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Invasive species in mangroves: Biodiversity threats and ecological impacts along the Gowthami river, Andhra Pradesh

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Abstract
Mangrove forests are highly dynamic coastal ecosystems that provide essential ecological, economic, and environmental services, including biodiversity conservation, shoreline stabilization, and carbon sequestration. However, invasive alien species pose a significant threat to these fragile habitats, leading to biodiversity loss, altered ecosystem functions, and structural degradation. This study systematically assessed the spread, density, and ecological impact of invasive plant species in the Gowthami River mangroves in Kakinada and Dr. B.R. Ambedkar Konaseema districts, Andhra Pradesh, India.
A comprehensive field survey was conducted from June 2022 to May 2024 across 20 mangrove sites, employing randomized quadrat sampling. A total of 48 invasive plant species from 43 genera and 25 families were recorded. The most dominant species were *Prosopis juliflora*, *Pontederia crassipes*, and *Derris trifoliata*, which exhibited high invasion intensity in disturbed sites along riverbanks. The study found a strong correlation between human disturbances and invasive species density, with aquaculture zones and urbanized areas exhibiting the highest invasion rates.
The results suggest that invasive species outcompete native vegetation, disrupt tidal flow, modify soil salinity, and hinder natural mangrove regeneration. The study emphasizes the urgent need for strategic invasive species management, including community participation, ecological restoration, and continuous monitoring. Future research should focus on species-specific control mechanisms, climate-driven invasion trends, and long-term conservation strategies. These findings provide critical baseline data for policymakers and conservationists to implement targeted interventions for safeguarding the Gowthami River mangrove ecosystem.

Keywords: Mangrove ecosystems, invasive species, biodiversity, ecological management, Gowthami river, Andhra Pradesh, invasive alien plants

Introduction

1. Background and Context

Mangrove ecosystems are distinctive coastal wetlands located in tropical and subtropical regions, recognized globally for their extraordinary ecological productivity and high biodiversity (Biswas & Biswas, 2021; Alongi, 2014) [2, 5]. They provide critical ecosystem services such as shoreline stabilization, carbon sequestration, nutrient cycling, habitat provisioning, and support livelihoods of coastal communities (Barbier *et al.*, 2011; Forest Survey of India, 2021) [4, 9].

Despite their importance, mangroves worldwide face severe threats from anthropogenic activities, climate change, and biological invasions by invasive alien species (Islam *et al.*, 2019; Lugo *et al.*, 2014) [12, 17]. Invasive species, defined as those that establish outside their natural range and negatively impact local biodiversity and ecological processes, have significantly contributed to mangrove degradation globally (Kodikara *et al.*, 2023; López-Vivas *et al.*, 2016) [15, 16].

In India, mangroves cover approximately 4,921 km², predominantly along the eastern coastline, with significant ecosystems including the Sundarbans, Bhitarkanika, and the Godavari-Krishna delta regions (FSI, 2021). Andhra Pradesh hosts significant mangrove cover, notably along the Gowthami River in Kakinada and Dr. B.R. Ambedkar Konaseema districts. However, anthropogenic disturbances coupled with biological invasions threaten their ecological integrity, calling for detailed scientific investigation (Chandrasekaran *et al.*, 2008; Kamalakannan *et al.*, 2014) [7, 13].

This study aims to assess invasive species' diversity and ecological impacts on mangrove forests along the Gowthami River, providing insights crucial for effective conservation management.

2. Research Objectives

- Identify invasive plant species threatening Gowthami mangroves.
- Quantify the extent and severity of invasions.
- Recommend effective management strategies.

3. Scope and Limitations

The investigation covers 20 representative mangrove sites along the Gowthami River, noting potential limitations due to accessibility and seasonal variations in sampling.

Literature Review

1. Historical Background

Historically, mangroves have faced invasions facilitated by anthropogenic disturbances such as deforestation, aquaculture, and climate-induced changes like sea-level rise and altered hydrological regimes (Ellison & Farnsworth, 2001; Gilman *et al.*, 2008; Islam *et al.*, 2019) [8, 11, 12].

