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The floristic quality assessment index as ecological health indicator for forest vegetation: A case study from Zabarwan Mountain Range, Himalayas

Shiekh Marifatul Haq [a], Muhammad Shoaib Amjad [b,c,*], Muhammad Waheed [d], Rainer W. Bussmann [a,e], Jarosław Proćków [f,*]

[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] Department of Geography, Earth and Environmental Sciences, 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] Department of Plant Biology, Institute of Environmental Biology, Wrocław University of Environmental and Life Sciences, Kożuchowska 5b, 51-631 Wrocław, Poland

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ABSTRACT

Evaluations ecosystem health-based field studies can assist decision-makers in formulating more targeted conservation policies to better manage ecosystems and landscape. To analyze forest characteristics in the Zabarwan Mountain Range we used the Floristic Quality Assessment Index (FQAI) technique to evaluate the ecosystem health status of the vegetation. According to our findings, the forest area showed an FQAI rating of 61.41. The FQAI ranked 54 of the plant species growing in the forest region at 0, 30 species at 1–3, 51 species at 4–6, 30 species at 7–8, and 17 species at 9–10. Of the 54 alien species ranking 0, thirteen species were invasive, 36 were naturalized, and five were casual. Amoung the forest types, the Broadleaved forest harbored most alien species (35%) and the scrub forest the least (6%). Based on habitat-wise distribution, the largest (38%) species pool was observed in natural forest habitats, while human-modified habitat types harbord 51% of species. Roadsides exhibited the by far highest alien species number (45%) together with other anthropogenic habitats. The investigation of indicator species revealed a separation between the various ranking groups, as evidenced by high indicator values. Important alien indicator species ranking 0 were i.e., *Aesculus indica, Ailanthus altissima, Celtis australis, Daucus carota, Poa bulbosa, Prunus armeniaca, Prunus cerasus, Quercus robur,* and *Salix alba,* which showed a significant p-value for indicator species analysis. The findings of this study provide a method for measuring vegetation communities' responses to alien invasions and as a result can serve for developing management methods to preserve ecosystems, particularly in protected areas, from this biodiversity threat.

1. Introduction

Ecosystem health is one of the most crucial concerns in ecosystem management and a significant element of ecosystem evaluation. A healthy ecosystem should be able to sustain and regenerate itself in addition to being self-active (Shu et al., 2021). Invasive alien plants (IAPs) have been shown to have significant negative ecological consequences on the overall stability of regional ecosystems (Rashid et al., 2021), altering ecosystem processes and species diversity (Powell et al., 2011), changeing native plant communities (Lazzaro et al., 2000; Vecchio et al., 2015; Vujanović et al., 2022), affecting food web structure (McCary et al., 2016), changeing soil microbial communities (Ricketts et al., 2018), affecting hydrology (Kolka et al., 2018), and disrupting nutrient availability and cycling (Weidenhamer and Callaway, 2010), ultimately leading to community-level effects on successional trajectories (Bowen and Stevens, 2018). They also impact native flora and fauna (Savage and Rieske, 2018; Montecchiari et al., 2020; Lenda et al., 2019; Kuebbing et al., 2014) often resulting in a variety of cascading effects (Kenis et al., 2017). Mountain forests, even in protected areas, are increasingly invaded by a wide variety of alien species, including both woody and herbaceous plants (Wavrek et al., 2017; Haq et al., 2021a,b,c). Although the proportion of invasive plants in the forest ecosystems is

* Corresponding authors at: Department of Botany, Women University of Azad Jammu & Kashmir, Bagh 12500, Pakistan (M.S. Amjad) and Department of Plant Biology, Institute of Environmental Biology, Wrocław University of Environmental and Life Sciences, Poland (J. Proćków).

E-mail addresses: marifat.edu.17@gmail.com (S.M. Haq), malikshoaib1165@yahoo.com (M.S. Amjad), F19-PhD-Bot-5013@uo.edu.pk (M. Waheed), rainer.bussmann@iliauni.edu.ge, rainer.bussmann@smnk.de (R.W. Bussmann), jaroslaw.prockow@upwr.edu.pl (J. Proćków).

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relatively small as compared to other terrestrial ecosystems (Essl et al., 2012), the prevalence of plant invasions in forest habitats is growing at an alarming rate (Martin et al., 2009). These invasions are mostly an effect of anthropogenic disturbances, roads and pedestrian trails which act as important corridors for the spread of invasive alien species (Karr et al., 2018). Such ruderal habitats typically tend to harbor disturbance tolerant and generalist alien plant species,which often act as a propagule source, spreading across the natural landscapes of adjoining areas affecting ecosystem functioning (Karr et al., 2018). Therefore, compared to interior core forests, the forest areas close to fragmented and disturbed habitats are more likely to be invaded (Kuhman et al., 2010).

Protected areas (PAs) are notable global conservation sites whose main objective is to preserve ecosystems and the species that depend on them (Dudley, 2008). These distinct ecosystems are either established for cultural and social reasons (Campos and Nepstad, 2006), habitat integrity (Brooks et al., 2004), threatened species (Liu et al., 2001), and ecosystem services (Brooks et al., 2004). In addition, PAs frequently contain priceless landscapes, are important markers of accelerated climate change, and may be impacted by other human-caused changes (such as modifications to the climate and patterns of land use) and degradation (Gaston et al., 2008). Even though special protection is provided by conservation efforts within PAs in many parts of the world, biodiversity continues to decline (Butchart et al., 2010). Even in the most well-protected and managed ecosystems, plant invasion is anticipated to be one of the major drivers of biodiversity loss (Lindars et al., 2003). Invasive species increase demands on the natural capital being conserved because they have the potential to decrease species diversity and ecological functions at a regional scale (Foxcroft et al., 2013). Humans are not only responsible for disturbances that facilitate alien species invasions, but through propagule transport also act as vectors for the dispersal of these plants within the forest landscape (Manning et al., 2018). This is especially true in protected areas, where roads, trails, and visitor traffic can be pervasive corridors and pathways for the dispersal of exotic plant species.

One of the most important aspects of sustainable forest resource management in such protected areas is the accurate assessment of biodiversity for resource management actions that have an impact on forest areas (Foxcroft et al., 2013). Managers, policymakers, and advocates for conservation must comprehend the circumstances in which PAs provide conservation benefits (Margules and Pressey, 2000). Despite the fact that scientific understanding of protected forests is rapidly expanding, there are still huge knowledge gaps in Himalayas. Some of the world's most important protected places, such as the Zabarwan Mountain Range in the Kashmir Himalaya, have received minimal research attention. In this context the current study was carried out with the aim of addressing following specific research questions: (i) what is the floristic composition of the various types of forests in the Zabarwan Mountain Range? (ii) what are the emergent patterns of functional characteristic diversity in the vegetation? (iii) what is the contribution of native and alien elements in the vegetation? and (iv) what does the Floristic Quality Assessment Index of the vegetation indicate about invasive species? Given the ecological and economic importance of the forests in the Zabarwan Mountain Range, the results from the present study will guide the decision-makers develop more targeted conservation policies to better manage ecosystems and landscapes in this Himalayan region, as an example for other protected areas worldwide.

