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DIVERSITY PHYTOSOCIOLOGICAL ANALYSIS OF INVASIVE ALIEN PLANT SPECIES ALONG DIFFERENT HABITATS OF JAUNPUR DISTRICT, UTTAR PRADESH, INDIA

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ABSTRACT

Invasive alien plant species constitute an important ecological challenge because their establishment and proliferation can modify native plant communities, reduce biodiversity and alter ecosystem processes. The present study was designed to assess the diversity, distribution and phytosociological characteristics of invasive alien plant species occurring in different habitats of Jaunpur District, Uttar Pradesh, India. Field investigations were proposed across four major habitat categories: agricultural field margins, roadside habitats, wastelands and riverine/seasonally moist habitats. Vegetation was assessed using quadrat-based sampling, and frequency, density, abundance, relative frequency, relative density, relative abundance and Importance Value Index (IVI) were calculated. An illustrative analysis indicated that *Parthenium hysterophorus*, *Ageratum conyzoides*, *Lantana camara*, *Eichhornia crassipes*, *Ipomoea carnea*, *Prosopis juliflora* and *Argemone mexicana* were among the important invasive or potentially invasive alien taxa requiring monitoring in the district. *Parthenium hysterophorus* showed particularly high occurrence in disturbed agricultural margins and wastelands, whereas *Eichhornia crassipes* and *Ipomoea carnea* were more closely associated with aquatic and wetland habitats. The findings demonstrate that habitat disturbance, agricultural intensification, roadside development, unmanaged wastelands and water-body degradation may facilitate alien plant establishment. Regular phytosociological monitoring combined with early detection, mechanical control, restoration of native vegetation and community participation is recommended for reducing invasion pressure in Jaunpur District.

KEYWORDS: Invasive Alien Plants, Phytosociology, Vegetation Analysis, Plant Diversity, IVI, Habitat Disturbance, Jaunpur, Uttar Pradesh, Invasion Ecology

Biological invasion is one of the major components of global environmental change. The introduction of plant species beyond their native geographical ranges may occur intentionally through horticulture, agriculture and forestry or unintentionally through transport, trade and other human activities. A plant becomes invasive when an introduced population establishes, reproduces and spreads sufficiently to influence the recipient ecosystem. Richardson *et al.* (2000) emphasized the importance of distinguishing introduced, naturalized and invasive plants because these stages represent different ecological processes.

An Invasive Alien Plant Species (IAPS) is defined as an alien plant that establishes, spreads rapidly, and causes measurable ecological, economic, or social harm in the introduced region. This definition emphasizes that invasiveness is not an inherent property of all alien plants but rather an outcome of interactions between species traits, environmental conditions, and disturbance regimes are transported across biogeographical barriers through human activities such as trade, agriculture, horticulture, and transportation. Establishment occurs when introduced individuals survive and reproduce under local environmental conditions. Naturalization refers to the formation of self-sustaining populations without continued human assistance. Finally, invasion is characterized by rapid population growth, spatial spread, and significant ecological impact (Blackburn *et al.,* 2011).

The invasion process is commonly conceptualized as a sequence of stages: introduction, establishment, naturalization, and invasion. During the introduction stage, propagules

Invasive alien plants can modify vegetation structure, resource availability, nutrient cycling, disturbance regimes and interactions among native species. Their impacts may include suppression of native regeneration, reduction in species richness, changes in soil properties, competition for water and nutrients, alteration of fire regimes and disruption of ecosystem services (Vitousek *et al.*, 1996; Mack *et al.*, 2000; Vilà *et al.*, 2011). The impacts are particularly pronounced where repeated anthropogenic disturbance creates open niches that can be exploited by rapidly growing alien species.

India possesses a diverse flora and a wide range of climatic and edaphic conditions that permit the establishment of numerous alien plant species. Several invasive plants, including *Lantana camara*, *Parthenium hysterophorus*, *Ageratum conyzoides*, *Chromolaena*

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odorata and *Prosopis juliflora*, have become widely distributed in different parts of the country. A recent synthesis of major invasive plants in India identified *Lantana camara* and *Parthenium hysterophorus* among the most widely distributed invasive taxa in the country.

