Prospect of Managing Invasive Plants by Native Insect Herbivores: A Case Study of Kashmir Himalaya

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Abstract

Biological invasions are considered a massive threat to native biodiversity engulfing both terrestrial and aquatic ecosystems worldwide while having cascading ecological and economic effects on the invaded regions. Kashmir Himalaya, an important constituent of the biodiversity hotspot, is heavily invaded by invasive alien plants. An inventory of species diversity of invasive plants and native insect herbivores was carried out in different terrestrial habitats of Kashmir Himalaya in the years 2018-19 and 2019-20. The results showed maximum value (3.39) of Shannon's diversity index at district Kupwara with minimum value (2.967) at district Srinagar. Margalef Index attained maximum value (5.966) at district Bandipora and a minimum value (4.724) at district Srinagar. Our data revealed maximum value of evenness (0.732) in district Baramulla with minimum value (0.650) at district Pulwama. Similarly, district Baramulla of North Kashmir showed highest Simpson value (0.957) while district Srinagar with minimum value (0.934). *Plantago major* belonging to the family Plantaginaceae was found to be the most dominant invasive plant species followed by *Taraxacum officinale* of family Asteraceae. *Altica himensis* was the most abundant native insect herbivore feeding on almost all invasive plant species with maximum damage on *Rumex hastatus* of Polygonaceae family. A total of 42 invasive plant species were recorded during the entire study period, of which 12 are worst invaders namely *Plantago major, Taraxacum officinale, Trifolium rapens, Trifolium pratense, Plantago lanceolata, Cyanodon dactylon, Anthemis cotula, Clinopodium umbrosum, Ranunculus arvensis, Veronica persica, Dactylis glomerata* and *Vulpia myuros*. A total of 14 native insect herbivores species were identified on these invasive alien plants, of which the prospect of 06 insect herbivore species as potential biocontrol agents is promising. Among the collected insect herbivores, a few namely *Chrysolina herbacea*, *Melanoplus differentialis*, *Pieris brassicae* and *Altica himensis* are being reared on native and invasive plant species under laboratory conditions. Preliminary results of these native insect herbivors as potential biocontrol agents against invasive alien plants are encouraging. These novel, non-coevolved insect herbivores can not only be exploited to control the spread of invasive plants but could also thwart huge economic losses associated with the management of invasive plants worldwide.

Introduction

Invasive species are newly introduced organisms that alter negatively the invaded habitats and bioregions. Due to globalization, the number of plant and animal species, translocated by humans and other animals, either deliberately or accidently, has drastically increased.[1–5] Biological invasions by aliens have been widely recognized as the second greatest threat to the global biodiversity, ecosystem structure and function.[1,3] Biological invasions have been shown to cause considerable changes in native species extinction likelihood, genetic composition of native populations, behaviour patterns, species richness and abundance, phylogenetic and taxonomic diversity, trophic networks, ecosystem productivity, nutrient cycling, hydrology, habitat structure, and various components of disturbance regimes.[6,7,8] In economic terms, the annual losses caused by Invasive Alien Species (IAS) in Australia, Brazil, India, South Africa, the United Kingdom and the United States have been calculated in the range of USD 300 billion per year.[9,10] In Europe alone, the economic costs of biological invasions are estimated to be at least EUR 12 billion per year.[11]

An important role in understanding the invasiveness of introduced alien species is often attributed to their release from natural enemies.[12] Alien species, which generally leave their specialized enemies behind, often encounter less herbivory than native species and thus may flourish in the new environment[13], this is known as the enemy release hypothesis[12,14,15]. Classical biological control provides an opportunity to partially reconstruct the natural enemy complex of an invading non-indigenous insect pest or weed[16] (Mills, 1994), and its application has been highly recommended to control established non-indigenous invasive insect pest or weed populations[17] (Wittenberg and Cock, 2001). Despite many proven benefits[18] (Greathead, 1995), classical biological control has recently come under scrutiny because introduced natural enemies may adversely affect native species, including rare and endangered species[19,20,21,22,23,24,25].

India has been one of the early adopters of Classical Biological Control (CBC) of insect pests and weeds alike. The first exceptional success in CBC of a weed was achieved with an incorrect introduction of mealybug, *Dactylopius ceylonicus* (Green) from Brazil in 1795, that was introduced in place of *Dactylopius coccus* Costa, which dramatically brought down the population of the prickly pear cactus, *Opuntia vulgaris* Miller, within 5 to 6 years in central and north India[26]. The *opuntia* experience resulted

in a series of introductions of phytophagous insects such as *Ophiomyia lantanae* (Froggatt) (ex-Mexico, via Hawaii in 1921) against lantana weed (*Lantana camara* L.) *Procecidochares utilis* Stone (ex-Mexico, via New Zealand in 1963) against crofton weed, *Ageratina adenophora* (Sprengel) and *Pareuchaetes pseudoinsulata* Rego Barros (ex-Trinidad in 1973) against Siam weed (*Chromolaena odorata*)[27]. In the post-independence era, CBC became more systematic and scientific with specific programmes managed by the erstwhile Indian Station of the Commonwealth Institute of Biological Control (CIBC) based in Bangalore. Later, country-specific programmes came under the purview of the All-India Coordinated Research Project (AICRP) on Biological Control of Crop Pests and Weeds, which was launched in 1977. This programme eventually came under the auspices of the Project Directorate of Biological Control (PDBC), which was formed in October 1993 under the Indian Council of Agricultural Research (ICAR), New Delhi.

The CBC finds an important place in the Perspective Plan ('Vision 2025') document of PDBC, Bangalore that aims at introducing the alien natural enemies of the alien organisms (which have become pests in the absence of natural checks in the new environment) in order to re-establish the balance between the pests and natural enemies. Although the results are checked and cross checked to avoid the damage to other species, many in the conservation biology community view this pest management technology as a high-risk enterprise because of the possibility of collateral damage to non-target species[23,25]. Moreover, little attention has been given to potential conflicts between insect biological control and weed biological control using invertebrate agents. Potential negative impacts of weed in question and candidate entomophagous biological control agents on weed biological control agents have been rarely considered before initiating a biological control programme and not even defined as a potential conflict of interest amongst practitioners and researchers of weed biological control. This is surprising as predation and parasitism were suspected as important factors in limiting the success of biological weed control agents[28,29].