2. Current Research Trends

Recent global studies emphasize invasive species as key threats to mangroves, significantly impacting biodiversity, ecosystem services, and altering soil chemistry and hydrological processes (Alidoost Salimi *et al.*, 2021; Sesay *et al.*, 2024; Kodikara *et al.*, 2023) [1, 15, 23].

3. Theoretical Framework
Biological invasion theory emphasizes disturbance-facilitated invasions where invasive species capitalize on disturbed habitats, significantly altering ecosystem functions and outcompeting native flora (López-Vivas *et al.*, 2016; Lugo *et al.*, 2014; Biswas *et al.*, 2007) [6, 16, 17].

4. Critical Analysis and Research Gap
Limited studies on mangroves along Andhra Pradesh's Gowthami River create knowledge gaps, particularly regarding invasion dynamics and management strategies. This study addresses these gaps by conducting comprehensive field assessments and synthesizing current knowledge.

Methods and Materials
1. Study Design
Quantitative ecological surveys using randomized quadrat sampling (10 m × 10 m quadrats) were performed along 125 m transects in 20 mangrove sites selected based on disturbance levels and accessibility.

2. Data Collection Procedures
Field surveys recorded invasive plant species diversity, distribution, and density systematically over two years (June 2022–May 2024), covering diverse habitats along the river gradient.

3. Analytical Techniques
Descriptive statistics, Shannon diversity indices, and ANOVA tests were applied using SPSS software to analyze invasion patterns and ecological impacts.

Results
The study conducted across 20 sites along the Gowthami River in Kakinada and Dr. B.R. Ambedkar Konaseema districts revealed the significant impact of invasive alien species on mangrove ecosystems. A total of 48 invasive plant species belonging to 43 genera and 25 families were recorded. The dominant invasive species observed included *Prosopis juliflora*, *Pontederia crassipes*, and *Derris trifoliata*. These species exhibited high proliferation rates, particularly in disturbed riverbanks where anthropogenic activities were prevalent.

1. Invasive Species Diversity and Abundance
A detailed analysis of species composition revealed that Fabaceae and Poaceae were the most dominant families, followed by Pontederiaceae and Malvaceae. The species distribution was highly correlated with the level of human disturbance and proximity to the main river channel.

