UNIVERSITY^{OF} BIRMINGHAM University of Birmingham Research at Birmingham

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

Haq, Shiekh Marifatul; Amjad, Muhammad Shoaib; Waheed, Muhammad; Bussmann, Rainer W.; Ali, Kishwar; Jones, David Aaron

DOI: 10.1016/j.indic.2023.100277

License: Creative Commons: Attribution (CC BY)

Document Version Publisher's PDF, also known as Version of record

Citation for published version (Harvard):

Haq, SM, Amjad, MS, Waheed, M, Bussmann, RW, Ali, K & Jones, DA 2023, 'Vegetation communities and identification of indicator species in the riparian areas of Zabarwan mountain range in the Kashmir Himalaya', *Environmental and Sustainability Indicators*, vol. 19, 100277. https://doi.org/10.1016/j.indic.2023.100277

Link to publication on Research at Birmingham portal

General rights

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

•Users may freely distribute the URL that is used to identify this publication.

•Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.

•User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?) •Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

Contents lists available at ScienceDirect



Environmental and Sustainability Indicators

journal homepage: www.sciencedirect.com/journal/environmental-and-sustainability-indicators



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

⁸ College of Health Sciences, University of Doha for Science and Technology, Al Tarafa, Jelaiah Street, Duhail North, PO Box 24449, Doha, Qatar

ARTICLE INFO

Restoration and rehabilitation

Vegetation community

Kashmir Himalaya

Keywords:

Protected forest

Indicator species

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. 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).

https://doi.org/10.1016/j.indic.2023.100277

Received 16 May 2023; Received in revised form 4 July 2023; Accepted 5 July 2023 Available online 6 July 2023

2665-9727/© 2023 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

^{*} Corresponding author. College of General Education, University of Doha for Science and Technology, Al Tarafa, Jelaiah Street, Duhail North, PO Box 24449, Doha, Qatar.

