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RESEARCH ARTICLE

Himalayan Hotspot with Alien Weeds: A Case Study of Biological Spectrum, Phenology, and Diversity of Weedy Plants of High Altitude Mountains in District Kupwara of J&K Himalaya, India

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Abstract Authentic certification, documentation, and ecological characterization of weed flora are of paramount importance for future studies that would help to formulate strategies for their management and conservation. Alien plants used to pose severe threats to ecosystems, and qualitative studies on weed flora in many interior regions of the Himalaya are still scarce. Patterns of species diversity, biological spectrum, and phenology of weeds growing in the Himalayas with invasive nature were investigated from 2017 to 2019 in thirty-eight localities of interior Kupwara district of Kashmir Himalaya from different agroecological zones. A hierarchical cluster analysis using the presence or absence data of flowering among plant species was performed and a complex Heatmap package was used. Data collected revealed a total of 158 plant species belonging to 115 genera and 35 families identified from a high altitude district Kupwara in India. The species distribution pattern across the families was unequal, with three families share more than half of the species documented, while fifteen families were monotypic. The family Asteraceae, Poaceae, and Brassicaceae were the most important weeds in terms of species abundance and species richness. Asteraceae represented by 35 species, as the dominant family followed by Poaceae with 19 species, and Brassicaceae by 14 species. In terms of functional trait diversity, the annual growth form was dominant over other forms such perennial or biannual. The phytogeographical analysis revealed that the maximum 91 species collected were native, while a minimum of 67 species reported as alien. Of the alien species, 25 were invasive, 35 naturalized, and 7 casual. The biological spectrum revealed the dominance of therophyte life form indicating the disturbed vegetation. The phenological spectrum revealed the maximum flowering period of weeds is between April and September where about 73%

Significance Statement Patterns of species diversity, biological spectrum, and phenology of Himalayan weeds with invasive nature were investigated from different agroecological zones. Total of 158 species under 115 genera and 35 families identified as weed plants growing in thirty-eight localities of Kupwara district. Out of these, 91 species are native and 67 are alien. Family Asteraceae (35 sp.), Poaceae (19 sp.), and Brassicaceae (14 sp.) were the most important weeds, in terms of species abundance and species richness. A hierarchical cluster analysis using the presence/absence data of flowering over the year among plant species was performed. Distances between clusters are recomputed by the Lance-Williams dissimilarity update formula according to the Ward clustering method. For that, we used the Complex Heatmap package. The biological spectrum revealed the dominance of therophyte life form, indicating the disturbed vegetation. This research data add important information about weed biodiversity patterns in the Himalayas and constitute baseline data for planning and implementation of conservation.

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of species were observed in full bloom. This research adds an important way to the basic information of biodiversity patterns in the Himalayas and constitutes baseline data for the planned implementation of conservation. The outcomes also provide the baseline information on alien weeds, their invasive nature as well as in for better prediction of phenological shifts associated with these species due to contemporary climate change. It also would help to design conservation and management plans for threatened or otherwise important species for future implementation.

Keywords Biological spectrum · Phenology · Himalayan weeds · Himalaya · Conservation

Introduction

Plant species exist in their current habitats as a consequence of habitat selection and incremental adaptation to environmental conditions, which are best suited to their requirements for survival [1, 2]. Climate change and biological invasions in the form of alien species are major drivers affecting biodiversity and ecosystem services [3]. Invasive weeds pose severe threats to ecosystems [4] and human-induced disturbances may enhance the threats [5, 6]. The climate changes in recent decades altered the population dynamics of native species, and thus, the geographic ranges and functioning of their ecosystem get disturbed. In extreme cases, climate-driven invasions could lead to completely transformed ecosystems where alien species dominate richness, which leads to loss of native species. Alien weeds can produce large numbers of viable offspring at considerable distances from parent plants, thus having the potential to spread quickly over large areas. Such changes are potentially problematic: economically in terms of agricultural production and other ecosystem services. Being hardy and vigorous in growth habits, weeds grow faster than agronomic crops thus results in a reduction of agricultural yield [7]. Ecologically weeds result in disrupted ecosystem functioning, with the potential for large numbers of species mismatches and extirpations [8]. The weed adapted several mixed reproductive strategies as a response to cope with environmental variation with these newly formed habitats. These mixed reproductive strategies have the benefits of different mating and reproductive avenues and may have evolved to optimize fitness in highly variable environments [9]. Quite often, the weeds generate strong propagules pressure leading to subsequent naturalization and spread of these species to hinterland [10], thus making the landscape more prone to biological invasions. However, in the modern era, due to massive anthropogenic disturbances, the suitability of these habitats inevitably changes. One of the most common outcomes of these disturbances is habitat fragmentation. No doubt such fragmentation can pose risks to the structure and functioning of natural ecosystems that ultimately result in the reduction of biodiversity [11]. But at the same time, these fragmented habitats serve as the most suitable habitats for several undesirable plant species, particularly weed flora to flourish.

The Indian Himalayan is currently facing many threats and is considered to be among the world's most threatened landscapes [12, 13]. These changes have led to the shrinkage of its natural habitat and the resultant threats to its biodiversity, thus increasing susceptibility to weed flora invasion. The specific edaphic conditions, altitudinal range, and environmental climatic factors determine the occurrence of specific species. Recent studies have demonstrated that climate warming has dramatically altered the population dynamics, distribution, and abundance of many terrestrial organisms in the Himalayan ecosystem. With a change in climatic conditions, the flowering periods of plant species have been affected, thereby resulting in phenological shifts. These shifts are a ubiquitous phenomenon and can be interpreted as a sensitive indicator of the ecological impacts of climate change. As a result, climate change may become one of the most important determinants for the distribution and composition of arable weeds. Thus, weed flora study provides the ideal experimental system to unravel the changing patterns of plant diversity and phenological shifts in this part of the Himalaya. An attempt has been made here to study the biological spectrum, phenology, and diversity of alien weedy plants of high altitude mountains in district Kupwara of J&K Himalaya, India. A study of these changing patterns can offer novel insights toward better understanding and sustainable management of weeds in the Himalayan ecosystem.

Materials and Methods

Study Area

Kupwara is one of 22 districts located in Jammu and Kashmir, (J&K) India (Fig. 1), and is considered as one of the backward frontier districts of J&K Himalaya with a geographical area of the district is 2379 sq.km. The district is situated at an average altitude of 5300 feet from the sea level. The northwest part of the district is bound by the line of actual control (LoC), while the southern portion is bound by the district Baramulla. The river Kishanganga, originating from the Himalayas, flows through the outer areas of the district from east to west. The district is encircled by the lofty mountains and deep gorges supporting diverse vegetation, with dense forests and rich wildlife make it