Lantana camara is particularly important because it can occupy disturbed forests, pasturelands, wastelands and other habitats. Its ecological success has been associated with high reproductive capacity, vegetative regeneration, phenotypic plasticity, competitive ability and possible allelopathic effects (Sharma *et al.*, 2005; Negi *et al.*, 2019). In India, *L. camara* has been reported to affect biodiversity, ecosystem structure and ecosystem services in invaded landscapes.

Similarly, *Parthenium hysterophorus* is a serious invasive weed of disturbed environments and agricultural landscapes. Its rapid growth, prolific seed production and ability to colonize open habitats make it particularly successful under conditions of repeated disturbance. Invasive alien plants can also have consequences beyond vegetation ecology, including agricultural losses, health concerns and impacts on rural livelihoods (Adhikari *et al.*, 2020).

The ecological significance of invasion is not determined solely by the presence of an alien plant. The density, frequency, abundance and dominance of the species within a plant community provide more informative measures of invasion intensity. Phytosociological methods therefore provide an effective framework for quantitatively describing plant community structure (Curtis and McIntosh, 1950; Mueller-Dombois and Ellenberg, 1974).

Jaunpur District is situated in the north-western part of the Varanasi Division of Uttar Pradesh. The district is characterized predominantly by a relatively flat plain landscape with river valleys, and the Gomti and Sai are among its major rivers. Agricultural activity is an important component of the local economy, while roads, settlements, cultivated land, wastelands and river-associated habitats provide a heterogeneous landscape for vegetation development. Official district information reports sandy, loamy and clayey soils and an average annual rainfall of approximately 987 mm.

Despite the ecological importance of invasive plants, systematic habitat-wise phytosociological information for Jaunpur District is comparatively limited. A quantitative assessment is therefore necessary to determine which invasive alien plants are most frequent and abundant, which habitats are most susceptible to invasion, and how alien species are associated with changes in native vegetation.

The present study was consequently undertaken to evaluate the phytosociological characteristics of invasive alien plant species along different habitats of Jaunpur District, Uttar Pradesh.

MATERIALS AND METHODS

Study Area

The investigation was designed for Jaunpur District, Uttar Pradesh, India. The district forms part of the eastern Uttar Pradesh landscape and contains agricultural areas, settlements, roadsides, wastelands, riverbanks, ponds and other seasonally moist habitats. The official district profile describes a predominantly flat plain topography and identifies the Gomti and Sai among the principal rivers. The district has sandy, loamy and clayey soils, and agriculture constitutes an important component of the regional economy.

For the present investigation, the landscape was divided into four broad habitat categories:

H1 – Agricultural field margins: bunds, crop margins and uncultivated strips.

H2 – Roadside habitats: roadsides, railway-associated margins and disturbed transportation corridors.

H3 – Wasteland/open disturbed habitats: vacant plots, abandoned fields and unmanaged open areas.

H4 – Riverine/wet habitats: riverbanks, ponds, drainage channels and seasonally moist areas.

The habitat classification was selected to represent major disturbance and moisture gradients occurring within the district.

Field Survey and Sampling Design

A systematic field survey should preferably be conducted during both rainy and winter seasons because annual and perennial invasive plants can show substantial seasonal differences in occurrence and abundance.

For the proposed study, representative sites were selected from each habitat category. Quadrats were established using standard vegetation-sampling procedures following the principles described by Curtis and McIntosh (1950), Mueller-Dombois and Ellenberg (1974).

For herbs and small plants, quadrats of 1 × 1 m may be used. For shrubs, 5 × 5 m quadrats may be employed, while trees can be sampled using 10 × 10 m or larger plots depending on vegetation structure.

Within every quadrat, the following observations should be recorded:

- species name;
- number of individuals;
- growth form;
- habitat type;
- percentage cover, where applicable;
- phenological condition;
- associated native species;
- evidence of disturbance;
- GPS coordinates and photographs.

Plant identification should be confirmed using standard regional floras, herbarium resources and accepted taxonomic databases.

Identification of Invasive Alien Plants

Species were considered for the invasive alien category only after confirming their alien status and invasive/naturalized behaviour from established floristic and invasion literature. Richardson *et al.* (2000) recommended careful distinction between alien, naturalized and invasive categories; therefore, mere exotic origin should not automatically be interpreted as ecological invasiveness.

Phytosociological Analysis

The following parameters were calculated.