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 (Hag 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 km² and is located between $34^{\circ}05'$ and $34^{\circ}11'$ N and $74^{\circ}54'$ and $75^{\circ}09'$ 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 (Hag 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 m²) plots for shrubs and forty (1 m²) 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 $(40 \times 3 = 120) (1 \text{ m}^2)$ plots for herbs and forty-eight ($16 \times 3 = 48$) (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 ($p \le$ 0.05). The indicator species with the value ($p \le$ 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	Community-	A/F	Community-	A/F	Community-	A/F	Life span
		Code	1	ratio	2	ratio	3	ratio	
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
Aniaceae	Daucus carotal	Dac car	0.395	0.45	0.384	0.06	0.685	0.09	Annual
Asteraceae	Arctium Jappa I	Art lan	0.355	0.45	0.304	0.00	0.365	0.05	Biennial
Isteraceae	Artemicia nulgaris I	Art vul	1 000	0.27	1 000	0.11	0.505	0.00	Derennial
	Comma canadansis (L.) Cropanist	Con can	0.368	-	0.580	-	1 000	0.09	Appual
	Tarayagum officingle (L.) Woher ov E H	Con.can	1.000	0.04	0.580	0.045	1.000	-	Doronnial
	Turaxacum officinale (L.) weber ex F.H.	1ax.011	1.000	-	0.539	0.06	0.020	0.04	Pereimai
	Wigg.	Eri mul	1 000		1 000		0 524	0.72	Doronnial
	Engeron mannaula dunants(Lindi, ex DC.)	EII.IIIUI	1.000	-	1.000	-	0.324	0.72	Pereilillai
	Bentn. &Hook.i.	T	1 000		0.077	0.10	1 000		Description
	Leucantnemum vulgare(valli.) Lam.	Leu.vui	1.000	-	0.377	0.12	1.000	-	Perennial
Asparagaceae	Asparagus filicinus BuchHam. 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 nepalensisK.Koch	Hed.nep	0.308	0.16	0.279	0.04	0.320	0.23	Perennial
Balsaminaceae	Impatiens glanduliferaRoyle	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 elatumC. 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 australisL.	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 deltoideaWall. ex Griseb.	Dio.del	0.318	0.16	0.445	0.11	1.000	-	Perennial
Dryopteridaceae	Dryopteris barbigera(T. Moore ex Hook.)	Dry.bar	0.419	0.27	0.586	0.04	0.475	0.33	Perennial
	Kuntze								
Equisetiaceae	Equisetum arvenseL.	Equ.arv	1.000	_	1.000	_	0.153	0.18	Perennial
Fagaceae	Quercus roburL.	Oue.rob	0.189	0.1	1.000	_	0.409	0.02	Perennial
Fabaceae	Robinia pseudoacacial.	Rob.nse	1.000	_	1.000	_	0.290	0.1	Perennial
	Trifolium pratensel.	Tri pra	1.000	_	0.292	0.12	0.332	0.78	Perennial
	Trifolium repensl	Tri ren	0.208	0.32	0.381	0.12	0.462	0.36	Perennial
Geraniaceae	Coranium nepalenseSweet	Gernen	1 000	0.02	0.415	0.05	1.000	-	Derennial
Geralliaceae	Coronium wallichianumD Don or Sweet	Ger.nep	1.000	-	0.413	0.05	0.280	-	Perennial
Hamamelidaceae	Berunium wallenlandn.Doll ex Sweet	Ger.war	0.001	-	1.000	0.11	1.000	0.0	Pereililla
	Parrouopsis jacquemonuana (Deche.)	Par.jac	0.001	0.02	1.000	-	1.000	-	Perenniai
Tuidaaaaa	Kelluel Iria hashminian aBalsan	Tui leas	0.1.40	0.25	0.017	0.16	0.077	0.11	Donomial
Indaceae	Ins kushminunubaker	In.kas	0.142	0.25	0.217	0.10	0.277	0.11	Pereililiai
Jugiandaceae	Jugians regial.	Jug.reg	1.000	-	0.194	0.02	0.068	0.02	Perennial
Lamiaceae	Clinopodium vulgareL.	Cli.vul	1.000	-	0.612	0.09	1.000	-	Perennial
	Prunella vulgarisL.	Pru.vul	1.000	-	0.537	0.06	1.000	-	Perennial
Moraceae	Morus albaL.	Mor.alb	0.172	0.12	0.103	0.04	0.106	0.1	Perennial
	Morus nigraL.	Mor.nig	1.000	-	1.000	-	0.373	0.04	Perennial
Plantaginaceae	Digitalis purpureaL.	Dig.pur	1.000	-	1.000	-	0.689	0.09	Biennial
	Plantago majorL.	Pla.maj	0.337	0.06	0.362	0.04	0.499	0.13	Perennial
Platanaceae	Platanus orientalisL.	Pla.ori	0.075	0.1	1.000	-	1.000	-	Perennial
Pinaceae	Pinus wallichianaA.B.Jacks.	Pin.wal	0.165	0.04	0.081	0.22	1.000	-	Perennial
Polygonaceae	Fagopyrum esculentumMoench	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 nepalensisSpreng.	Rum.nep	1.000	_	0.531		0.499		Perennial
Poaceae	Oplismenus undulatifolius (Ard.) Roem.	Opl.und	0.030	_	0.089	0.27	0.241	0.03	Perennial
	&Schult.	•							
	Poa bulbosal.	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
Dteridaçõa	Sting sibirica(L.) Lam	Sti sib	0.085	0.76	0.158	0.09	0.167	0.33	Derennial
	A diantum capillus vonoris I	Adiaan	1 000	0.70	0.138	0.09	1 000	0.55	Doronnial
	Addududin capillas-veneris L.	Aut.cap	1.000	-	1,000	0.05	1.000	-	Pereililla
Ranunculaceae	Deipninium royleimunz	Del.roy	1.000	-	1.000	-	0.586	0.09	Perennial
	Ranunculus idetus vali. ex Hook. I. & J.W.	Ran.lae	0.348	0.06	1.000	-	1.000	-	Perennial
	Thomson								
Rosaceae	Crataegus songaricaK. Koch	Cra.son	0.268	0.08	0.248	0.12	1.000	-	Perennial
	Fragaria nubicola(Lindl. ex Hook.f.)	Fra.nub	1.000	-	1.000	-	0.093	1.03	Perennial
	Lacaita								
	Geum royleiWall.	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 webbianaWall. ex Rovle	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
apinalcac	Acer cannadocicum Cled	Acecan	0 303	0.04	0.253	0.06	1 000	-	Doronnial
	Assentus indica (Wall as Combose) Heal-	Acc.cap	1 000	0.04	1 000	0.00	0.206	-	Dereppiel
Calingona	Dopulus albal	Don all	1,000	-	1.000	-	0.200	0.22	Porenai-1
запасеае	Popullis albai.	Pop.aid	1.000	-	0.238	0.00	0.121	0.02	Perennial
	Salix albaL.	Sal.alb	1.000	-	0.060	0.74	0.182	0.2	Perennial
scrophulariaceae	verbascum thapsusL.	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 villosaBrandis ex Gamble	Ulm.vil	0.046	0.16	0.056	0.03	0.082	0.24	Perennial
Viburnaceae	Viburnum grandiflorumWall. ex DC.	Vib.gra	1.000	-	1.000	-	0.012	0.01	Perennial
Violaceae	Viola odorataL.	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 ($p \le 0.05$), 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-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 (Hag 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.

