiriana, Oplismenus undulatifolius, Ranunculus laetus* and *Platanus orientalis* are examples of species that appear to prefer a semiarid environment on the bottom left side. The species shown in the center of the diagram—*Trifolium pratense, Artemisia vulgaris, Juglans regia, Populus alba, Rumex nepalensis, Geranium wallichianum, Urtica dioica, Strobilanthes urticifolia* and *Celtis australis*—indicate that these species are widespread in nature throughout all communities and do not appear to have a clear preference for particular habitats (Fig. 5). The longest gradient recorded for axis 1 in DCA ordination for species and community types was 1.572, with an eigenvalue of 0.395. The length of the gradient and the eigenvalue of axis 2 were 2.09 and 0.377, respectively.

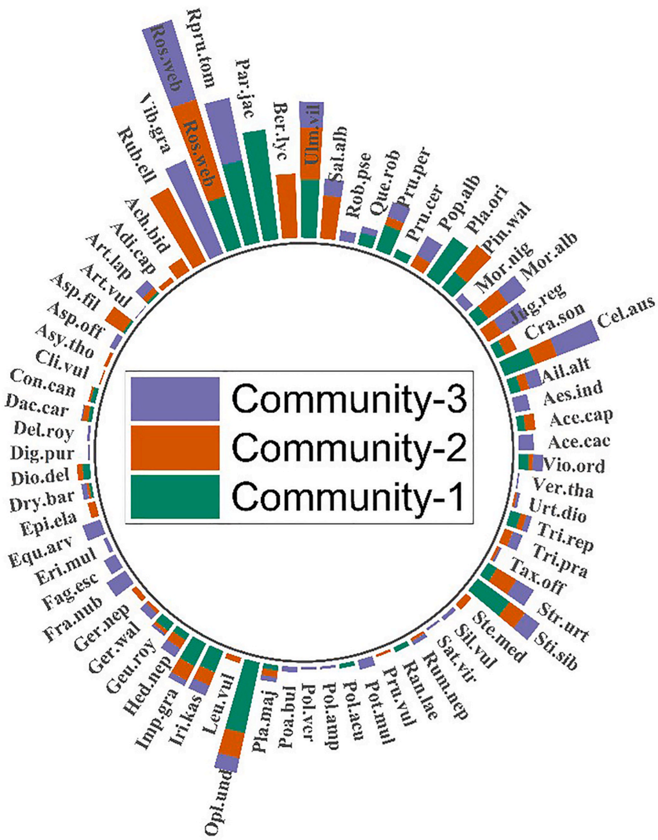

Fig. 4. Radial bar graph showing the Importance Value Index (IVI) of vegetation along the riparian zones in the Zabarwan Range of the Kashmir Himalayas. Table 1 displays the full name of each species.