India with about 10 per cent of the world fauna of insects is one of the 12 megadiversity nations in the world in terms of insect diversity. Our insect biodiversity is unique as evidenced by the high level of endemism. At the generic level, endemism is as high as 75% in Hymenoptera and 45% in Coleoptera and at the species level, it is 68% in Hymenoptera and 46% in Hemiptera[30]. As a novel resource the invasive plants can affect the performance of native insect herbivores and their natural enemies such as parasitoids and predators, and this can lead to host shifts of these herbivores and natural enemies[31]. Thus, on one hand the resident insect herbivores can provide the first line of defense against the invasive species, on the other hand the invasive plants can influence the spatial and temporal dynamics of native insect (meta) populations and communities, ultimately leading to changes at the landscape level; however, the impact of invasive plants on the population dynamics of resident insect species has been rarely examined. Thus, the need of the hour is to identify the local native insect herbivores which can be augmented to act as a first line of defense against alien invasive plant species, and alternatively evaluate the impact of these alien invasive species on identified native potential biocontrol agents. Kashmir Himalaya is a part of the Himalayan biodiversity hotspot that is heavily invaded by alien plant species. Despite harmful impacts of these invasive species on native biodiversity, economic and ecological systems of the region, a holistic field-based intensive sampling study for management of invasive species is lacking, which merits urgent research attention, because the resultant research knowledge base will guide better management. An assessment of the invasive plant species and native insect herbivore diversity of the North, Central and South Kashmir regions of Kashmir Himalaya was carried out during the years 2018-19 and 2019-20. The current study provides an inventory of the diversity of invasive plant species as well as native insect herbivores feeding on them and their relative abundance with special reference to species richness and evenness in forty-five sites of nine districts of Kashmir Himalaya.

Material And Methods

a) Field Surveys and Sampling

Surveys were conducted in different terrestrial habitats like forests, grasslands, horticultural and agricultural fields of Kashmir valley during years 2018-19 and 2019-20. Insect herbivores were collected from native and invasive plant species. The sampling was done from leaves, inflorescence, seeds and stem of native and invasive plants by collecting infested plant parts. The study sites comprised of invasion prone landscapes is shown in Table 1. Specimens collected during the whole study do not include any threatened species and hence it does not affect the survival of any threatened or vulnerable species as listed in IUCN Red list of threatened species. Further, the permission for sampling of plant and insect herbivores was granted by DST-SERB, Government

of India, New Delhi vide file no. EMR/2017/000215, dated 28th September, 2018 for a period of three years from 11th October 2018 to 10th October 2021.

Table 1
The select study areas with geographical coordinates in Kashmir Himalaya.

Study regions	Districts	Coordinates	Names of locations
North Kashmir	Bandipora	34.5052ºN/74.6869ºE	Sadunara, Ajas, Watapora, Aragam, Sumbal, Hajin
	Baramulla	34.1595ºN/74.3587ºE	Pattan, Sopore, Mazhama, Kreeri, Boniyar
	Kupwara	34.5262ºN/74.2546ºE	Bhangus Valley and adjoining areas
Central Kashmir	Budgam	33.9349ºN/74.6400ºE	Main Budgam, Tosa maidan, Panzan, Pallar, Mamath
	Ganderbal	34.2165ºN/74.7719ºE	Zazuna, Badampora, Kharbagh, Kurhoom
	Srinagar	34.0837ºN/74.7973ºE	Harwan, Shalimar, Nishat, Batapora, Foreshore roadside, KUBG
South Kashmir	Anantnag	33.7311ºN/75.1487ºE	Kokernag, Dooru, Akingam, Verinag, Qazigund
	Kulgam	33.6450ºN/75.0180ºE	Bag-e-wanpoh, Wanigund, Noorabad, Tarigam, Frisal
	Pulwama	33.8716ºN/74.8946ºE	Kakapora, Pampore, Khrew, Pohoo, Newa, Ratnipora

b) Identification

The adult and juvenile stages of the insects were preserved in small airtight vials while the genitalia were studied by placing them on cavity slides. These processed structures were studied and illustrated under Leica S9D fitted with MC 170 HD camera. Some of the insect species collected were identified by using relevant taxonomic keys and a few were identified by Dr. M. E. Hassan, Scientist D at Zoological Survey of India, Kolkata. The holotype specimen of each insect species was preserved and kept in the museum of the Department of Zoology, University of Kashmir for future reference. All the 42 plant specimens collected were processed at the Entomology Research Laboratory, Department of Zoology, University of Kashmir and were identified by Dr. Anzar and Dr. Akhtar, a subject experts besides following identification protocol of Khuroo *et al.* (2008)[32]. Each invasive plant species is provided with its scientific name, family and voucher specimen number with voucher numbers ranging from 3755-KASH to 3796-KASH (Table 2) while the plant specimens were deposited in internationally recognized Kashmir University Herbarium (KASH). All legal procedures and regulations were adopted during the whole study as per recommendations of IUCN.

Table 2
Plant species along with their accession/voucher no.'s deposited to Kashmir University Herbarium (KASH).

Species	Family	Common name	Origin	Accession/Voucher
Achillea millefolium	Asteraceae	Common Yarrow	Asia, Europe and North America	3755-KASH
Althea rosa	Malvaceae	Hollyhock	China	3756-KASH
Amaranthus caudatus	Amaranthaceae	Love-lies-bleeding	South America	3757-KASH
Anthemis cotula	Asteraceae	Chamomile	Mediterranean region and southwest Asia east to Iran	3758-KASH
Arctium lappa	Asteraceae	Burdock	Europe	3759-KASH
Bromus inermis	Poaceae	Bromes	Europe	3760-KASH
Cirsium arvense	Asteraceae	Californian thistle	Europe, Australia, western Asia	3761-KASH
Clinopodium umbrosum	Lamiaceae	Shady Calamint	Europe, Australia	3762-KASH
Cyanodon dactylon	Poaceae	Beremuda grass	Europe, Africa, Australia	3763-KASH
Dactylis glomerata	Poaceae	Orchard grass	Australia	3764-KASH
Daucus carota	Apiaceae	Bird's nest	Europe, Africa	3765-KASH
Erigeron multicaulis	Asteraceae	Many-Stemmed Himalayan Fleabane	North America	3766-KASH
Euphorbia helioscopia	Euphorbiaceae	Madwoman's milk	Europe, Australia	3767-KASH
Impatiens parviflora	Balsaminaceae	Small balsam	Eurasia	3768-KASH
Indigofera heterantha	Leguminosae	True indigo	South Africa	3769-KASH
Medicago polymorpha	Fabaceae	California Burclover	Europe, Africa	3770-KASH
Mentha longifolia	Lamiaceae	Wild mint	Australia	3771-KASH
Plantago major	Plantaginaceae	Fleaworts	Europe	3772-KASH
Plantago lanceolata	Plantaginaceae	Ribgrass	Africa, Europe	3773-KASH
Poa annua	Poaceae	Annual bluegrass	America	3774-KASH
Polygonum aviculare	Polygonaceae	Knotgrass	Europe	3775-KASH
Polygonum hydropiper	Polygonaceae	Water pepper	Europe	3776-KASH
Ranunculus arvensis	Ranunculaceae	Corn buttercup	Africa, Europe	3777-KASH
Ranunculus laetus	Ranunculaceae	Cheerful buttercup	Europe	3778-KASH
Ranunculus muricatus	Ranunculaceae	Rough-fruited Buttercup	Africa, Europe	3779-KASH

