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RESEARCH ARTICLE

Distribution pattern and management of invasive alien plant species in Sikkim Himalaya, India

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Abstract

An assessment of the distribution pattern of Invasive Alien Plant species in the Sikkim Himalayas was conducted at different elevation gradients and accordingly, management strategies were recommended to combat the ever -increasing condition of invasive plant species threatening the sensitive ecoregions. Among the most relevant factors supporting the present study were changes in the importance value index (IVI), variety, and evenness. There is a greater percentage of domination of invasion at lower elevations than at higher elevations. Species diversity, dominance, and evenness values decreased significantly at higher elevations; interestingly, the fraction of invaded regions is lower at higher elevations. Several factors may contribute to the large cover of invasive plants at lower elevations, including the enabling climate and anthropogenic activities. As a result of invasive alien plant species, such as *Ageratum conyzoides*, *Ageratina adenophora*, *Bidens pilosa*, *Chromolaena odorata*, *Lantana camara*, *Mikania micrantha* and *Parthenium hysterophorus*, native vegetation, and fauna may suffer adverse consequences, as well as socioeconomic conditions and health issues. This study determined that the invasion of these invasive alien plants in different elevations in the Sikkim Himalaya impacts ecosystem services and depletes several species of commercial importance. The current study recommends quick action to control harmful invasive alien plant species in the Sikkim Himalaya.

Keywords

Altitude; ecosystem; Himalayas; invaded; management

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Introduction

Invasive alien plant species, as defined by the European Union (1), are those for which it has been established that their introduction or spread threatens or adversely affects ecosystem services and biodiversity. According to Nugent et al., (2), invasive plant species are rapidly spreading across the world, causing significant alterations to vital ecosystems. This proliferation has led to the deterioration of ecosystems and the disruption of ecological services, negatively impacting human health, economics, and ecological services in some regions (3). When plants travel from their native range to a new ecosystem, they may be exposed to different environmental conditions, resulting in land-use-induced biological invasions of flora and fauna (4).

Anthropogenic activities, high tourism rates, and pollution also threaten native diversity (5). Ecologists are divided on which threat is more severe, with around 27.3% considering invasive alien plant species to be the greatest threat (5). Previous research has shown that vegetation composition, soil nutrient ratio, geographical altitudes, and solar radiation play a crucial role in determining the success of invasion (6). The Indian Himalayan region (IHR) is a biodiversity hotspot that sustains millions of lives through the circulation of energy and biomass. Although research on plant invasion has expanded rapidly on a global scale, investigations into IHR remain limited (7). However, many recent studies have made this topic well-known in the area (8–11). A recent publication reports that the rate of species invasion in the Sikkim Himalaya is continuously influenced by altering land cover and land use, as well as regionally-scaled biotic and abiotic factors (12). Biological invasions have serious economic consequences and can cause significant losses in various industries globally. While not all alien species become invasive, some native species can also dominate in a particular area. The Convention on Biological Diversity (CBD) (13) recognizes global biotic invasions as a major priority. Recent research by the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (14) has shown that conservation efforts alone cannot halt biodiversity loss, and invasive alien plant species are one of the main causes of the present biodiversity crisis. The harm caused by invasive alien plant species to biodiversity, ecosystem services, sustainable development, and human well-being is typically underestimated and poorly understood by decision-makers. In response, IPBES began a thematic assessment of IAPS and their management in 2019. Although various methods have been proposed for controlling invasive species, their implementation remains limited. Several researchers have evaluated the management status of invasive alien plant species (IAPS) in India (15–17). The invasive plant species pose a significant threat to indigenous plants, fauna, farmland, animals, and ultimately humans (18–19). Phytosociological studies have been conducted worldwide to determine the species composition, dispersion, and diversity along gradients in the (12, 20–22). The light intensity plays a crucial role in the growth and reproduction of *Ageratum conyzoides*, *Ageratina adenophora*, *Bidens pilosa*, *Chromolaena odorata,* and *Lantana camara* thrives in areas of Himalayan degradation with ample light, spreading through dense scrambling thickets, forest patches, and roadsides. This expansion poses a significant threat to already endangered grassland obligate species. Unfortunately, there is a lack of knowledge regarding effective control measures for invasive species and habitat degradation in the Himalayan region, hampering management and recovery efforts. To address this knowledge gap, we conducted experiments to evaluate the spread of these highly invasive plants and the effectiveness of different control methods. Our study focused on *Ageratum conyzoides*, *Ageratina adenophora*, *Bidens Pilosa,* and *Chromolaena odorata,* comparing and analyzing their invasive tendencies. The findings of this research aim to inform forest managers and policymakers, enabling them to develop comprehensive invasive species management plans for the Sikkim Himalayan ecosystem. These plans are crucial for the long-term conservation of the habitat, which serves as a refuge for rare and imperiled species while supporting human well-being.