Frequency

[Frequency(%)=\frac{\text{Number of quadrats in which species occurs}{\text{Total number of quadrats studied}}\times100]

Density

[Density=\frac{\text{Total number of individuals of a species}{\text{Total number of quadrats studied}}]

Abundance

[Abundance=\frac{\text{Total number of individuals} {\text{Number of quadrats in which species occurs}}]

Relative Frequency

[Relative\ Frequency (%)=\frac{\text{Frequency of a species} {\text{Sum of frequencies of all species}}\times100]

Relative Density

[Relative\ Density (%)=\frac{\text{Density of a species} {\text{Sum of densities of all species}}\times100]

Relative Abundance

[Relative\ Abundance (%)=\frac{\text {Abundance of a species}{\text{Sum of abundances of all species}}\times100]For herbaceous communities, the conventional IVI may be calculated as:[IVI=Relative \Frequency+ Relative\Density+ Relative\ Dominance]

Where basal area or percentage cover is unavailable, a frequency-density-abundance-based importance measure may be reported separately rather than incorrectly treating abundance as dominance. Standard phytosociological procedures should be followed consistently (Mueller-Dombois and Ellenberg, 1974).

Diversity Analysis

Species diversity was estimated using the Shannon–Wiener diversity index:[H'=\sum p_i\ln p_i]where (p_i) is the proportion of individuals belonging to species (i).Pielou's evenness was calculated as: [J'=\frac{H'}{\ln S}]where (S) is total species richness (Pielou, 1966; Magurran, 2004).

Assessment of Invasion Pressure

Habitat-wise invasion pressure can be assessed from:

- number of invasive alien species;
- mean density of invasive species;
- total invasive cover;
- cumulative IVI;
- proportion of quadrats occupied by invasive plants;
- invasive-to-native species ratio.

Higher values of these parameters indicate comparatively greater invasion pressure.

Statistical analysis

The data may be subjected to one-way ANOVA to determine whether density or diversity differs significantly among habitats. Pearson correlation may be used to examine relationships between invasive abundance and native species richness. Where assumptions of parametric tests are not met, appropriate non-parametric tests should be used. Statistical significance may be evaluated at ($p<0.05$).

RESULTS AND DISCUSSION

The numerical values below are illustrative model data, included to demonstrate how the Results section and tables can be presented. They are not claimed as actual field observations from Jaunpur District.

Invasive Alien Species Recorded

The model dataset included seven frequently encountered invasive or potentially invasive alien taxa representing different growth forms and habitats.

The model species list illustrates the importance of separating habitat-specific invaders from broadly distributed invaders. Recent Indian literature identifies several of these taxa among major invasive plants and emphasizes their ability to alter ecosystem structure and native vegetation.

Table 1: Representative invasive alien plant species considered in the study

S. No.	Species	Family	Growth form	Principal habitat
1	*Ageratum conyzoides* L.	Asteraceae	Herb	H1, H2, H3
2	*Argemone mexicana* L.	Papaveraceae	Herb	H1, H2, H3
3	*Lantana camara* L.	Verbenaceae	Shrub	H2, H3
4	*Parthenium hysterophorus* L.	Asteraceae	Herb	H1, H2, H3
5	*Prosopis juliflora* (Sw.) DC.	Fabaceae	Tree/shrub	H2, H3
6	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Aquatic herb	H4
7	*Ipomoea carnea* Jacq.	Convolvulaceae	Shrub	H4

Habitat-wise Occurrence

Table 2: Illustrative habitat-wise occurrence of invasive alien plant species

Species	Agricultural margins H1	Roadsides H2	Wasteland H3	Riverine/wet H4
Ageratum conyzoides	+++	+++	++	+
Argemone mexicana	++	++	+++	+
Lantana camara	+	+++	+++	+
Parthenium hysterophorus	+++	+++	+++	+
Prosopis juliflora	+	++	+++	+
Eichhornia crassipes	–	–	+	+++
Ipomoea carnea	–	+	++	+++

+++ = high occurrence; ++ = moderate occurrence; + = low occurrence; – = not recorded in the illustrative dataset.

The model distribution suggests that *Parthenium hysterophorus* and *Ageratum conyzoides* may be associated particularly strongly with disturbed terrestrial habitats, whereas *Eichhornia crassipes* and *Ipomoea carnea* may show stronger association with wet habitats. *Lantana camara* and *Prosopis juliflora* may become important in unmanaged wastelands and transportation corridors.

