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Altitudinal distribution and diversity patterns of invasive alien plant species in Champawat district, Kumaun Himalaya

Mahima Garkoti[1], Neha Joshi[1], Ravindra Kumar[1], Chandrshekhar Oli[2], Dhani Arya[1*]
[1] Department of Botany, Soban Singh Jeena University, Almora, Uttarakhand, India
[2] Department of Zoology, S.V.G.P.G. College, Lohaghat, Uttarakhand, India
Corresponding author: Dhani Arya
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Abstract
The Himalayan region is a globally recognized biodiversity hotspot currently facing escalating ecological threats from invasive alien plant species. This study evaluates the diversity and distribution patterns of alien flora across an altitudinal gradient (700 m – 2200 m asl) in the Champawat district of Kumaun Himalaya, India. The gradient was stratified into three distinct elevational zones: lower, middle, and higher. Field surveys conducted during September–October 2024 documented a total of 57 alien plant species across 49 genera and 20 families. Growth form analysis revealed a heavy skew toward herbaceous structures, with herbs comprising 82% of the recorded flora, followed by shrubs (14%) and trees (4%), with Asteraceae emerging as the most species-rich family. Taxonomically, 27 species were classified as strictly invasive, while the remaining elements comprised naturalized, casual, or cultivated cohorts, predominantly originating from South and Tropical America. Species richness exhibited a distinct hump-shaped pattern along the gradient, peaking within mid-altitudinal zones (1200 m – 1600 m asl) before significantly declining at higher elevations. This distribution implies that mid-elevation regions, characterized by intense anthropogenic disturbances and climate transitions, serve as primary hubs for alien plant establishment. Ultimately, this study provides a vital empirical checklist necessary to design and implement effective localized management and conservation strategies for the region.

Keywords: Alien flora, altitudinal gradient, Champawat, diversity patterns, invasive species

Introduction

The Indian Himalayan Region is a global biodiversity hotspot supporting vital ecosystems that sustain millions of people (Palni & Rawal, 2013; Singh, 2014; Sharma *et al.*, 2016; Khanduri *et al.*, 2017) [18, 31, 29, 9]. However, this fragile biodiversity is increasingly threatened by biological invasions—the intentional or accidental human-assisted spread of non-native species (Carlton, 1996; Mack *et al.*, 2000; Richardson *et al.*, 2000) [1, 14, 25]. Global trade, tourism, and transport accelerate this dissemination past natural geographic boundaries (Mack *et al.*, 2000; Eiswerth *et al.*, 2005) [14, 5]. Introduced alien flora become invasive upon establishing outside native ranges, out-competing indigenous species, altering competitive dynamics, and destabilizing local ecological networks (Sujay *et al.*, 2010; Pant & Sharma, 2010) [32, 19].These invasive plants present critical global challenges by driving habitat loss, extinctions, environmental shifts, altered hydrology, and ecosystem breakdown (Drake *et al.*, 1989; Parker *et al.*, 1999; Mack *et al.*, 2000; Mooney, 2005; Pimental *et al.*, 2007; Charles & Dukes, 2007; Herron *et al.*, 2007; Pejchar & Mooney, 2009; McGeoch *et al.*, 2010) [4, 20, 14, 17, 23, 2, 6, 22, 16]. While some exotic plants benefit farming or forestry, others turn into aggressive invaders that damage human welfare and incur massive economic costs (Vitousek *et al.*, 1997; Sujay *et al.*, 2010; Kohli *et al.*, 2012) [33, 32, 11]. Though mountain ecosystems historically resisted plant invasions, their vulnerability is rapidly escalating due to climate change, land-use modifications, and continuous propagule pressure along transport corridors (McDougal *et al.*, 2011) [15].

The Indian Himalayan Region faces increasing biodiversity threats from biological invasions, accelerated by human activity, trade, and climate change (Palni & Rawal, 2013; Singh, 2014; Sharma *et al.,* 2016; Khanduri *et al.,* 2017) [18, 31, 29, 9]. These invasive species disrupt local ecosystems, altering competitive dynamics and native biodiversity. In mountainous terrain, altitude acts as a primary environmental filter where variables like temperature, moisture, and atmospheric pressure shift sharply (Körner, 2007) [12]. These environmental shifts and localized human disturbances frequently produce mid-domain peaks or hump-shaped diversity patterns where alien flora exploit optimal ecological niches (McDougall *et al.*, 2011) [15]. Despite risks to native floristic diversity in the Kumaun Himalaya, comprehensive checklists and altitudinal distribution data remain scarce. This study bridges this knowledge gap by compiling and evaluating invasive plant diversity along an altitudinal gradient in Champawat district, providing an empirical baseline required to implement effective management and conservation strategies.