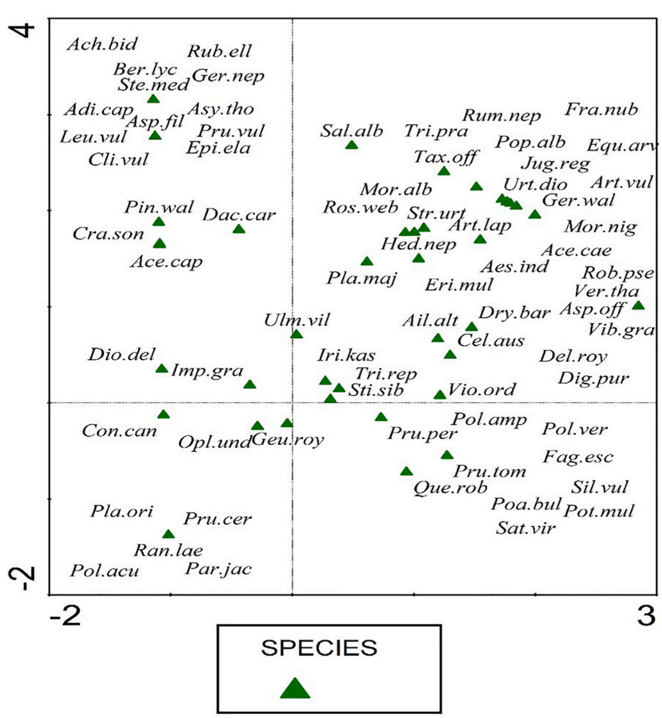

Fig. 5. DCA diagram showing the distribution of vegetation along the riparian zones in the Zabarwan Range of the Kashmir Himalayas. Table 1 displays the full name of each species.

3.7. Indicator species analysis

The results of the analysis of the indicator species of the riparian vegetation showed the distinction of key species in different communities. In Community-1 *Ulmus villosa, Parrotiopsis jacquemontiana, Prunus tomentosa,* and *Oplismenus undulatifolius* have a significant indicator value ($p \leq 0.05$), while in Community-2 *Berberis lycium*, *Rosa webbiana*, *Rubus ellipticus* and *Ulmus villosa* have a significant p-value (Table 1). *Celtis australis*, *Prunus tomentosa, Viburnum grandiflorum,* and *Rosa webbiana* were indicator species of Community-3 (Fig. 6). *Ulmus villosa* is a common indicator species in Community-1 and Community-2, while *Prunus tomentosa* is a common indicator species in Community-3 and Community-1. *Rosa webbiana* was found as indicator species in Community-2 and Community-3 while *Celtis australis* and *Viburnum grandiflorum* restricted to Community-3.

4. Discussion

Riparian forests are incredibly diverse, provide a wide range of ecosystem services, and can be extremely important to the way the forest landscape functions as a link between various forest habitats (Alimpić et al. 2022). Therefore, it is advisable to take into account how riparian forests specifically contribute to connectivity and related landscape management (de la Fuente et al. 2018). The best way to learn about behaviour, habitat, niches, vegetation structure, and various plant interactions in an ecosystem is through the study of plant community associations. In the current study, it was discovered that micro-environmental factors were primarily responsible for the significant differences in vegetation community patterns between the various topographic sites from upstream to downstream sites (Nepal et al. 2018; Ali et al., 2022). The species richness data from the present study, which ranged from 32 to 49, is consistent with the findings of numerous phytosociological studies conducted in the Himalayas (Green et al. 1995; Jansson et al. 2005; Altaf et al. 2022). The riparian area has a wide range of habitats, microclimates, and ecological conditions, which contribute to the high level of species richness in the riparian ecosystem. Herbaceous plants clearly have an advantage over other life forms when they invade new habitats. This may be due to characteristics such as short lifespans, rapid reproductive cycles, large numbers of seeds, small size, easy dispersal (Haq et al. 2022b).

In the riparian zone, three communities were found to accumulate species from 38 different families. Inline are the findings of Yang et al. (2012), who also reported 38 families from the reservoir water level fluctuation zone. The plant distribution at the family level shows similarities with the vegetation communities of Himalayan regions where some workers (Haq et al. 2019c, 2022c, 2022d; Nafeesa et al. 2021) have reported Rosaceae, Asteraceae, Poaceae, and Lamiaceae as the most dominant families. This demonstrates cross-ecosystem connectivity via networks of indicator families or species interactions at the land-water interface, and is an excellent example of connectivity between existing habitats. Inline are the findings of Badry et al. (2019), who identified Rosaceae as the dominant family from the Nile River in Upper Egypt. Furthermore, it was observed that these families dominated the floristic composition along the irrigation and drainage canals. This is explained by their extensive ecological toleration range, efficient seed dispersal abilities, migration effectiveness, and local water depth conditions (Santamaría, 2002). The current study emphasizes the unequal distribution of species across families, with 23 families having only one species, which is comparable to earlier reported values from various riparian vegetation (Badry et al. 2019; Kujur et al. 2022; Haq et al. 2023a). The differences in microhabitat, morphological traits, life span, and dynamic ecological niche explain the great diversity in families (Wu et al. 2022), which demonstrated a heterogeneous distribution of vegetation in riparian zones.