Materials and Methods

Study site

The study was conducted in Sikkim, a north-eastern state of India, at various altitudinal gradients up to <2800 m (Fig. 1). Sikkim is located between 27°04'46" to 28°07'48"

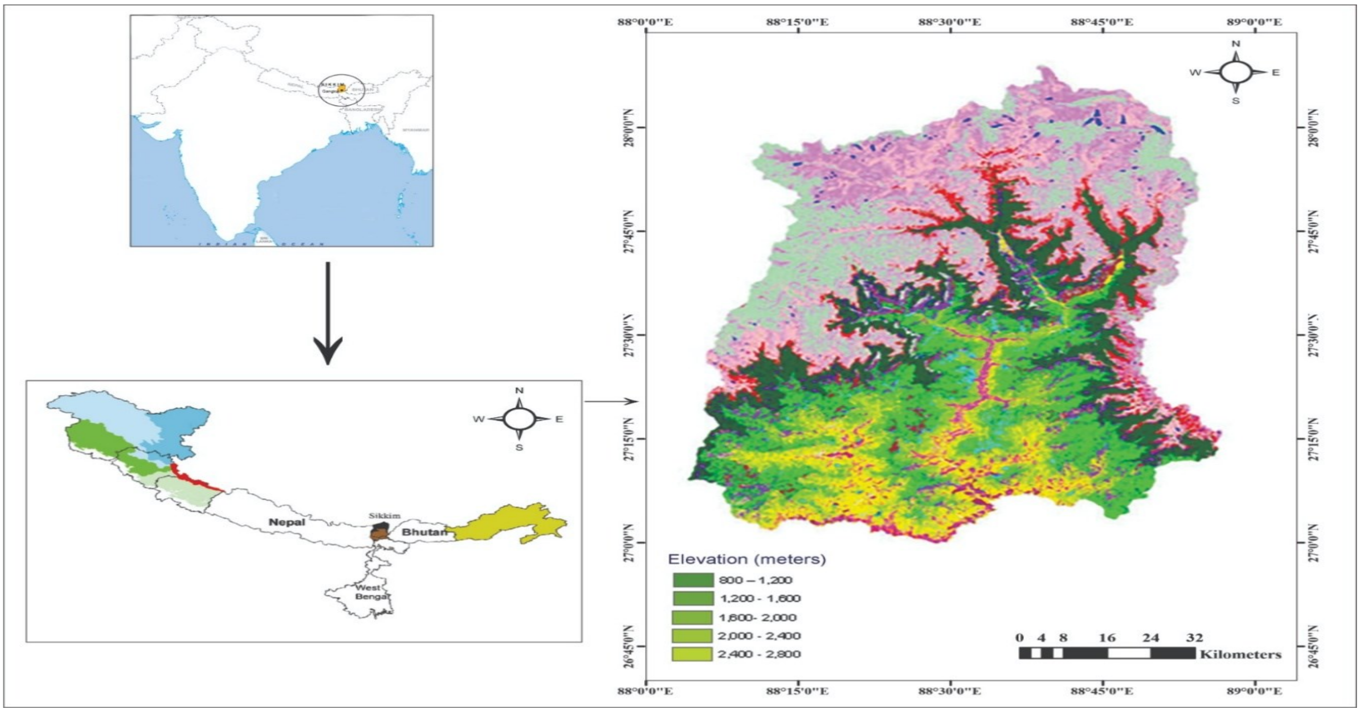

Fig. 1. Study site depicting the sampling gradients in Sikkim Himalayas.

North latitudes and 88°00'58" to 88°55'25" East longitudes, covering an area of 7096 sq. km in the upper part of the Teesta basin. It experiences a diverse range of climates, from subtropical to wet temperate monsoon (~2540 to 3810 mm average annual precipitation) depending on the dramatic landscape. Sikkim extends approximately 114 km from North to South and 64 km from East to West, with altitudes ranging from 300 to 8598 m. It serves as a unique reservoir of flora and fauna that provide essential ecosystem services.

Data collection

During the post-rainy season of two consecutive years, 2019 and 2021 (September–November), a quadrat-based study was conducted in the Sikkim Himalayan Region across various altitudinal gradients ranging from <800m to 2800 m. Phytosociological studies were carried out by placing a total of 104 quadrats measuring 5×5m along these gradients. Plant samples were identified through herbarium specimens of LWG, CNH, and BSHC, with voucher specimens submitted to LWG in Lucknow, India, as listed in Table 1.

Data analysis

The vegetation parameters, including density, frequency, and dominance, were calculated for each altitudinal gradient. The Importance Value Indices (IVIs) for each plant species were computed using the formula:

Importance value index (IVI) = R. Den. + R.F. + R.D.

where, R. Den.= Relative density,

R.F. = Relative Frequency, and R.D. = Relative Dominance.