2. Materials and methods

2.1. Study area

The Zabarwan range of the Kashmir Himalayan in India, harbors

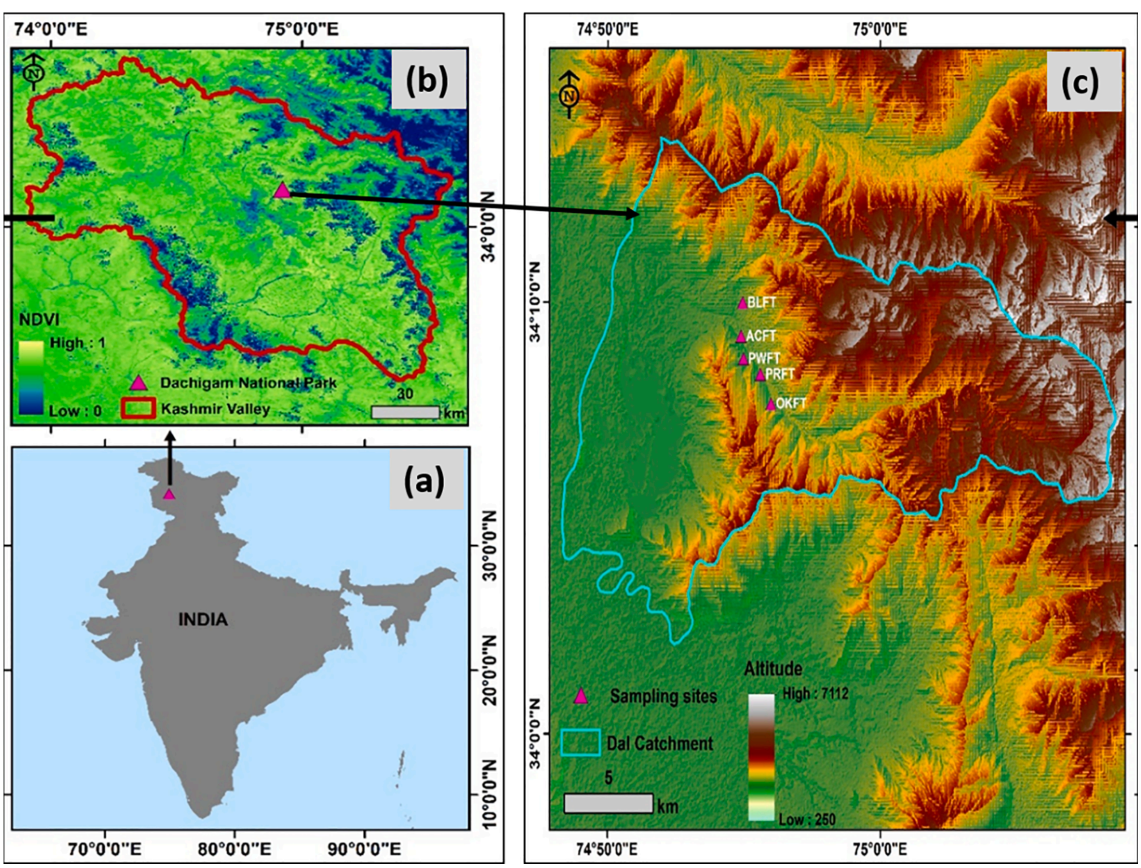

Fig. 1. Map of the study area: (a) Jammu & Kashmir, India (b), and Kashmir Valley (c) Dachigam National Park with sampling forest types in the Zabarwan range, India.

representative forest stands of Dachigam National Park (DNP), (Fig. 1). It stretches from 34° 05′ N to 34° 11′ N and 74° 54′ E to 75° 09′ E, covering an area of 141 km^2 (Fig. 1). The park has been a protected area since 1910, originally under the control of the Maharaja of J&K, then in 1981 it was designated as a National Park. DNP features a moderate climate, with warm and pleasant summers and cold and hard winters. The average rainfall in the area is 660 mm, however, unlike in other parts of the country, there is no such thing as a rainy season. In the summer, the average maximum temperature is 27 °C, while minimum the winter, it about 2 °C. Meadows are interspersed throughout the coniferous and broadleaved forests that dominate the park. The wildlife includes over twenty species of mammals and over 150 kinds of birds, including the last surviving population of the endangered Hangul (*Cervus elaphushanglu*). In the DNP, deciduous trees and shrubs predominate (e.g., *Acer caesium, Populus alba, Prunus armeniaca, Celtis australis, Salix alba, Ulmus villosa*), with a few coniferous tree species (e.g., *Cedrus deodara, Pinus wallichiana*). Other abundant broadleaf trees and shrubs are e.g., *Ailanthus altissima, Aesculus indica, Quercus robur, Rubus ulmifolius,* and *Prunus tomentosa*. The riparian vegetation includes species such as *Ulmus wallichiana*, *Populus ciliata, Aesculus indica*, *Rosa webbiana*, *Morus alba*, *Salix alba, Juglans regia*, *Buddleja davidii, Ailanthus altissima* etc. The northern aspects carry dense forests with *Pinus wallichiana*, *Platanus orientalis, Parrotiopsis jacquemontiana*, *Prunus armeniaca* etc. *Quercus robur* and *Robina pseudoacacia* are two invasive species planted in the the park for reforestation. See Haq et al. (2019a) for a thorough description of the study area.

2.2. Sampling design and measurements

The Dachigam National Park's forest working plan was used to verify administrative jurisdiction, geographical position, and forest vegetation kinds. Several field reconnaissance surveys and botanical collections were conducted in 2018–2021 to collected data from various forest types. Coniferous forest (PNFT), Oak forest (OKFT), *Acacia* forest (ACFT), Broad leaved forest (BLFT), and Scrub (*Parrotiopsis jacquemontiana*) (SRFT) are the main forest types found in the Dachigam National Park (Champion and Seth, 1968; Haq et al., 2021a,b,c). The height and geo-coordinates of DNP forest sites were measured using a GPS device called the Garmin eTrex (Garmin International, Inc., Olathe, KS). During the field inquiry, pertinent data on the plant specimens were recorded, and standard herbarium techniques were employed in this work, as described by Bridson and Forman (1999). The plant species were identified by comparing herbarium samples kept at the University of Kashmir's Centre for Biodiversity and Taxonomy and examining pertinent taxonomic literature (Stewart, 1972; eFloras). The PlantList (https://www.theplantlist.org) specialized taxonomic database was utilized to update the nomenclature of documented species.

To record data on the floristic diversity of the study area, the quadrant method of vegetation sampling was used (Haq et al., 2020). In each of the selected forest types, four sample plots of 31.6 m × 31.6 m (0.1 ha) size were laid for tree sampling in all four directions, namely NE, NW, SW, and SE. Within each (0.1 ha) plot, two 5 m × 5 m sub-plots were used to record shrub density. Five 1 m × 1 m plots (four in corners and one in the centre) have been laid out for herbaceous diversity. The current study sampled 60 forest stands (a total of 12 plots per forest type). For each forest type, twenty-four (5 m × 5 m) quadrants for shrubs and sixty (1 m × 1 m) quadrants for herbs were randomly laid out for understory diversity. The current study sampled three hundred (60 × 5 = 300) quadrants (1 m × 1 m) for herbs and one hundred twenty (24 5 = 120) plots (5mx 5 m) for shrubs.

2.3. Floristic Quality Assessment Index (FQAI)

The Floristic Quality Assessment Index (FQAI), developed to measure the degree of human disturbance in an area by taking into account the presence of cosmopolitan, native, as well as alien species, is used to assess the naturalness of an area based on the presence of ecologically significant species (Wilhelm and Ladd, 1988). To calculate the FQAI, a species list for the entire forest area was generated. Each species' coefficient of conservatism (sensitivity to anthropogenic disturbance rating) to various degrees of environmental factors was assigned to each species in the community. The rating on the list was given a value between 0 and 10 using the method described by (Andreas and Lichvar, 1995; Wilhelm and Ladd, 1988; Haq et al., 2021a,b,c), and the index was derived as: $FQAI = R/ N^{1/2}$, Where R = total of all the coefficients of conservatism values of each species. N = the number of native species. Followed that, the entire forest vegetation were divided into five ranges i.e., ranking 0, ranking 1–3, ranking 4–6, ranking 7–8, and ranking 9–10.

2.4. Ecological traits

Four different seasons were used to field examine the study area. For each species, thorough field observations on ecological elements like habit and Raunkiaer's life form were made (Raunkiaer, 1934; Perez-Harguindeguy et al., 2016). Furthermore, the following habitat types were recorded for each species: dry slope (DS), wet places (WP), plantation (PL), natural forest (NF), shady places (SP), riverine (RV), roadside (RS), and pedestrian trail (PT) (Haq et al. (2019a,b,c)). Secondary sources included manuals, floras, and newly published research papers (Andrabi et al., 2015; Haq et al., 2020); and specialized internet pages (GRIN: Germplasm Resource Information Network) (https://www.efloras.org) were used to classified as native and alien plant species based on accessible data sources.

2.5. Data analysis

Data was analyzed using Principal Component Analysis (PCA) and chord diagrams (Haq et al., 2020). The multi-dimensional data was analysed using PCA to identify hypothetical variables (components) that could explain as much variance as possible. In order to do that, we calculated the singular valued composition of the (centred and potentially scaled) data matrix using a matrix of presence/absence of the regions under study. PCA was carried out using R Studio 4.0.1 software. The program circlize package (Gu et al., 2014) was used to construct chord diagrams in R software 4.0.1. (R Core Team, 2020). This graph allowed us to identify which species were linked to different haitat types and ranking category and how many of each species were included in each category (Haq et al., 2022). The ggplot2 program in R software version 3.5.1 was used to visualize the contribution of several Raunkiaer life types (R Core Team, 2020). Additionally, using PAST software, indicator species analysis was used to comprehend the indicator species for each ranking type (Dufrêne and Legendre, 1997). The maximum indicator value's statistical significance was ascertained using the Monte Carlo Test of significance, and indicator values were calculated in accordance with (Yun and Abdiyani, 2019).