Phytosociological Characteristics

Table 3: Illustrative phytosociological parameters of invasive alien plants

Species	Frequency (%)	Density (individuals m^{-2})	Abundance	Relative frequency (%)	Relative density (%)	IVI*
Parthenium hysterophorus	72	8.6	11.9	18.4	24.1	42.5
Ageratum conyzoides	64	6.9	10.8	16.4	19.3	35.7
Lantana camara	48	3.2	6.7	12.3	9.0	21.3
Argemone mexicana	43	2.8	6.5	11.0	7.8	18.8
Prosopis juliflora	36	1.7	4.7	9.2	4.8	14.0
Eichhornia crassipes	31	5.1	16.5	7.9	14.3	22.2
Ipomoea carnea	28	2.4	8.6	7.2	6.7	13.9

*IVI shown here is an illustrative relative frequency + relative density measure. For a publication-quality IVI, relative dominance/cover should also be measured.

The illustrative data indicate that *Parthenium hysterophorus* had the highest overall frequency and density among terrestrial invasive species. Its high occurrence across disturbed habitats suggests considerable ecological plasticity. *Ageratum conyzoides* also exhibited relatively high frequency and density. In contrast, *Eichhornia crassipes* displayed a comparatively high abundance in the quadrats where it occurred, reflecting its tendency toward dense local populations in favourable aquatic habitats.

Habitat-wise Diversity

Table 4: Illustrative diversity characteristics

Habitat	Species richness of invasive plants	Shannon index (H′)	Pielou evenness (J′)	Relative invasion pressure
Agricultural margins	5	1.42	0.88	High
Roadsides	6	1.61	0.90	High
Wastelands	6	1.58	0.88	Very high
Riverine/wet habitats	4	1.19	0.86	Habitat-specific high

The illustrative results suggest that wastelands and roadsides could support relatively high invasive plant richness because of frequent disturbance and open microsites. Agricultural field margins may also act as invasion corridors because they experience repeated soil disturbance and receive propagules from adjacent habitats.

Wetlands showed comparatively lower invasive species richness in the model dataset but greater dominance by habitat-specialist species such as *Eichhornia crassipes* and *Ipomoea carnea*.

The present analysis highlights the ecological importance of habitat heterogeneity in determining invasive alien plant distribution. Invasive plants do not occur uniformly throughout a landscape; instead, their occurrence is strongly influenced by disturbance, resource availability, propagule pressure, moisture regime and competitive interactions with native vegetation.

The high model frequency of *Parthenium hysterophorus* in agricultural margins, roadsides and wastelands is consistent with its well-known ability to colonize disturbed habitats. Such environments frequently contain open microsites, reduced competition and repeated soil disturbance, which can facilitate establishment of opportunistic species. Invasive alien plants are often favoured by anthropogenic disturbance because disturbance reduces existing biotic resistance and creates resource-rich sites suitable for colonization.

Ageratum conyzoides similarly represents an invasive herb capable of occupying disturbed vegetation. High frequency and density in roadsides and field margins would indicate a substantial propagule supply and repeated opportunities for establishment.

The ecological significance of *Lantana camara* requires particular attention. Lantana invasion has been extensively documented in India, where the species occurs across a range of habitats and can alter vegetation structure and biodiversity. Sharma *et al.* (2005) identified several traits that contribute to its invasive success, including vegetative reproduction, phenotypic plasticity, competitive ability and tolerance of disturbance. Negi *et al.* (2019) further reported that Lantana has invaded extensive areas of the Indian subcontinent and can alter biodiversity, landscape ecology and ecosystem services.

The occurrence of *Prosopis juliflora* in open and disturbed habitats is also ecologically relevant. Dense stands of invasive woody plants may modify light penetration, litter accumulation, soil conditions and the regeneration environment for native species. Where such species become dominant, the vegetation can gradually shift from diverse native communities toward simplified communities dominated by a small number of alien species.

Aquatic habitats require a different management perspective. *Eichhornia crassipes* can form dense floating mats under favourable nutrient and hydrological conditions. Such dense growth may reduce light penetration and interfere with gas exchange and water movement, thereby influencing aquatic organisms and native aquatic vegetation. This illustrates why invasive plant assessment should encompass not only terrestrial habitats but also ponds, drainage channels and river-associated wetlands.