Dominance = Basal area × Density where,

Basal area = πr2 (π = 3.14 is constant and r = basal radius of plant stem).

Ecological Indices were calculated as per the formula

Shannon Index (H); H' $= -\sum_{i=1}^{s} Pi\ lnpPi$

Simpson's Index (λ) was calculated as per the formula

λ = $= \sum_{i=1}^{s} (ni/N)2$

The Evenness Index (E) was calculated as per the formula

E = H' /lnS

pi = the proportion of individuals belonging to i^{th} species, **ln** = the natural log, **S** = the number of species, **ni** = the number of individuals of i^{th} species, and **N** = total number of species.

The distribution of species was analyzed using Whitford's index, which was derived from the formula: Abundance (A) divided by frequency (F). This ratio indicates whether the species dispersion is regular (0.025), random (0.025–0.05), and contagious (>0.05).

Management strategies

Sikkim Himalayas is home to a diverse and rich number of angiosperms. There are 114 invasive alien species known from the Sikkim Himalayas, most of which are spread across altitudes and all the anthropogenic areas (11). These invasive species not only cause environmental damage but also have economic repercussions, as they reduce biological diversity, limit access to resources, affect human health, and alter ecosystem functions (23–24). The invasion of exotic plants has been exacerbated by human activities, leading to challenges in managing these invasive species due to factors such as insufficient allocation, financing limits, lack of awareness among stakeholders, managers, and the public (19), and the fluctuating climate (18).

Despite being a biodiversity hotspot with a picturesque landscape, the Sikkim Himalayas are severely affected by invasive alien species, which can be observed throughout the terrain (11). To combat these invasive species, several methods have been employed, such as promoting the growth of specific native plant species through environmental regeneration to counteract the negative effects caused by the invading species, using crop competitiveness strategies in combination with mechanical control methods, and implementing cutting-root stock techniques and planting native grasses and legumes, as recommended by the CBD (13). Policymakers must increase public awareness campaigns to inform people about the proliferation of invasive alien species in the state and prevent their further spread.

Results and Discussion

Floristic composition

The community and distribution of species in a particular location are shaped by environmental characteristics and species competition (25), which may change gradually or rapidly in response to habitat exposure and climate variations in the targeted region (26). Understanding how species respond to changing environmental conditions is critical to maintaining ecosystem integrity, particularly in the face of increasing disturbances caused by invasive plant species that can quickly alter ecosystem community structure and processes (27). With this in mind, we conducted a study to examine the distribution pattern and phytosociological attributes of invasive alien plant species and their associates at various altitudes in Sikkim Himalaya to assess their invasiveness and potential management. Our investigation, spanning from elevations of <800m to <2800m, contains 69 associated plant species from 62 genera and 25 families. Of these, 38 were invasive alien species, 29 were indigenous, and one each was causal and cultivated to the Sikkim Himalaya. The Asteraceae family was most prevalent with 26 species, followed by Solanaceae (8 spp.), Lamiaceae (5 spp.), Acanthaceae, Amranthaceae, and Urticaceae (3 spp. each), Melastomataceae and Polygonaceae (2 spp. each), while the remaining 17 families were represented by solitary species (Table 1). The associated species exhibited various growth forms, including 48 herbs, 19 shrubs, 1 climber, and 1 grass (Table 1). The species identified in this study are similar to those reported by other researchers in the Indian Himalayan regions (8, 11, 28–30). Most of the species had American nativity, accounting for 31 percent of the total species. Notably, *Ageratum conyzoides*, *Ageratina adenophora*, *Bidens pilosa*, *Chromolaena odorata*, *Crassocephalum crepidioides*, *Erigeron karvinskianus*, *Lantana camara*, *Mikania micrantha*, *Parthenium hysterophorus*, and others were found to dominate almost every selected gradient.