The characteristics of riparian habitats are clearly influenced by anthropogenic disturbance and underlying hydrological factors, which

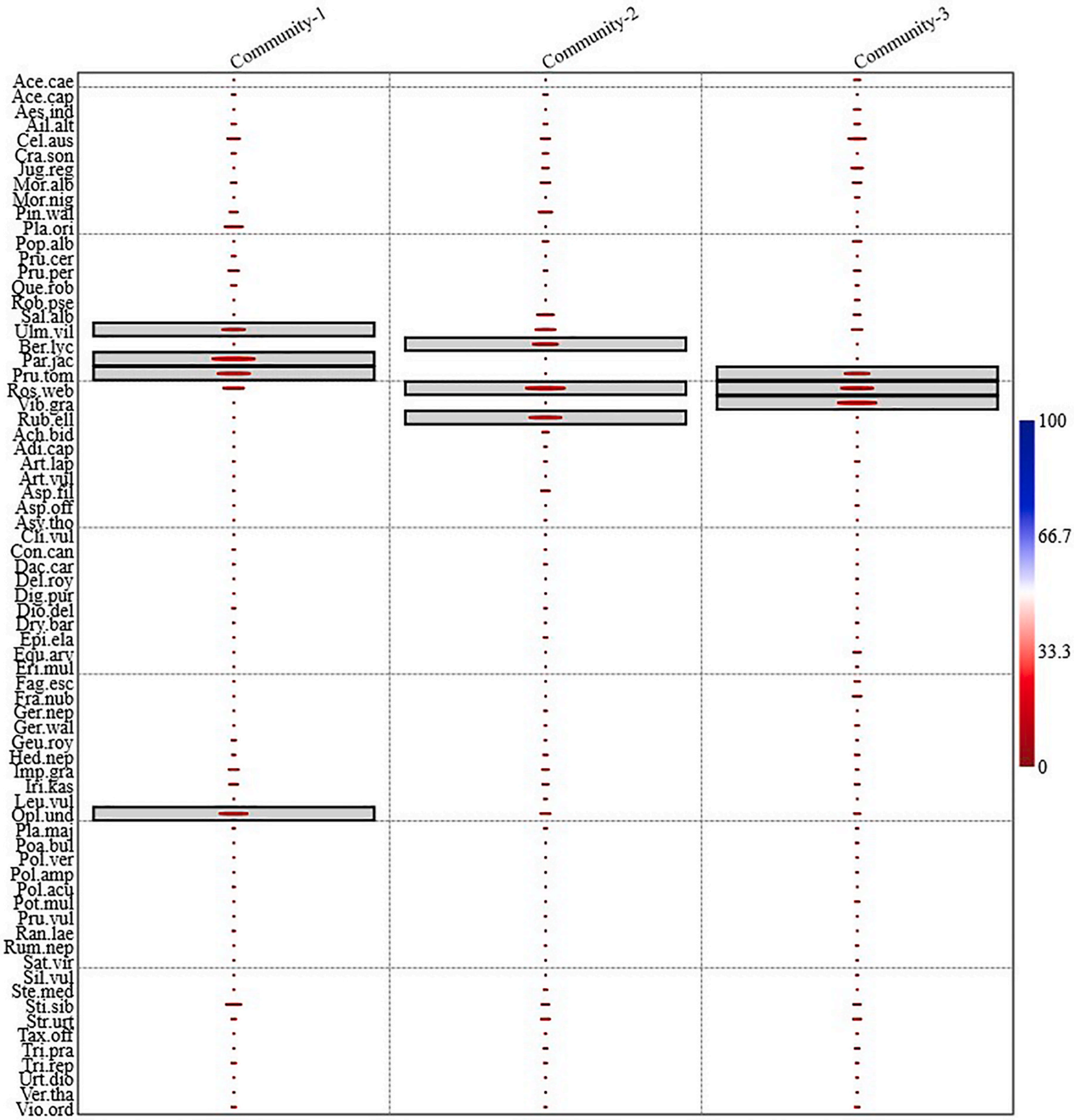

Fig. 6. Graph showing the indicator species in communities with a significant p-value of vegetation along the riparian zones in the Zabarwan Range of the Kashmir Himalayas. Table 1 displays the full name of each species. The bar in the figure shows the indicator species with a significant *p*-value. The bigger the dot, the more significant the *p*-value of the species.

also have an impact on species diversity and riparian vegetation distribution (Fernandes et al. 2011; Khan et al., 2022a, b). Diversity indices show notable variations in riparian vegetation between various types of plant communities. The diversity of plants in the riparian zone is similar to that found in much of the Himalayan region. These recorded diversity values are comparable to those provided by Singh et al. (2016) in the Garhwal Himalaya, Shaheen et al. (2012) in the Pakistan Himalaya and Rawat et al. (2018) in the Eastern Himalayas, Altaf et al. (2022) from the Kashmir Himalaya. Shannon diversity was also seen to be higher at the Community-2 and Community-3 sampling sites, demonstrating that the vegetation there is more diverse. Surface water hydrology is typically regarded as the most important predictor of riparian vegetation diversity. Water dynamics, such as flooding, significantly affect the characteristics of riparian habitat both temporally and spatially (Fraaije et al. 2015; Ali et al. 2022b). This could be due to the high diversity and species richness found at the upper end of the stream. Therefore, the availability of habitat for a variety of plant species can be increased through a management strategy (Haq et al. 2022a, 2022d).

The timing, frequency, and magnitude of flooding events are the main factors in determining community characteristics and can have either positive or negative impacts on the ability of the ecosystem to function, (Guo et al. 2020). Intermittent low-intensity floods are common during the rainy season, with only temporary changes in the floodplain