Species	Family	Common name	Origin	Accession/Voucher
Rubus ulmifolius	Rosaceae	Elm leaf blackberry	Europe	3780-KASH
Rumex hastatus	Polygonaceae	Heartwing Sorrel	Australia	3781-KASH
Sambucas wightianna	Caprifoliaceae	Kashmir Elder	Australia	3782-KASH
Solanum pseudo-capsicum	Solanaceae	Jerusalem cherry	Australia, Africa	3783-KASH
Stellaria media	Caryophyllaceae	Chickweed	Eurasia	3784-KASH
Stipa sibirica	Poaceae	Needle grass	Bohemia	3785-KASH
Synedrella nodiflora	Asteraceae	Synedrella	Tropical America; Mexico, West Indies, Florida	3786-KASH
Taraxacum officinale	Asteraceae	Common dandelion	Europe	3787-KASH
Trifolium pratense	Fabaceae	Red clover	Europe	3788-KASH
Trifolium rapens	Fabaceae	White clover	Europe	3789-KASH
Urtica dioica	Urticaceae	Stinging Nettle	Africa, Europe	3790-KASH
Verbascum Thapsus	Scrophulariaceae	Common mullein	Europe	3791-KASH
Veronica persica	Scrophulariaceae	Bird eye speedwell	Australia	3792-KASH
Vincea rosa	Apocynaceae	Periwinkle	Madagascar	3793-KASH
Vulpia myuros	Poaceae	Rat's-tail fescue	Europe	3794-KASH
Xanthium spinosum	Asteraceae	Bathurst burr	South America	3795-KASH
Xanthium strumarium	Asteraceae	Common cocklebur	Africa	3796-KASH

c) Statistical analysis

The data collected from the field sampling of 9 districts covering all the three regions (North, South and Central) of Kashmir Himalaya was analyzed by PAST 3, Version 1.0.0.0.0 software to work out various biodiversity indices such as Relative abundance, Shanon-Weiner index, Margalef index, Simpson index, and Evenness for drawing logical conclusions.

Results

Extensive surveys were conducted for collection, identification and documentation of invasive plant species and native insect herbivores in different districts of Kashmir Himalaya. A total of 09 districts were surveyed for a period of two years (2018-19 & 2019-20). Based on field surveys, highest number of invasive plant species were observed from district Kupwara (41), followed by district Baramulla (37), district Bandipora (31), district Budgam (27), district Kulgam (24), district Ganderbal (19), district Anantnag (17), district Pulwama, (15) and district Srinagar (12) (Fig. 1A) while maximum native insect herbivore species feeding on these invasive plant species were also reported from district Kupwara (15) and district Baramulla (15), followed by district Bandipora (14), district Budgam (12), district Kulgam (11), district Pulwama (10), district Ganderbal (10), district Anantnag (10), and district Srinagar (08) (Fig. 1G). In district Kupwara, 05 sites visited, and data collected suggested *Plantago major* (92) as the most abundant invasive plant species, followed by *Trifolium rapens* (91), *Taraxacum officinale* (78), and *Plantago lanceolata* (55) while the most abundant herbivores found were *Altica himensis* (170) followed by *Chrysolina herbaceae* (112), *Agrotis nigrisigna* (103) and *Nezara viridula* (102). In district Baramulla, 05 sites were visited which revealed *Ranunculus arvensis* (70) as strong

invasive species followed by *Dactylis glomerata* (61), *Plantago major* (60) and *Clinopodium umbrosum* (59). The dominant native insect herbivore in district Baramulla was *Altica himensis* (144) followed by *Agrotis nigrisigna* (98) and *Chrysolina herbacea* (87). In case of district Bandipora of the Northern region, 06 sites were selected for the data collection, where *Plantago major* (88) was the most abundant invasive plant species followed by *Cyanodon dactylon* (45) *Plantago lanceolata* (40) and *Taraxacum officinale* (39) while potential insect herbivores were *Altica himensis* (120) and *Plagiodera* sp., (97).

From Central region, three districts were selected with 15 sites, 05 from district Budgam, 04 from district Ganderbal and 06 from Srinagar (Table 1). *Plantago lanceolata* (50) and *Trifolium pratense* (50) were reported as the dominant invasive plant species followed by *Trifolium rapens* (41) and *Stellaria media* (39) in district Budgam. Native herbivore species sighted here were *Chrysolina herbacea* (100), the dominant one, followed by *Agrotis nigrisigna* (72), *Plagiodera* sp., (72) and *Altica himensis* (53). Most abundant invasive plant species in district Ganderbal were *Plantago major* (72) and *Trifolium rapens* (70) while prospective insect herbivores were *Nezara viridula* (87), *Chrysolina herbacea* (62) and *Agrotis nigrisigna* (60). A total of 05 sites visited in the capital district Srinagar, *Trifolium rapens* (51), *Taraxacum officinale* (49), *Plantago lanceolata* (48), *Plantago major* (42), *Cyanodon dactylon* (36), *Vulpia myuros* (29), *Trifolium pratense* (24), *Veronica persica* (20), *Anthemis cotula* (14), *Stellaria media* (14) and *Ranunculus arvensis* (10) were chief invasive plant species whereas only 04 potential insect herbivores namely *Chrysolina herbacea* (51), *Nezara viridula* (49) and *Agrotis nigrisigna* (32) were reported.