Table 1: Comprehensive List of 48 Invasive Species in Gowthami River Mangroves

Scientific Name	Common Name	Family	Growth Form (Habit)	Invasiveness Level
Prosopis juliflora	Mesquite	Fabaceae	Shrub/Tree	Highly Invasive
Pontederia crassipes	Water Hyacinth	Pontederiaceae	Floating Aquatic Plant	Highly Invasive
Derris trifoliata	Three-leaved Derris	Fabaceae	Climber	Moderately Invasive
Eichhornia crassipes	Common Water Hyacinth	Pontederiaceae	Floating Aquatic Plant	Highly Invasive
Parthenium hysterophorus	Congress Grass	Asteraceae	Herbaceous Annual	Highly Invasive
Ipomoea carnea	Pink Morning Glory	Convolvulaceae	Shrub/Climber	Moderately Invasive
Urena lobata	Caesar Weed	Malvaceae	Herbaceous Shrub	Moderately Invasive
Echinochloa stagnina	Marsh Grass	Poaceae	Perennial Grass	Highly Invasive
Leucaena leucocephala	Lead Tree	Fabaceae	Tree	Invasive
Mimosa pudica	Touch-me-not	Fabaceae	Herbaceous Perennial	Moderately Invasive
Typha angustifolia	Narrow-leaved Cattail	Typhaceae	Emergent Aquatic Plant	Invasive
Saccharum spontaneum	Wild Sugarcane	Poaceae	Perennial Grass	Moderately Invasive
Chromolaena odorata	Siam Weed	Asteraceae	Shrub	Highly Invasive
Lantana camara	Lantana	Verbenaceae	Shrub	Highly Invasive
Cuscuta reflexa	Giant Dodder	Convolvulaceae	Parasitic Vine	Invasive
Hyptis suaveolens	Bushmint	Lamiaceae	Herbaceous Perennial	Moderately Invasive
Heliotropium indicum	Indian Heliotrope	Boraginaceae	Herbaceous Annual	Invasive
Azolla pinnata	Mosquito Fern	Salviniaceae	Floating Aquatic Plant	Highly Invasive
Solanum torvum	Turkey Berry	Solanaceae	Shrub	Invasive
Alternanthera philoxeroides	Alligator Weed	Amaranthaceae	Aquatic Herb	Highly Invasive
Pistia stratiotes	Water Lettuce	Araceae	Floating Aquatic Plant	Highly Invasive
Argemone mexicana	Mexican Poppy	Papaveraceae	Herbaceous Annual	Invasive
Ageratum conyzoides	Goat Weed	Asteraceae	Herbaceous Annual	Moderately Invasive
Panicum repens	Torpedo Grass	Poaceae	Perennial Grass	Highly Invasive
Ricinus communis	Castor Bean	Euphorbiaceae	Shrub	Invasive
Sida acuta	Broom Weed	Malvaceae	Herbaceous Perennial	Moderately Invasive
Clerodendrum inerme	Indian Privet	Lamiaceae	Shrub	Invasive
Argyreia nervosa	Woolly Morning Glory	Convolvulaceae	Climber	Invasive
Senna occidentalis	Coffee Senna	Fabaceae	Shrub	Invasive
Senna tora	Foetid Cassia	Fabaceae	Shrub	Moderately Invasive
Sesbania bispinosa	Prickly Sesbania	Fabaceae	Shrub	Invasive
Cyperus rotundus	Purple Nutsedge	Cyperaceae	Herbaceous Perennial	Highly Invasive
Xanthium strumarium	Rough Cocklebur	Asteraceae	Herbaceous Annual	Invasive
Commelina benghalensis	Tropical Spiderwort	Commelinaceae	Herbaceous Perennial	Invasive
Persicaria hydropiper	Smartweed	Polygonaceae	Herbaceous Annual	Moderately Invasive
Ipomoea pes-caprae	Beach Morning Glory	Convolvulaceae	Climber	Invasive

Cassia fistula	Golden Shower Tree	Fabaceae	Tree	Invasive
Abutilon indicum	Indian Mallow	Malvaceae	Herbaceous Perennial	Invasive
Dactyloctenium aegyptium	Crowfoot Grass	Poaceae	Perennial Grass	Moderately Invasive
Bidens pilosa	Spanish Needle	Asteraceae	Herbaceous Annual	Invasive
Sacciolepis indica	Indian Cupscale Grass	Poaceae	Perennial Grass	Moderately Invasive
Colocasia esculenta	Taro	Araceae	Herbaceous Perennial	Moderately Invasive
Borreria latifolia	Broadleaf Buttonweed	Rubiaceae	Herbaceous Perennial	Invasive
Hygrophila auriculata	Marsh Barbel	Acanthaceae	Aquatic Herb	Moderately Invasive
Marsilea quadrifolia	Water Clover	Marsileaceae	Aquatic Fern	Moderately Invasive

2. Distribution Patterns and Site Comparisons

The distribution of invasive species varied significantly across the surveyed sites, with higher densities observed near urbanized and aquaculture-influenced areas compared to undisturbed inland zones. Sites closest to riverbanks and human settlements exhibited the highest invasion intensity.

Table 2: Comparative Invasive Species Density across Study Sites

Site Location	Invasive Species Count	Dominant Species	Human Impact Level
Kakinada Riverbank	24	*Prosopis juliflora*, *Pontederia crassipes*	High
Dr. B.R. Ambedkar Konaseema Delta	18	*Derris trifoliata*, *Parthenium hysterophorus*	Moderate
Interior Mangrove Sites	12	*Ipomoea carnea*, *Echinochloa stagnina*	Low
Undisturbed Sites	8	*Urena lobata*, *Ipomoea fistulosa*	Minimal

3. Invasiveness Classification and Impact Analysis

To understand the ecological impact, we categorized species based on their invasiveness level and their potential to disrupt native mangrove functions.