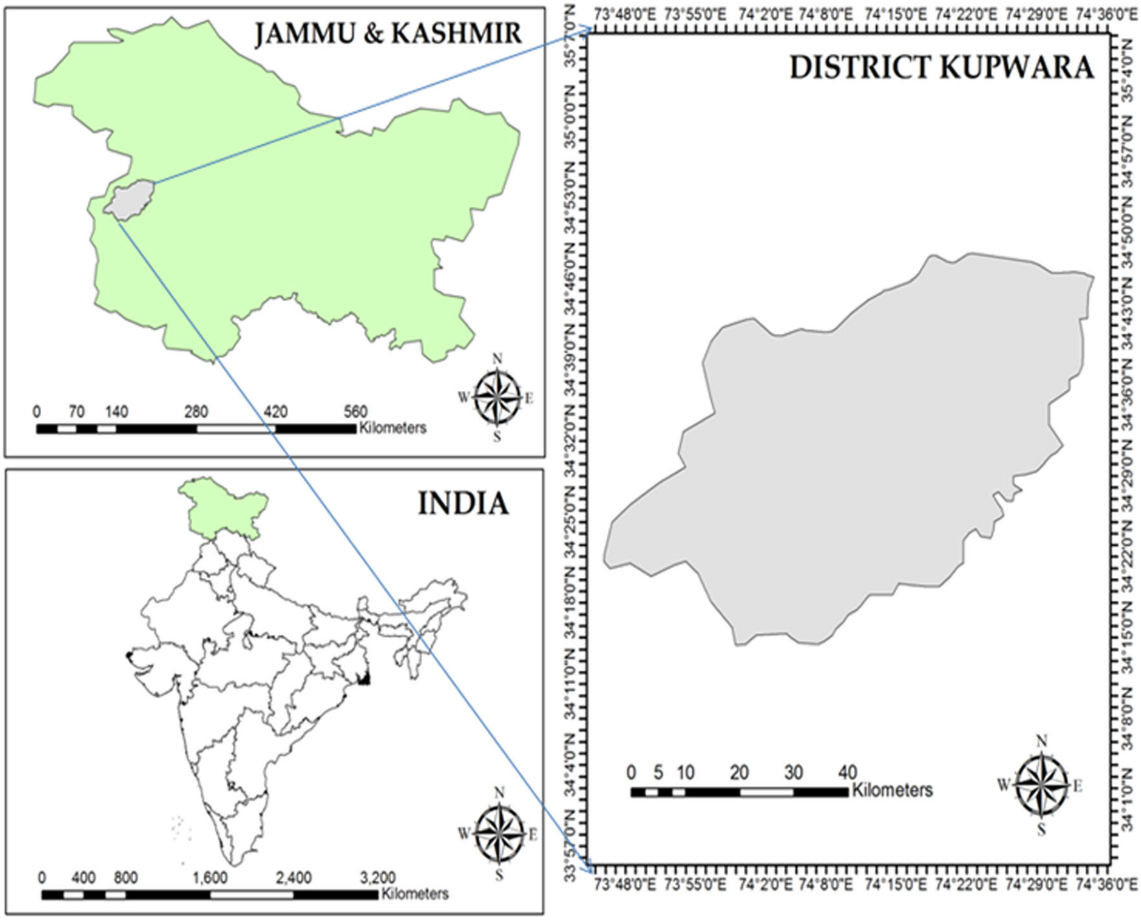

Fig. 1 Map of Jammu & Kashmir showing Kashmir Himalaya (Study area)

significant from tourism and wildlife point of view. The vegetation is mostly dominated by semi-evergreen to evergreen coniferous forests, at higher altitudes, coniferous evergreen forests are interspersed with scrub forest type; grassland meadows patches are quite common.

Field Surveys and Selection Sites

A total of thirteen field surveys were carried out from 2017 to 2019 to get an understanding of the topography, accessibility, and distribution of the different alien flora growing in the study area. Data were collected from thirty-eight localities (Aloosa, Battergam, Chowkibal, Cheerkoot, Dedikoot, Dardpora, Dahama, Dolipora, Drugmulla, Gungloosa, Gushi, Gulgam, Ganapora, Guzriyal, Halmatpora, Hayan, Hayihama, Kachihama, Kralpora, Lalpora, Lonahari, Langate, Panzgam, Paddergund, Palapora, Pooshpora, Pandit pora, Magam, Meelyal, Sogam, Shumnag, Karlpora, Teker, Taratpora, Tangdhar, Trehgam, Wadipora, Wilgam) situated in the interior area of Kupwara district (Table 1, Fig. 2). The geographic coordinate of the selected study areas was recorded by using Garmin Oregon 650 GPS navigation device. The flowering and the fruiting stages of plants which are often seen from early March to mid-October were targeted to collect data on alien species. During the field investigation, the detailed relevant data on locality, altitude, habitat, habit, and diagnostic charters of all the plant species specimens were recorded in the field diary. The specimens of the collected plants from the field were dried, preserved, labeled, and mounted on herbarium sheets (42 cm × 28 cm ± 2 cm) following standard herbarium techniques. The specimen was identified using relevant taxonomic works of the literature and was further authenticated by matching the plant specimens with those deposited in KASH and RRLH (acronym of herbarium is in accordance with Thiers 2020, available at http://sweetgum.nybg.org/science/ih/).

Biological Spectrum and Phenology

The field studies for the data collection on biological spectrum and phenology corresponded with the time of

Table 1 Geographic coordinates and habitat characteristics of the selected sites in district Kupwara in Kashmir Himalaya

Selection sites	Geographic coordinates			Habitat characterized
	Latitude	Longitude	Elevation (m)	
Aloosa	34°25′23.87″	74°02′19.77″	2506	Himalayan coniferous forests and meadows, interspersed with scrub forest type
Battergam	34°28′49.77″	74°08′52.03″	1771	Himalayan subtropical semi-evergreen to temperate coniferous forests
Chowkibal	34°24′40.11″	73°57′28.89″	2316	Himalayan temperate evergreen to mixed coniferous forests, and grasslands
Cheerkoot	34°22′50.73″	74°00′12.86″	2283	Typical Himalayan temperate evergreen coniferous forests
Dedikoot	34°24′37.16″	74°08′40.38″	1857	Temperate semi-evergreen to mixed coniferous forests
Dardpora	34°26′38.69″	74°00′44.59″	2306	Himalayan temperate evergreen to mixed coniferous forests, and grasslands
Dahama	34°25′18.72″	74°06′33.53″	2020	Typical Himalayan temperate evergreen coniferous forests
Dolipora	34°23′30.18″	74°05′08.95″	2316	Himalayan temperate evergreen to mixed coniferous forests, and grasslands
Drugmulla	34°25′28.74″	74°30′20.04″	1656	Himalayan temperate coniferous forests
Gungloosa	34°26′17.37″	74°06′55.78″	2185	Typical Himalayan temperate evergreen coniferous forests
Gushi	34°27′43.93″	74°09′39.01″	1801	Temperate semi-evergreen to mixed coniferous forests
Gulgam	34°28′15.91″	74°08′16.00″	1807	Temperate semi-evergreen to mixed coniferous forests
Ganapora	34°17′55.01″	74°17′33.91″	1652	Himalayan mixed evergreen to temperate coniferous forests
Guzriyal	34°31′55.17″	74°07′37.98″	1857	Temperate semi-evergreen to mixed coniferous forests
Halmatpora	34°30′57.95″	74°10′04.92″	1751	Himalayan mixed evergreen to temperate coniferous forests
Hayan	34°27′25.53″	74°07′10.53″	1891	Temperate semi-evergreen to mixed coniferous forests
Hayihama	34°31′17.61″	74°10′51.98″	1692	Himalayan mixed evergreen to temperate coniferous forests
Kachihama	34°28′27.05″	74°00′55.16″	2283	Typical Himalayan temperate evergreen coniferous forests
Kralpora	34°26′27.87″	74°03′02.07″	2287	Typical Himalayan temperate evergreen coniferous forests
Lalpora	34°32′33.35″	74°27′46.15″	1880	Temperate semi-evergreen to mixed coniferous forests
Lonahari	34°27′45.42″	74°01′11.03″	2088	Typical Himalayan temperate evergreen coniferous forests
Langate	34°22′32.13″	74°17′55.38″	1601	Himalayan mixed evergreen to temperate coniferous forests
Panzgam	34°29′03.10″	74°04′20.25″	1930	Temperate semi-evergreen to mixed coniferous forests
Paddergund	34°25′57.64″	74°06′33.53″	2045	Typical Himalayan temperate evergreen coniferous forests
Palapora	34°21′36.42″	74°09′49.07″	1969	Temperate semi-evergreen to mixed coniferous forests
Pooshpora	34°27′00.26″	74°07′42.24″	1945	Temperate semi-evergreen to mixed coniferous forests
Panditpora	34°17′00.23″	74°17′12. 79″	1750	Himalayan mixed semi-evergreen to temperate coniferous forests
Magam	34°23′15.29″	74°11′37.83″	1683	Himalayan temperate coniferous forests
Meelyal	34°28′46.04″	74°00′18.14″	2636	Himalayan coniferous alpine forests and alpine meadows
Sogam	34°30′10.67″	74°22′34.83″	1762	Himalayan temperate coniferous forests
Shumnag	34°26′39.02″	74°05′03.67″	2106	Typical Himalayan temperate evergreen coniferous forests
Karlpora	34°29′58.44″	74°07′04.25″	1792	Himalayan mixed broad-leaved evergreen to temperate coniferous forests
Teker	34°28′27.09″	74°09′50.82″	1779	Himalayan mixed broad-leaved evergreen to temperate coniferous forests
Taratpora	34°22′01.07″	74°03′44.37″	2023	Typical Himalayan temperate evergreen coniferous forests
Tangdhar	34°23′50.82″	73°51′38.39″	1855	Temperate semi-evergreen to mixed coniferous forests
Trehgam	34°37′09.01″	74°03′02.07″	2026	Typical Himalayan temperate evergreen coniferous forests
Wadipora	34°24′27.56″	74°14′13.23″	1619	Himalayan mixed broad-leaved evergreen to temperate coniferous forests
Wilgam	34°24′05.68″	74°02′31.12″	2716	Himalayan coniferous forests and meadows

