



RESEARCH ARTICLE

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

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ARTICLE HISTORY

Received: 19 September 2023 Accepted: 24 December 2023

Available online

Version 1.0: 19 February 2024



Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care etc. See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

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CITE THIS ARTICLE

Nayak R, Verma A K, Manika N, Chaudhary L B, Behera S K, Bargali K, Pandey V N. Distribution pattern and management of invasive alien plant species in Sikkim Himalaya, India. Plant Science Today (Early Access). https://doi.org/10.14719/pst.2968

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

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 wellknown 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 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"

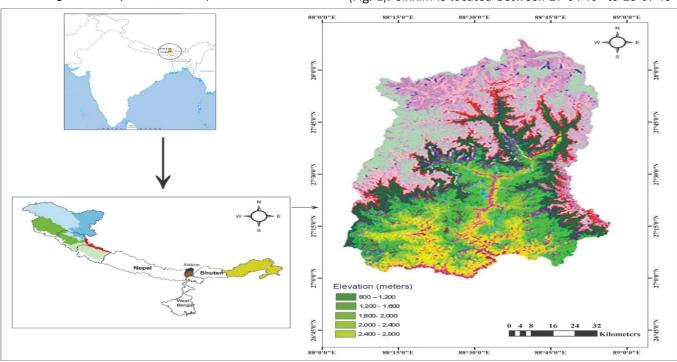


Fig. 1. Study site depicting the sampling gradients in Sikkim Himalayas.

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 = $\Pi r2$ ($\Pi = 3.14$ 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

$$\lambda = \sum_{i=1}^{s} (ni/N)2$$

The Evenness Index (E) was calculated as per the formula E = H' / lnS

 \mathbf{pi} = the proportion of individuals belonging to ith species, \mathbf{ln} = the natural log, \mathbf{S} = the number of species, \mathbf{ni} = the number of individuals of ith species, and \mathbf{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 mechanical control methods, and implementing cuttingroot 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

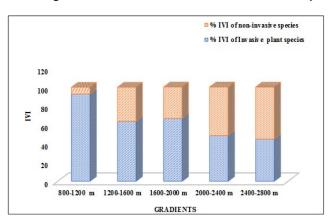


Fig. 2. IVI values in different altitudinal gradients.

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

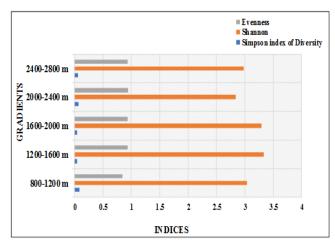


Fig. 3. Diversity indices of overall plant species at different altitudinal gradients

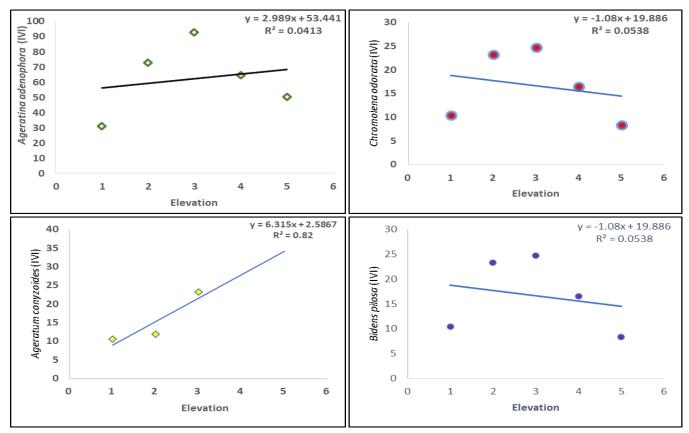


Fig. 4. Correlation analysis between importance value index (IVI) of top four invasive alien plant species at five elevational gradients in the study area 800–1200 m, 1200–1600 m, 1600–2000 m, 2000–2400 m and 2400–2800 m.

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.

Acknowledgements

The Director of the CSIR-National Botanical Research Institute, Lucknow, is acknowledged by the authors for providing the required assistance and support. We acknowledge G.B. Pant National Institute of Himalayan Environment, Almora, Uttarakhand for financial support under the National Mission on Himalayan Studies (NMHS) scheme of the Ministry of Environment, Forest and Climate Change, Government of India (NMHS-2017/LG-01/475). Sincere gratitude is expressed for the permission given by the Department of Forest, Environment and Wildlife Management, Government of Sikkim, Gangtok, to undertake research fieldwork in Sikkim, and all in-charges of herbaria consulted are also acknowledged.