Materials and Methods

Study Area

The study was conducted in the Champawat district, located in the southeastern part of the Kumaun Himalaya in Uttarakhand, India. It lies exactly between latitude 29.3356167 and longitude 80.0902372.

The region exhibits a highly rugged terrain with a distinct altitudinal gradient ranging from 700 m to 2200 m above sea level (asl). Characterized by diverse microclimatic conditions, the district spans sub-tropical to temperate zones, supporting varied forest ecosystems and a rich repository of indigenous flora. The climate is generally characterized by cool winters, warm summers, and a pronounced monsoon season. To systematically evaluate the distribution patterns of alien flora, the study area was stratified along the elevational gradient into three distinct bioclimatic zones:

Lower Altitudinal Zone: 700 m to 1200 m asl, characterized by sub-tropical vegetation, higher mean temperatures, and extensive river valleys.
Middle Altitudinal Zone: 1200 m to 1700 m asl, representing a transitional eco-tonal belt with mixed sub-tropical and temperate pine forests, marked by high human settlements.
Higher Altitudinal Zone:1700 m to 2200 m asl, dominated by temperate moist oak forests, lower annual temperatures, and sharper topographic slopes.

Field Sampling and Data Collection
Extensive and rigorous field surveys were carried out during September and October 2024 in multiple locations to document the occurrence and distribution of alien plant species across all three altitudinal zones. The sampling routes were selected along random and systematic transport corridors, forest margins, agricultural lands, and disturbed habitats to ensure complete representation of the regional flora. Within each altitudinal zone, opportunistic botanical explorations and targeted plots were utilized to maximize the recording of non-native plant species. During the field encounters, critical morpho-taxonomic features, growth forms, specific elevations, and habitat types were carefully recorded for each specimen. The elevation of site was recorded by Gps essential app.

Vegetational sampling
Stratified random sampling was done along an altitudinal gradient for vegetation assessment. A 50m × 50m area was selected at each sampling site (stand). The study area was divided into three altitudinal ranges: lower (700 m–1200 m), middle (1200 m–1700 m), and higher (1700 m–2200 m). A total of 18 sites (stands) were investigated, with six stands in each altitudinal range. Each stand was sampled on both northern and southern aspects to account for variation in vegetation.
At each stand, 10 quadrats for trees, 20 for shrubs, and 40 for herbs were laid on each aspect (northern and southern). Thus, a tota l numbers of quadrats laid was 360 for trees, 720 for shrubs, and 1440 for herbs across all the sites. Quadrat sizes were 10 × 10 m for trees, 5 × 5 m for shrubs, and 1 × 1 m for herbs (Curtis & Mcintosh, 1950) [3]. Within each quadrat, all species of trees, shrubs, and herbs were recorded Specimens were collected, and herbarium sheets were prepared for taxonomic identification using standard regional floras. Invasive plant species were identified from the published literature and databases and defined as non-native species exhibiting rapid spread and ecological impact. Special emphasis was given to recording their presence, distribution, and abundance across different altitudinal ranges and aspects. During the field encounters, critical morpho-taxonomic features, growth forms, specific elevation, and habitat types were carefully recorded for each specimen.

Taxonomic Identification and Documentation
The collected plant specimens were processed, pressed, and dried following standard herbarium techniques (Jain & Rao, 1997) [8]. Plant specimens were collected from non-protected areas along the altitudinal gradient from different sites in Champawat district in accordance with institutional and local guidelines for biodiversity research.
Voucher specimens of all wild plant species recorded during the study were collected, processed, pressed, and dried following standard herbarium techniques. Each specimen was assigned a numerical series from (MG-01 to MG-57).
Taxonomic identification of the collected specimens was carried out by Mr. Sangam Sharma. After identification, all voucher specimens were deposited in the Herbarium of the Department of Botany, Soban Singh Jeena University, Almora, Uttarakhand, India.
At present, accession numbers have not been assigned by the institute. However, the specimens are systematically catalogued using the author-assigned codes and are preserved as part of a publicly accessible institutional collection. The deposited specimens are available for examination and future reference upon reasonable request to the Department of Botany, Soban Singh Jeena University.