From Southern region, a total of 03 districts were selected namely Anantnag, Kulgam and Pulwama with 05, 05 and 06 study sites, respectively (Table 1). In Anantnag district, the data from the select 05 sites revealed that *Plantago major* (59) is the most abundant invasive plant species followed by *Taraxacum officinale* (56), *Trifolium pratense* (48) and *Trifolium rapens* (48), while potential insect herbivores reported were *Nezara viridula* (83) followed by *Altica himensis* (67), *Agrotis nigrisigna* (64), *Chrysolina herbacea* (59) and *Formica spp.* (34). In district Kulgam, a total of 24 invasive plant species were reported from all 05 select sites and the native herbivore species feeding on them were 12 species. Out of all 24 plant species, *Taraxacum officinale* (60) was the most abundant insect species followed by *Trifolium pratense* (56), *Trifolium rapens* (52), *Anthemis cotula* (40) and *Plantago major* (40). From all 12 native insect herbivores species feeding on these invasive plant species, 02 insect species *Chrysolina herbacea* (78) and *Altica himensis* (73) were found to be potential herbivores attacking primarily *Plantago major* (40) and *Rumex hastatus* (09). Similarly, 06 sites were visited in district Pulwama with *Taraxacum officinale* (70), *Trifolium pratense* (42) and *Plantago lanceolata* (38) as the most abundant invasive alien plant species while *Nezara viridula* (96), *Chrysolina herbacea* (64) and *Plagiodera sp.* (59) were abundant insect herbivores.

The significance of the data of 09 districts of Kashmir Himalaya was analyzed by PAST 3, Version 1.0.0.0.0 software by subjecting it to different diversity indices like Shannon-Weiner index (H), Simpson's index (D), Margalef's index (MI), Evenness index (J) and Relative Abundance (RA) as depicted in Tables 3 and 4. On comparing the data of invasive plant species in various districts of Southern, Central and Northern regions of Kashmir Himalaya, the total number of invasive plant species was highest in district Kupwara (1017) followed by Baramulla (891) and Bandipora (718) (Fig. 1B). Total number of individuals of native insect herbivores feeding on invasive plants was highest in number in district Kupwara (770) followed by district Baramulla (616) and district Bandipora (615) of Kashmir Himalaya as shown in Table 4 and Fig. 1H. Simpson's diversity index was highest at district Kupwara (0.955), while least at district Srinagar (0.893) which signified that Kupwara had high dominance of invasive plant species (Fig. 1C). Similarly, Simpson's index for native insect herbivores was highest at district Bandipora (0.885) and Kupwara (0.879) followed by Baramulla (0.868) and Kulgam (0.859) while it was minimum at Srinagar (0.803) (Fig. 1I). Shannon-Weiner index (H) was highest in the district Kupwara indicating that these districts have maximum diversity of invasive plant species (Fig. 1D). On the other when the same index was applied to native insect herbivores feeding on these invasive plants, data depicted the highest value of H was at districts Bandipora (2.395) and Kupwara (2.358) and least at district Srinagar (1.764), revealing that the Bandipora and Kupwara districts have high diversity of native insects while district Srinagar had least diversity (Fig. 1J). Species evenness for invasive plant species depicted the highest value of 0.880 at district Pulwama and lowest of 0.709 at district Kupwara which illustrated that invasive plant species were more evenly distributed at district Pulwama (Fig. 1E) while in case of native insect herbivores, maximum value of 0.737 was observed at Anantnag and minimum 0.603 at district Baramulla (Fig. 1K). Margalef's diversity index (MI) had its peak value at district Kupwara (5.776) and lower most at district Srinagar (1.882) which in other words means that Kupwara shows maximum distribution pattern and richness of invasive plant species while it

was minimum in district Srinagar (Fig. 1F). Following results were obtained on applying same index on native insect herbivores feeding on these invasive plants with a peak value of 2.335 at district Baramulla and only 1.334 at district Srinagar (Fig. 1L).

The Relative Abundance of all the invasive plant species and insect herbivore species at nine locations was also worked out by dividing the number of individuals of a species to the total number of individuals of all species and expressed as percentage (Figs. 2 and 3). Perusal of data revealed that *Plantago major* (9.372%) was the most dominant invasive plant species and highly flourished in Northern regions than Central and Southern regions. It was followed by *Taraxacum officinale* (8.557%), *Trifolium rapens* (8.185%), *Trifolium pratense* (7.104%) and *Plantago lanceolata* (6.821%). On the other hand, *Altica himensis* were the most dominant native insect herbivores feeding on these invasive plants with a total percentage of 17.640% followed by *Chrysolina herbacea* (16.809%), *Nezara viridula* (15.456%) *Agrotis nigrisigna* (14.221%) and *Plagiodera* spp. (9.425%).

Table 3
Diversity indices values of invasive plant species in 09 districts of Kashmir Himalaya.

Zone	**North Kashmir**			**Central Kashmir**			**South Kashmir**		
District	Bandipora	Baramulla	Kupwara	Budgam	Ganderbal	Srinagar	Anantnag	Kulgam	Pulwama
Species	31	37	41	27	19	12	17	24	15
No. of Individuals	718	891	1017	655	538	345	497	569	414
Simpson Index	0.950	0.952	0.955	0.948	0.920	0.893	0.922	0.935	0.914
Shannon-Weiner Index	3.193	3.244	3.37	3.087	2.708	2.335	2.658	2.902	2.58
Evenness	0.786	0.693	0.709	0.811	0.789	0.860	0.839	0.759	0.880
Margalef Index	4.562	5.3	5.776	4.009	2.863	1.882	2.577	3.626	2.323

Table 4
Diversity indices values of native insect species in 09 districts of Kashmir Himalaya.

Zone	**North Kashmir**			**Central Kashmir**			**South Kashmir**		
District	Bandipora	Baramulla	Kupwara	Budgam	Ganderbal	Srinagar	Anantnag	Kulgam	Pulwama
No. of species	15	16	16	13	11	8	11	12	11
No. of individuals	615	616	770	434	391	190	389	409	398
Simpson index	0.885	0.868	0.879	0.856	0.857	0.803	0.857	0.859	0.851
Shannon-Weiner index	2.395	2.267	2.358	2.113	2.087	1.764	2.094	2.114	2.042
Evenness	0.731	0.603	0.660	0.636	0.732	0.729	0.737	0.69	0.700
Margalef index	2.18	2.335	2.257	1.976	1.675	1.334	1.677	1.829	1.67

No. of species (A), No. of individuals (B), Simpson index (C), Shannon-Weiner index (D), Species evenness (E) and Margalef index (F) of invasive plants; No. of species (G), No. of individuals (H), Simpson index (I), Shannon-Weiner index (J), Species Evenness (K) and Margalef index (L) of native insect herbivores.