3. Results

3.1. Forest composition and distribution of species

From the study area, 181 plant species from 129 genera and 56 families were reported (Table 1). The distribution of families was unequal, with 11 families accounting for half of the species and 45 families for the remaining groups, many of which (21) were monotypic families (Table 1). The research region's most species-rich families were the Rosaceae, with 19 species (10 %), Asteraceae, with 16 species (9 %), Lamiaceae, with 10 species (6 %), Fabaceae, with 9 species (5 %), and Poaceae, with 9 species (5 %) (Table 1). In the floristic research, therophytes (38 %) outnumbered phanerophytes (33 %), geophytes (13 %), hemicryptophytes (12 %), chamaephytes (5 %), and hydrophytes (1 %) (Table 1). On the basis of plant habit, the flora of the region could be divided into herbs (70 %), trees (14 %), shrubs (13 %), climbers (2 %)

Table 1
Database of floristic and functional trait diversity in the Zabarwan Mountain Range, Himalayas.

Family	Species	Codes	Habitat #	Growth Form	FQAI**	Life-form*	Nativity
Acanthaceae	*Strobilanthes urticifolia* Wall. ex Kuntze	Str. urt	RV,DS	Herb	5	THE	N
	Strobilanthes wallichii Nees	Str. wal	RV,WP	Herb	5	THE	N
Adoxaceae	*Viburnum grandiflorum* Wall. ex DC.	Vib. Gra	NF,RS,RV,DS,WP	Shrub	5	PHE	N
Amaranthaceae	*Achyranthes aspera* L.	Ach. asp	RV,RS	Herb	5	CHA	N
	Achyranthes bidentata Blume	Ach. bid	RV,PT	Herb	5	HCP	N
	Amaranthus caudatus L.	Ama.cad	RS, PT	Herb	0	THE	E
	Bassia Scoparia (L.) A.J.Scott	Bas. Sco	NF,DS,SP	Herb	0	THE	E
	Chenopodium album L.	Che. alb	RS,PT	Herb	0	THE	E
	Chenopodium foliosum Asch.	Che. fol	RS,PT	Herb	0	THE	E
	Clinopodium vulgare L.	Cli. vul	NF,RS,RV	Herb	4	HCP	N
	Clinopodium umbrosum (M.Bieb.) Kuntze	Cli. umb	NF,WP,RS	Herb	0	HCP	E
Araliaceae	*Aralia cachemirica* Decne.	Ara. cac	NF, WP, PT	Herb	9	GEO	N
Asparagaceae	*Asparagus filicinus* Buch.-Ham. ex D.Don	Asp. fil	RS,NF	Herb	4	PHE	N
	Asparagus officinalis L.	Asp. off	RS,WP	Herb	0	CHA	E
	Polygonatum acuminatifolium Kom.	Pol. acu	NF,WP,SP	Herb	7	GEO	N
	Polygonatum verticillatum (L.) All.	Pol. ver	NF,SP	Herb	7	GEO	N
Aspleniaceae	*Asplenium ofeliae* Salgado	Asp.ofe	RV,NF,WP	Herb	7	HCP	N
Asteraceae	*Achillea millefolium* L.	Ach. mil	DS, RS, RV	Herb	3	HCP	N
	Artemisia absinthium L.	Art. abs	PT,RV,RS,NF	Herb	2	CHA	N
	Taraxacum campylodes G.E.Haglund	Tar. cam	PT,RS,NF,	Herb	2	THE	N
	Artemisia gmelinii Weber ex Stechm.	Art.gme	PT	Herb	3	CHA	N
	Arctium lappa L.	Arc. lap	RV,PL,RS	Herb	0	THE	E
	Artemisia vulgaris L.	Art. vul	PT,NF	Herb	0	THE	E
	Carpesium abrotanoides L.	Car. abr	RS,PL	Herb	3	THE	N
	Carpesium cernuum L.	Cap. cer	RS	Herb	3	THE	N
	Erigeron canadensis L.	Eri. can	RS,NF	Herb	0	THE	E
	Erigeron multiradiatus (Lindl. ex DC.) Benth. &Hook.f.	Eri. mul	PT,NF	Herb	3	THE	N
	Galinsoga parviflora Cav.	Gal. par	PT,NS	Herb	0	THE	E
	Leucanthemum vulgare (Vaill.) Lam.	Leu. vul	RS,DS	Herb	0	THE	E
	Senecio chrysanthemoides DC.	Sen. chr	RS,NF,RV,DS	Herb	3	THE	N
	Senecio vulgaris L.	Sen.vul	RS	Herb	0	THE	E
	Sigesbeckia orientalis L.	Sig. ori	RS	Herb	0	THE	E
	Sonchus oleraceus (L.) L.	Son. ole	RS,PT	Herb	0	THE	E
Araliaceae	*Hedera nepalensis* K.Koch	Hed. nep	RV,NF.SP	Climber	3	PHE	N
Apiaceae	*Daucus carota* L.	Dau. car	RS,PT,PL	Herb	0	GEO	E
	Heracleum candicans Wall ex DC.	Her. can	NF,RS	Herb	9	HCP	N
	Selinum wallichianum (DC.) Raizada & H.O. Saxena	Sel.wal	NF	Herb	4	GEO	N
Balsaminaceae	*Impatiens brachycentra* Kar. &Kir.	Imp. bra	WP,NF,RS	Herb	4	THE	N
	Impatiens glandulifera Royle	Imp. gla	WP,SP,PL	Herb	5	THE	N
Berberidaceae	*Berberis pachyacantha* Bien. ex Koehne	Ber. pac	NF,SP	Shrub	6	PHE	N
	Berberis lycium Royle	Ber. lyc	NF,RS,RV	Shrub	6	PHE	N
	Epimedium elatum C. Morren & Decne.	*Epi.* ela	NF,WP	Herb	6	GEO	N
	Sinopodophyllum hexandrum (Royle) T.S.Ying	Sin. hex	NF,SP	Herb	9	HCP	N
Boraginaceae	*Myosotis arvensis* (L.) Hill	Myo. arv	SP,RS,NF	Herb	5	HCP	N
Brassicaceae	*Barbarea intermedia* Boreau	Bar. int	RS, NF	Herb	0	THE	E
	Capsella bursa-pastoris Medik.	Cap. bur	PT,NF, RS,PL,SP	Herb	0	THE	E
	Sisymbrium officinale (L.) Scop.	Sis. off	RS,NF	Herb	0	THE	E
	Sisymbrium loeselii L.	Sis. loe	RS,NF	Herb	0	THE	E
Cannabaceae	*Celtis australis* L.	Cel. aus	RV,NF,RS	Tree	0	PHE	E
Cannabinaceae	*Cannabis sativa* L.	Can. sat	RS,PL	Herb	0	THE	E
Campanulaceae	*Asyneuma thomsonii* (C.B.Clarke) Bornm.	Asy. tho	WP,RS,NF	Herb	8	HCP	N

(*continued on next page*)

Table 1 (*continued*)