four different seasons, viz. spring (March to April), summer (May to August), autumn (September to November), winter (December to February). During field sampling, the detailed field observations on ecological traits such as flowering period, habit, and Raunkiaer's life form for each species were recorded as per Raunkiaer [14, 15]. All the recorded alien weeds were categorized into four sub-types such as chamaephytes (0–0.5 m tall under-shrubs or large

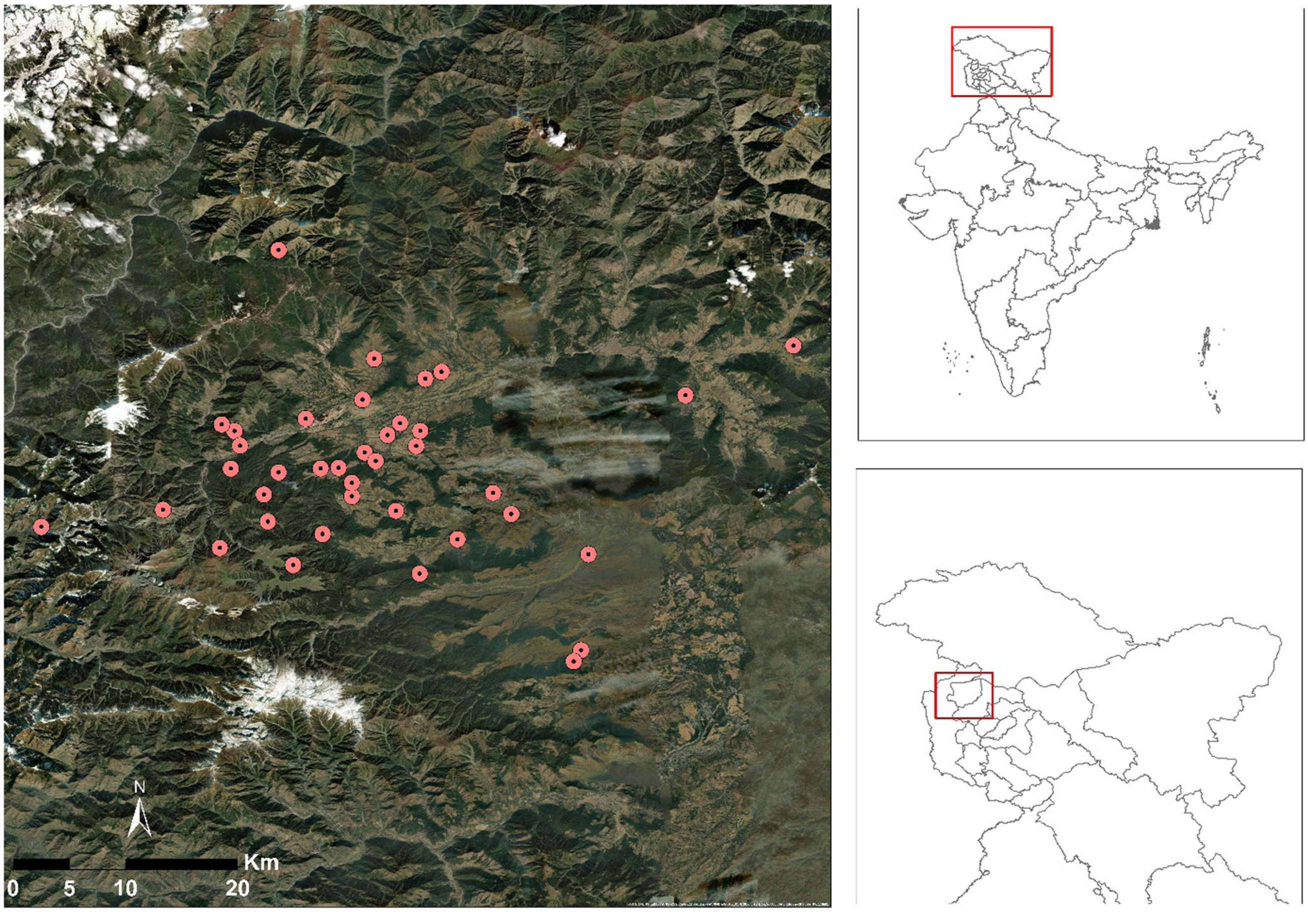

Fig. 2 Location and marking of the selected sites on gradient basis in district Kupwara Himalaya

herbs), hemicryptophytes (growing holding soil surface, all prostrate under-shrubs and herbs that die back each year), geophytes (weeds having resting buds lying beneath the surface of the dry ground as rhizomes, bulbs, corms, tubers on stems, and roots/root-buds) and, therophytes (annuals completing their life cycles under favorable climate and survive unfavorable conditions in the form of seeds). The phenological data of all the collected species were obtained from their field observations and collection of samples in different seasons, published manuals, and regional floras.

Phytogeography

The native phytogeographical range of the plant species collected from the study area was obtained using secondary sources such as manuals, regional floras, and recently published research works; specialized internet web pages (GRIN: Germplasm Resource Information Network), (www.efloras.org) were also consulted. Based on available data sources plant species were categorized into native and alien species.