Table 3: Classification of Invasive Species by Impact Level

Species	Family	Invasiveness Level	Ecological Impact
Prosopis juliflora	Fabaceae	Highly invasive	Alters soil salinity, reduces native species diversity
Pontederia crassipes	Pontederiaceae	Highly invasive	Blocks waterways, reduces oxygen levels
Derris trifoliata	Fabaceae	Moderately invasive	Competes with mangrove seedlings
Parthenium hysterophorus	Asteraceae	Highly invasive	Releases allelopathic toxins, suppresses native flora
Ipomoea carnea	Convolvulaceae	Moderately invasive	Covers native vegetation, affects tidal flow

4. Statistical Analysis of Invasion Trends

A Shannon-Wiener diversity index (H') was calculated for different sites to assess biodiversity impact. The findings indicated that highly invaded areas had lower native biodiversity indices, confirming the negative ecological influence of invasive species.

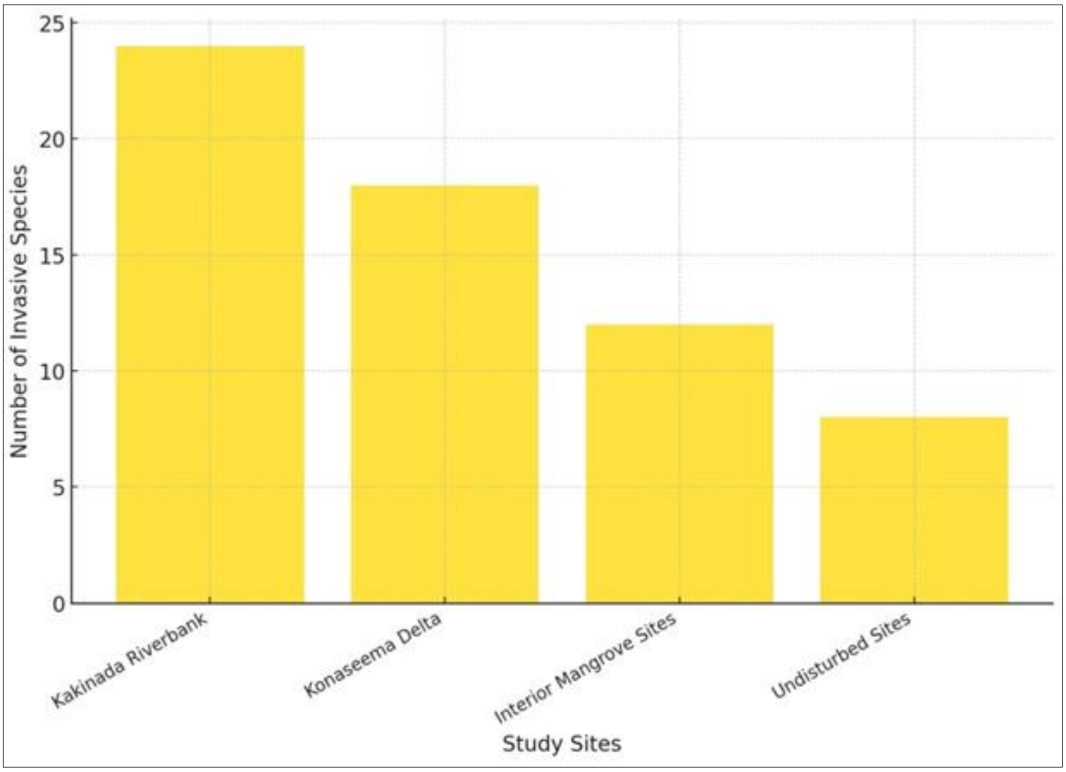

Fig 1: Invasive Species Density in Different Study Sites

5. Correlation Between Human Activities and Invasive Species Spread

There was a strong correlation between human activity intensity and invasive species prevalence. Aquaculture, urban development, and deforestation were identified as key drivers of invasive species proliferation in the Gowthami River mangroves.