herbaceous community. There have been no long-lasting large floods since 2014 in the river basin, so the woody species community has undergone little structural change in recent years. Our results are further supported by several authors who noted that variations in flooding frequency and duration can change the composition, richness, and diversity of species in only a few meters or even centimeters (Sun et al. 2018). In riparian ecosystems, the distribution of vegetation plays a pivotal role in hydrology (Lu et al. 2021). The complexity and combination of vegetation communities prevail as a result of many factors, including ecosystem services, climate change, and anthropogenic activities (Guo et al. 2019). Disturbances are the main drivers that change the structure of the community, create landscape mosaics, and set the initial stages for successional dynamics and structural development (Haq et al. 2019a). The riparian ecosystems of the region, which host a large number of species, are facing habitat transformations due to human-induced disturbances such as climate change, road construction, fragmentation, and development (Richardson et al. 2007; Ali et al. 2014; Ullah et al., 2022). Due to the deterioration of the road that passes through the area, which is intended to view animals in their natural habitat within the park, the main disturbances along the riparian stretches are caused by tourism activities, particularly in the lower and middle sections of the stream. Furthermore, the small Zoo inside the park meant for the captive breeding program attracts thousands of visitors every year, who throw edibles, leftovers, and wrappers near the stream banks, even into the stream as well, which disturbs the ecological balance at the site to a great extent. Although, as in the upper patches, the disturbance is comparatively less due to the presence of dense forests and the lack of proper passage connectivity. However, certain scholars and researchers go there to carry out various research programs, which cause relatively little disturbance. This is the reason why the upper patch possesses such a high species richness as compared to the rest.