While summarizing the two years data (2018-19 and 2019-20), a total of 42 invasive plant species were recorded, of which 12 are worst invaders namely *Plantago major, Taraxacum officinale, Trifolium rapens, Trifolium pratense, Plantago lanceolata, Cyanodon dactylon, Anthemis cotula, Clinopodium umbrosum, Ranunculus arvensis, Veronica persica, Dactylis glomerata* and *Vulpia myuros*. A total of 14 native insect herbivores species were identified on these invasive alien plants, of which the prospect of 06 insect herbivore species as potential biocontrol agents is promising. The rearing of these insect species is worked out under laboratory conditions, followed by green house and in-situ experiments. Overall, 09 districts surveyed during the study period revealed highest number of invasive plant species in district Kupwara of Northern region of Kashmir Himalaya, while the lowest were in district Srinagar. The most dominant invasive plant species from North Kashmir was *Plantago major* (9.139%) with its maximum dominance in district Kupwara (3.503%). From Central Kashmir, most abundant invasive plant species was found in district Budgam (42.587%), where *Trifolium rapens* (10.533%) and *Plantago major* (10.403%) were found dominantly while from South Kashmir, maximum invasive plant species were found in district Kulgam (38.445%) and *Taraxacum officinale* (12.567%) was the dominant plant species found during our survey. From North Kashmir, *Altica himensis* was the most dominant native insect herbivore species. Likewise, from Central Kashmir, *Chrysolina herbacea* was the dominant one while from South Kashmir, *Nezara viridula* was found to be the most abundant native insect herbivore feeding on various invasive plant species.

Among the collected insect herbivores, a few viz., *Chrysolina herbacea*, *Melanoplus differentialis*, *Pieris brassicae* and *Altica himensis* are being reared on native and invasive plants under laboratory conditions to check their efficacy as potential biocontrol agents. The field observations of native insect herbivores feeding on invasive plant species in select sites are shown in Fig. 4.

A. *Altica himensis* feeding on *Urtica dioica*; B. Larvae of *Aglais cashmeriensis* feeding on *Urtica dioica*; C. Damage on *Rumex hastatus* by *Altica himensis*; D.Spittle bug on *Cannabis sativa*; E. *Altica himensis* feeding on *Rumex hastatus*; F. *Chrysolina herbaceae* on *Mentha longifolia;* G. manual insect collection; H. *Chrysolina herbacia* feeding on *Mentha longifolia;* I. *Altica himensis* feeding on *Rumex hastatus;* J .Infestation in *Vitis flora* by *Altica himensis*; K. *Euphorbia* flowers with visiting pollinators; L.Mating process of *Chrysolina herbacia* on *Mentha longifolia.*

Discussion

Diversity enables us to understand the relationship between the habitat and ecosystem[33]. Our study revealed a total of 42 invasive plant species with 12 worst invaders. Less number of alien plant species reported during the study period were due to small sample size as our main focus is on their management by native insect herbivores. Further, no taxonomic work has been carried out on native insect herbivores which are specialists on invasive plant species in this part of the world. Different species of invasive plants documented attract wide variety of native insect fauna, which play a vital role in their population decline. Invasive plant and native pest studies carried out in around 45 study areas of Kashmir Himalaya, during different seasons of the years 2018-19 and 2019-20, revealed the presence of 42 invasive plant species and 16 native insect herbivores feeding on them. Our study reveals that the alien flora of some selected sites of Kashmir Himalaya comprised of 42 plant species belonging to 19 families. All invasive plants are not equally fed by native insect herbivores. Some plants are infested and preferred for oviposition and larvae development while some are even not showing any presence of native insect herbivores upon them. In our study, all enlisted and documented invasive plants have also been reported by Khuroo *et al.* 2007[34], where they enlisted the total alien flora of the region ca. 571 plant species, belonging to 352 genera and 104 families. These invasive plants can pose a serious threat to native biodiversity of Kashmir Himalaya. Invasive alien species are known to erode native species richness and driving species to extinction35,36,37. Maximum alien species were reported from district Kupwara. The process of invasion has long been discussed and debated by researchers as the alien species threatened the existence of endangered species, integrity of ecosystems and their depredation cost national economies tens of billions of dollars every year[38]. Invasion of alien species is more crucial for the Indian economy and is at a higher risk[39,]. Keeping these above facts under consideration, a promising management strategy should be available to reduce their indiscriminate spreading and loss to our native diversity. One of the promising management strategies is biological control, where native natural insect species feed on these invasive plant species are seen and is being considered as a safe and cost effective, alternative strategy against many alien plant species. The introduction of coevolved natural enemies from an alien species home range (classical biological control) has been one of the key methods for suppressing invasive species[40,41,42]. However, host specificity tests of natural enemies are required worldwide before release; as insects introduced for biocontrol of invasive plants may negatively affect native plants due to potential host

shifts and/or host range expansion[23,43,44,42]. These deliberate introductions of alien insects may subsequently lead to direct or indirect cascading effects on native food webs and ecosystems[45,46] and even affect human health[47].

Some invasive plants are extremely damaged by these native herbivores. *Rumex hastatus*, commonly known as Heartwing Sorrel belonging to the family Polygonaceae was the most affected allien species in Kashmir Himalaya by *Altica himensis. Cirsium arvense*, commonly known as Californian thistle, grown at altitudes above 2400 m as an invasive plant in Kashmir Himalaya[34] showing the presence of *Chrysolina herbacia* and *Formica* spp. *Cyanodon dactylon*, belongs to the family Poaceae is native to Europe, Africa, Australia and much of Asia. It has been introduced to the America and is grown widely in Kashmir Himalaya. Large number of native insect species took shelter at the bottom and vigorously visit *Cyanodon dactylon* that is highly variable and various subspecies have been distinguished in many regions[48]. *C. dactylon* is treated as the second most important weed in the world after *Cyperus rotundus*[49]. *Heliothis armigera* and *Agrotis nigrisigna* were feeding on medicinal invasive plants such as *Mentha longifolia* and *cannabis sativa*. *Aphis affinis* were seen to fed on *Mentha longifolia* while *Aphis citricola* and *Aphis craccivora* on *Althea rosea. Aphis fabae* and *Aphis gossypii* fed on *Althea rosea*, *Plantago major* and *Taxaracum officinale.* These findings are in agreement with that of Meshran, (1994)[50], Bhat and Ahanger (2018)[51]. Similar observations supporting the present study have been made in other regions of the world. Perusal of our study revealed that *Altica himensis* were the most dominant native insect herbivores in North Kashmir, feeding on *Rumex acetosa*, *Rumex hastatus*, *Rumex dentatus* and other invasive plants although these are not dominant beetles as compared to *Psylliodes tenebrosus* and *Phyllotreta striolata*[52].