Data Analysis

We performed a hierarchical cluster analysis using the presence/absence data of flowering over the year among plant species. Distances between clusters are recomputed by the Lance-Williams dissimilarity update formula according to the Ward clustering method. For that, we used the package "Complex Heatmap" [16]. The contribution of different Raunkiaer's life forms was developed using the *ggplot2* package in R software ver, 3.5.1 (http://www.R-project.org).

Results and Discussion

Vegetation Composition and Functional Traits

The present study recorded 158 species, taxonomically distributed among 115 genera in 35 families (Table 1). The annual with 69 species (44%) was the dominant life span category, followed by perennial 66 species (42%), biennial 8 species (5%), annual, perennial 7 species (4%), annual, biennial 6 species (4%), and annual, biennial, perennial 2 species (1%) (Table 2). The floristic analysis revealed the therophytes 86 species (54%) were the dominant life form followed by hemicryptophytes 60 species (38%), geophytes 6 species (4%), chamaephytes 5 species (3%), and cryptophyte 1 species (1%) in the study area (Table 2; Fig. 3).

Species–Family Relationship

The distribution of species across 35 families is disproportionate with half of the species contributed by 3 families, while as remaining half represented by 32 families including single species representation by 15 families. Asteraceae was the dominant family with 35 species (22%) followed by Poaceae 19 species (12%), Brassicaceae 14 species (9%), Fabaceae 10 species (6%), Lamiaceae 8 species (5%), and Caryophyllaceae 6 species (4%). The rest of the species were represented by Plantaginaceae, Apiaceae, Boraginaceae, Chenopodiaceae, Polygonaceae, Ranunculaceae, Polygonaceae, Geraniaceae, Amaranthaceae, and other families. The monotypic families are Asparagaceae, Cannabinaceae, Convolvulaceae, Cyperaceae, and Violaceae. The detailed species–family relationship is presented in Fig. 4.

Phytogeographical Analysis

The phytogeographical analysis revealed that the maximum 91 (58%) species recorded from the study area were native, while a minimum of 67 (42%) species were alien. Of the 67 alien species, at present 25 were invasive, 35 naturalized, and 7 casuals (Fig. 5). Floristic groups of alien species varied within the families, with Asteraceae (20 sp.) (30%), Brassicaceae (8 sp.) (12%), Poaceae (7 sp.) (11%), Fabaceae (5 sp.) (8%), Chenopodiaceae, and Ranunculaceae (4 sp.)(6%) each, and remaining 18 species (27%), were represented by other families such as Apiaceae, Lamiaceae, Malvaceae, Plantaginaceae, and Amaranthaceae.

Phenology

The weed flora in the present study showed considerable variation in flowering phenology (Fig. 6). Different species bloom in different seasons. We observed that most (73%) species (e.g., *Abutilon theophrasti, Achillea millefolium, Artemisia absinthium, Artemisia tournefortiana, Arctium lappa, Avena sativa, Brachiaria eruciformis, Cannabis sativa, Carthamus lanatus, Clinopodium umbrosum, Daucus carota, Erigeron bonariensis, Hibiscus trionum, Lactuca serriola, Malva sylvestris, Saccharum spontaneum, Solanum americanum, Veronica anagallis-aquatica,* etc.) flowering from April to September (Fig. 6). Few (25%) species, such as *Stellaria aquatica, Cardamine hirsuta, Cynoglossum wallichii, Mazus pumilus, Neslia paniculata, Rumex hastatus*, etc (bloomed between October and March) showed flowers in other months of the year. This observed variation in the flowering phenological response among various species was attributed to temperature variation in different seasons. Some species showed more than one flowering peak during the year, for example, *Artemisia vulgaris*. In addition, *Duchesnea indica* and *A. vulgaris* had a flowering period of 8 and 9 months, blooming for almost the entire year. This observed variation in the flowering phenological response among various species was attributed to temperature variation in different seasons. Most of the species were observed to have peak flowering during the summer season, mostly in June and July. In general, the flowering season occurred at the beginning of spring, extending until the end of summer (Fig. 6). The cluster that grouped in one limb is more similar in flowering timings and shows proximity to each other. Most of the species depicted peak flowering during the summer season, mostly in June and July. Some weeds (e.g., *Sigesbeckia orientalis*) were sensitive to low temperatures and flowers in October.

It has been observed that human pressures with development activities and other biotic components cause impacts in the ecological processes, both at the landscape scale and the scale of local patches which influence species composition and habitat characteristics at different scales [17]. The environment places direct selection pressure on functional traits and filters out species with traits that are not suitable for that environment [18]. Studying functional traits provides information on the direct physiological adaptations of plants to certain environments. The present study has documented 158 species belonging to 35 families. The number of species recorded in the present study is higher than reported by several workers in other Himalayan regions [19]. Asteraceae, Poaceae, Brassicaceae, Fabaceae, and Lamiaceae were the families having a higher number of species. Due to wide ecological amplitude, the plant species of the Asteraceae family are diverse in habitat. The above-mentioned families were also found dominant in some other parts of Himalayan regions by previous research workers [20]. The present study highlights the disproportionate distribution of species across families and 15 families were monotypic. These values are more or less similar to the earlier reported values from various regions of Western Himalaya [21].

Patterns of Functional Diversity

The life form is a measurable trait in comparing geographically separated plant habitats and is also regarded as a potential indicator of prevailing environmental conditions

Table 2 Floristic composition, functional traits, and invasive status of weed flora in district Kupwara, Himalaya