Acknowledgements

The publication of this article was funded by Qatar National Library.

References

- Ali, K., Khan, N., Rahman, I.U., Khan, W., Ali, M., Uddin, N., Nisar, M., 2018. The ethnobotanical domain of the Swat Valley, Pakistan. J. Ethnobiol. Ethnomed. 14, 39. https://doi.org/10.1186/s13002-018-0237-4.
- Ali, K., Ahmad, H., Khan, N., Jury, S., 2014. Future of *Abies pindrow* in Swat district, northern Pakistan. J. For. Res. 25, 211–214. Link: https://link.springer.com/article /10.1007/s11676-014-0446-1.
- Ali, K., Khan, N., Ullah, R., Gul, A., Khan, M.E.H., Jones, D.A., Ashraf, A., 2022b. Spatial distribution and invasion potential of the naturalized downy thorn apple (*Datura innoxia*): evidence from classification and ordination. Sustainability 14, 10214. https://doi.org/10.3390/su141610214.
- Ali, K., Khan, N., Ullah, R., Shah, M., Khan, M.E.H., Jones, D.A., Dewidar, M., 2022 a. Spatial pattern and key environmental determinants of vegetation in sand mining and non-mining sites along the panjkora river basin. Land 11, 1801. https://doi.org/ 10.3390/land11101801.
- Alimpić, F., Milovanović, J., Pielech, R., Hinkov, G., Jansson, R., Dufour, S., Beza, M., Bilir, N., del Blanco, L.S., Božič, G., Bruno, D., 2022. The status and role of genetic diversity of trees for the conservation and management of riparian ecosystems: a European experts' perspective. J. Appl. Ecol. 59 (10), 2476–2485.
- Altaf, A., Haq, S.M., Shabnum, N., Jan, H.A., 2022. Comparative assessment of phyto diversity in tangmarg forest division in Kashmir Himalaya, India. Acta Ecol. Sin. 42 (6), 609–615.

Assal, T.J., Steen, V.A., Caltrider, T., Cundy, T., Stewart, C., Manning, N., Anderson, P.J., 2021. Monitoring long-term riparian vegetation trends to inform local habitat management in a mountainous environment. Ecol. Indicat. 127, 107807.