Categorization of Invasion Status and Nativity
To accurately define the invasion status, nativity, and ecological origin of the documented flora, the final species checklist was cross-referenced and standardized using three authoritative national inventories of India:

1. **Alien Flora of India:** Comprising 1,599 species (Khuroo *et al*., 2012) [10].
2. **Naturalized Alien Flora of Indian States:** Comprising 499 species (Inderjit *et al*., 2018) [7].
3. **Global Register of Introduced and Invasive Species - India (GRIIS 1.3):** Comprising 2,082 species (Sankaran *et al*., 2021) [27].

Based on these frameworks, species were categorized into explicit ecological cohorts: Invasive (In), Naturalized (N), Naturalized/Invasive (N/I), Casual/Naturalized (Ca/N), Alien, and Cultivated (Cl). Growth forms were classified structurally into Herbs (H), Shrubs (S), and Trees (T). Geographic origins and native ranges were traced globally to map introduction pathways.

Results and Discussion

Taxonomic Composition and Lineage Dominance
The systematic field inventory (Table 1) presents details of botanical names, families, growth forms, occurrence, nativity, and altitudinal distribution of the recorded species. In total, 57 alien plant species belonging to 49 genera and 20 families were documented within the study area (Fig. 1).

Table 1: Checklist of alien plant species along with their growth form, occurrence status, nativity, and altitudinal distribution in Champawat district

S.N.	Botanical Name	Family Name	Growth Form	Occurrence Status	Nativity	Altitude (m)
1	*Ageratina adenophora* (Spreng.) R.M King & H Rob.	Asteraceae	S	In	Central America	700-2200
2	*Ageratum conyzoides* (L.) L.	Asteraceae	H	In	South America	700-1600
3	*Alternanthera sessilis* (L.) R.Br. ex DC.	Amaranthaceae	H	In	Tropical America	700-1000
4	*Alysicarpus vaginalis* (L.) DC.	Fabaceae	H	N/I	Southeast Asia	900-1400