Ipomoea carnea may similarly become locally dominant along wet and seasonally flooded areas. Its occurrence emphasizes the importance of considering hydrological disturbance and nutrient enrichment when assessing invasion risk.

A major ecological concern is the possible relationship between invasive plant abundance and native vegetation decline. However, the presence of an invasive plant alone does not demonstrate causation. To establish a statistically defensible effect on native vegetation, plots with different levels of invasion should be compared while accounting for habitat type and environmental variables. Studies of invasive plants have shown that impacts can include changes in community composition, ecosystem functions and biodiversity, although the magnitude and direction of impacts vary among species and ecosystems (Mack *et al.*, 2000; Vilà *et al.*, 2011).

The conceptual framework proposed by Richardson *et al.* (2000) is useful in this context because it distinguishes invasion from simple alien occurrence. A species should be regarded as invasive based on evidence of establishment and spread rather than merely because it is non-native. This distinction is especially important in regional studies where the flora contains numerous introduced ornamental, agricultural and naturalized species.

The observed or expected association between invasive plants and roadsides is particularly important from a landscape perspective. Roads can function as dispersal corridors because vehicles, humans, livestock and surface-water runoff can transport seeds and vegetative propagules. Road construction also creates disturbed soil and open habitats. Consequently, roadsides may act as starting points from which invasive plants spread into adjacent agricultural fields and wastelands.

Agricultural margins are another important invasion interface. Repeated cultivation, irrigation, movement of farm machinery and removal of native vegetation can facilitate alien plant establishment. Field bunds may provide relatively undisturbed locations where invasive plants complete their reproductive cycle and subsequently disperse into cultivated fields.

Wastelands are likely to be especially vulnerable because they combine reduced management with high disturbance. If abandoned agricultural land remains unmanaged for several years, invasive plants may establish persistent populations and alter the trajectory of natural succession. Lantana, Parthenium and Prosopis can therefore be regarded as important candidates for long-term monitoring.

The invasion process may also be influenced by climate and land-use change. Recent research indicates that invasive plant spread across India is occurring at substantial spatial scales and that invasion can have ecological and socioeconomic implications. This strengthens the need for district-level monitoring rather than restricting invasive-species assessments to protected forests.

The results also have implications for ecosystem services. Invasive plants may affect fodder availability, agricultural productivity, access to water, recreational values and other benefits derived from ecosystems. A recent review specifically examining plant invasions and human wellbeing in India emphasized that ecological impacts can intersect with rural livelihoods and resource dependence (Adhikari *et al.*, 2024).

Thus, the phytosociological assessment of Jaunpur should not be considered merely an inventory exercise. Frequency, density, abundance and IVI can provide an empirical basis for identifying priority species and priority habitats. Species with high frequency and high density across multiple habitat types should receive priority for monitoring, while species with very high abundance in specific habitats should be addressed through habitat-specific management.

CONCLUSION

The phytosociological assessment of invasive alien plants provides an important framework for understanding the distribution and ecological significance of alien species across different habitats. The model analysis indicates that disturbed habitats such as roadsides, agricultural margins and wastelands may represent important invasion hotspots, while aquatic habitats may be characterized by strong dominance of a smaller number of habitat-specific invasive species.

Among the species considered, *Parthenium hysterophorus* and *Ageratum conyzoides* may be particularly important in disturbed terrestrial habitats, whereas *Lantana camara* and *Prosopis juliflora* require monitoring because of their capacity to establish persistent populations. *Eichhornia crassipes* and *Ipomoea carnea* require specific attention in wet and aquatic environments.

The ecological effects of invasive plants should be assessed through comparisons of invaded and relatively uninvaded vegetation, rather than inferred solely from presence. Long-term monitoring of frequency, density, abundance, cover, IVI, native species richness and diversity will allow more reliable assessment of invasion trends.

For Jaunpur District, an integrated strategy involving early detection, habitat-wise monitoring, mechanical control, restoration of native vegetation, public awareness and GIS-based mapping would provide a scientifically sound approach to invasive alien plant management. Such efforts are particularly important in an agricultural landscape where vegetation, water resources and human livelihoods are closely interconnected.

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