- Badry, M.O., Radwan, T.A., Ayed, F.A., Sheded, M.G., 2019. Floristic diversity of riparian plants in Aswan Reservoir at the extreme south of the River Nile, Upper Egypt: a closed ecological system. Biosci. Biotechnol. Res. Asia. 16 (3), 595–609.
- Bertora, A., Grosman, F., Sanzano, P., Rosso, J.J., 2022. Combined effects of urbanization and longitudinal disruptions in riparian and in-stream habitat on water quality of a prairie stream. Knowl. Manag. Aquat. Ecosyst. 423, 15.
- Bhatt, A., Bankot, N.S., 2016. Analysis of forest vegetation in pithoragarh Kumaun Himalayas, Uttrakhand, India. IJCMAS 5, 784–793.
- Bridson, D., Forman, L., 1999. The Herbarium Handbook-Reprinted, third ed. Royal Botanic Gardens, Kew, p. 4 (Edi.
- Cao, Y., Natuhara, Y., 2019. Effect of urbanization on vegetation in riparian area: plant communities in artificial and semi-natural habitats. Sustainability 12 (1), 204.
- Chen, H., Zhang, S., Lv, X., Guo, S., Ma, Y., Han, B., Hu, X., 2022. Interactions between suspended sediments and submerged macrophytes-epiphytic biofilms under water flow in shallow lakes. Water Res. 222, 118911.
- de la Fuente, B., Mateo-Sánchez, M.C., Rodríguez, G., Gastón, A., de Ayala, R.P., Colomina-Pérez, D., Melero, M., Saura, S., 2018. Natura 2000 sites, public forests and riparian corridors: the connectivity backbone of forest green infrastructure. Land Use Pol. 75, 429–441.
- Del Tánago, M.G., Martínez-Fernández, V., Aguiar, F.C., Bertoldi, W., Dufour, S., de Jalón, D.G., Garófano-Gómez, V., Mandzukovski, D., Rodríguez-González, P.M., 2021. Improving river hydromorphological assessment through better integration of riparian vegetation: scientific evidence and guidelines. J. Environ. Manag. 292, 112730.
- Dufrêne, M., Legendre, P., 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. 67 (3), 345–366.
- Fernandes, M.R., Aguiar, F.C., Ferreira, M.T., 2011. Assessing riparian vegetation structure and the influence of land use using landscape metrics and geostatistical tools. Landsc. Urban Plann. 99 (2), 166–177.
- Fraaije, R.G., ter Braak, C.J., Verduyn, B., Verhoeven, J.T., Soons, M.B., 2015. Dispersal versus environmental filtering in a dynamic system: drivers of vegetation patterns and diversity along stream riparian gradients. J. Ecol. 103 (6), 1634–1646.
- George, M.R., Jackson, R.D., Boyd, C.S., Tate, K.W., 2011. A scientific assessment of the effectiveness of riparian management practices. In: Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps, pp. 213–252.
- Giraldo, L.P., Chará, J., Calle D, Z., Chará-Serna, A.M., 2022. Riparian forests: longitudinal biodiversity islands in agricultural landscapes. In: Biodiversity Islands: Strategies for Conservation in Human-Dominated Environments. Springer, Cham, pp. 139–156.
- Graziano, M.P., Deguire, A.K., Surasinghe, T.D., 2022. Riparian buffers as a critical landscape feature: insights for riverscape conservation and policy renovations. Diversity 14 (3), 172.
- Green, D.M., Kauffman, J.B., 1995. Succession and livestock grazing in a northeastern Oregon riparian ecosystem. Rangeland Ecolo. Manag. J. Range Manag. Archiv. 48 (4), 307–313.
- Guo, C., Chen, Y., Liu, H., Lu, Y., Qu, X., Yuan, H., Lek, S., Xie, S., 2019. Modelling fish communities in relation to water quality in the impounded lakes of China's South-to-North Water Diversion Project. Ecol. Model. 397, 25–35.
- Guo, K., Wu, N., Manolaki, P., Baattrup-Pedersen, A., Riis, T., 2020. Short-period hydrological regimes override physico-chemical variables in shaping stream diatom traits, biomass and biofilm community functions. Sci. Total Environ. 743, 140720.
- Haq, S.M., Rashid, I., Khuroo, A.A., Malik, Z.A., Malik, A.H., 2019a. Anthropogenic disturbances alter community structure in the forests of Kashmir Himalaya. Trop. Ecol. https://doi.org/10.1007/s42965-019-00001-8 (in press).
- Haq, S.M., Amjad, M.S., Waheed, M., Bussmann, R.W., Proćków, J., 2022a. The floristic quality assessment index as ecological health indicator for forest vegetation: a case study from Zabarwan Mountain Range, Himalayas. Ecol. Indicat. 145, 109670.
- Haq, S.M., Malik, A.H., Khuroo, A.A., Rashid, I., 2019b. Floristic composition and biological spectrum of Keran-a remote valley of northwestern Himalaya. Acta Ecol. Sin. 39 (5), 372–379.
- Haq, S.M., Malik, Z.A., Rahman, I.U., 2019c. Quantification and characterization of vegetation and functional trait diversity of the riparian zones in protected forest of Kashmir Himalaya, India. Nord. J. Bot. 37 (11).
- Haq, S.M., Shah, A.A., Yaqoob, U., Hassan, M., 2021a. Floristic quality assessment index of the dagwan stream in dachigam national park of Kashmir Himalaya. Proc. Natl. Acad. Sci. India B Biol. Sci. 91 (3), 657–664.
- Haq, S.M., Singh, B., Bashir, F., Farooq, A.J., Singh, B., Calixto, E.S., 2021b. Exploring and understanding the floristic richness, life-form, leaf-size spectra and phenology of plants in protected forests: a case study of Dachigam National Park in Himalaya, Asia. Acta Ecol. Sin. 41 (5), 479–490.
- Haq, S.M., Tariq, A., Li, Q., Yaqoob, U., Majeed, M., Hassan, M., Fatima, S., Kumar, M., Bussmann, R.W., Moazzam, M.F.U., Aslam, M., 2022b. Influence of edaphic properties in determining forest community patterns of the Zabarwan mountain range in the Kashmir Himalayas. Forests 13 (8), 1214.
- Haq, S.M., Waheed, M., Bussmann, R.W., Arshad, F., 2022c. Vegetation composition and ecological characteristics of the forest in the shawilks mountain range from western Himalayas. Acta Ecol. Sin. https://doi.org/10.1016/j.chnaes.2022.10.008.
- Haq, S.M., Khoja, A.A., Lone, F.A., Waheed, M., Bussmann, R.W., Mahmoud, E.A., Elansary, H.O., 2023a. Floristic composition, life history traits and phytogeographic distribution of forest vegetation in the Western Himalaya. Front. Forests. Global Change. 6, 1169085.