5	*Amaranthus viridis* L.	Amaranthaceae	H	Ca/N	Pantropical (South America)	900-1000
6	*Barleria cristata* L.	Acanthaceae	H	N	Paleotropical	900-1600
7	*Bidens pilosa* L.	Asteraceae	H	In	South America	700-2000
8	*Calotropis gigantea* (L.) Dryand.	Apocynaceae	S	In	Tropical Africa	900-1000
9	*Calotropis procera* (Aiton) W.T Aiton	Apocynaceae	S	In	Tropical Africa	700-900
10	*Cannabis sativa* L.	Cannabaceae	H	In	Central Asia	1000-1600
11	*Chromolaena odorata* (L.) R.M King & H Rob.	Asteraceae	H	In	Central America	1200-1300
12	*Crotalaria juncea* L.	Fabaceae	S	N/I	Tropical America	1000-1100
13	*Crassocephalum crepidioides* (Benth.) S Moore	Asteraceae	H	In	Tropical America	1700-2200
14	*Conyza canadensis* (L.) Cronquist	Asteraceae	H	In	North America	1200-1300
15	*Conyza bonariensis* (L.) Cronquist	Asteraceae	H	N	West Asia	1400
16	*Cynodon dactylon* (L.) Pers.	Poaceae	H	In	Africa, Europe, Asia	700-2200
17	*Desmodium triflorum* (L.) DC.	Fabaceae	H	N/I	Pantropical	1700-2200
18	*Digitaria sanguinalis* (L.) Scop.	Poaceae	H	N/I	Temperate Eurasia	700-1600
19	*Drymaria cordata* (L.) Willd. ex-Schult.	Caryophyllaceae	H	N/I	Paleotropical	1000-1900
20	*Erigeron floribundus* (Kunth) Sch.Bip.	Asteraceae	H	N	South America	700-1000
21	*Erigeron karvinskianus* DC.	Asteraceae	H	In	Mexico	700-1200
22	*Erigeron annuus* (L.) Pers.	Asteraceae	H	N	North America	700-1000
23	*Erigeron sumatrensis* Retz.	Asteraceae	H	Alien	South America	700-1100
24	*Euphorbia hirta* L.	Euphorbiaceae	H	In	Mexico	1000-1700
25	*Galinsoga parviflora* Cav.	Asteraceae	H	In	Tropical America	700-1300
26	*Galinsoga quadriradiata* Ruiz & Pav.	Asteraceae	H	In	Mexico	1200-2000
27	*Hedera helix* L.	Araliaceae	H	N	Europe, N. Africa, W. Asia	1400-2200
28	*Imperata cylindrica* (L.) Raeusch.	Poaceae	H	In	Southeast Asia	700-1300
29	*Lantana camara* L.	Verbenaceae	S	In	Tropical America	700-1000
30	*Lawsonia inermis* L.	Lythraceae	S	N	Mexico	700-1000
31	*Mitracarpus hirtus* (L.) DC.	Rubiaceae	H	N/I	Tropical Africa	700-1200
32	*Origanum vulgare* L.	Lamiaceae	H	Alien	Eurasia	700-2100
33	*Oxalis corniculata* L.	Oxaliaceae	H	In	South America	1400-2200
34	*Oxalis latifolia* Kunth	Oxaliaceae	H	In	Brazil	700-1000
35	*Parthenium hysterophorus* L.	Asteraceae	H	In	Central America	700-800
36	*Plantago major* L.	Plantaginaceae	H	Alien	Europe	1400-2000
37	*Poa annua* L.	Poaceae	H	N	Europe	700-1000
38	*Salvia officinalis* L.	Lamiaceae	H	Cl	Mediterranean Region	1700-2000
39	*Sida cordifolia* L.	Malvaceae	H	N/I	Pantropical	700-900
40	*Sida cordata* (Burm.f.) Borss.Waalk.	Malvaceae	H	In	Tropical America	700-800
41	*Sigesbeckia orientalis* L.	Asteraceae	H	N/I	China, Japan, Australia	700-2200
42	*Solanum nigrum* L.	Solanaceae	H	In	Europe, N. Africa, W. Asia	1400-1900
43	*Sonchus arvensis* L.	Asteraceae	H	In	Cryptogenic	1600-2200
44	*Spermacoce pusilla* Wall.	Rubiaceae	H	N/I	Paleotropical	1200-2200
45	*Tridax procumbens* (L.) L.	Asteraceae	H	In	Mexico	700-900
46	*Trifolium repens* L.	Fabaceae	H	N/I	Europe	700-2200
47	*Triumfetta rhomboidea* Jacq.	Malvaceae	H	In	Tropical America	700-900
48	*Urena lobata* L.	Malvaceae	S	In	Tropical Africa	700-1200
49	*Verbascum thapsus* L.	Scrophulariaceae	H	N	Europe and Africa	1700-1800
50	*Verbena rigida* Spreng.	Verbenaceae	H	Ca/N	South America	700-900
51	*Viola odorata* L.	Violaceae	H	Ca/N	Europe and Africa	1400-1600
52	*Xanthium strumarium* L.	Asteraceae	H	In	South America	700-1000
53	*Zornia gibbosa* Span.	Fabaceae	H	N/I	Pantropical	700-1000
54	*Prunus mahaleb* L.	Rosaceae	S	Alien	Southern Europe	1700-1800
55	*Bauhinia variegata* L.	Fabaceae	T	Cl	Southeast Asia	700–1200
56	*Juglans regia* L.	Juglandaceae	T	Alien	Central Asia	1700-1800
57	*Boehmeria nivea* (L.) Gaudich.	Urticaceae	H	Cl	Tropical Asia	900-1100

Abbreviations Key: H: Herb; S: Shrub; T: Tree; In: Invasive; N: Naturalized; Alien: Non-native/Unclassified element; N/I: Naturalized/Invasive; Ca/N: Casual/Naturalized; Cl: Cultivated.

Their growth form distribution analysis (Fig. 2) revealed a heavy skew toward herbaceous structures, with herbs comprising 82% (47 species) of the total alien flora, followed by shrubs at 14% (8 species) and trees at 4% (2 species).