Family	Species	Codes	Habitat #	Growth Form	FQAI**	Life-form*	Nativity
Caprifoliaceae	*Lonicera quinquelocularis* Hard.	Lon. qui	NF,RS,RV	Shrub	6	PHE	N
	Lonicera spinosa (Decne.) Jacq. exWalp.	Lon. spi	NF,DS	Shrub	7	PHE	N
	Lonicera webbiana Wall. ex DC.	Lon. web	NF,DS,RS	Shrub	6	PHE	N
Caryophyllaceae	*Stellaria media* (L.) Vill.	Ste. med	WP,PT,NF	Herb	0	THE	E
	Silene vulgaris (Moench) Garcke	Sil. vul	NF,RS	Herb	7	HCP	N
Datiscaceae	*Datisca cannabina* L.	Dat. can	NF,RV,DS	Herb	3	PHE	N
Dioscoreaceae	*Dioscorea deltoidea* Wall. ex Griseb.	Dio. del	NF,RS, DS	Climber	9	GEO	N
Dryopteridaceae	*Dryopteris barbigera* (T. Moore ex Hook.) Kuntze	Dry. bar	SP,WP,NF	Herb	7	GEO	N
	Dryopteris stewartii Fraser-Jenk.	Dry. ste	SP,WP,NF	Herb	7	GEO	N
Elaeagnaceae	*Elaeagnus umbellata* Thunb.	Ela. umb	RS,RV	Shrub	0	PHE	E
Equisetiaceae	*Equisetum arvense* L.	Eqi. arv	RV,SP, WP	Herb	1	HYD	N
Euphorbiaceae	*Euphorbia falcata* L.	Eup. fal	RS.PT	Herb	0	THE	E
	Euphorbia helioscopia L.	Eup. hel	RS,PT	Herb	0	THE	E
Fagaceae	*Quercus robur* L.	Que. rob	PL	Tree	0	PHE	E
Fabaceae	*Desmodium elegans* DC.	Des. ele	RV,RS	Shrub	4	PHE	N
	Indigofera hebepetala Baker	Ind. heb	RS	Shrub	6	PHE	N
	Indigofera heterantha Brandis	Ind. het	RS,NF,PL,RV,DS	Shrub	6	PHE	N
	Melilotus officinalis subsp. *alba* (Medik.) H.Ohashi & Tateishi	Mel. off	PT,WP	Herb	2	PHE	N
	Medicago polymorpha L.	Med. pol	PT,SP	Herb	0	THE	E
	Trifolium alexandrinum L.	Tri. ale	PT	Herb	3	THE	N
	Trifolium pratense L.	Tri. pra	PT,NF	Herb	3	THE	N
	Trifolium repens L.	Tri. rep	PT,NF,RS,RV	Herb	3	THE	N
Geraniaceae	*Geranium nepalense* Sweet	Ger. nep	NF,RS,DS	Herb	5	THE	N
	Geranium pratense L.	Ger. pra	NF,RV,DS	Herb	5	THE	N
	Geranium wallichianum D.Don ex Sweet	Ger. wal	NF,RS,RV,DS	Herb	5	THE	N
Hamamelidaceae	*Parrotiopsis jacquemontiana* (Decne.) Rehder	Par. Jac	NF,RS,RV, DS	Shrub	5	PHE	N
Iridaceae	*Iris hookeriana* Foster	Iri. hoo	RV,NP	Herb	7	GEO	N
	Iris kashmiriana Baker	Iri. kas	RV,NP,PL	Herb	7	GEO	N
Juglandaceae	*Juglans regia* L.	Jug. reg	NF,PL,DS	Tree	0	PHE	E
Hyperiaceae	*Hypericum perforatum* L.	Hyp. per	WP,RS,NF	Herb	3	CHA	N
Lamiaceae	*Mentha arvensis* L.	Men. arv	WP,PL	Herb	0	GEO	E
	Mentha longifolia (L.) L.	Men. lon	WP,RS,PL,NF	Herb	1	GEO	N
	Nepeta connata Royle ex Benth.	Nep. con	NF	Herb	7	THE	N
	Nepeta linearis Royle ex Benth.	Nep. lin	NF,RS	Herb	6	THE	N
	Perilla frutescens (L.) Britton	Per. fru	SP	Herb	6	THE	N
	Prunella vulgaris L.	Pru. vul	PT,NF,RS,RV	Herb	6	THE	N
	Salvia moorcroftiana Wall. exBenth.	Sal. moo	DS,RS	Herb	5	THE	N
	Thymus linearis Benth.	Thy. lin	DS,NF,RS	Sub-shrub	5	PHE	N
Malvaceae	*Lavatera kashmiriana* Mast.	Lav.kas	NF,DS	Herb	9	CHA	N
	Malva neglecta Wallr.	Mal. neg	RS,NF,PL	Herb	3	THE	N
Mimosaceae	*Robinia pseudoacacia* L.	Rob. pse	RS,PL	Tree	0	PHE	E
Moraceae	*Morus alba* L.	Mor. alb	NF,RS,PT	Tree	0	PHE	E
	Morus nigra L.	Mor. nig	NF,PL	Tree	0	PHE	E
Oleaceae	*Jasminum officinale* L.	Jas. off	NF,RS	Shrub	6	PHE	N

(*continued on next page*)

Table 1 (*continued*)

Family	Species	Codes	Habitat #	Growth Form	FQAI**	Life-form*	Nativity
Onagraceae	*Epilobium hirsutum* L.	*Epi.* hir	WP,SP	Herb	4	THE	N
Orchidaceae	*Cypripedium cordigerum* D.Don	Cyp. cor	NF,RV	Herb	9	HCP	N
	Cephalanthera longifolia (L.) Fritsch	Cep.lon	NF,RS	Herb	9	GEO	N
	Dactylorhiza hatagirea (D.Don) Soó	Dac. hat	NF, RV, PT	Herb	9	GEO	N
	Epipactis royleana Lindl.	*Epi.* roy	NF,RV	Herb	9	GEO	N
	Goodyera repens (L.) R.Br.	Goo. rep	NF,RS,PL	Herb	9	GEO	N
	Oreorchis micrantha Lindl.	Ore. mic	NF	Herb	9	THE	N
	Neottia ovata (L.) Bluff & Fingerh.	Neo. ova	NF	Herb	9	GEO	N
Oxalidaceae	*Oxalis acetosella* L.	Oxa. ace	SP,NF,RS	Herb	4	THE	N
	Oxalis corniculata L.	Oxa. cor	SP,DS	Herb	0	THE	E
Pinaceae	*Abies pindrow* (Royle ex D.Don) Royle	Abi. pin	NF, RS, DS,PT	Tree	7	PHE	N
	Cedrus deodara (Roxb. ex D.Don) G.Don	Ced. deo	PT,NF, RS,PL,SP	Tree	7	PHE	N
	Pinus wallichiana A.B.Jacks.	Pin. Wal	NF,PT,RV,DS,WP,RS	Tree	6	PHE	N
Platanaceae	*Platanus orientalis* L.	Pla. ori	NF,RS	Tree	7	PHE	N
Plantaginaceae	*Digitalis purpurea* L.	Dig. pur	RS,NF	Herb	0	THE	E
	Plantago lanceolata L.	Pal. lan	PT,NF.RS,WP	Herb	3	THE	N
	Plantago major L.	Pal. maj	PT,RS,NF,	Herb	3	THE	N
	Digitalis purpurea L.	Dig. pur	RS,NF	Herb	0	THE	E
	Veronica persica Poir.	Ver. per	WP	Herb	4	THE	N
Poaceae	*Bromus japonicas* Thunb.	Bro. jap	PT,RS	Herb	2	THE	N
	Cynodon dactylon (L.) Pers.	Cyn. dac	PT,NF,RS,RV	Herb	1	HCP	N
	Oplismenus burmanni (Retz.) P.Beauv.	Opl. bur	PT	Herb	1	THE	N
	Poa annua L.	Poa. ann	WP,NF,RS	Herb	5	THE	N
	Poa bulbosa L.	Poa. bul	RS,NF	Herb	0	THE	E
	Poa pratensis L.	Poa. pra	PT,RS	Herb	0	HCP	E
	Setaria viridis (L.) P.Beauv.	Set. vir	PT	Herb	3	THE	N
	Sorghum halepense (L.) Pers.	Sor. hal	PL	Herb	0	HCP	E
	Stipa sibirica (L.) Lam.	Sti. sib	NF,RV,RS	Herb	7	HCP	N
Polygonaceae	*Fagopyrum esculentum* Moench	Fag. esu	RV,NF	Herb	0	THE	E
	Persicaria amplexicaulis (D.Don) RonseDecr.	Per. amp	RV,NF.DS	Herb	4	GEO	N
	Persicaria hydropiper (L.) Delarbre	Per. hyd	WP,NF,RS	Herb	3	GEO	N
	Polygonum molle D. Don	Pol. mol	WP	Herb	7	GEO	N
	Rumex dentatus L.	Rum den	RS,DS	Herb	0	CHA	E
	Rumex nepalensis Spreng.	Rum nep	NF,PT,RS,DS	Herb	5	HCP	N
Pteridaceae	*Adiantum capillus-veneris* L.	Adi. cap	SP, NF	Herb	5	HCP	N
	Adiantum raddianum C. Presl	Adi. rad	SP, NF	Herb	5	HCP	N
	Pteris cretica L.	Pte. cre	RV,NF,WP	Herb	4	HCP	N
Primulaceae	*Erodium cicotarium* (L.) L'Hér.	Ero. cic	PT,RS	Herb	2	THE	N
Ranunculaceae	*Aconitum heterophyllum*Wall. ex Royle	Aco. het	NF, WP,SP	Herb	9	CHA	N
	Actaea spicata L.	Ace. spi	NF, RV, PT	Herb	8	CHA	N
	Clematis montana Buch.-Ham. ex DC.	Cle. mon	NF,WP,RS	Shrub	7	PHE	N
	Delphinium cashmerianum Royle	Del. cas	NF,DS	Herb	9	THE	N
	Delphinium roylei Munz	Del. roy	RV,PL,DS	Herb	7	THE	N
	Ranunculus hirtellus Royle	Ran. hir	WP,NF	Herb	0	THE	E
	Ranunculus laetus Wall. ex Hook. f. &J.W. Thomson	Ran. lae	WP,RS,NF	Herb	0	GEO	E
	Ranunculus palmatifidus Riedl	Ran. pal	WP,NF,RS	Herb	4	GEO	N
	Thalictrum cultratum Wall.	Tha. cul	NF	Herb	7	CHA	N
Rosaceae	*Cotoneaster affinis* Lindl.	Cot. aff	DS,RS,NP	Shrub	7	PHE	N
	Cotoneaster nummularius Fisch. &C.A.Mey.	Cot. num	DS,RS,NP	Shrub	9	PHE	N
	Crataegus monogyna Jacq.	Cra. mon	NF,RS	Tree	5	PHE	N
	Crataegus songarica K. Koch	Car. Son	NF,RS	Tree	0	PHE	E
	Fragaria nubicola (Lindl. ex Hook.f.) Lacaita	Far. Nub	NF,SP,RS	Herb	6	THE	N
	Filipendula vestita (Wall. ex G.Don) Maxim.	Fil. Ves	NF,DS	Shrub	7	PHE	N
	Geum roylei Wall.	Geu. ela	NF,RS,PL	Herb	3	HCP	N
	Geum urbanum L.	Geu. urb	NF,RS	Herb	3	HCP	N
	Potentilla multifida L.	Pot. mul	PT	Herb	4	THE	N
	Prunus armeniaca L.	Pru. arm	PL	Tree	0	PHE	E
	Prunus avium (L.) L.	Pru. avi	PL	Tree	0	PHE	E
	Prunus cerasus L.	Pru. cer	PL	Tree	0	PHE	E