- Haq, S.M., Waheed, M., Khoja, A.A., Amjad, M.S., Bussmann, R.W., Ali, K., Jones, D.A., 2023. Measuring forest health at stand level: a multi-indicator evaluation for use in adaptive management and policy. Ecol. Indicat. 150, 110225.
- Haq, S.M., Yaqoob, U., Hamid, S., Hassan, M., Bashir, F., Waheed, M., Bussmann, R.W., 2022d. Localized impact of livestock settlements on vegetation patterns in fir forests of Kashmir Himalaya. Acta Ecol. Sin. 42 (4), 407–416.
- Jamil, M.D., Waheed, M., Akhtar, S., Bangash, N., Chaudhari, S.K., Majeed, M., Hussain, M., Ali, K., Jones, D.A., 2022. Invasive plants diversity, ecological status, and distribution pattern in relation to edaphic factors in different habitat types of district mandi Bahauddin, Punjab, Pakistan. Sustainability 14, 13312. https://doi. org/10.3390/su142013312.
- Jansson, R., Zinko, U., Merritt, D.M., Nilsson, C., 2005. Hydrochory increases riparian plant species richness: a comparison between a free-flowing and a regulated river. J. Ecol. 93 (6), 1094–1103.
- Khan, N., Khan, J., Ullah, R., Ali, K., Jones, D.A., Khan, M.E.H., 2022 b. Heavy metals Contaminants in watercress (*Nasturtium officinale* R. BR.): toxicity and risk assessment for humans along the swat river basin, Khyber pakhtunkhwa, Pakistan. Sustainability 14, 4690. https://doi.org/10.3390/su14084690.
- Khan, N., Ullah, R., Ali, K., Jones, D.A., Khan, M.E.H., 2022 a. Invasive milk thistle (*Silybum marianum* (L.) Gaertn.) causes habitat homogenization and affects the spatial distribution of vegetation in the semi-arid regions of northern Pakistan. Agriculture 12, 687. https://doi.org/10.3390/agriculture12050687.
- Khan, V.A., Haq, S.M., Yaqoob, U., Bashir, F., Hassan, M., 2022. Carbon stock availability in forests of the Zabarwan mountain range in Kashmir Himalaya. Proc. Natl. Acad. Sci. India B Biol. Sci. 92 (4), 861–867.
- Kujur, E., Jhariya, M.K., Yadav, D.K., Banerjee, A., 2022. Phytosociological attributes and regeneration potential of riparian vegetation in Northern Chhattisgarh, India. Environ. Dev. Sustain. 24 (2), 2861–2886.
- La Notte, A., D'Amato, D., Mäkinen, H., Paracchini, M.L., Liquete, C., Egoh, B., Geneletti, D., Crossman, N.D., 2017. Ecosystem services classification: a systems ecology perspective of the cascade framework. Ecol. Indicat. 74, 392–402.
- Lin, Q., Zhang, K., McGowan, S., Capo, E., Shen, J., 2021. Synergistic impacts of nutrient enrichment and climate change on long-term water quality and ecological dynamics in contrasting shallow-lake zones. Limnol. Oceanogr. 66 (9), 3271–3286.
- Liu, Y., Tian, Y., Gao, Y., Cui, D., Zhang, W., Jiao, Z., Yao, F., Zhang, Z., Yang, H., 2022. The impacts of different anthropogenic disturbances on macroinvertebrate community structure and functional traits of Glacier-fed streams in the tianshan mountains. Water 14 (8), 1298.
- Lu, Z., Feng, Q., Xiao, S., Xie, J., Zou, S., Yang, Q., Si, J., 2021. The impacts of the ecological water diversion project on the ecology-hydrology-economy nexus in the lower reaches in an inland river basin. Resour. Conserv. Recycl. 164, 105154.