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	1	II	Ш	IV	V
Acmella radicans (Jacq.) R.K.Jansen	Asteraceae	IN	Mexico to NW. Venezuela and Bolivia, Caribbean	АН	5.25				
Adenostemma lavenia (L.) Kuntze	Asteraceae	N	Tropical and Subtropical Asia	АН			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	АН	10.61	11.80	23.24		
Amaranthus spinosus L.	Amaranthaceae	IN	Mexico to Trop. America	АН	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.	РН			3.52		
Bidens pilosa L.	Asteraceae	IN	Tropical & Subtropical America	АН	10.38	23.28	24.70	16.50	8.37
Blumea lacera (Burm.f.) DC.	Asteraceae	N	Tropical & Subtropical Asia to SW. Pacific.	АН	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.	АН			5.85	13.36	7.40
Cannabis sativa L.	Cannabaceae	IN	SE. European Russia to Xinjiang and Pakistan.	АН	1.09				4.43
Celosia argentea L.	Amaranthaceae	IN	Tropical Africa. Sahara to Tropical	АН	1.50	5.15			
Cenchrus purpureus (Schumach.) Morrone	Poaceae	IN	Africa, Aldabra, Arabian Peninsula.	AG	6.13	5.17			
Cestrum elegans.	Solanaceae	С	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.	АН		4.54			
Crassocephalum crepidioides (Benth.) S.Moore	Asteraceae	IN	Tropical & S. Africa, Madagascar.	АН	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.	АН	7.12	9.03			
Eclipta prostrata (L.)	Asteraceae	IN	Temp. & Subtropical America.	АН	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.	АН				15.04	
Elatostema monandrum (D.Don) Hara	Asteraceae	N	Indian Subcontinent to China.	АН			8.00		

			Mexico to Tropical						
Erigeron bonariensis (L.)	Asteraceae	IN	America.	AH		6.79			
Erigeron canadensis (L.) Erigeron karvinskianus	Asteraceae	IN 	New World.	AH		2.50			8.47
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	Urticaceae	N	Tropical & Subtropical	S		16.54	6.45	52.16	37.53
diversifolia (Link) Friis			Old World. Himalaya to China &	PH		10.51	0.15	32.10	
Gynura nepalensis DC. Heliotropium indicum	Asteraceae 	N	N. Indo-China. Peru to Brazil and N.						10.31
(L.) Ipomoea purpurea (L.)	Boraginaceae	IN	Argentina Tropical & Subtropical	АН			10.56		
Roth	Convolvulaceae	IN	America	АН			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 Tropical & S. Africa,	S	27.08	5.44			
Laportea interrupta (L.) Chew	Urticaceae	N	Arabian Peninsula, Mozambique, Tropical & Subtropical Asia to NW. Pacific.	АН		23.59	7.59		
Lepidagathis incurva (BuchHam. ex D.Don)	Acanthaceae	N	Tropical & Subtropical Asia.	PH		3.64			
Melissa axillaris (Benth.)	Lamiaceae	N	Nepal to S. China and	PH	1.72		6.58	8.95	5.09
Bakh.f. Mesosphaerum	Lamiaceae	IN	W. Malesia. Mexico to Tropical	AH	10.16				
suaveolens (L.) Kuntze Mikania micrantha		IN	America. Tropical & Subtropical	CL	9.54	5.95	4.43		
Kunth Nicandra physalodes (L.)	Asteraceae		America.						
Gaertn. Nicotiana	Solanaceae	IN	Peru to NW. Argentina.	AH	9.18	6.64	7.45		
plumbaginifolia Viv. Melastoma	Solanaceae	IN	Mexico to Guatemala.	AH		2.40			
<i>malabathricum</i> (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.	АН	70.04				
Persicaria chinensis (L.) H.Gross	Polygonaceae	N	Tropical & Subtropical Asia.	S		10.28			
Pilea scripta (Buch	Urticaceae	N	NE. Pakistan to China	PH		16.0	6.19	6.33	
Ham. ex D.Don) Wedd. Pogostemon glaber	Lamiaceae	N	Himalaya to S. China	S				10.54	
Benth.	Laimaceae	IN	and Indo-China. Nepal to S. Central	3				10.54	
Rubus lineatus Reinw. ex Blume	Rosaceae	N	China and W. & S. Malesia.	S			13.87	9.87	20.28
Scoparia dulcis (L.)	Plantaginaceae	IN	Tropical & Subtropical	AH		4.00			
Sida acuta Burm.f.	Malvaceae	N	America. Tropics & Subtropics.	S		7.50			
Solanum americanum Mill.	Solanaceae	IN	New World	AH			7.39		
	Solanaceae	N	Temp. Eurasia,	A11	2.20				
Solanum nigrum (L.)	Solanaceae	N	Macaronesia, N. & NE. Tropical Africa.	AH	2.30				
Solanum torvum Sw.	Solanaceae	IN	Mexico to N. South America, Caribbean, E.	S		4.13			
Calana da mara Dana I	Calamana	INI	Brazil. S. Tropical America to	A11			4.66		7.04
Solanum viarum Dunal Spermacoce latifolia	Solanaceae	IN 	N. Argentina. Mexico to Tropical	AH			4.66		7.84
Aubl. Swertia bimaculata	Rubiaceae	IN	America.	AH			2.64		
(Siebold & Zucc.) Hook.f. & Thomson ex C.B.Clarke	Gentianaceae	N	Nepal to Japan and N. Indo-China	АН				8.10	
Synedrella nodiflora (L.) Gaertn.	Asteraceae	IN	Tropical & Subtropical America	АН	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	A at = == == =	181	S. Central & S. Europe to China and Indo-	A11	2.00				
(L.)	Asteraceae	IN	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
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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)	0.01 (6)		0.00 (54)
Solanum viarum Spermacoce latifolia			0.21 (C) 0.12 (C)		0.03 (RA)
' Synedrella nodiflora	0.12 (C)		. ,		
Tithonia diversifolia	0.03 (RA)				
Tridax procumbens	0.1 (C)	0.08 (C)			
Xanthium strumarium	0.06 (C)				