The analysis of manipulative field studies revealed that native herbivores suppressed alien plants, whereas alien herbivores facilitated both the abundance and species richness of alien plants[53]. Both outcomes suggest that plants are especially susceptible to novel, generalist herbivores that they have not been selected to resist. Thus, native herbivores provide biotic resistance to plant invasions, but the widespread replacement of native with alien herbivores (in biocontrol programmes) eliminates this ecosystem service, facilitates plant invasions, and triggers an invasional “meltdown” [54]. Therefore, the need of the hour is to exploit the potential of native herbivores, which are evolutionarily novel enemies that alien invaders may not be adapted to deter, in order to limit the establishment or spread the invasive alien species. Alternatively, as a novel resource the invasive plants can affect the performance of native insect herbivores and their natural enemies such as parasitoids and predators, and this can lead to host shifts of these herbivores and natural enemies[31]. Thus, on one hand the resident insect herbivores can provide the first line of defense against the invasive species, on the other hand the invasive plants can influence the spatial and temporal dynamics of native insect (meta) populations and communities, ultimately leading to changes at the landscape level. Preliminary results of these native insect herbivores as potential biocontrol agents against invasive alien plants are encouraging notwithstanding, more field studies are underway to gather comprehensive information of invasive plants species and native insect herbivores. Here in Kashmir Himalayan, no any invasive species were deliberately introduced for any specific purpose. The reason behind there invasion may be due to global trade, tourism and hitchhike mechanisms. In addition to the alien invasive from across political borders, invasion of pests can also occur from one geographic location to another within the same country.

Conclusion

Globalization has increased import and export of almost all products including agricultural and horticultural products and has increased the movement of propagating material and seeds that has elevated the risk of invasive species entering India[55]. Once these invasive plants became established in new natural or semi natural ecosystems, these threaten the native biodiversity and may lead to huge economic losses. These invasive species are considered as a major driver of biodiversity loss worldwide due to their fast growth, early maturity, ability to go without food and water for a longer time, efficient means of spread and high reproduction. Native insect pests have caused significant damage to almost all visited fields like forests, grasslands, horticultural and agricultural fields of Kashmir Himalaya during years 2018-19 and 2019-20. In order to overcome from these flourished invasive plants biological control seems to be the competent method, where natural enemies are playing an important role to keep them in check in their early stages. The present study highlighted the diversity of native insect herbivore species feeding on different invasive plant species in Kashmir Himalaya with an overall 49 observatory sites selected which accounted for invasion process due to open landscape areas. Field visits were made to the selected sites in order to collect invasive plant species and native insect herbivores. A total 14 native insect pest species were collected that were feeding and causing damage to different

parts of invasive plants particularly to foliage. Preliminary results of these native insect herbivores as potential biocontrol agents against invasive alien plants are encouraging. These novel, non-coevolved insect herbivores can not only be exploited to control the spread of invasive plants but could also thwart huge economic losses have associated with the management of invasive plants worldwide.

Declarations

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Author's contributions

T.A. and I.R. contributed to the study conception and design. Material preparation and analysis were performed by T.A. and R.A. Data collections were done by M.M. and N.A. The first draft of the manuscript was written by T.A. and all authors commented on previous versions of the manuscript. All authors read, reviewed and approved the final manuscript.

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Conflicts of interest/Competing interests: The authors declare that we don't have any conflicts of interest.

Data availability statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study. The datasets analysed are field based studies of the authors.

Ethics declarations

Our research is based on the conservation of global biodiversity where population expansion of invasive plants is checked by classical biological controlling measures. Biological invasions by aliens have been widely recognized as the second greatest threat to the global biodiversity, ecosystem structure and function. The study does not include any threatened species and hence it does not affect to the survival of any threatened or vulnerable species as listed in IUCN Red list of threatened species. All authors accept and oblige that all legal procedures and regulations were adopted during the whole study as per recommendations of IUCN. Further, the permission for sampling of plant and insect herbivores was granted by DST-SERB, Government of India, New Delhi vide file no. EMR/2017/000215, dated 28th September, 2018 for a period of three years from 11th October 2018 to 10th October 2021.