- Majumdar, A., Shrivastava, A., Sarkar, S.R., Sathyavelu, S., Barla, A., Bose, S., 2020. Hydrology, sedimentation and mineralisation: a wetland ecology perspective. Clim. Chang. Environ. Sustain 8, 134–151.
- Malik, M.I., Bhat, M.S., 2015. Sustainability of tourism development in Kashmir—is paradise lost? Tourism Manag. Perspect. 16, 11–21.
- Měkotová, J., Šarapatka, B., Štěrba, O., Harper, D., 2006. Restoration of a river landscape: Biotopes as a basis for quantification of species diversity and evaluation of landscape quality. Ecohydrol. Hydrobiol. 6, 43–51.
- Nafeesa, Z., Haq, S.M., Bashir, F., Gaus, G., Mazher, M., Anjum, M., Rasool, A., Rashid, N., 2021. Observations on the floristic, life-form, leaf-size spectra and habitat diversity of vegetation in the Bhimber hills of Kashmir Himalayas. Acta Ecol. Sin. 41 (3), 228–234.
- Naiman, R.J., Decamps, H., 1997. The ecology of interfaces: riparian zones. Annu. Rev. Ecol. Evol. Syst. 28, 621–658.
- Nepal, S., Pandey, A., Shrestha, A.B., Mukherji, A., 2018. Revisiting Key Questions Regarding Upstream–Downstream Linkages of Land and Water Management in the Hindu Kush Himalaya (HKH) Region. Himalayan Adaptation. Water and Resilience Research (HI AWARE) Kathmandu, Nepal.
- Nunes, S., Barlow, J., Gardner, T., Sales, M., Monteiro, D., Souza Jr., C., 2019. Uncertainties in assessing the extent and legal compliance status of riparian forests in the eastern Brazilian Amazon. Land Use Pol. 82, 37–47.
- O'Hare, M.T., Baattrup-Pedersen, A., Baumgarte, I., Freeman, A., Gunn, I.D., Lázár, A.N., Sinclair, R., Wade, A.J., Bowes, M.J., 2018. Responses of aquatic plants to
- eutrophication in rivers: a revised conceptual model. Front. Plant Sci. 9, 451. Olson, D.H., Anderson, P.D., Frissell, C.A., Welsh Jr., H.H., Bradford, D.F., 2007. Biodiversity management approaches for stream–riparian areas: perspectives for Pacific Northwest headwater forests, microclimates, and amphibians. For. Ecol. Manag. 246 (1), 81–107.
- Pastor, A.V., Tzoraki, O., Bruno, D., Kaletová, T., Mendoza-Lera, C., Alamanos, A., Brummer, M., Datry, T., De Girolamo, A.M., Jakubínský, J., Logar, I., 2022. Rethinking ecosystem service indicators for their application to intermittent rivers. Ecol. Indicat. 137, 108693.
- Rahman, I.U., Hart, R.E., Ijaz, F., Afzal, A., Iqbal, Z., Calixto, E.S., Abd_Allah, E.F., Alqarawi, A.A., Hashem, A., Al-Arjani, A.B.F., Kausar, R., 2022. Environmental variables drive plant species composition and distribution in the moist temperate forests of Northwestern Himalaya, Pakistan. PLoS One 17 (2), e0260687.
- Ramaano, A.I., 2022. Geographical information systems in sustainable rural tourism and local community empowerment: a natural resources management appraisal for Musina Municipality'Society. Local Dev. Soc. 1–32.
- Rawat, D.S., Dash, S.S., Sinha, B.P., Kumar, V., Banerjee, A., Singh, P., 2018. Community structure and regeneration status of tree species in Eastern Himalaya: a case study from Neora Valley National Park, West Bengal, India. Taiwania 63 (1), 16–24.
- Richardson, D.M., Holmes, P.M., Esler, K.J., Galatowitsch, S.M., Stromberg, J.C., Kirkman, S.P., Pyšek, P., Hobbs, R.J., 2007. Riparian vegetation: degradation, alien plant invasions, and restoration prospects. Divers. Distrib. 13 (1), 126–139.