Taxonomically, the Asteraceae family demonstrated an overwhelming dominance with 18 species. This was followed by Fabaceae (6 species), Poaceae (4 species), and a consistent lower-level representation of two species each for Rubiaceae, Lamiaceae, Oxaliaceae, Malvaceae, Apocynaceae, Amaranthaceae, and Verbenaceae. The remaining families were represented by only a single species. The family-wise distribution of invasive alien plant species (Fig. 3) This pronounced dominance of Asteraceae, Fabaceae, and Poaceae mirrors broader trends across the Indian Himalayan Region (IHR), which is directly attributed to their global evolutionary size and high multi-species richness (Rao, 1994; Sekar, 2012) [24, 28]. The extensive success of herbaceous alien flora in high-elevation ecosystems is linked to their rapid life cycles, high reproductive output, and efficient seed dispersal mechanisms (such as the wind-dispersed pappus in Asteraceae), enabling them to quickly colonize open, human-disturbed environments (Mack *et al.*, 2000; Richardson *et al.*, 2000) [14, 25].

Invasion Status and Biogeographic Origins

Analysis of the invasion status in (Fig. 4) revealed that true invasive aliens represent the largest cohort at 47% (27 species), followed by naturalized/invasive elements with 18% (10 species), strictly naturalized species 14% (8 species), alien elements 9% (5 species), cultivated taxa 7% (4 species), and casual/naturalized variants by 5% (3 species). The aggressive expansion of these invasive structures usually comes at a direct cost to indigenous flora, driving severe declines in species diversity at highly disrupted sites (Singh *et al.*, 2002) [30].

The Biogeographic tracking demonstrated that South and Tropical America function as the primary donor regions for this non-native flora (Fig. 5), showing the origin of non-native flora. The descending order of species origins follows: South America > Tropical America > Mexico > Tropical Africa > Central Asia > Pantropical > Paleotropical > Central America. This pattern confirms that annual herbaceous flora originating from South and Tropical America possess a significantly elevated probability of successfully establishing, naturalizing, and expanding across the vulnerable ecosystems of the IHR (Khuroo *et al.*, 2012) [10].

Altitudinal Distribution Patterns

The distribution of alien plant species richness across the altitudinal gradient (700 m to 2200 m asl) displayed a highly pronounced hump-shaped pattern. Total alien species density followed a distinct descending order across the designated elevational ranges: 1200–1600 m > 700–1000 m > 1700–2200 m, as shown in (Fig. 6) which representing a species richness across altitudinal gradient. Historically, mountain ecosystems were assumed to be at low risk of biological invasion due to harsh topoclimatic constraints (Pauchard *et al.*, 2009; McDougal *et al.*, 2021) [21, 15]. However, modern anthropogenic pressures have driven a drastic change in the vegetation of mountain terrains (Lomolino, 2001) [13]. The mid-elevation peak observed in Champawat district is driven by intense human interference, including tourism, road construction, expanding agriculture, and rapid urbanization, which create extensive ecological niches and continuous open habitats (Vitousek *et al.*, 1997) [33]. Conversely, the decline in invasive richness above 1700 m asl suggests that colder temperatures, frost, and shorter growing seasons act as severe environmental filters, restricting sub-tropical invaders to lower zones (Körner, 2007) [12].