Distribution pattern and diversity indices

The study observed the highest and lowest Importance Value Index (IVI) values of different plant species at various altitude gradients. *Parthenium hysterophorus* had the highest IVI value (70.04) at 800–1200 m, while *Elsholtzia blanda* exhibited the lowest IVI value (1.08). *Ageratina adenophora* had the highest IVI value (72.88, 92.73, 64.63, and 50.32) at altitudinal gradients 1200–1600 m, 1600–2000 m, 2000–2400 m, and 2400–2800 m, respectively. *Nicotiana plumbaginifolia*, *Spermacoce latifolia*, and *Cannabis sativa* had the lowest IVI values at their respective altitudinal gradients. The invaded plant species had the highest IVI values (92.57%) at 800–1200 m, high IVI values, and dominance over other associates, possibly due to their high reproductive vigor and ability to outcompete others in completing their life cycle (31) followed by 63.59% and 66.74% at 1200–1600 m and 1600–2000 m, respectively (Fig. 2 and Table 1). However, at higher elevations (2000–2800 m), the IVI values were less than 50%. The plant species showed different distribution patterns at various altitude gradients, with most species exhibiting a contagious distribution pattern at elevations of 800–1200 m, 1600–2000 m, and 2400–2800 m, and a random distribution pattern at gradients of 1200–1600 m and 2000–2400 m. *Ageratina adenophora* dispersion pattern shifted from contagious (800–1200 m) to random (1200–1600 m) and back to contagious at higher elevations (2000–2800 m). *Bidens pilosa* distribution pattern changed from contagious (800–2400 m) to random at higher elevations (2400–2800 m), while *Chromolaena odorata* distribution pattern changed from contagious (800–2000 m) to random (2400–2800 m) at higher elevations (Table 2). The Shannon index (H) showed maximum diversity at altitude gradients of 1200–1600 m and lower diversity at 2000–2400 m. The evenness index (E) showed a declining trend in species evenness at lower altitudes with higher richness (Fig. 3). Invaded elevations had a higher number of exotic species than native ones, while uninvaded elevations had a higher proportion of native plants. The IVI values of almost all targeted species showed an insignificant (>0.05) negative correlation with elevational gradients. However, members of invasive alien plants species like *A. adenophora, Ageratum conyzoides* and *Bidens pilosa* IVI values increased significantly at lower and middle elevations (Fig. 4), which aligns with the finding of Sekar (9), who also identified Asteraceae and Solanaceae as the primary contributors of invasive alien plant species in the IHR. which may be due to anthropogenic activities such as construction and tourism or changing climate, leading to favorable micro-habitats being invaded in successive years (32). These invasive species pose a serious threat to the native flora of the forest ecosystem in the study area (33). Some species, such as *Lantana camara* and *Parthenium hysterophorus*, have harmful effects on indigenous species (34). Our study revealed the rapid spread of *Ageratina adenophora, Chromolaena odorata*, and *Lantana camara* across all elevation gradients in Sikkim state, extending beyond 2800 meters. The success of these invasive species in the targeted elevational gradients can be attributed to their high germination rates, adaptability to diverse habitats, and other advantageous traits that enable them to thrive in various landscapes (35). Contrary to suggestions that the introduction of invasive species has already reached its peak, our analysis demonstrates that their spread is exponentially increasing, with no signs of saturation in the studied ecosystem. Numerous studies have focused on the invasion biology and control measures of invasive alien plant species in different regions worldwide (36). Considering the factors mentioned above, the invasion, presence, and further spread of these invasive species are detrimental to the Sikkim Himalayas, as they diminish the available natural habitats for native plants, resulting in the depletion of plant diversity, productivity, and ultimately, the delivery of various ecosystem services for the livelihoods of local people (30). Apart from the selected invasive plant species, numerous other invasive plants are

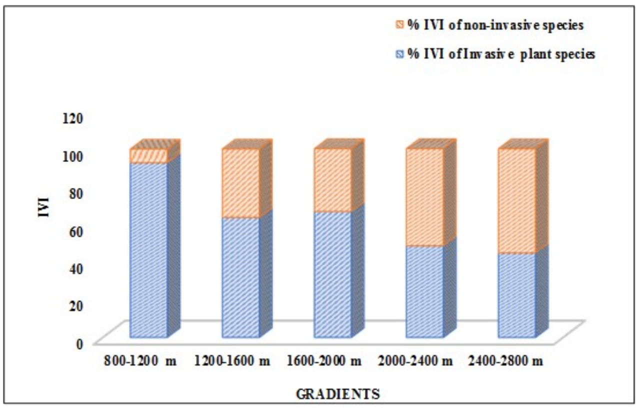

Fig. 2. IVI values in different altitudinal gradients.

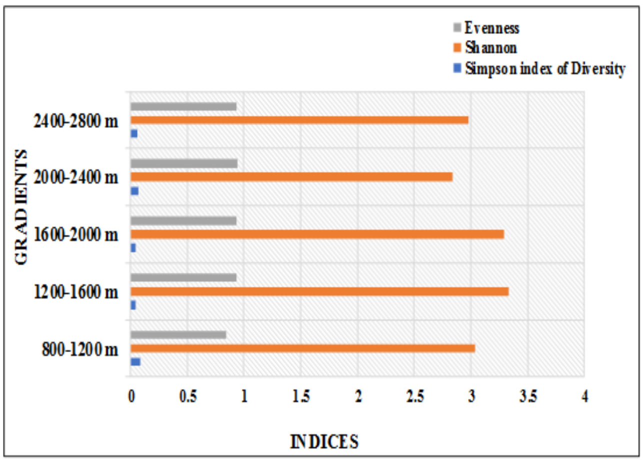

Fig. 3. Diversity indices of overall plant species at different altitudinal gradients