The abundance and frequency (A/F) ratios were used to evaluate the pattern of species distribution, and it shows that most species were widely distributed at the sites. Previous research by Shameem et al. (2010) also described a contagious pattern of distribution. Natural vegetation exhibits a predominance of contagious distribution due to a small but significant variation in environmental conditions, whereas random distribution is only present in extremely uniform environments (Sharma and Sharma, 2022). These findings are further supported by the research by Bhatt and Bankot (2016) and Sharma and Raina (2018), which showed that vegetation has the highest contagious distribution, followed by a regular distribution pattern. Most of the contagious distribution of the Himalayas was found to be the most common (Malik and Bhat, 2015). However, observations indicated that the contagious distribution in the vegetation profile of the riparian flora is correlated with the divergence of factors and showed that the clustering of plant communities from site to site is mainly due to micro-environmental changes. At the lower end, there is a direct impact of the settlement of sediment loading and turbidity; thus, plant communities show a functional relationship between an ecological response and a particular flow alteration. Both natural and anthropogenic disturbances are considered to be one of the controlling factors in plant distribution patterns, along the riparian zones (Ali et al. 2014; Cao and Natuhara, 2019), and a change in plant species composition with respect to disturbance was also observed in the present study. The higher species richness was observed at the upper end of the stream as ecotone was dominated by the *Pinus wallichiana* forest type, while at the lower end broad-leaved tree species (*Populus alba*, *Ulmus villosa*, *Platanus orientalis*, *Celtis australis* and *Prunus persica*) were dominated (Haq et al. 2021a, 2021b; Ali et al. 2018).

The findings of the stand ordination and indicator species analysis suggested that the three types of communities were distinguished by differences in vegetation, and this was corroborated by significantly high indicator values for range of species. *Ulmus villosa* is a common indicator species in Community-1 and Community-2, while *Celtis australis* and *Viburnum grandiflorum* are restricted to Community-3. The different habitat preferences that arise from a species' long-term adaptation to environmental factors may make this possible. A species will evolve to perform better in one habitat than in others when conditions are favourable for a long time (Rivaes et al. 2017). Protecting and/or restoring forest habitats is an essential first step in providing more habitat and thereby increasing species richness. At the lower end of the stream, there is a direct impact of settlement of sediment loading and turbidity; thus, plant communities show functional relationship between an ecological response and a particular flow alteration (Chen et al. 2022). The characteristics of indicator species that were adapted to a high-light environment and flooding disturbance made them desirable for restoration in riparian zones.

5. Conclusions

The analysis of vegetation communities is a crucial step in developing effective resource management strategies that affect the riparian zone. We have listed 71 plant species in the current study, with the Rosaceae family serving as the main family. In particular, in the lower reaches of the stream, tourism-related activities are the main source of disturbance in the riparian areas. The significant indicator value of the riparian vegetation ($p \leq 0.05$) of *Ulmus villosa, Parrotiopsis jacquemontiana, Prunus tomentosa, Rosa webbiana, Celtis australis, Viburnum grandiflorum* and *Oplismenus undulatifolius* revealed the indicator species in various communities along the riparian zones. The degree of similarity and dissimilarity among the plant associations in the riparian zones was determined using the ordination technique. The identified indicator species define the proportionate maximum contribution of various plant species to vegetation associations. These plants can be used for riparian zone restoration because they function best ecologically and have the ability to regenerate in these environments. In order to maintain biodiversity, we propose using a combination of multiple layers and multiple native species in the restoration design. The results of this study contribute to the evaluation of best management practices, and the species found can be used to restore riparian zones in the area, as well as habitats similar to that elsewhere in the world.

Author's contributions

Shiekh Marifatul Haq: Conceptualization, Methodology, Data curation, Formal data analysis, Validation, writing first draft; **Muhammad Shoaib Amjad:** Conceptualization, Methodology, Supervision, Formal data analysis, Project administration; Writing, Reviewing and Editing; **Muhammad Waheed:** Writing, Reviewing and Editing; **Rainer W. Bussmann, Kishwar Ali and David Aaron Jones:** Rewriting, Reviewing and Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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