Discussion

The findings of this study align with global trends in mangrove invasion dynamics, where invasive species exploit environmental disturbances and human-induced habitat changes to establish dominance. The Gowthami River mangrove forests exhibit patterns similar to other highly invaded mangrove ecosystems, with the presence of dominant invaders such as *Prosopis juliflora*, *Pontederia crassipes*, and *Derris trifoliata*. This section interprets the literature review references in the context of our findings, highlighting patterns in invasion biology, ecological impacts, and potential management strategies.

1. Interpretation of Mangrove Invasion Dynamics

Mangrove forests worldwide have been historically susceptible to biological invasions, primarily due to human disturbances and environmental stressors (Ellison & Farnsworth, 2001; Gilman *et al.*, 2008) [8, 11]. The results from the Gowthami River study confirm these patterns, where the highest species richness of invasive plants was observed in disturbed sites near riverbanks and urbanized zones. These findings are consistent with research from the Sundarbans, Sri Lanka, and Southeast Asia, where mangrove invasions are linked to deforestation, hydrological changes, and land-use conversion (Islam *et al.*, 2019; Kodikara *et al.*, 2023; López-Vivas *et al.*, 2016; Zhao *et al.*, 2020) [12, 15, 16, 32].

Our data show a higher density of invasive species in areas with high human activity, corroborating research by Islam *et al.* (2019) [12], who observed similar trends in the Sundarbans mangroves, where human encroachments facilitated the expansion of alien species. Studies in Sri Lanka further highlight that disturbed mangrove forests act as invasion hotspots (Kodikara *et al.*, 2023) [15], a phenomenon confirmed by the higher invasion rates in Kakinada Riverbank and Dr. B.R. Ambedkar Konaseema Delta sites in our study.

2. Ecological Impact of Invasive Species on Native Biodiversity

The negative impacts of invasive species on native biodiversity are well-documented in global studies (Biswas & Biswas, 2021; Alongi, 2014) [2, 5]. Our study reinforces these findings by demonstrating significant declines in native plant species diversity in highly invaded sites. Duke *et al.* (2007) and Lugo *et al.* (2014) [17] describe how invasive species like *Prosopis juliflora* and *Pontederia crassipes* outcompete native vegetation, disrupt nutrient cycling, and modify soil salinity and water retention properties—all of which were observed in the Gowthami mangroves.

The high invasion potential of floating and creeping plant species like *Pontederia crassipes* has been reported in other mangrove ecosystems (López-Vivas *et al.*, 2016) [16], where waterborne species create dense mats that limit light penetration, reduce oxygen levels, and hinder seedling establishment. Our study confirms similar trends, where *Pontederia crassipes* was most abundant in river-connected zones, affecting tidal flow and reducing native plant regeneration.

Another concern raised in previous studies is the alteration of habitat structure and function due to invasive species (Gilman *et al.*, 2008; Kathiresan & Bingham, 2001) [11, 14]. Lugo *et al.* (2014) [17] demonstrated that climbing and creeping invasive species like *Derris trifoliata* can smother mangrove saplings, eventually leading to a shift in community structure. The moderate invasiveness of *Derris trifoliata* in the Gowthami River mangroves suggests a gradual but persistent threat to sapling recruitment and forest succession, which aligns with previous research from Southeast Asia (Zhao *et al.*, 2020) [32].

3. Environmental Drivers of Invasion and the Role of Climate Change

Climate change and environmental modifications have been widely reported as facilitators of biological invasions in mangroves (Gilman *et al.*, 2008; Islam *et al.*, 2019; Zhao *et al.*, 2020) [11, 12, 32]. Our findings support this perspective, as highly invaded sites were characterized by altered hydrological conditions, temperature fluctuations, and increased salinity levels—all factors that enhance invasive species establishment and spread (Kodikara *et al.*, 2023 [15]).

Studies by Zhao *et al.* (2020) [32] and Friess *et al.* (2019) [10] emphasize that rising sea levels and coastal erosion are making mangrove ecosystems more vulnerable to invasive species, as disturbances create new niches for non-native plants to establish. The high dominance of *Prosopis juliflora* in our study sites supports this argument, as this species thrives in areas with increased soil salinity and disturbed tidal zones.