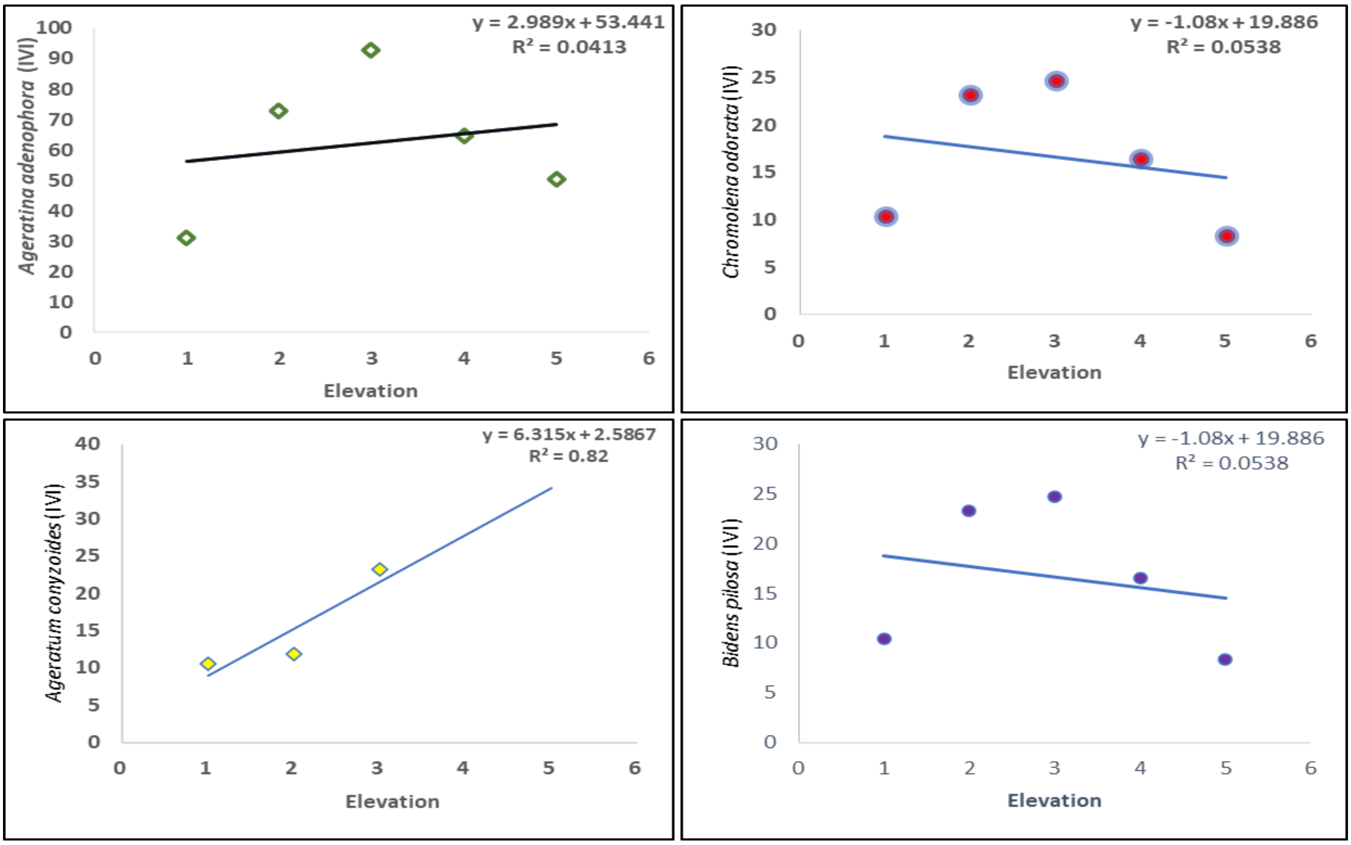

Fig. 4. Correlation analysis between importance value index (IVI) of top four invasive alien plant species at five elevational gradients in the study area 800–1200 m, 1200–1600 m, 1600–2000 m, 2000 –2400 m and 2400–2800 m.

spreading throughout the region, directly or indirectly contributing to the decline in plant diversity and productivity.