(*continued on next page*)

Table 1 (*continued*)

Family	Species	Codes	Habitat #	Growth Form	FQAI**	Life-form*	Nativity
	Prunus persica (L.) Batsch	Pru. per	PL	Tree	0	PHE	E
	Prunus tomentosa Thunb.	Pru. tom	RS,NF	Shrub	5	PHE	N
	Rubus ellipticus Sm.	Rub. ell	PT,RS	Shrub	3	PHE	N
	Rubus ulmifolius Schott	Rub. Ulm	RS,PT,NF	Shrub	0	PHE	E
	Rosa moschata Herrm.	Ros. mos	RV,RS,NF	Shrub	6	PHE	N
	Rosa webbiana Wall. ex Royle	Ros. web	NF,RS	Shrub	6	PHE	N
	Sorbaria tomentosa (Lindl.) Rehder	Sor. tom	NF,RS	Shrub	7	PHE	N
Rubiaceae	*Galium aparine* L.	Gal. apa	NF,PT	Herb	5	THE	N
	Rubia cordifolia L.	Rub. cor	RV	Herb	7	THE	N
Salicaceae	*Salix alba* L.	Sal. alb	PL	Tree	0	PHE	E
	Salix disperma Roxb. exD.Don.	Sal. dis	RV	Tree	5	PHE	N
	Populus alba L.	Pop. alb	PL,RS	Tree	0	PHE	E
	Populus ciliata Wall. exRoyle	Pop. cil	PL,RS	Tree	3	PHE	N
Sapindaceae	*Acer caesium* Wall. exBrandis	Ace. cae	NF, WP, RV	Tree	9	PHE	N
	Acer cappadocicum Gled.	Ace. cap	NF RS, WP	Tree	8	PHE	N
	Aesculus indica (Wall. ex Cambess.) Hook.	Aes. Ind	RS, NF, PT, PL	Tree	0	PHE	E
Scrophulariaceae	*Buddleja davidii* Franch.	Bud. dav	RV,RS	Shrub	0	PHE	E
	Verbascum thapsus L.	Ver. tha	DS,RS,NF	Herb	4	PHE	N
Simaroubaceae	*Ailanthus altissima* (Mill.) Swingle	Ail. Alt	RS, PL	Tree	0	PHE	E
Smilacaceae	*Smilax aspera* L.	Smi. asp	NF	Climber	7	PHE	N
	Smilax elegans Wall. ex Kunth	Smi. ele	NF	Climber	7	PHE	N
Solanaceae	*Solanum americanum* Mill.	Sol. ame	PT	Herb	0	THE	E
	Solanum pseudocapsicum L.	Sol. pse	DS,WP	Sub-shrub	7	THE	N
Ulmaceae	*Ulmus villosa* Brandis ex Gamble	Ulm. vil	NF,PT	Tree	7	PHE	N
	Ulmus wallichiana Planch.	Ulm. wal	NF,PT	Tree	7	PHE	N
Urticaceae	*Urtica dioica* L.	Urt. dio	PL,NF.RV,RS,DS	Herb	0	THE	E
Violaceae	*Viola biflora* L.	Vio. bif	NF	Herb	5	THE	N
	Viola odorata L.	Vio. odo	NF,RV,SP	Herb	5	THE	N
					FQAI = 692		

*Raunkiaerlifeform: PHE-phanerophyte, GEO-geophyte, THE-Therophyte, HCP-Hemicryptophyte, CHA-Chamaephyte, HYD-Hydrophyte, CRP-Cryptophyte; **Floristic quality assessment index: (FQAI) values; #Habitat types: Dry slope (DS), Wet places (WP), Plantation (PL), Natural Forest (NF), Shady place (SP), Riparian vegetation (RV), and Roadside (RS), Pedestrian trail (PT).

and sub shrubs (1 %) (Table 1).

3.2. Extent of invasion across forest types

The flora of the studied region included 127 (70 %) native species and 54 (30 %) alien species. Of these 13 alien species were invasive, 36 were naturalised, and 5 were casual. Asteraceae (8 species), Rosaceae (6 species), Amaranthaceae, Brassicaceae (4 species), and Poaceae (3 species) were the most prevalent alien species families. The broadleafed forest type had the highest percentage of alien species (35 %) followed by Oak forest (22 %), *Acacia* & Coniferous forest (11 % each), and Scrub forest (6 %) (Table 1). In the FQAI analysis the Coniferous forest had the highest FQAI value (51.25), followed by the Scrub forest (41.5), broadleafed (38.61), *Acacia* (33.5), and lowest (27.71) at Oak forest.

3.3. Habitat-wise distribution

Over 38 % of the entire species pool in the research area was growing in natural forest habitat, 11 % along riverine zones, and 51 % were scattered throughout the remaining human-alter habitat types, primarily on roadside (18 %) and pedestrian route (13 %) (Fig. 2). At habitat level, the level of invasion also varied across habitat types, with roadsides showing the highest number of alien species (45 % species) followed by pedestrian trails and plantations (13 % species), natural forest (11 % species), wet places & riverine (7 % species), and lowest (2 % species) at dry and shady places **(**Table 1**).** The FQAI analysis showed that the natural forest habitat had the highest FQAI value (57.45), followed by roadside (39.75), riverine (32.55), dry places (30.39), wet places (28.59), shady places (24.77), pedestrian trails (24.51), and lowest (12.02) at plantations.

Our results were further supported by PCA which showed variation depending on habitat preferences of woody species. PC1 accounts for 17.3 % of the variation in species habitat preference, with PC2 accounting for the remaining 16.9 % (Fig. 3). Our study found that species were associated with particular habitats based on their indicator species. One example are species like *Leucanthemum vulgare*, *Clinopodium vulgare*, *Daucus carota*, *Rubus ulmifolius* and *Rumex nepalensis* were associated with degraded habitats like road side and pedestrian trails. Dry habitat included species like *Geranium wallichianum*, *Senecio chrysanthemoides, Rumex dentatus* and *Artemisia absinthium. Delphinium cashmerianum*, *Filipendula vestit*, *Lavatera kashmiriana*, *Persicaria amplexicaulis*, *Viburnum grandiflorum*, were regarded indicator species for natural forest and riverine habitats. Wet habitat included species like *Impatiens glandulifera*, *Veronica persica, Ranunculus hirtellus*, and the plantation habitat