Botanical name/family	Family	Growth form	Flowering phenology	Raunkiaer life form	Native (N)/Exotic (E)	Alien status
Abutilon theophrasti Medik.	Malvaceae	Perennial	July–September	Chamaephyte	E	CS
Achillea millefolium L.	Asteraceae	Perennial	July–September	Hemicryptophyte	N	RN
Agrostis stolonifera L.	Poaceae	Annual	July–August	Hemicryptophyte	N	RN
Amaranthus caudatus L.	Amaranthaceae	Annual	June–August	Therophyte	E	NT
Amaranthus viridis L	Amaranthaceae	Annual	June–August	Therophyte	E	NT
Anagallis arvensis L.	Primulaceae	Annual	May–July	Therophyte	N	RN
Anthemis cotula L.	Asteraceae	Annual	May–June	Therophyte	E	IN
Arabidopsis thaliana (L.) Heynh.	Brassicaceae	Annual	April–June	Therophyte	E	NT
Arctium lappa L.	Asteraceae	Perennial	June–August	Hemicryptophyte	E	NT
Artemisia absinthium L.	Asteraceae	Perennial	June–September	Chamaephyte	N	RN
Artemisia scoparia Waldst. & Kitam.	Asteraceae	Biennial	July–August	Hemicryptophyte	N	RN
Artemisia tournefortiana Rchb.	Asteraceae	Perennial	July–September	Therophyte	N	RN
Artemisia vulgaris L.	Asteraceae	Perennial	August–November	Hemicryptophyte	E	NT
Arthraxon lanceolatus (Roxb.) Hochst.	Poaceae	Perennial	August–September	Therophyte	N	RN
Asparagus officinalis L.	Asparagaceae	Perennial	July–August	Geophyte	E	NT
Avena sativa L.	Poaceae	Annual	June–August	Therophyte	E	CS
Bassia scoparia (L.) A.J.Scott	Chenopdiaceae	Annual	June–August	Chamaephyte	E	CS
Bellis perennis L.	Asteraceae	Perennial	April–July	Hemicryptophyte	E	NT
Bidens biternata (Lour.) Merr. & Sherff	Asteraceae	Annual	August–September	Therophyte	E	NT
Bothriochloa ischaemum (L.) Keng	Poaceae	Perennial	June–August	Hemicryptophyte	N	RN
Brachiaria eruciformis (Sm.) Griseb.	Poaceae	Annual	July–September	Hemicryptophyte	N	RN
Bromus japonicus Thunb.	Poaceae	Annual	May–June	Therophyte	N	RN
Cannabis sativa L.	Cannabinaceae	Annual	August–September	Therophyte	E	NT
Capsella bursa-pastoris (L.) Medik.	Brassicaceae	Annual	March–July	Therophyte	N	RN
Cardamine hirsuta L.	Brassicaceae	Annual	March–May	Therophyte	N	RN
Carduus edelbergii Rech.f.	Asteraceae	Biennial	May–August	Therophyte	N	RN
Carduus onopordioides Fisch. ex M.Bieb.	Asteraceae	Perennial	May–September	Chamaephyte	E	IN
Carthamus lanatus L.	Asteraceae	Annual	June–August	Therophyte	E	IN
Centaurea iberica Trevir. ex Spreng.	Asteraceae	Perennial	May–July	Therophyte	N	RN
Cerastium arvense L.	Caryophyllaceae	Perennial	April–August	Hemicryptophyte	E	NT
Cerastium glomeratum Thuill.	Caryophyllaceae	Annual	April–September	Therophyte	N	RN
Chenopodium album L.	Chenopdiaceae	Annual	July–September	Therophyte	E	IN
Chenopodium foliosum Asch.	Chenopdiaceae	Annual	June–September	Therophyte	E	IN
Cichorium intybus L.	Asteraceae	Perennial	June–August	Hemicryptophyte	N	RN
Cirsium arvense (L.) Scop.	Asteraceae	Perennial	May–August	Hemicryptophyte	E	IN
Cirsium wallichii DC.	Asteraceae	Perennial	May–August	Therophyte	N	RN
Clinopodium umbrosum (M.Bieb.) Kuntze	Lamiaceae	Perennial	July–September	Therophyte	N	RN
Clinopodium vulgare L.	Lamiaceae	Perennial	June–August	Hemicryptophyte	N	RN
Conium maculatum L.	Apiaceae	Perennial	May–June	Therophyte	E	IN
Convolvulus arvensis L.	Convolvulaceae	Perennial	April–August	Therophyte	E	IN

Table 2 continued

Botanical name/family	Family	Growth form	Flowering phenology	Raunkiaer life form	Native (N)/Exotic (E)	Alien status
Crepis sancta (L.) Bornm.	Asteraceae	Annual	April–June	Therophyte	N	RN
Cynodon dactylon (L.) Pers.	Poaceae	Perennial	May–August	Hemicryptophyte	N	RN
Cynoglossum lanceolatum Forssk.	Boraginaceae	Perennial	June–August	Hemicryptophyte	N	RN
Cynoglossum wallichii var. glochidiatum (Wall. ex Benth.) Kazmi	Boraginaceae	Biennial	April–May	Hemicryptophyte	N	RN
Cyperus rotundus L.	Cyperaceae		June–September	Geophyte	N	RN
Datura stramonium L.	Solanaceae	Annual	July–October	Therophyte	E	IN
Daucus carota L.	Apiaceae	Biennial	June–September	Hemicryptophyte	E	IN
Descurainia sophia (L.) Webb ex Prantl	Brassicaceae	Biennial	April–June	Therophyte	N	RN
Dianthus caryophyllus L	Caryophyllaceae	Perennial	June–August	Hemicryptophyte	E	CS
Duchesnea indica (Jacks.) Focke	Rosaceae	Perennial	March–October	Hemicryptophyte	N	RN
Dysphania botrys (L.) Mosyakin & Clemants	Chenopdiaceae	Annual	July–September	Hemicryptophyte	E	IN
Echinochloa colona (L.) Link	Poaceae	Annual	July–September	Therophyte	E	NT
Epilobium hirsutum L.	Onagraceae	Annual	June–August	Therophyte	N	RN
Equisetum arvense L.	Equisetaceae	Perennial	–	Hemicryptophyte	N	RN
Erigeron bonariensis L.	Asteraceae	Annual,biennial	June–September	Therophyte	E	NT
Erigeron canadensis L.	Asteraceae	Annual	April–September	Therophyte	E	IN
Erigeron multicaulis Wall. ex DC.	Asteraceae	Perennial	July–August	Therophyte	N	RN
Erodium cicutarium (L.) L'Hér.	Geraniaceae	Annual	April–July	Therophyte	N	RN
Euphorbia helioscopia L.	Euphorbiaceae	Annual	April–July	Therophyte	E	NT
Euphorbia hispida Boiss.	Euphorbiaceae	Annual	June–September	Therophyte	E	NT
Foeniculum vulgare Mill.	Apiaceae	Perennial	July–September	Hemicryptophyte	E	CS
Fumaria indica (Hausskn.) Pugsley	Papaveraceae	Annual	April–June	Therophyte	N	RN
Gagea lutea (L.) Ker Gawl.	Liliaceae	Perennial	April–June	Geophyte	N	RN
Galinsoga parviflora Cav.	Asteraceae	Annual	June–August	Therophyte	E	NT
Galium aparine L.	Rubiaceae	Annual	March–July	Therophyte	N	RN
Geranium nepalense Sweet	Geraniaceae	Perennial	June–October	Therophyte	N	RN
Geranium rotundifolium L.	Geraniaceae	Annual	June–July	Therophyte	N	RN
Geum urbanum L.	Rosaceae	Perennial	May–August	Hemicryptophyte	N	RN
Hibiscus trionum L.	Malvaceae	Annual	July–September	Chamaephyte	E	NT
Hordeum murinum L.	Poaceae	Annual	May–September	Therophyte	N	RN
Hypericum perforatum L.	Hypericaceae	Perennial	May–July	Hemicryptophyte	N	RN
Lactuca dissecta D.Don	Asteraceae	Perennial	May–June	Therophyte	N	RN
Lactuca serriola L.	Asteraceae	Annual, biennial	July–September	Therophyte	N	RN
Lepedium latifolium L.	Brassicaceae	Annual	April–July	Hemicryptophyte	E	NT
Lepidium sativum L.	Brassicaceae	Annual	May–June	Therophyte	E	NT
Lepidium virginicum L.	Brassicaceae	Annual	July–September	Therophyte	E	NT
Lespedeza juncea (L.f.) Pers.	Fabaceae	Annual	June–August	Therophyte	N	RN
Leucanthemum vulgare (Vaill.) Lam.	Asteraceae	Perennial	June–August	Hemicryptophyte	E	IN
Lithospermum officinale L.	Boraginaceae	Perennial	June–July	Therophyte	N	RN
Lolium perenne L.	Poaceae	Annual	May–August	Hemicryptophyte	N	RN
Lolium temulentum L.	Poaceae	Annual	June–July	Therophyte	E	IN
Lotus corniculatus L.	Fabaceae	Perennial	May–September	Hemicryptophyte	N	RN
Malva neglecta Wall.	Malvaceae	Annual	May–September	Therophyte	N	RN