Conclusion

Although invasive alien plant species are recognized as a threat to ecosystem health, endemic vegetation, and human well-being, their impact remains a topic of debate worldwide. The UN-IPBES recently identified biotic invasive plants as significant drivers of ecosystem depletion, with their spread primarily resulting from anthropogenic disturbances. If such disturbances persist in the long run, the emergence of new invasive alien species is likely. However, a clear understanding of the various mechanisms involved in the arrival, spread, and establishment of these species in new areas can enable effective management of invasive alien species. Biotic invasion is a global emerging problem, alongside biodiversity erosion, native floral loss, climate change, unsustainable agriculture, and ecosystem disturbances, which warrants in-depth research to understand their interacting impacts on native flora and human health. Therefore, future studies should focus on using various environmental stressors to evaluate their impacts on biodiversity, livelihoods, and human health in Himalayan regions. Although the Sikkim Himalayan zones harbor a wealth of exclusive species, their spread by invasive species puts them in danger, indicating that these species thrive in the highlands of the Himalayas. Consequently, more attention should be given to these invasive species, and concrete management methods should be developed to address plant invasions in the Sikkim Himalaya and other highland areas. Additionally, ecosystem indicators for invasive alien plants and developing concrete risk assessment protocols require further research. Furthermore, the lack of biodiversity ecological models in the Himalayan ecosystem, including the Sikkim Himalaya, poses a challenge in establishing interrelationships among global biodiversity changes, ecosystem health, and services, which necessitates future studies.

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Authors' contributions

RN and AKV both contributed equally to this manuscript. RN & AKV performed the species assessments and conducted the analysis. RN, AKV & NM led the writing of the manuscript. LBC & SKB gave valuable suggestions and their reviews have helped in improving the contents of this manuscript. VNP & KB acting as Ph.D. supervisors. All the authors contributed critically to the draft and gave final approval for publication.

Compliance with ethical standards

Conflict of interest : Authors do not have any conflict of interests.

Ethical issues: None.

Table 1. The list of associated plant species found in targeted altitudinal gradients with importance value index (IVI)

					IVI (Different Gradients)				
					800 –1200 m	1200 – 1600 m	1600 – 2000 m	2000 – 2400 m	2400 – 2800 m
Plant species	**Family**	**Status**	**Native range**	**Growth Form**	**I**	**II**	**III**	**IV**	**V**
Acmella radicans (Jacq.) R.K.Jansen	Asteraceae	IN	Mexico to NW. Venezuela and Bolivia, Caribbean	AH	5.25				
Adenostemma lavenia (L.) Kuntze	Asteraceae	N	Tropical and Subtropical Asia	AH			6.22		
Ageratina adenophora (Spreng.) R.M.King & H.Rob..	Asteraceae	IN	Mexico	S	31.25	72.88	92.73	64.63	50.32
Ageratum conyzoides L.	Asteraceae	IN	Mexico	AH	10.61	11.80	23.24		
Amaranthus spinosus L.	Amaranthaceae	IN	Mexico to Trop. America	AH	1.52				
Anaphalis contorta (D.Don) Hook. f.	Asteraceae	N	Pakistan to China and N. Myanmar.	PH					25.34
Anaphalis margaritacea subsp. *margaritacea*	Asteraceae	N	Indian Subcontinent to Russian Far East and Japan, N. America.	PH					11.24
Artemisia vulgaris L.	Asteraceae	N	Temp. Eurasia to Indochina, N. Africa.	PH		15.18	10.32	20.60	39.28
Astilbe rivularis Buch. -Ham. ex D.Don	Saxifragaceae	N	Himalaya to Central China and Indo-China, Borneo, Jawa.	PH			3.52		
Bidens pilosa L.	Asteraceae	IN	Tropical & Subtropical America	AH	10.38	23.28	24.70	16.50	8.37
Blumea lacera (Burm.f.) DC.	Asteraceae	N	Tropical & Subtropical Asia to SW. Pacific.	AH	1.47				
Buddleja asiatica Lour.	Scrophulariaceae	N	Central & S. China to Tropical Asia and the Marianas.	S	1.48				
Calceolaria mexicana Benth.	Calceolariaceae	IN	Mexico to Bolivia.	AH			5.85	13.36	7.40
Cannabis sativa L.	Cannabaceae	IN	SE. European Russia to Xinjiang and Pakistan.	AH	1.09				4.43
Celosia argentea L.	Amaranthaceae	IN	Tropical Africa.	AH	1.50	5.15			
Cenchrus purpureus (Schumach.) Morrone	Poaceae	IN	Sahara to Tropical Africa, Aldabra, Arabian Peninsula.	AG	6.13	5.17			
Cestrum elegans.	Solanaceae	C	Mexico.	S				11.94	
Chromolaena odorata (L.) R.M.King & H.Rob.	Asteraceae	IN	Tropical & Subtropical America.	S	28.68	5.56	7.81	10.80	11.61
Cleome rutidosperma DC.	Cleomaceae	IN	Cape Verde, Tropical Africa.	AH		4.54			
Crassocephalum crepidioides (Benth.) S.Moore	Asteraceae	IN	Tropical & S. Africa, Madagascar.	AH	5.44	7.14			13.35
Datura metel L.	Solanaceae	IN	Texas to Colombia.	S	11.08				
Dicliptera bupleuroides Nees	Acanthaceae	N	Afghanistan to S. Central China and Indo-China.	PH	10.35				
Dysphania ambrosioides (L.)	Amaranthaceae	IN	America, Subantarctic Islands.	AH	7.12	9.03			
Eclipta prostrata (L.)	Asteraceae	IN	Temp. & Subtropical America.	AH	3.79	5.56			
Edgeworthia gardneri (Wall.) Meisn.	Thymelaeaceae	N	Central Himalaya to China (NW. Yunnan) and N. Indo-China.	S		5.84			
Elsholtzia blanda (Benth.)	Lamiaceae	N	Central Himalaya to S. China and Indo-China, N. Sumatera.	S	1.08	4.38			
Elsholtzia strobilifera (Benth.)	Lamiaceae	N	Himalaya to S. Central China and N. Myanmar, Taiwan.	AH				15.04	
Elatostema monandrum (D.Don) Hara	Asteraceae	N	Indian Subcontinent to China.	AH			8.00		