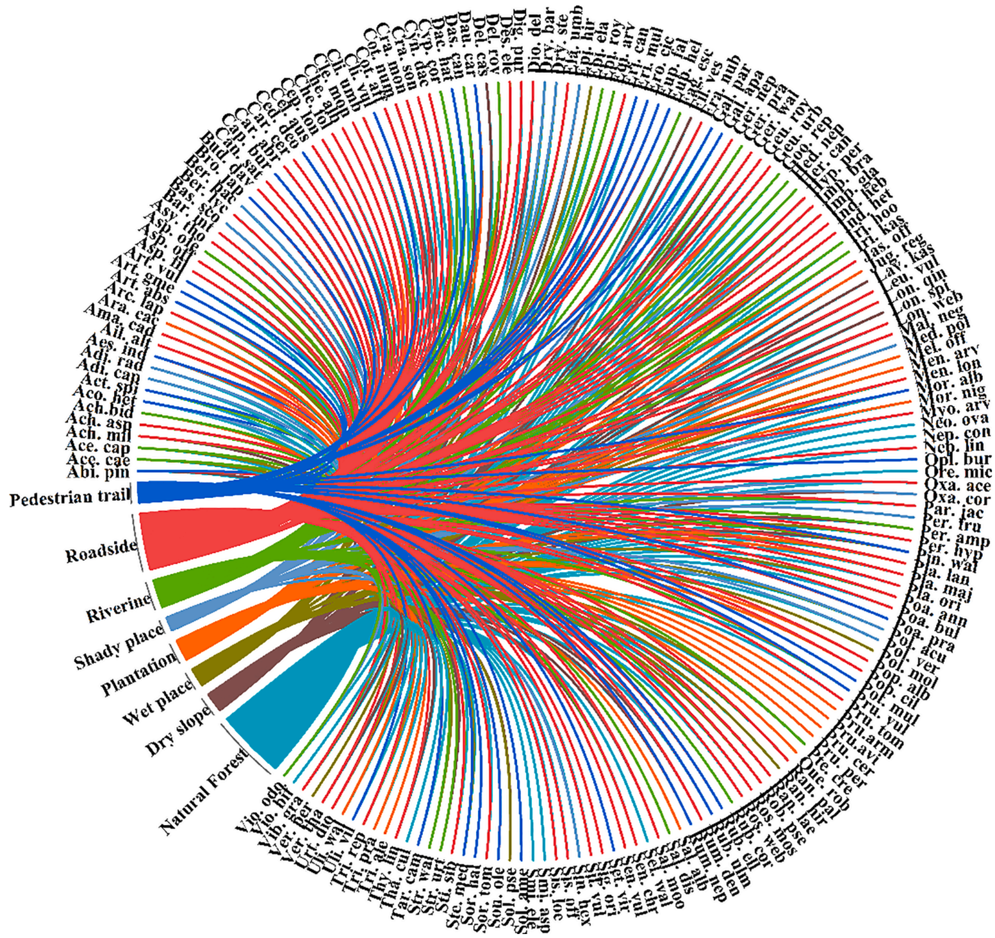

Fig. 2. Species distribution according the habitat types in the Zabarwan Mountain Range, India. The direction of the lines demonstrates which species are related to which habitat types, and the thickness of each bar demonstrates the number of species found in each type of habitat. In Table 1, the species' full names are listed.

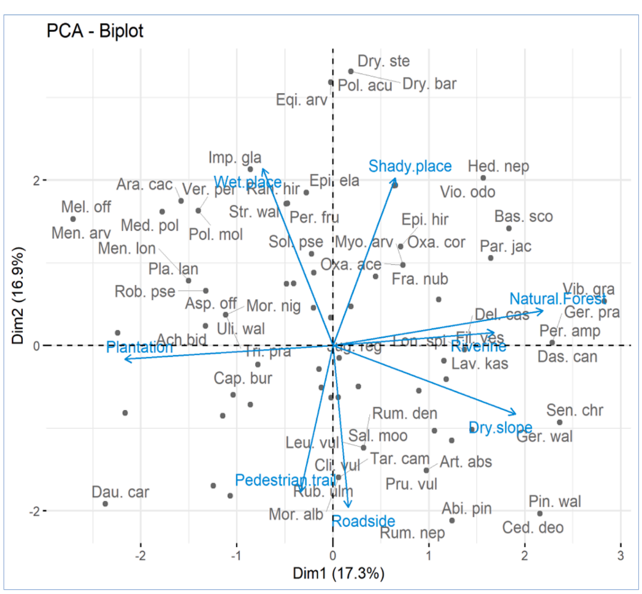

Fig. 3. Principal Component Analysis (PCA) illustrating the relationship of species and the habitat types in the Zabarwan Mountain Range, India.

included *Robinia pseudoacacia, Ulmus wallichiana, Plantago lanceolata* (Fig. 3).

3.4. Floristic Quality Assessment Index (FQAI)

The total number of conservatism coefficients for the forest was 692 with FQAI = 61.41 on the FQAI scale. The FQAI found that 54 (30 %) of the plant species growing in the forest region were ranked 0, with 30 (17 %) ranking 1–3, 51 (28 %) ranking 4–6, 30 (16 %) ranking 7–8, and 17 (9 %) ranking 9–10 (Fig. 4). Vulnerable species included *Aralia cachemirica, Heracleum candicans, Lavatera kashmiriana, Sinopodophyllum hexandrum, Dioscorea deltoidea, Delphinium roylei,* among others. The FQAI values of each species in the forest area are presented in the Table 1.

3.5. Indicator species analysis

The investigation of indicator species revealed separation between the various ranking groups. In the ranking 0 group ten species showed a significant p-value for indicator species analysis. Important indicator species in ranking 0 were *Aesculus indica, Ailanthus altissima, Celtis australis, Daucus carota, Poa bulbosa, Prunus armeniaca, Prunus cerasus, Quercus robur,* and *Salix alba.* In ranking 1–3 the most significant indicator species were *Carpesium abrotanoides, Cynodon dactylon, Geum urbanum, Hedera nepalensis, Oplismenus burmanni, Oxalis acetosella, Plantago major, Trifolium pretense*, and *Trifolium repens.* In ranking 4–6 the indicator species were *Achyranthes bidentate, Crataegus monogyna, Fragaria nubicola, Geranium nepalense, Impatiens glandulifera, Perilla*

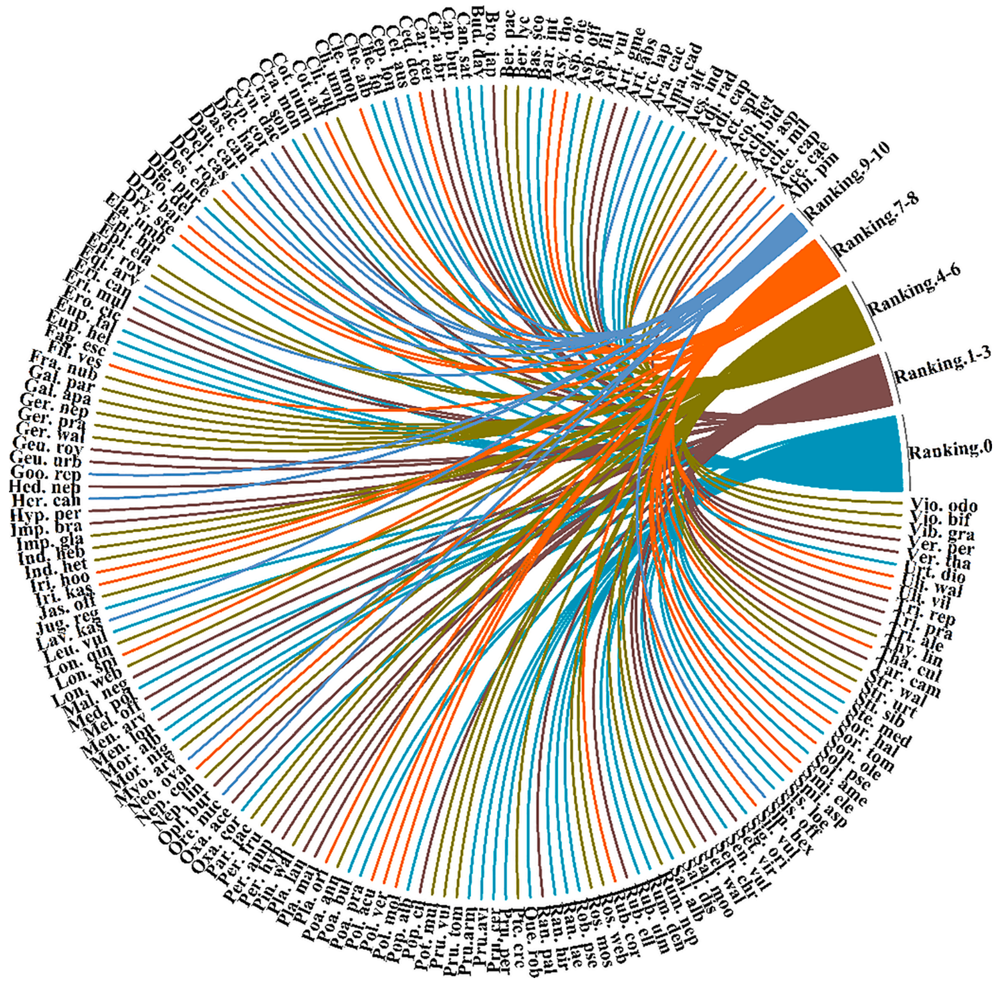

Fig. 4. Species distribution according the Floristic assessment index ranking in the Zabarwan Mountain Range, India. The thickness of each bar indicates the number of species in each ranking category, and the direction of the lines indicates which species are linked to which types of ranking. Table 1 displays the species' full name.

frutescens, Salvia moorcroftiana, Viburnum grandiflorum, and *Viola odorata.* In ranking 7–8 following species have a significant value of indicator analysis *Asplenium ofeliae, Asyneuma thomsonii, Delphinium roylei, Dryopteris barbigera, Iris hookeriana, Polygonatum verticillatum, Sorbaria tomentosa, Stipa sibirica,* and *Ulmus wallichiana.* In ranking 9–10 the siginificant indicator species were *Acer caesium, Cephalanthera longifolia, Cotoneaster nummularius, Cypripedium cordigerum, Dioscorea deltoidea,* and *Polygonatum acuminatifolium* (Fig. 5).