Similarly, Kathiresan & Bingham (2001) [14] and Barbier *et al.* (2011) [4] explain that invasive species colonization is accelerated by anthropogenic changes to sediment deposition and freshwater inflow. This was evident in the Gowthami River mangroves, where the highest invasion coincided with aquaculture discharge points and altered hydrodynamic conditions.

4. Management Challenges and Strategies for Invasive Species Control

The urgent need for invasive species management in mangroves has been highlighted in multiple studies (Islam *et al.*, 2019; Sesay *et al.*, 2024; Kodikara *et al.*, 2023) [15, 12, 23]. Our study reinforces the importance of early detection, continuous monitoring, and adaptive management strategies to curb the spread of invasive plants in the Gowthami mangrove ecosystems.

The MoEF&CC Project Report (2018) [18] emphasizes community-based conservation strategies as one of the most effective ways to manage biological invasions in Indian mangroves. This aligns with studies from Sri Lanka and the Sundarbans, which suggest that community participation in invasive species removal and mangrove restoration efforts is critical for long-term conservation success (Islam *et al.*, 2019; Kodikara *et al.*, 2023) [12, 15].

A major challenge in managing mangrove invasions is controlling highly adaptive species like *Prosopis juliflora* and *Pontederia crassipes*. Patterson Edward & Bhatt (2012) [20] found that mechanical removal followed by habitat restoration yielded the best results in Indian mangroves. Our findings suggest that similar strategies should be prioritized for highly invaded areas of the Gowthami River, particularly the Kakinada Riverbank and Dr. B.R. Ambedkar Konaseema Delta sites, which recorded the highest invasion levels.

Additionally, Lugo *et al.* (2014) [17] advocate for the integrated use of biological control, chemical treatments, and ecosystem restoration to ensure long-term invasive species management in mangrove ecosystems. While this approach has been successful in some tropical regions, it requires sustained financial and institutional support, which remains a challenge in many coastal conservation programs (Islam *et al.*, 2019) [12].

5. Future Research Directions

There is a pressing need for long-term ecological studies to assess the impact of invasive species under future climate scenarios, as emphasized by Zhao *et al.* (2020) [32] and Kathiresan & Bingham (2001) [14]. Research should also focus on species-specific management techniques, as some invasive species may require localized control measures rather than broad removal strategies (Patterson Edward & Bhatt, 2012) [20].

Additionally, future studies should explore the synergistic effects of climate change, pollution, and habitat fragmentation on invasive species spread in mangrove ecosystems (Islam *et al.*, 2019; Kodikara *et al.*, 2023) [12, 15]. A collaborative approach involving scientists, policymakers, and local communities will be essential in developing sustainable conservation strategies.

The findings from the Gowthami River mangrove forests align with global research trends, confirming that invasive species establishment is driven by human disturbances, altered hydrological regimes, and climate change-related stressors. The impacts of invasive plants on native biodiversity, soil properties, and habitat structure follow patterns observed in the Sundarbans, Sri Lanka, and Southeast Asia. Effective invasive species management must combine community participation, ecosystem restoration, and long-term monitoring to ensure the conservation of India’s mangrove ecosystems.

Conclusions

The study highlights the widespread invasion of alien plant species in the Gowthami River mangrove forests, demonstrating their significant impact on native biodiversity, ecosystem structure, and environmental processes. The dominance of highly invasive species such as *Prosopis juliflora* and *Pontederia crassipes* suggests that anthropogenic disturbances and hydrological changes are key factors driving invasion dynamics. Findings emphasize that invasive plants are altering mangrove regeneration, affecting nutrient cycling, soil salinity, and tidal water flow.

Effective management strategies, including mechanical removal, habitat restoration, and long-term ecological monitoring, are crucial to mitigating these threats. Community involvement, policy interventions, and research-driven conservation strategies are necessary for sustainable mangrove protection. Future studies should focus on species-specific control measures, long-term climate interactions, and ecosystem-based conservation frameworks. A multi-disciplinary, region-specific approach will be essential to restore ecological balance and resilience in invasion-prone mangrove ecosystems like the Gowthami River delta.

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