Table 2 continued

Botanical name/family	Family	Growth form	Flowering phenology	Raunkiaer life form	Native (N)/Exotic (E)	Alien status
Malva parviflora L.	Malvaceae	Annual	May–August	Therophyte	N	RN
Malva sylvestris L.	Malvaceae	Perennial	July–September	Hemicryptophyte	E	NT
Marrubium vulgare L.	Lamiaceae	Perennial	May–July	Hemicryptophyte	E	IN
Matricaria matricarioides (Less.) Porter	Asteraceae	Annual	June–July	Therophyte	E	IN
Mazus pumilus (Burm.f.) Steenis	Phrymaceae	Annual	April–May	Therophyte	N	RN
Medicago lupulina L.	Fabaceae	Annual, perennial	April–July	Hemicryptophyte	N	RN
Medicago minima (L.) L.	Fabaceae	Annual	April–June	Hemicryptophyte	N	RN
Medicago polymorpha L.	Fabaceae	Annual, Perennial	April–June	Therophyte	E	NT
Medicago sativa L.	Fabaceae	Annual, perennial	April–August	Hemicryptophyte	E	NT
Melilotus albus Medik.	Fabaceae	Annual	June–September	Therophyte	E	NT
Mentha arvensis L.	Lamiaceae	Perennial	July–October	Hemicryptophyte	N	RN
Mentha longifolia (L.) L.	Lamiaceae	Perennial	July–September	Hemicryptophyte	E	NT
Myosotis arvensis (L.) Hill	Boraginaceae	Annual	May–June	Therophyte	E	NT
Myosotis stricta Link ex Roem. & Schult.	Boraginaceae	Annual	April–June	Therophyte	N	RN
Myriactis nepalensis Less.	Asteraceae	Perennial	July–September	Therophyte	N	RN
Nasturtium officinale R.Br.	Brassicaceae	Perennial	May–October	Hemicryptophyte	N	RN
Nepeta cataria L.	Lamiaceae	Perennial	June–August	Hemicryptophyte	N	RN
Neslia paniculata (L.) Desv.	Brassicaceae	Annual	April–May	Therophyte	N	RN
Oenothera rosea L'Hér. ex Aiton	Onagraceae	Perennial	April–August	Therophyte	N	RN
Onopordum acanthium L.	Asteraceae	Biennial	July–September	Geophyte	E	NT
Oxalis corniculata L.	Oxalidaceae	Perennial	May–June	Hemicryptophyte	N	RN
Persicaria hydropiper (L.) Delarbre	Polygonaceae	Annual	July–September	Therophyte	N	RN
Phleum pratense L.	Poaceae	Perennial	July–August	Hemicryptophyte	N	RN
Plantago lanceolata L.	Plantaginaceae	Annual, biennial, perennial	May–August	Therophyte	N	RN
Plantago major L.	Plantaginaceae	Perennial	May–September	Hemicryptophyte	N	RN
Poa angustifolia L.	Poaceae	Perennial	May–July	Therophyte	N	RN
Poa annua L.	Poaceae	Annual	March–August	Therophyte	N	RN
Poa bulbosa L.	Poaceae	Perennial	March–July	Hemicryptophyte	N	RN
Polygonum aviculare L.	Polygonaceae	Annual, perennial	June–August	Therophyte	N	RN
Polypogon fugax Nees ex Steud.	Poaceae	Annual	May–June	Therophyte	N	RN
Potentilla reptans L.	Rosaceae	Perennial	June–August	Hemicryptophyte	N	RN
Ranunculus arvensis L.	Ranunculaceae	Annual, biennial	March–April	Hemicryptophyte	N	RN
Ranunculus laetus Wall. ex Hook.f. & J.W.Thomson	Ranunculaceae	Perennial	May–August	Hemicryptophyte	E	NT
Ranunculus muricatus L.	Ranunculaceae	Annual, biennial, perennial	April–June	Therophyte	E	NT
Ranunculus sceleratus L.	Ranunculaceae	Annual, perennial	May–July	Therophyte	E	NT
Raphanus raphanistrum subsp. *sativus* (L.) Domin	Brassicaceae	Biennial	June–August	Hemicryptophyte	E	CS
Rorippa islandica (Oeder) Borbás	Brassicaceae	Annual, biennial	May–June	Geophyte	N	RN

Table 2 continued

Botanical name/family	Family	Growth form	Flowering phenology	Raunkiaer life form	Native (N)/Exotic (E)	Alien status
Rumex dentatus L.	Polygonaceae	Annual, biennial	June–July	Hemicryptophyte	N	RN
Rumex hastatus D.Don	Polygonaceae	Annual/Biennial	April–May	Hemicryptophyte	N	RN
Rumex nepalensis Spreng.	Polygonaceae	Perennial	May–July	Hemicryptophyte	N	RN
Saccharum spontaneum L.	Poaceae	Perennial	July–September	Hemicryptophyte	N	RN
Salvia moorcroftiana Wall. ex Benth.	Lamiaceae	Perennial	May–June	Hemicryptophyte	N	RN
Scandix pecten-veneris L.	Apiaceae	Annual	April–July	Therophyte	N	RN
Scrophularia lucida L.	Scrophulariaceae	Perennial	April–May	Hemicryptophyte	E	CS
Scrophularia polyantha Royle ex Benth.	Scrophulariaceae	Perennial	June–July	Hemicryptophyte	N	RN
Senecio vulgaris L.	Asteraceae	Annual, biennial	April–September	Therophyte	E	NT
Setaria viridis (L.) P.Beauv.	Poaceae	Annual	July–September	Therophyte	N	RN
Sigesbeckia orientalis L.	Asteraceae	Annual	October–November	Therophyte	E	NT
Silene conoidea L.	Caryophyllaceae	Annual	May–June	Hemicryptophyte	N	RN
Sisymbrium irio L.	Brassicaceae	Annual	June–August	Therophyte	E	IN
Sisymbrium loeselii L.	Brassicaceae	Annual, biennial	June–August	Therophyte	E	IN
Sisymbrium officinale (L.) Scop.	Brassicaceae	Annual	April–June	Therophyte	E	IN
Sium latijugum C.B.Clarke	Apiaceae	Annual	August–October	Hemicryptophyte	N	RN
Solanum americanum Mill.	Solanaceae	Annual, perennial	June–September	Therophyte	E	NT
Sonchus arvensis L.	Asteraceae	Perennial	May–July	Hemicryptophyte	E	IN
Sonchus asper (L.) Hill.	Asteraceae	Annual	May–June	Therophyte	E	IN
Sonchus oleraceus (L.) L.	Asteraceae	Annual	May–July	Therophyte	E	IN
Sorghum halepense (L.) Pers.	Poaceae	Perennial	June–September	Geophyte	E	IN
Stachys floccosa Benth.	Lamiaceae	Perennial	June–August	Geophyte	N	RN
Stellaria aquatica (L.) Scop.	Caryophyllaceae	Annual	April–May	Therophyte	N	RN
Stellaria media (L.) Vill.	Caryophyllaceae	Annual, perennial	March–October	Therophyte	N	RN
Taraxacum campylodes G.E.Haglund	Asteraceae	Perennial	March–August	Hemicryptophyte	N	RN
Trifolium pratense L.	Fabaceae	Biennial, perennial	May–August	Hemicryptophyte	N	RN
Trifolium repens L.	Fabaceae	Perennial	May–September	Hemicryptophyte	N	RN
Tussilago farfara L.	Asteraceae	Perennial	February–April	Therophyte	E	IN
Urtica dioica L.	Urticaceae	Perennial	June–August	Therophyte	E	NT
Verbascum thapsus L.	Scrophulariaceae	Perennial	June–August	Hemicryptophyte	N	RN
Verbena officinalis L.	Verbenaceae	Annual	June–August	Hemicryptophyte	N	RN
Veronica anagallis L.	Plantaginaceae	Perennial	May–September	Hemicryptophyte	E	NT
Veronica anagallis-aquatica L.	Plantaginaceae	Perennial	June–September	Therophyte	N	RN
Veronica arvensis L.	Plantaginaceae	Annual	May–June	Therophyte	N	RN
Veronica persica Poir.	Plantaginaceae	Annual	March–July	Therophyte	N	RN
Vicia sativa L.	Fabaceae	Annual	May–June	Therophyte	E	NT
Viola odorata L.	Violaceae	Perennial	February–April	Therophyte	N	RN
Xanthium spinosum L.	Asteraceae	Annual	July–October	Therophyte	E	IN