4. Discussion

4.1. Patterns of vegetation composition and distribution of plant species

Forest community structure is influenced by both biotic and anthropogenic factors to varying effect (Jakovac et al., 2021). Floristic diversity provides a clear picture of floristic health that can be used to develop conservation plans and policies (Haq et al., 2022). The floristic composition of Zabarwan Mountain Range included 181 species. The current studys' species richness was higher than that reported by other researchers in Himalayan-protected forests (Qureshi and Bhatti, 2010). Our results can be compared to those of other studies carried out in the Himalayan mountain region, where Rosaceae and Asteraceae were also the most prevalent representative families (Chhetri and Shrestha, 2019; Rahman et al., 2022). The species distribution values within families were comparable to those previously reported from various Himalayan regions (Rahman et al., 2018; Haq et al., 2021a,b,c), and they might be indicative of a specific vegetation type.

4.2. Patterns of functional diversity

In comparison to taxonomic identity alone, the growth form is a quantitative measure in comparing geographically dispersed plant habitats and is also viewed as a potential predictor of current environmental circumstances (Lavorel and Garnier, 2002). The study region had a higher number of trees (14 %) than shrubs (13 %), which is an indicator for the functioning of a forest ecosystem (Khan et al., 2015a,b,c). Various studies in Himalayan regions dispute this pattern (Qureshi et al., 2014; Choudhary and Nama, 2014). However, our results are supported by the findings of Khan et al. (2015a,b,c) and Haq et al. (2019a,b,c) from Himalayas. The bispectrum is the fraction of distinct life forms in an existing flora in a certain location or spot. The biological spectrum is a significant physiognomic feature that is often utilized for vegetation study. It reflects plant adaptation to micro and macro climates (Khan et al., 2018). Therophytes are an indicator of anthropogenic impact and are also usually associated with unfavorable dry environmental conditions (Vakhlamova et al., 2016; Blumler 2018). Rahman et al. (2018), Haq et al. (2021), and Nafeesa et al. (2021) all found therophytes as the dominant species in their study region, indicateing similar environmental and habitat conditions (Khan et al., 2018). The lifeforms present in a vegetation type are determined by its genetic pool and tolerance for the microclimatic and bioclimatic habitat circumstances in a certain place (Hussain et al., 2015). Therophytes are frequently found in areas with low precipitation and brief vegetative growth seasons, such as along roadsides and in other dispersed habitats, and their prevalence frequently rises when alien weedy forbs are introduced like *Arctium*

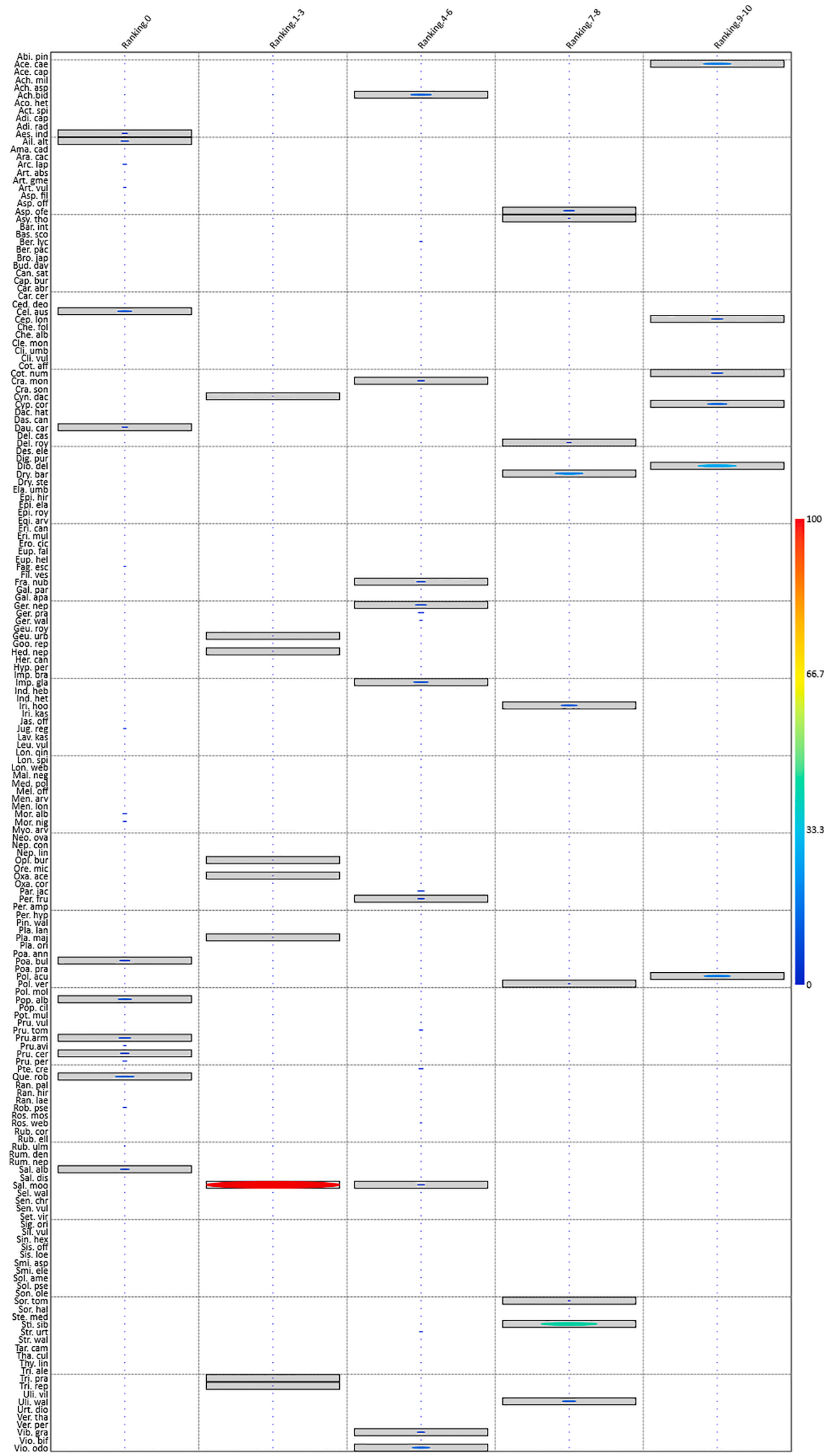

Fig 5. Indicator species analysis diagram showing species with significant p-value in various ranking categories in the Zabarwan Mountain Range, India.

lappa, Leucanthemum vulgare, Sigesbeckia orientalis, Erigeron canadensis, Erigeron multiradiatus (Mamariani et al., 2009; Haq et al., 2019a,b,c). Phanerophyte dominance reflects the peak vegetation (Qureshi and Bhatti, 2010) and the preponderance of hemicryptophytes can be attribued to cold and mountainous climates (Shimwell, 1971; Archibold, 1995).

4.3. Patterns of Habitat-wise distribution

As a result of anthropogenic impact causing changes in land use patterns, species pools, and habitats, intact natural forest habitats are at risk of becoming fragmented and degraded (Bhatt and Bhatt, 2016; Mishra et al., 2003a,b; Haq et al., 2019a). Our findings are corroborated by Qureshi and Bhatti (2010), who from Pakistan reported the greatest diversity of species in a natural forest habitat. Susceptibility to disturbances is also highly influenced by forest management operations linked with changes in plant composition and structure (Seidl et al., 2011). Furthermore, the clustering of comparable habitats (such as roadside and pedestrian routes; dry slopes, plantations, and shady places), all of which are predominantly human-modified ecosystems, suggests that ecological filtering is prevalent in the region (Grime, 1998; Nafeesa et al., 2021). There are a variety of ecological mechanisms, both abiotic and biotic filters, that control species richness at the local level, requiring the required functional features to reach a location (i.e., overcome a dispersion filter) and establish under the ecological niche's conditions (Kraft et al., 2015). As a result, at a small spatial scale, there is a strong interplay between abiotic environmental variables and biotic interactions that shapes community patterns (Adler et al., 2013).