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Figures

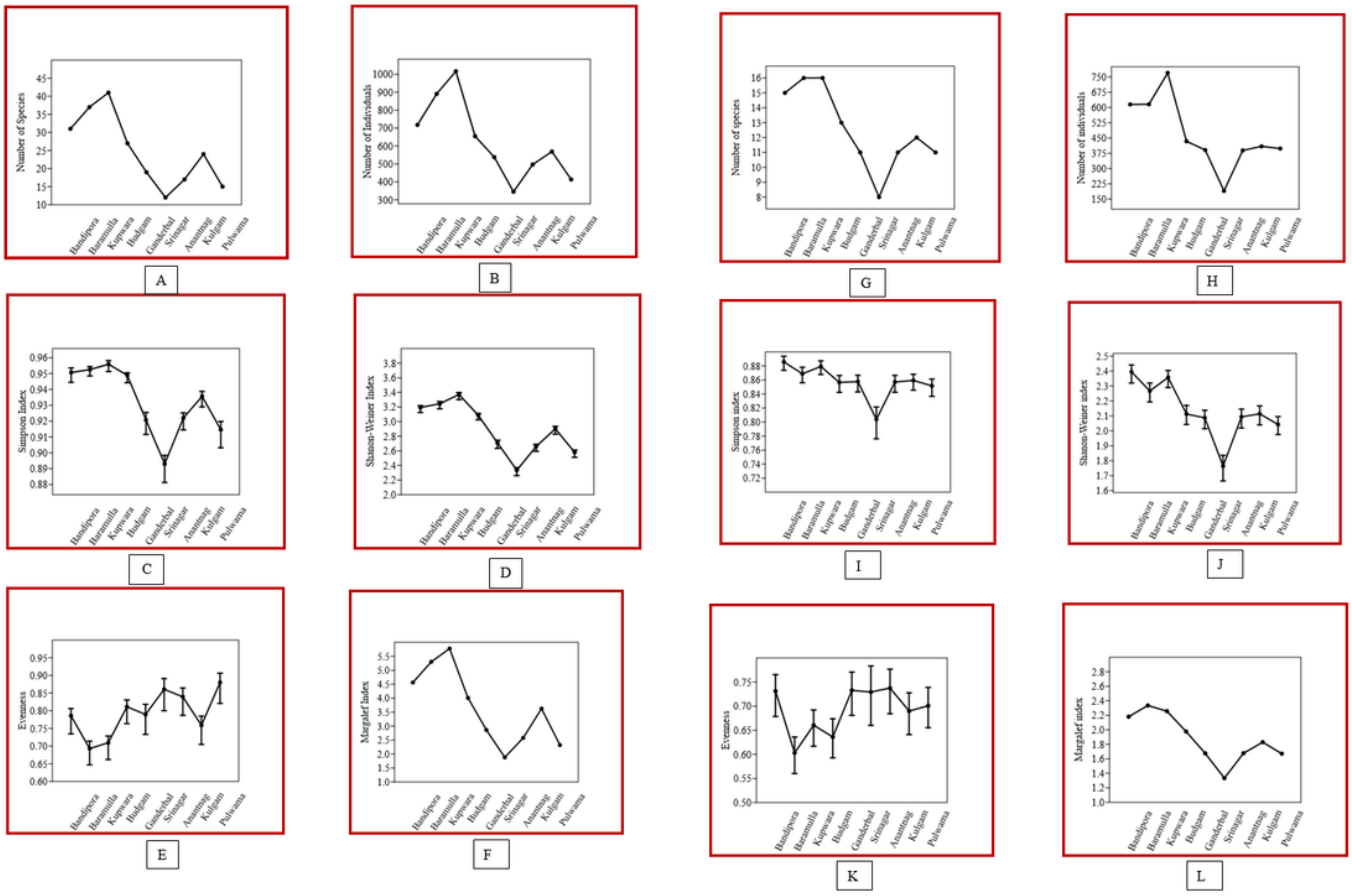

Figure 1

Graphical representation of various diversity indices of invasive plants and their native insect herbivores in different districts of Kashmir Himalaya: No. of species (A), No. of individuals (B), Simpson index (C), Shannon-Weiner index (D), Species evenness (E) and Margalef index (F) of invasive plants; No. of species (G), No. of individuals (H), Simpson index (I), Shannon-Weiner index (J), Species Evenness (K) and Margalef index (L) of native insect herbivores.