Erigeron bonariensis (L.)	Asteraceae	IN	Mexico to Tropical America.	AH		6.79			
Erigeron canadensis (L.)	Asteraceae	IN	New World.	AH		2.50			8.47
Erigeron karvinskianus DC.	Asteraceae	IN	Mexico to Venezuela.	PH	3.75			14.89	18.12
Euphorbia hirta (L.)	Euphorbiaceae	IN	Tropical & Subtropical America	AH	4.75				
Fagopyrum esculentum Moench	Polygonaceae	CA	E. Tibet to China	AH			5.35		
Galinsoga parviflora Cav.	Asteraceae	IN	Mexico to Tropical America.	AH				13.08	
Galinsoga quadriradiata Ruiz & Pav.	Asteraceae	IN	Mexico to S. Trop. America	AH				12.55	4.46
Girardinia diversifolia (Link) Friis	Urticaceae	N	Tropical & Subtropical Old World.	S		16.54	6.45	52.16	37.53
Gynura nepalensis DC.	Asteraceae	N	Himalaya to China & N. Indo-China.	PH					10.31
Heliotropium indicum (L.)	Boraginaceae	IN	Peru to Brazil and N. Argentina	AH			10.56		
Ipomoea purpurea (L.) Roth	Convolvulaceae	IN	Tropical & Subtropical America	AH			8.76		
Justicia adhatoda (L.)	Acanthaceae	N	Afghanistan to Indo-China.	S	1.29	5.75			
Lantana camara (L.)	Verbenaceae	IN	Mexico to Tropical America	S	27.08	5.44			
Laportea interrupta (L.) Chew	Urticaceae	N	Tropical & S. Africa, Arabian Peninsula, Mozambique, Tropical & Subtropical Asia to NW. Pacific.	AH		23.59	7.59		
Lepidagathis incurva (Buch.-Ham. ex D.Don)	Acanthaceae	N	Tropical & Subtropical Asia.	PH		3.64			
Melissa axillaris (Benth.) Bakh.f.	Lamiaceae	N	Nepal to S. China and W. Malesia.	PH	1.72		6.58	8.95	5.09
Mesosphaerum suaveolens (L.) Kuntze	Lamiaceae	IN	Mexico to Tropical America.	AH	10.16				
Mikania micrantha Kunth	Asteraceae	IN	Tropical & Subtropical America.	CL	9.54	5.95	4.43		
Nicandra physalodes (L.) Gaertn.	Solanaceae	IN	Peru to NW. Argentina.	AH	9.18	6.64	7.45		
Nicotiana plumbaginifolia Viv.	Solanaceae	IN	Mexico to Guatemala.	AH		2.40			
Melastoma malabathricum (L.) Smith	Melastomataceae	N	Seychelles, Tropical & Subtropical Asia to N. & E. Australia.	S			5.50	10.69	
Oxyspora paniculata (D.Don) DC.	Melastomataceae	N	Himalaya to S. China and Indo-China.	S			17.57		16.52
Parthenium hysterophorus (L.)	Asteraceae	IN	Tropical & Subtropical America.	AH	70.04				
Persicaria chinensis (L.) H.Gross	Polygonaceae	N	Tropical & Subtropical Asia.	S		10.28			
Pilea scripta (Buch. -Ham. ex D.Don) Wedd.	Urticaceae	N	NE. Pakistan to China	PH		16.0	6.19	6.33	
Pogostemon glaber Benth.	Lamiaceae	N	Himalaya to S. China and Indo-China.	S				10.54	
Rubus lineatus Reinw. ex Blume	Rosaceae	N	Nepal to S. Central China and W. & S. Malesia.	S			13.87	9.87	20.28
Scoparia dulcis (L.)	Plantaginaceae	IN	Tropical & Subtropical America.	AH		4.00			
Sida acuta Burm.f.	Malvaceae	N	Tropics & Subtropics.	S		7.50			
Solanum americanum Mill.	Solanaceae	IN	New World	AH			7.39		
Solanum nigrum (L.)	Solanaceae	N	Temp. Eurasia, Macaronesia, N. & NE. Tropical Africa.	AH	2.30				
Solanum torvum Sw.	Solanaceae	IN	Mexico to N. South America, Caribbean, E. Brazil.	S		4.13			
Solanum viarum Dunal	Solanaceae	IN	S. Tropical America to N. Argentina.	AH			4.66		7.84
Spermacoce latifolia Aubl.	Rubiaceae	IN	Mexico to Tropical America.	AH			2.64		
Swertia bimaculata (Siebold & Zucc.) Hook.f. & Thomson ex C.B.Clarke	Gentianaceae	N	Nepal to Japan and N. Indo-China	AH				8.10	
Synedrella nodiflora (L.) Gaertn.	Asteraceae	IN	Tropical & Subtropical America	AH	2.83				
Synotis cappa (Buch. -Ham. ex D.Don) C.Jeffrey & Y.L.Chen	Asteraceae	N	Himalaya to China & Indo-China	S			2.65		
Tithonia diversifolia (Hemsl.) A.Gray	Asteraceae	IN	Mexico to Central America.	S	11.73				
Tridax procumbens (L.)	Asteraceae	IN	Mexico to Tropical America.	PH	4.83	2.82			
Viola inconspicua Blume	Violaceae	N	Mascarenes, Assam to Japan and W. & N. Central Malesia.	PH	1.84				
Xanthium strumarium (L.)	Asteraceae	IN	S. Central & S. Europe to China and Indo-China, Taiwan, NW. Africa.	AH	3.89				