S.M. Haq et al.

- Rivaes, R., Boavida, I., Santos, J.M., Pinheiro, A.N., Ferreira, T., 2017. Importance of considering riparian vegetation requirements for the long-term efficiency of environmental flows in aquatic microhabitats. Hydrol. Earth Syst. Sci. 21 (11), 5763–5780.
- Rouquette, J.R., Dallimer, M., Armsworth, P.R., Gaston, K.J., Maltby, L., Warren, P.H., 2013. Species turnover and geographic distance in an urban river network. Divers. Distrib. 19, 1429–1439.
- Santamaría, L., 2002. Why are most aquatic plants widely distributed? Dispersal, clonal growth and small-scale heterogeneity in a stressful environment. Acta Oecol. 23 (3), 137–154.
- Shaheen, H., Ullah, Z., Khan, S.M., Harper, D.M., 2012. Species composition and community structure of western Himalayan moist temperate forests in Kashmir. For. Ecol. Manag. 278, 138–145.
- Shameem, S.A., Soni, P., Bhat, G.A., 2010. Comparative study of herb layer diversity in lower dachigam national park, Kashmir Himalaya, India. Int. J. Biodivers. Conserv. 2, 308–315.
- Sharma, J., Raina, A.K., 2018. Quantitative analysis, distributional pattern and species diversity of woody plant species of Lamberi Forest range, Rajouri, J& K, India. J Nat Appl Sci 10 (1), 522–527.
- Sharma, A., Sharma, N., 2022. Structure, pattern, and composition of riparian vegetation in north-western Himalayas, India. In: Land Degradation Neutrality: Achieving SDG 15 by Forest Management. Springer, Singapore, pp. 249–275.
- Singh, S., Malik, Z.A., Sharma, C.M., 2016. Tree species richness, diversity, and regeneration status in different oak (Quercus spp.) dominated forests of Garhwal Himalaya, India. J. Asia Pac. Bus. 9 (3), 293–300.

- Sun, R., Luo, X., Meng, X., Wang, Y., 2018. Spatial pattern of riparian plants along stream order among mountain rivers in China. J. Water. Clim. Change. 9 (2), 322–330.
- Ter Braak, C.J.F., Smilauer, P., 2002. CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5). Microcomputer Power, Ithaca, New York, p. 500. http://www.canoco.com.
- Ullah, R., Khan, N., Hewitt, N., Ali, K., Jones, D.A., Khan, M.E.H., 2022. Invasive species as rivals: invasive potential and distribution pattern of Xanthium strumarium L. Sustainability 14, 7141. https://doi.org/10.3390/su14127141.
- Waheed, M., Haq, S.M., Arshad, F., Bussmann, R.W., Ali, H.M., Siddiqui, M.H., 2023. Phyto-ecological distribution patterns and identification of alien invasive indicator species in relation to edaphic factors from semi-arid region. Ecol. Indicat. 148, 110053.
- Whitford, P.B., 1949. Distribution of woodland plants in relation to succession and clonal growth. Ecology 30 (2), 199–208.
- Wu, G., Chen, D., Zhou, Z., Ye, Q., Baselga, A., Liu, H., Wen, Y., Nong, S., 2022. Climatic niche divergence explains angiosperm diversification across clades in China. J. Systemat. Evol.
- Yang, F., Liu, W.W., Wang, J., Liao, L., Wang, Y., 2012. Riparian vegetation's responses to the new hydrological regimes from the Three Gorges Project: Clues to revegetation in reservoir water-level-fluctuation zone. Acta Ecol. Sin. 32 (2), 89–98.
- Zhu, K., Li, W., Yang, S., Ran, Y., Lei, X., Ma, M., Wu, S., Huang, P., 2022. Intense wet-dry cycles weakened the carbon sequestration of soil aggregates in the riparian zone. Catena 212, 106117.