 $^{{}^{\}star}\text{A=Abundance, C= Contagious, F=Frequency, RA= Random}$

References

- Regulation EU (2014) Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species. Official J EU. 57: 35–55.
- O'Reilly-Nugent A, Palit R, Lopez-Aldana A, Medina-Romero M, Wandrag E, Duncan RP. Landscape effects on the spread of invasive species. Curr. Landsc Ecol Rep. 2016; 1: 107–14. https:// doi.org/10.1007/s40823-016-0012-y
- Jones BA. Tree shade, temperature, and human health: evidence from invasive species-induced deforestation. Ecol Econ. 2019; 156: 12–23. https://doi.org/10.1016/ j.ecolecon.2018.09.006
- Negi VS, Pathak R, Rawal RS, Bhatt ID, Sharma S. Long-term ecological monitoring on forest ecosystems in Indian Himalayan Region: criteria and indicator approach. Ecol Indic. 2019; 102: 374–81. https://doi.org/10.1016/j.ecolind.2019.02.035
- Young AM, Larson BM. Clarifying debates in invasion biology: a survey of invasion biologists. Environ. Res. 2011; 11: 893–98. https://doi.org/10.1016/j.envres.2011.06.006
- Uddin MN, Robinson RW. Can nutrient enrichment influence the invasion of Phragmites australis? Sci Total Environ. 2018; 613: 1449–59. https://doi.org/10.1016/j.scitotenv.2017.06.131
- Lowry E, Rollinson EJ, Laybourn AJ, Scott TE, Aiello-Lammens ME. Biological invasions: a field synopsis, systematic review, and database of the literature. Ecol Evol. 2013; 3: 182–96. https:// doi.org/10.1002/ece3.431
- Khuroo AA, Reshi ZA, Malik AH, Weber E, Rashid I, Dar GH. Alien flora of India: taxonomic composition, invasion status and biogeographic affiliations. Biol Invasions. 2012; 14: 99–113. https://doi.org/10.1007/s10530-011-9981-2
- Sekar KC. Invasive alien plants of Indian Himalayan region Diversity and Implication. Am. J. Plant Sci. 2012; 3: 177–84. https://doi.org/10.4236/ajps.2012.32021
- Jaryan V, Uniyal SK, Gupta RC, Singh RD. Alien flora of Indian Himalayan state of Himachal Pradesh. Environ Monit Assess. 2013; 185: 6129–53. https://doi.org/10.1007/s10661-012-3013-2
- Nayak R, Verma AK, Manika N, Bargali K, Pandey VN, Behera SK, Chaudhary LB. Alien species in the flora of Sikkim Himalaya, India J Econ Taxon Bot. 2020; 44: 119–37.
- Verma AK, Nayak R, Manika N, Bargali K, Pandey VN, Chaudhary LB, Behera SK. Monitoring the distribution pattern and invasion status of *Ageratina adenophora* across elevational gradients in Sikkim Himalaya, India. Environ Monit Assess. 2023; 195: 1–17. https://doi.org/10.1007/s10661-022-10549-z
- CBD. Implementation of India's national Biodiversity action plan: An overview. Ministry of Environment, Forest and Climate Change, Government of India. 2019
- IPBES. Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. 2019
- 15. Reshi ZA, Khuroo AA. Alien plant invasions in India: Current status and management challenges. Proc. Natl Acad Sci India Sect B: Biol Sci. 2012; 82: 305–12. https://doi.org/10.1007/s40011-012-0102-5
- 16. Rana RS, Dhillon BS, Khetarpal RK. Invasive alien species: the Indian scene. *Indian J Plant Gene. Resour.* 2003; 16: 190–13.
- Mandal FB. The management of alien species in India. Int J Biodivers Conserv. 2011; 3: 467–73.
- Hellmann JJ, Byers JE, Bierwagen BG, Dukes JS Five potential consequences of climate change for invasive species. Conserv Bio. 2008; 22: 534–43. https://doi.org/10.1111/j.1523-1739.2008.00951.x
- 19. DL, Phillips-Mao L, Quiram G, Sharpe L, Stark R, Sugita S, Weiler