*A=Annual; CL=Climber; C= Cultivated; CA= Causal; G=Grass; H=Herb; IN= Invasive; N=Native; P=Perennial; S=Shrub

Table 2. Distribution pattern of invasive alien plant species at different altitudinal gradients

	A/F ratio and distribution status at different gradients.				
Invasive alien plant species	**800–1200 m**	**1200–1600 m**	**1600–2000 m**	**2000–2400 m**	**2400–2800 m**
Acmella radicans	0.11 (C)				
Ageratina adenophora	0.10 (C)	0.05 (RA)	0.07 (C)	0.06 (C)	0.06 (C)
Ageratum conyzoides	0.06 (C)	0.03 (RA)	0.08 (C)		
Amaranthus spinosus	0.3 (C)				
Bidens pilosa	0.22 (C)	0.08 (C)	0.10 (C)	0.07 (C)	0.04 (RA)
Calceolaria mexicana			0.05 (RA)	0.07 (C)	0.1 (C)
Cannabis sativa	0.1 (C)				0.07 (C)
Celosia argentea	0.3 (C)	0.08 (C)			
Cenchrus purpureus	0.07 (C)	0.03 (RA)			
Chromolaena odorata	0.33 (C)	0.24 (C)	0.14 (C)	0.04 (RA)	0.03 (RA)
Cleome rutidosperma		0.08 (C)			
Crassocephalum crepidioides	0.7 (C)	0.03 (RA)			0.03 (RA)
Datura metel	0.08 (C)				
Dysphania ambrosioides	0.10 (C)	0.03 (RA)			
Eclipta prostrata	0.06 (C)	0.03 (RA)			
Erigeron bonariensis		0.03 (RA)			
Erigeron canadensis		0.02 (RA)			0.17 (C)
Erigeron karvinskianus	0.22 (C)			0.04 (RA)	0.06 (C)
Euphorbia hirta	0.11 (C)				
Galinsoga parviflora				0.02 (RA)	
Galinsoga quadriradiata				0.04 (RA)	0.06 (C)
Heliotropium indicum			0.12 (C)		
Ipomoea purpurea			0.02 (RA)		
Lantana camara	0.09 (C)	0.05 (RA)			
Mesosphaerum suaveolens	0.03 (RA)				
Mikania micrantha	0.14 (C)	0.09 (C)	0.04 (RA)		
Nicandra physalodes	0.03 (RA)	0.02 (RA)	0.06 (C)		
Nicotiana plumbaginifolia		0.08 (C)			
Parthenium hysterophorus	0.07 (C)				
Scoparia dulcis		0.04 (RA)			
Solanum americanum			0.03 (RA)		
Solanum torvum		0.05 (RA)			
Solanum viarum			0.21 (C)		0.03 (RA)
Spermacoce latifolia			0.12 (C)		
Synedrella nodiflora	0.12 (C)				
Tithonia diversifolia	0.03 (RA)				
Tridax procumbens	0.1 (C)	0.08 (C)			
Xanthium strumarium	0.06 (C)				

*A=Abundance, C= Contagious, F=Frequency, RA= Random

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