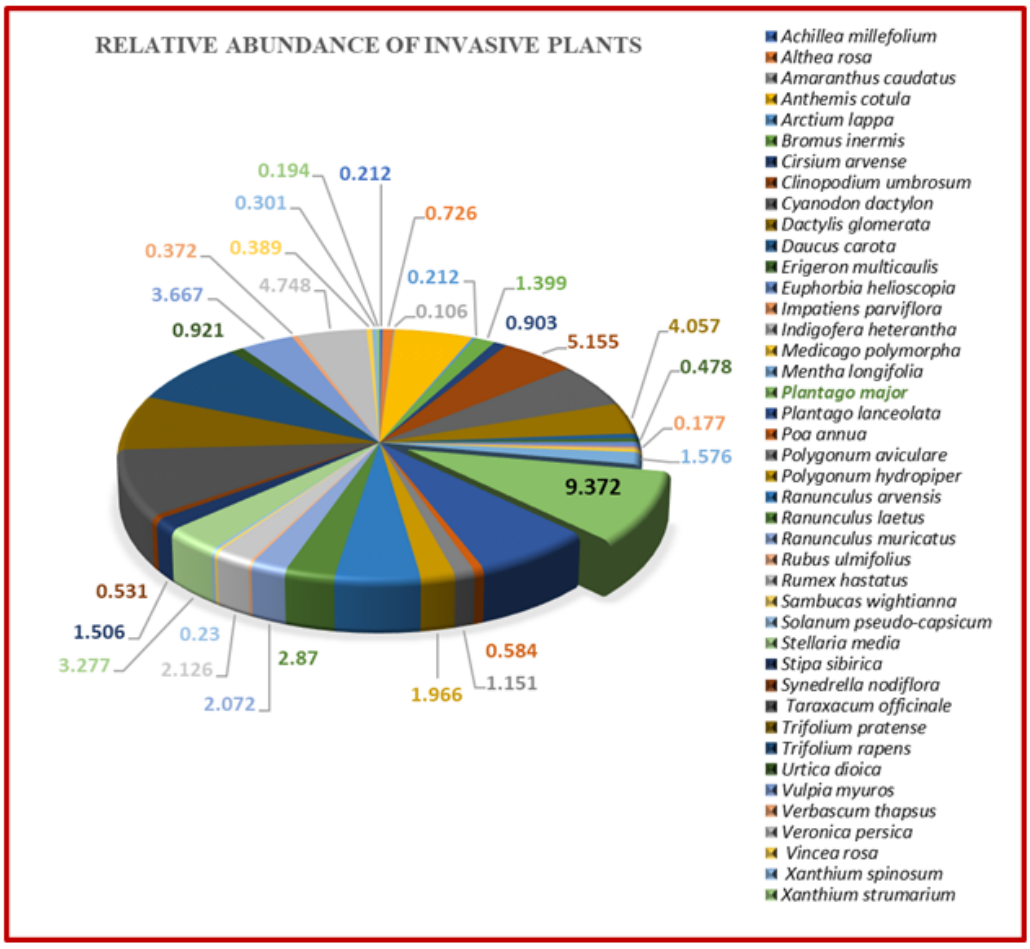

Figure 2

Relative abundance of invasive plant species

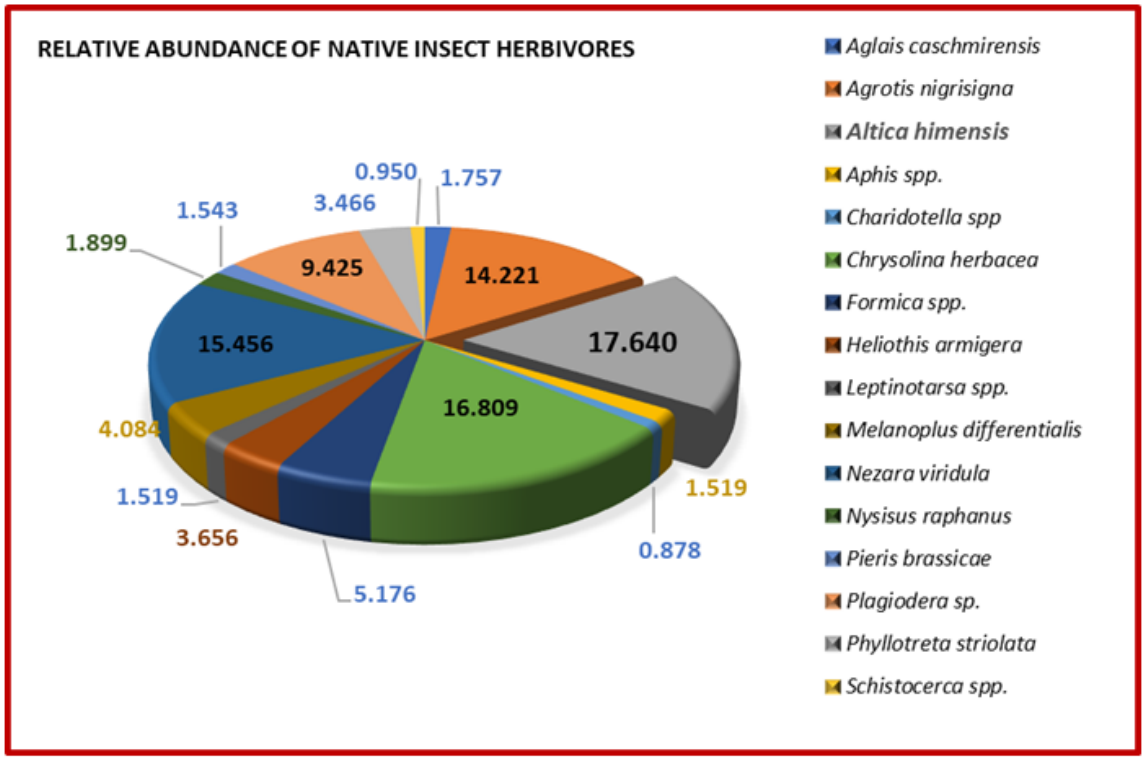

Figure 3

Relative abundance of native insect herbivores

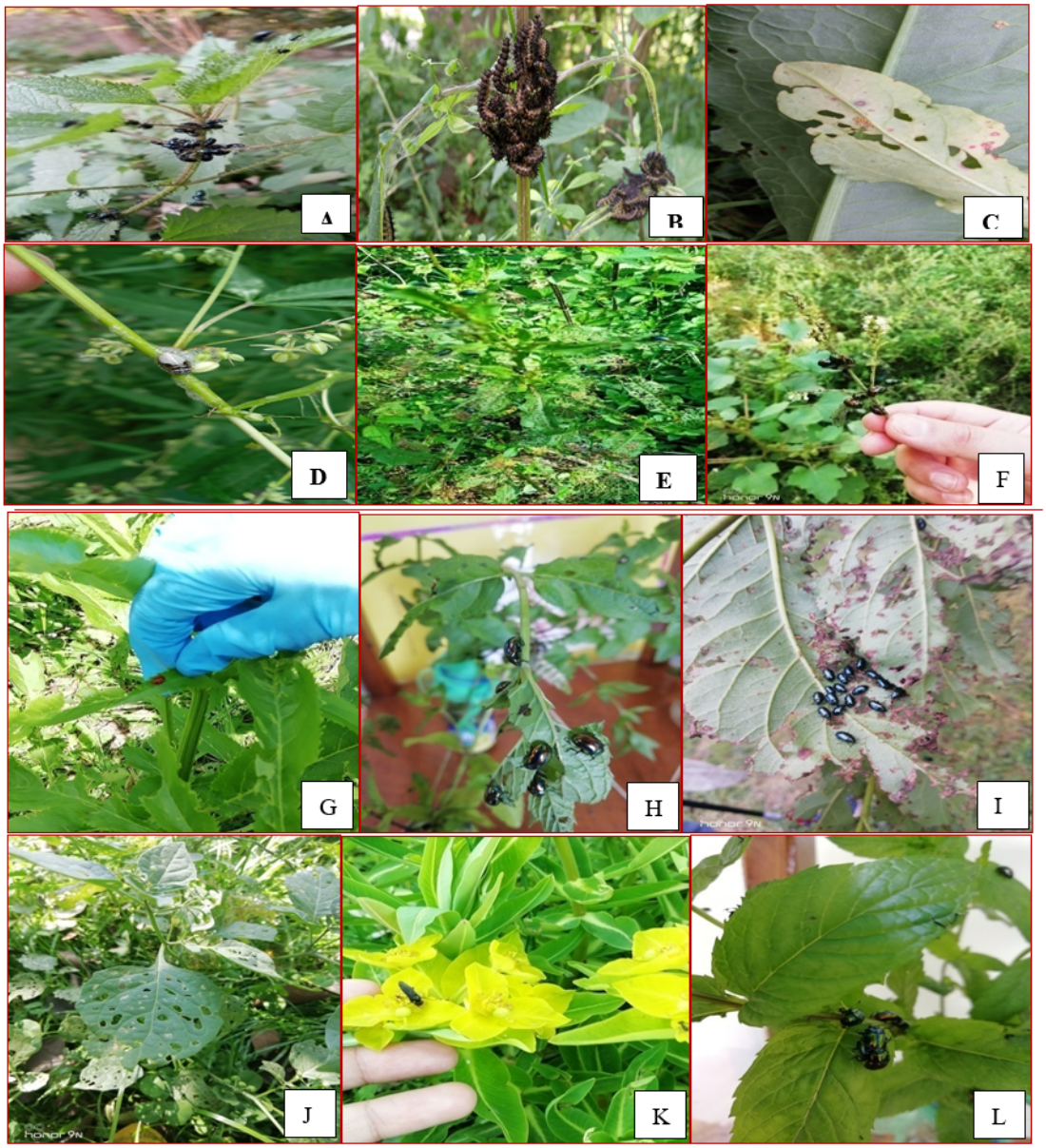

Figure 4

Field observations of native insect herbivores feeding on invasive plant species in various selected sites. A. Altica himensis feeding on Urtica dioica; B. Larvae of Aglais cashmeriensis feeding on Urtica dioica; C. Damage on Rumex hastatus by Altica himensis; D.Spittle bug on Cannabis sativa; E. Altica himensis feeding on Rumex hastatus; F. Chrysolina herbaceae on Mentha longifolia; G. manual insect collection; H. Chrysolina herbacia feeding on Mentha longifolia; I. Altica himensis feeding on Rumex hastatus; J .Infestation in Vitis flora by Altica himensis; K. Euphorbia flowers with visiting pollinators; L.Mating process of Chrysolina herbacia on Mentha longifolia.