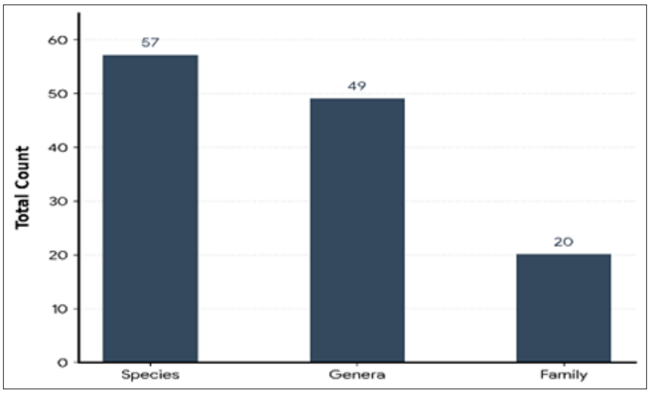

Fig 1: Different taxa of alien plant species recorded in the study area

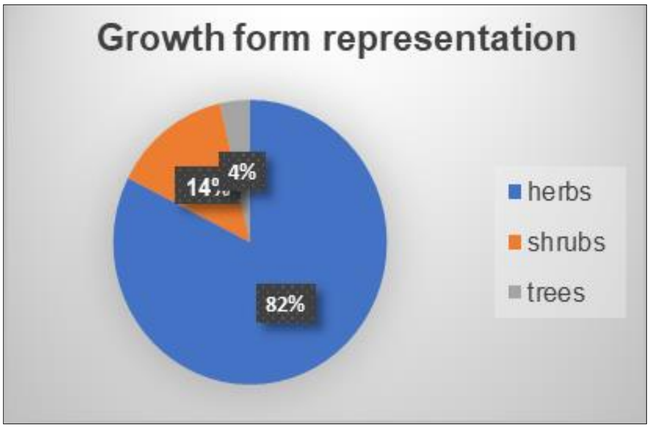

Fig 2: Growth form distribution of alien plant species expressed in percentage

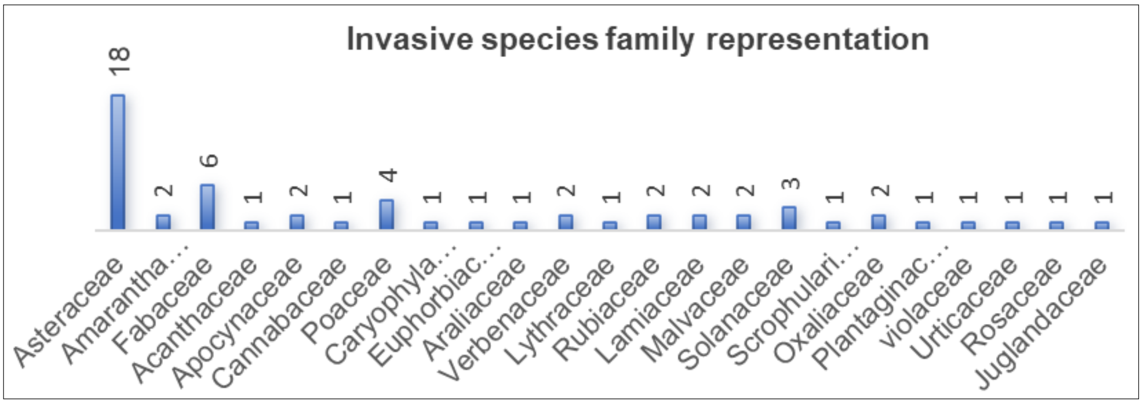

Fig 3: Family-wise distribution of invasive alien plant species showing number of species in each family