4.4. Floristic Quality Assessment Index (FQAI)

The FQAI accounts for both the level of tolerance each native species has for particular environmental conditions as well as the presence of alien species, making it a sensitive measure of changes in plant species composition and providing information about the state of an ecosystem's processes and biotic interactions (Herman et al., 1997; Haq et al., 2021a,b,c). FQAI values for woods ranging from 10 to 80 were reported by Wilhelm and Ladd (1988). Both Andreas and Host (1983) and Andreas and Bryan (1990) obtained FQAI values of 37.53 from disturbed Silica Sand Quarry Bog and Flatiron Lake Bog, respectively. Because the study region is located in a protected forest area, there may be little human disturbance, which may account for the variations in floristic index values, which may explain the high results. The fact that 9 % of the species in the forest community are relatively uncommon and listed as endangered plants is most likely responsible for the forest community's high conservatism coefficient. Among the 181 documented species, indicator species analysis revealed 10 indicators responding to ranking 0, most of them being associated to disturbed habitats, with each habitat type frequently containing one or more indicator species similar to Rahman et al. (2020), and Haq et al. (2021), who also reported the presence of one or more indicator species in various habitats/plant communities. Taking species combinations into account increases the flexibility of the indicator species analysis. Many of the indicator species found in our study, such as *Aralia cachemirica, Heracleum candicans, Lavatera kashmiriana, Sinopodophyllum hexandrum, Dioscorea deltoidea*, and *Delphinium roylei*, are of great conservation importance. The highest FQAI value was found for Coniferous forests, while the lowest was found in Oak forests. This could be because invasive alien species such as *Quercus robur*, *Juglans regia* and *Robinia pseudoacacia* were intentionally planted in Oak forest to provide food for wildlife. Therefore, oak forests that have been heavily managed by humans have a higher proportion of alien species and may be more species-poor than coniferous natural forests (Chmura, 2020). Furthermore, in undisturbed coniferous and scrub forest, invasive species are rare, and alien propagules fail to survive the natural crown in these ecosystems. While most non-native species cannot survive in natural forest habitats, there are a few exceptions. *Arctium lappa, Sigesbeckia orientalis, Sisymbrium loeselii, Capsella bursa-pastoris,* and *Cannabis sativa* are common along Kashmir's shaded abandoned roadsides and riverine habitats (Haq et al., 2019a,b,c). In open forest stands, *Leucanthemum vulgare, Digitalis purpurea,* and *Daucus carota* also invade dry and wet habitats (Altaf et al., 2021). These invasive alien plants are also reported as potential invaders in other Himalayas regions as well (Rashid et al., 2021; Nafeesa et al., 2021). Of the various drivers, disturbance usually facilitates plant species invasion by overwhelming physical as well as environmental obstacles. It has been observed that by changing resource and habitat availability, the parameters which cause disturbances can filter the composition of a community and effect species occurrence (Gianoli and Escobedo, 2021).

4.5. Patterns of invasion

The level of invasion varies greatly among forest habitats within particular regions, implying that some ecosystems are more vulnerable to invasion than others (Medvecká et al., 2018). The unintentional introduction of invasive alien species as a result of human and traffic movement has created new options for alien plant dissemination in the area. Aliens made up about 30 % of the total species recorded, and they thrived in anthropogenic settings rather than slightly fragmented forest habitats (González-Moreno et al., 2013). Alien plant species, regardless of their life history strategy, have more phenotypic plasticity than native plants (Davidson et al., 2011) and are usually superior to natives in numerous fitness components (Kleunen et al., 2010). As a result, they colonize disturbed areas more resourcefully than native species. Within each family, alien species were distributed differently, with Asteraceae being the most prevalent. While conducting research on floristic diversity in the Indian Himalayas, Muzafar et al. (2019) identified Asteraceae as the dominant family. Members of the Asteraceae family, which are both prospective and present dominating invaders of highly disturbed areas like roadsides and pedestrian pathways, have been shown to be characterised by frequent and chronic anthropogenic disturbances (Von der Lippe and Kowarik, 1997). Because of this, disturbed areas typically include a significant number of foreign species belonging to these families. Aliens are taxonomically divided into various families because they typically share biological traits that make it simpler for them to move across habitats and establish themselves there, as is the case in the study region (Rashid et al., 2021).

The most frequently invasive species growing in the national park included trees like *Ailanthus altissima, Robinia pseudoacacia, Quercus robur,* shrubs like *Buddleja davidii, Rubus ulmifolius,* and herbs such as *Leucanthemum vulgare, Sonchus oleraceus.* There have also been reports of these invasive alien plants as potential invaders in forests in other Himalayan regions (Haq et al., 2019a). A trend that results from a variety of factors is the loss of plant species diversity when communities switch from native desirable plants to monospecific stands of invasive species (Turner et al., 1997). Invasions can also change the dietary preferences of forest wild fauna, which are heavily influenced by the shifting flora composition associated with alien plants (Loo, 2008). Some wild faunal species will benefit when native plant species are replaced by alien species, but others will suffer as a result. Specialized native herbivores like *Cervus elaphus hanglu, Moschus chrysogaster, Capricornis sumatreansis, Semnopithecus entellus, Eoglaucomys fimbriatus,* and *Marmota caudate* that are primary consumers and primarily consume native flora for nutritional (Lovett et al., 2016). This may in turn affect the secondary consumers such as *Martes fluvigula, Panthra pardus, Ursus arctos* for which the primary consumers act as prey base. Such interactions between altering vegetation composition, structure, and population control mechanisms may result in adverse responses to primary consumer invasions, while secondary consumers like *Ursus thibetanus* and *Ursus arctos* experience only mild effects (Engelkes et al., 2012). Variations in the intensity of invasion were visible in the numbers and ratios of non-native species in the surveyed forest area. In the current study, it was found that alien plants spread more quickly in broadleaf forest types than in temperate coniferous forests, in line with what Medvecká et al. (2018) had previously reported. The majority of non-native trees including *Robinia pseudoacacia* and *Ailanthus altissima* in the broadleaf forest types were introduced deliberately as fodder for wild animals. These alien trees species inhibit the growth of other plants by producing allelopathic chemicals (Vítková et al., 2017), thus leading to changes in forest understory vegetation (Woziwoda et al., 2014). Increased *Quercus robur* density, both within and outside patches of its colonisation, is thought to result in the loss of forest uniqueness and and has been documented in other parts of the world (Głowacki et al., 2016). *Q. robur* species inhibit the natural restocking of both native woody and herbaceous species (Haq et al., 2019c), and self-reproduction makes it difficult to regulate, reduce, or eradicate this tree species (Major et al., 2013). As a result, low-altitude forest types near riparian zones were more invaded than higher-elevation coniferous-dominated forests, which agrees with the findings of Medvecká et al. (2018). The variety of ecological phenomena that have limited the absence of species from a place, either because they are unable to sustain the new abiotic conditions (habitat) or simply because the changing conditions have altered biotic interactions (e.g. competition with invasive alien plants).

4.6. Conservation implications

The FQAI of vegetation indicated that protected forest areas are not immune to invasive alien species incursions, as previously thought. The existing state of knowledge about the threat, provides a road map for forest management. In coping with various forest threats/disturbances, the management plan may include controlling before the disturbance. These include enacting restrictions to prohibit the import of invasive alien species (*Leucanthemum vulgare, Quercus robur, Robinia pseudoacacia*) and improving habitat recovery by modifying structure through species restoration of alternative native tree species (*Cedrus deodara, Ulmus wallichiana, Pinus wallichiana, Aralia cachemirica, Heracleum candicans, Lavatera kashmiriana, Sinopodophyllum hexandrum, Dioscorea deltoidea*, and *Delphinium roylei)*. Managing disturbance itself, e.g., tourist flow, can be done by preventative actions that reduce the intensity or frequency of the disturbance. In order to manage the ecosystem's orginal state as soon as the disturbance occurs (for example, by building roads), or to manage the ecosystem's recovery more quickly (for example, by planting and restoration), which reduces the vulnerability of the system to future disturbances. Finding out how disturbances affect forests and monitoring potential impacts of land use and climate change on disturbance regimes are important steps in adaptive management. This type of data is critical for initiating management activities and achieving targeted objectives. In order to record, conserve, and sustain the region's plant diversity, the current study will offer baseline data to researchers, decision-makers, land managers, and local people. Furthermore, by analysing species features with an indicator species approach, the study may be an appropriate choice for the restoration of degraded ecosystems in this area, as well as the generation of scientifically informed management solutions.

5. Conclusion

The FQAI is a method for assessing how vegetation communities adapt to alien invasions, and the current study highlights that even protected ecosystems are susceptible to alien invasions. The study identifies key indicator species in the ranking groups, which can help decision-makers develop more targeted conservation policies to better manage ecosystems and landscapes. When compared to other forest types, broadleaf forest had the highest percentage of alien species. The level of invasion varied across habitat types at the habitat level, with roadsides having the most alien species, followed by pedestrian trails and plantations. By forecasting forest ecosystem health, the findings could aid in the assessment and valuation of ecosystem goods and services in this protected Himalayan region.

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CRediT authorship contribution statement

Shiekh Marifatul Haq: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft. **Muhammad Shoaib Amjad:** Conceptualization, Supervision, Formal analysis, Methodology, Project administration, Validation, Writing – review & editing. **Muhammad Waheed:** Writing – review & editing. **Rainer W. Bussmann:** Writing – review & editing . **Jarosław Proćków:** Conceptualization, Supervision, Formal analysis, Project administration, Validation, Writing – review & 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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