- A. A framework for sustainable invasive species management: Environmental, social, and economic objectives. J Environ Manage. 2011; 92: 14–22. https://doi.org/10.1016/j.jenvman.2010.08.025
- Bhattarai KR, Måren IE, Subedi SC. Biodiversity and invasibility: Distribution patterns of invasive plant species in the Himalayas. Nepal J Mt Sci. 2014; 11: 688–96. https://doi.org/10.1007/s11629-013-2821-3
- 21. Kosaka Y, Saikia B, Mingki T, Tag H, Riba T, Ando K. Roadside distribution patterns of invasive alien plants along an altitudinal gradient in Arunachal Himalaya, India. Mt Res Dev. 2010; 30: 252 –58. https://doi.org/10.1659/mrd-journal-d-10-00036.1
- 22. Moktan S, Das AP. Plant species Richness and Phytosociological attributes of the Vegetation in the cold temperate zone of Darjiling Himalaya, India. Int Res J Environ Sci. 2014; 3: 14–19.
- Pejchar L. Mooney HA. Invasive species, ecosystem services and human well-being. Trends Ecol Evol. 2009; 24: 497–04. https:// doi.org/10.1016/j.tree.2009.03.016
- 24. BA, McDermott SM. Health impacts of invasive species through an altered natural environment: assessing air pollution sinks as a causal pathway. Environ Resour Econ. 2018; 71: 23–43. https:// doi.org/10.1007/s10640-017-0135-6
- Zhang R, Tielbörger K. Density-dependence tips the change of plant-plant interactions under environmental stress. Nat Commun. 2020; 11: 2532. https://doi.org/10.1038/s41467-020-16286-6
- Dormann CF, Bobrowski M, Dehling DM, Harris DJ. Biotic interactions in species distribution modelling: 10 questions to guide interpretation and avoid false conclusions. Glob Ecol Biogeogr. 2018; 27: 1004–16. https://doi.org/10.1111/geb.12759
- Soliveres S, Smit C, Maestre FT. Moving forward on facilitation research: response to changing environments and effects on the diversity, functioning and evolution of plant communities. Biol Reviews. 2015; 90: 297–13. https://doi.org/10.1111/brv.12110
- Pergl J, van Kleunen M, Hejda M, Babu CR, Majumdar S, Singh P. Pyšek P. Naturalized alien flora of the Indian states: biogeographic patterns, taxonomic structure, and drivers of species richness. Biol Invasions. 2018; 20: 1625–38. https:// doi.org/10.1007/s10530-017-1622-y
- 29. Moktan S, Das AP. Diversity and distribution of invasive alien plants along the altitudinal gradient in Darjiling Himalaya, India. Pleione. 2013; 7: 305–13.
- Pathak R, Negi VS, Rawal RS, Bhatt ID. Alien plant invasion in the Indian Himalayan Region: state of knowledge and research priorities. Biodivers Conserv. 2019; 28: 3073–102. https://doi.org/10.1007/s10531-019-01829-1
- Sher AA, El Waer H, González E, Anderson R, Henry AL, Biedron R, Yue P. Native species recovery after reduction of an invasive tree by biological control with and without active removal. Ecol Eng. 2018; 111: 167–75. https://doi.org/10.1016/j.ecoleng.2017.11.018
- 32. Negi PS. Hajra PK. Alien flora of Doon valley, northwest Himalaya. Curr Sci. 2007; 968–78.
- Kikvidze Z, Suzuki M, Brooker R. Importance versus intensity of ecological effects: why context matters. Trends Ecol Evol. 2011; 26: 383–88. https://doi.org/10.1016/j.tree.2011.04.003
- 34. Singh KP, Shukla AN, Singh JS. State-level inventory of invasive alien plants, their source regions and use potential. Curr Sci. 2010; 99: 107–14.
- Ansong M. Pickering C. Are weeds hitchhiking a ride on your car?
 A systematic review of seed dispersal on cars. PloS One. 2013; 8: e80275. https://doi.org/10.1371/journal.pone.0080275
- Priyanka N, Joshi PK. Assessment of plant invasion and forest fires linkage-a case study of *Lantana camara*. Int J Sci Technol Res. 2013; 2: 40–46.