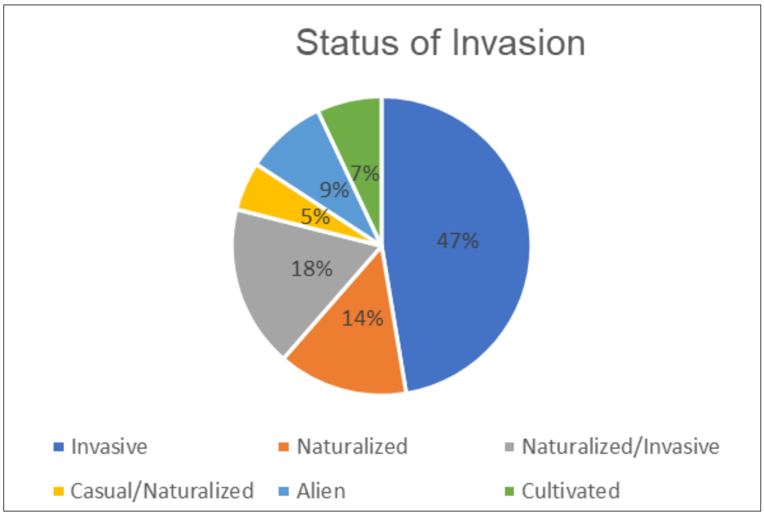

Fig 4: Status of invasion of alien plant species in the study area

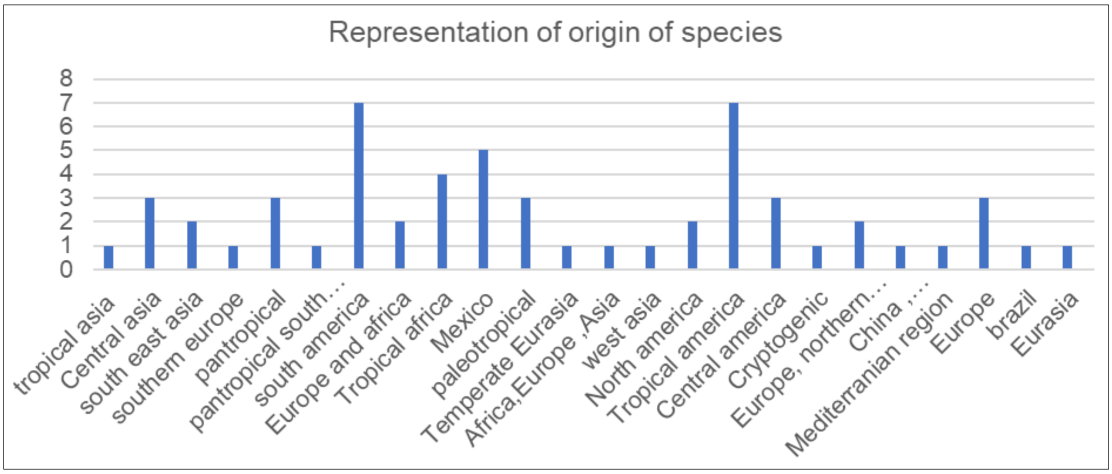

Fig 5: Native range of non-native plant species recorded in the study area

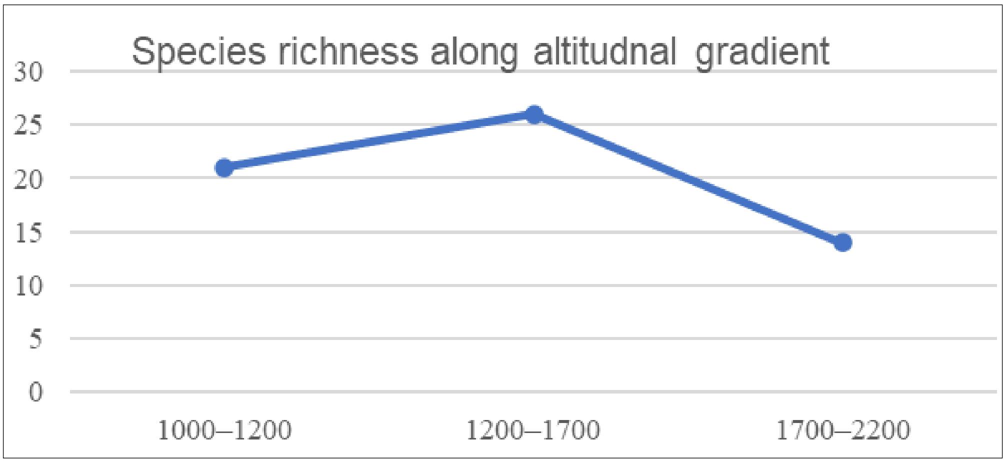

Fig 6: Species richness along an altitudinal gradient

Conclusion

This study establishes a crucial botanical baseline by documenting 57 alien plant species across an altitudinal gradient in the Champawat district of Kumaun Himalaya. The findings clearly demonstrate a distinct hump-shaped distribution pattern, revealing that mid-altitudinal zones (1200–1600 m asl) are under severe ecological pressure due to intense anthropogenic disturbances, climate variability, and expanding transport corridors. The high dominance of herbaceous invaders, predominantly originating from South and Tropical America, poses an immediate threat to the region's precious native floral diversity, traditional agriculture, and vital forest ecosystem services. The uncontrolled proliferation of these aggressive alien species has emerged as a critical concern for foresters, ecologists, and conservationists. Ultimately, this structural checklist serves as an empirical framework for policymakers to prioritize high-risk species, implement targeted eradication measures, and design localized habitat restoration strategies to safeguard this global biodiversity hotspot.

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