Alien invasive status: *IN* invasive, *RN* regional native, *NT* naturalized, *CS* casual than do the taxonomic identity alone [22]. The biological spectrum reflects the adaptation of plants concerning its micro and macro climates and is vital physiognomic attributes, which are broadly used for vegetation analysis. The common life form classes were therophytes, hemicryptophytes, and geophytes indicate the adaptation of plants to variable environmental factors, especially climate. The results of the present study are further supported by the findings of Manhas et al. [23] who attributed the trend to high anthropogenic disturbance in the region and limited habitat niche for the vegetation. The therophytes as the dominant life form in the study area is the indication of high human disturbances, and this life form is usually associated with unfavorable dry environmental conditions, and this is an adopted strategy for their survival. The present findings agree with Singh et al. [19] reported the dominance of therophytes in their study area. Thus, the similar biological spectrum in different regions shows similarity in environmental and habitat conditions. The plausible reason for the predominance of hemicryptophytes is due to the cold and mountainous climate. Generally, they ensure the prevention of water loss by standing as dry or by physiological, anatomical, and morphological adaptations. The geophytes remain dormant by their underground

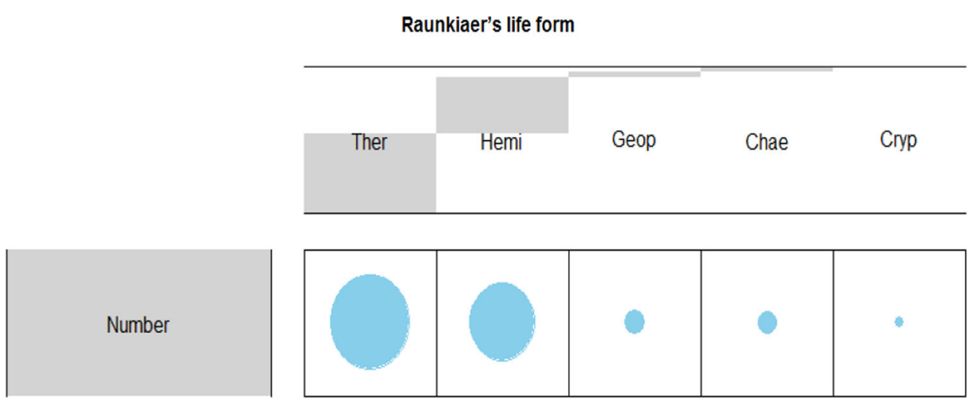

Fig. 3 The biological spectrum of the weed flora in the study area

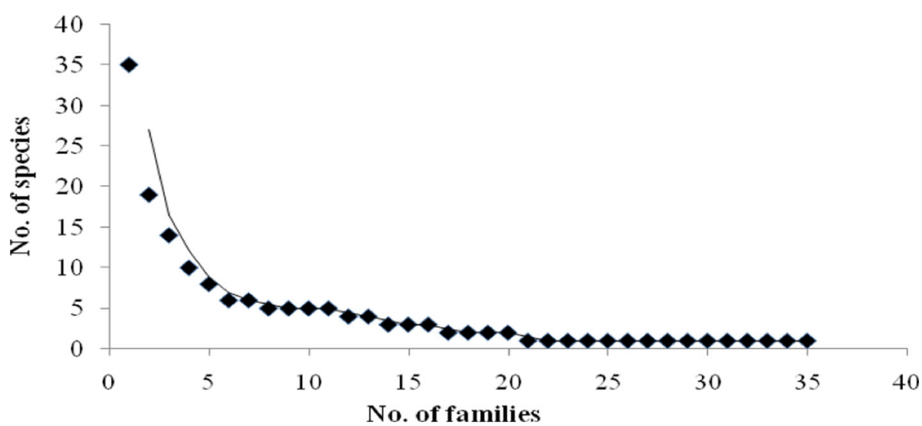

Fig. 4 Species–family relationship of weed flora in the study area

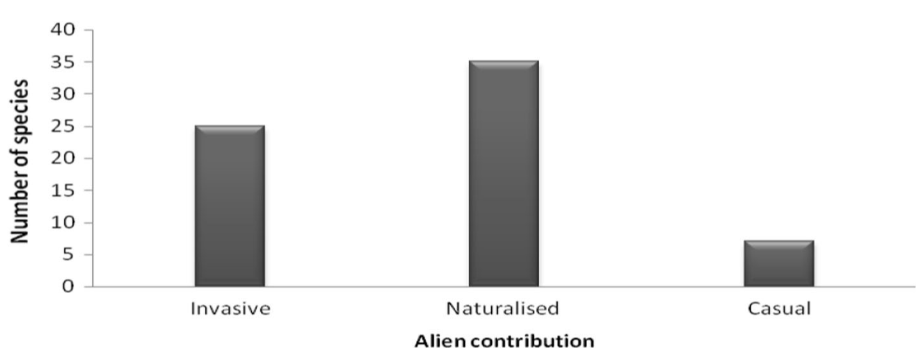

Fig. 5 Number of naturalized, invasive and casual alien species in weed flora

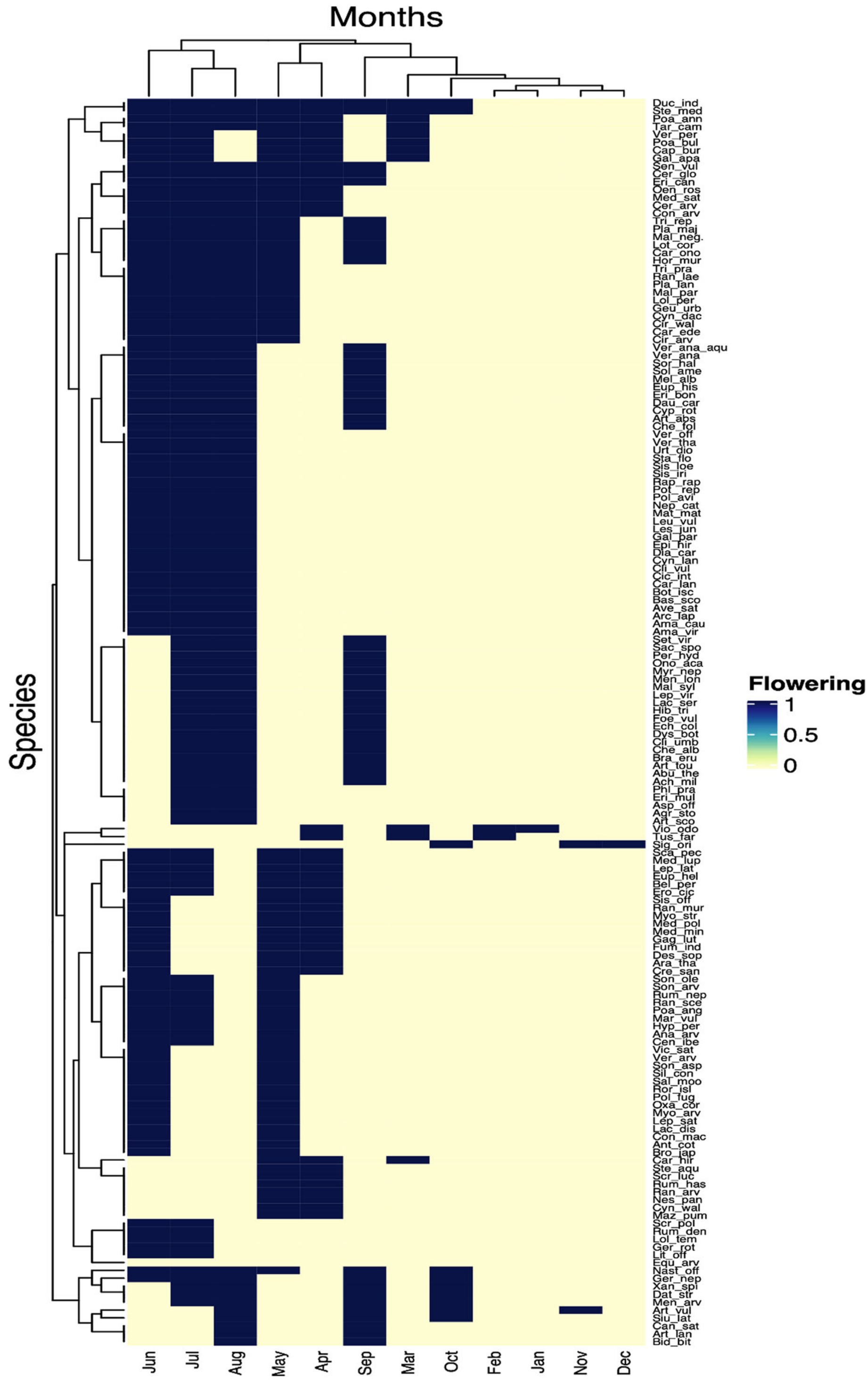

Fig. 6 Months clustering dendrogram based on phenological response

perennating parts under unfavorable seasons and appear on the return of favorable spring season. The predominance of therophytes is usually associated with high anthropogenic disturbance and the introduction of exotic weedy forbs, such as *Arctium lappa, Erigeron canadensis, Erigeron multiradiatus, Leucanthemum vulgare,* and *Sigesbeckia orientalis,* of this life form. The therophytes are adapted to occupy vacant niches as a result of anthropogenic disturbances.

Patterns of Invasion

The habitats within particular regions differ in the level of invasion usually varies strongly among different habitats, suggesting that some habitats are more susceptible to invasions than others. The unintentional introductions of invasive alien species through the development of transportation corridors have created new opportunities for the dispersal of alien plants in the area. Out of total species recorded 42% of species were alien, which mostly thrive in the anthropogenically disturbed habitats. These values are comparable with those reported by Kohli et al. [24] from the Himachal Pradesh and Adhikari et al. [25] from Arunachal Pradesh of Indian Himalayas. The unintentional introduction of alien species in the sub-urban region through the development of linear corridors and the creation of other distributed habitats create new opportunities for the dispersal of alien plants. Generally, the species with broad realized niches are probable to pass through these filters and likely to invade new ecosystems after disturbance. Thus, the disturbances facilitate invasions by non-native species, especially as they are increasing in frequency and intensity at local and global scales due to anthropogenic influences such as climate and land-use changes. The most invasive plant species growing in the region include species such as *Anthemis cotula, Convolvulus arvensis, Carduus onopordioides, Datura stramonium, Erigeron canadensis,* and *Sisymbrium loeselii*. These invasive alien plants are also reported as potential invaders in other parts of the Himalayas regions [26].

Since alien plant species tend to have more phenotypic plasticity than native plants and are usually superior to natives in numerous fitness components, they tend to colonize disturbed areas more resourcefully than native species, regardless of their life history strategy [3]. Distribution of alien species varied within the families, with Asteraceae representing the most dominant ones. Other studies on floristic diversity also reported Asteraceae as a dominant family in a biodiversity hotspot in Indian Himalayas. It has been observed that particularly the members of the family Asteraceae which are potential and actual dominant invaders of highly disturbed areas and are tolerant of human-induced disturbance regimes. Thus, the disturbed areas often have a very high proportion of exotic species belonging to these families. Therefore, the taxonomic grouping of the exotic species in certain families, as found in the study area, occurs because they tend to share ecological traits that promote their successful transport and establishment in new landscapes.

Patterns of Phenology

It has been reported that the location-specific phenophase shifts coupled with the changes in climate affect individual plant species and their regional ecosystems. The phenological spectrum of the flora revealed a maximum of species flowering season starts from April to September in which a total of 73% plant species were observed. Two major flowering periods were observed in the study area. Findings are in line with those of Malik and Malik [27] reported two flowering seasons in other parts of the Himalayan region and also aligned with a study conducted by Van Sahaik et al. [28] on phenological parameters with respect to flowering plants of tropical forests. In the investigated area, the majority of the species initiated flowering at the end of March and early April, and these investigation results are further supported by Zhang et al. [29] who attributed the trend to the onset of warmer weather. This investigation is in agreement with a similar result in their floristic and phenological investigations. Less flowering was observed from November to February. However, the present results are further supported by Malik and Malik [27]. The majority of species were in flower during April, which shows similarity with reported observations by Singh et al. [19] from other parts of the Himalayas.

Conclusion

The present study on the weed flora of district Kupwara of Western Himalaya denotes the possibility of the utilization of approaches of Raunkiaer's system to ascertain the remarkable distinctions between the alien flowering plant communities in high altitude forested regions of Himalaya and elsewhere in the world, their association led by the existing ecological parameters and environmental gradients. The data presented here will help to understand the composition of weed plant species, and analysis of life forms gives a clear-cut picture of the biological spectrum in the Kupwara district in Kashmir Himalaya. The study mainly focuses on the documentation of diversity and ecological characteristics of weed flora which provide insights to policymakers for their better management. In the present study, both therophytes, hemicryptophytes, and geophytes share the importance of depicting the "thero-hemicryto-geophytic" phytoclimates, and thus, finding is helpful to compare and contrast the adjacent natural forest types and vegetation along the environmental gradients, revealing more information on the ecosystem than the mere alien species. Further documenting flowering phenology will serve as baseline data for understanding the flowering shifts due to contemporary climate change associated with this area of Himalaya. The presence of dominant therophytes indicates the influence of more anthropogenic disturbances in the Kupwara area which favors the growth of more therophytic species.

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Compliance with Ethical Standards

Conflict of interest We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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