

Understanding and Managing Invasive Alien Species in India



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EXECUTIVE SUMMARY

CONTEXT AND PURPOSE

Invasive alien species (IAS) are among the most significant drivers of biodiversity loss worldwide. India, with its rich and varied ecosystems, faces mounting ecological, economic, and social costs from the spread of non-native species introduced intentionally or inadvertently. IAS threaten native biodiversity, disrupt ecosystem services, and undermine livelihoods, particularly those of rural and forest-dependent communities. Despite growing recognition of these threats, policy and management responses remain fragmented and under-resourced. This policy report brings together current information on the impacts, management, and governance of IAS in India. Its purpose is to highlight knowledge gaps, assess existing institutional frameworks, and propose pathways for a more coordinated and effective national response.

KEY FINDINGS



ECOLOGICAL IMPACT

IAS are degrading India's ecosystems at scale. In forests, *Lantana camara* has spread over 40 per cent of India's protected areas, forming dense thickets that suppress native flora, alter nutrient cycling, and reduce forage for herbivores. In arid and semi-arid regions, *Neltuma juliflora* alters soil chemistry and water availability, leading to biodiversity loss and reduced grazing land for pastoralists. Grasslands face encroachment from multiple woody invasive plants, which alter habitats for endangered animals, displace native plant species, and impact ecosystem functions. Freshwater and island ecosystems are equally imperilled by both plant and animal IAS: *Eichhornia crassipes* (water hyacinth) blocks irrigation canals, lowers dissolved oxygen, and increases mosquito breeding, while alien fish such as tilapia and African catfish outcompete indigenous species critical for fisheries.



ECONOMIC COSTS

IAS generate staggering economic losses. Global cost assessments estimate that invasions have cost India over INR eight trillion between 1960 and 2020. *Parthenium hysterophorus* infestations in croplands diminish yields of maize, sorghum, and other staples, adding to farmer distress. IAS insect pests have also imposed vast economic costs on Indian farmers. Efforts to control IAS in agricultural lands often fail, diverting scarce resources from other rural development priorities.



SOCIAL AND LIVELIHOOD IMPLICATIONS

The impacts of invasions reach deeply into daily life, compounding social and economic inequities. In Central India, dense thickets of *Lantana camara* restrict access to fuelwood and non-timber forest products, forcing women and girls to walk longer distances and spend more hours collecting necessities. In Gujarat, pastoralists face livestock weight loss and declining milk yields as grazing lands are overrun by *Neltuma juliflora*. Aquatic invasives clog village ponds and irrigation canals, disrupting both agriculture and drinking water supply. These burdens are not borne equally: women, smallholder farmers, and the most marginalised communities shoulder the heaviest costs, further entrenching cycles of poverty and vulnerability.



KNOWLEDGE AND DATA GAPS

Despite these pressing challenges, information on IAS remains fragmented. India lacks a centralised, regularly updated inventory of invasive species. Most studies focus on a handful of well-known invasives such as *Lantana* or *Parthenium*, while lesser-known but fast-spreading species receive little attention. This greatly reduces the efficacy of early detection, rapid response, and long-term monitoring.



POLICY AND GOVERNANCE

Governance responses remain weak and fragmented. Plant quarantine laws address agricultural pests but overlook invasive vertebrates and aquatic species. The Wildlife Protection Act, 1972, prioritises wildlife and habitat protection but lacks specific provisions to address IAS. Forestry operations often inadvertently aid invasions by clearing land or planting non-native species. Without a coordinated national strategy, management efforts remain ad hoc, underfunded, and limited in scope.



MANAGEMENT AND CONTROL STRATEGIES

India has experimented with a wide range of management approaches, yet results remain mixed. Early detection and rapid response are recognised as the most cost-effective measures, but surveillance systems are weak, and responses are often delayed. Long-term monitoring using updated national databases and atlases is essential. Prevention through quarantine and biosecurity measures is effective in stopping invasions at early stages. Surveillance methods such as spatial and molecular technology can strengthen management. Mechanical and chemical controls are often deployed against species such as *Lantana* and *Parthenium*, but these approaches are labour-intensive and rarely sustainable at scale. Biological control has seen partial success—for instance, with *Parthenium*. However, this requires careful monitoring to avoid unintended consequences. Ecosystem-based approaches, including the reintroduction of native species, show promise when linked with long-term community engagement. Integrated Pest Management and emerging molecular tools offer new directions but demand significant investment in research and capacity building. Community-driven efforts, such as participatory *Lantana* removal programmes, highlight the potential of locally tailored management practices, although they remain constrained by inconsistent funding and technical support. Consideration of approaches such as novel ecosystems may also pave the way for adaptive management of entire landscapes.



POLICY GAPS AND CHALLENGES

India's response to invasive alien species remains fragmented and reactive. While several ministries and departments (agriculture, forestry, fisheries, environment, and trade) have mandates that touch upon IAS, there is little cross-sectoral coordination. Existing legal instruments, such as the Plant Quarantine (Regulation of Import into India) Order, include only a limited number of recognised IAS, offering inadequate coverage, especially for invasive plants. The Wildlife Protection Act, 1972, similarly lacks provisions to address invasive fauna, even as species like African catfish and red-eared slider turtles spread unchecked.

Enforcement capacity is weak: frontline staff are rarely trained in IAS identification or management, and dedicated funding streams are scarce. State-level agencies often lack both expertise and resources to implement control programmes. At the same time, scientific and monitoring gaps constrain risk assessments and early warning systems. Finally, management interventions frequently proceed without engaging local communities, reducing effectiveness and creating social resistance. Together, these gaps leave India ill-equipped to stem the accelerating ecological and economic costs of invasions.



RECOMMENDATIONS

To strengthen India's response to IAS, this brief proposes the following priority actions:

1. Develop a comprehensive national IAS strategy (see Section 7.1)

- Establish a legally backed national policy that integrates the ecological, economic, and social dimensions of invasions.
- Ensure alignment across agriculture, forestry, environment, fisheries, and trade sectors.

2. Create a centralised IAS inventory and monitoring system (see Section 6.4)

- Build and maintain a dynamic, publicly accessible database of invasive species inclusive of distribution maps with dates, to measure spatial spread.
- Invest in regular monitoring, citizen science initiatives, and use digital tools for early detection.

3. Strengthen early warning and rapid response mechanisms (see Section 6.1)

- Establish dedicated IAS units at national and state levels.
- Develop protocols for prevention, quarantine, and eradication before invasions spread widely.

4. Invest in capacity building and research (see Section 6.3)

- Train frontline staff in IAS identification, risk assessment, and control techniques.
- Expand research on lesser-known invasives, impacts on human livelihoods and well-being, ecological restoration, and cost-effective management approaches.

5. Promote community-based management and build awareness across civil society (see Section 7.4)

- Engage local communities, particularly women and marginal stakeholders, in IAS control programmes.
- Provide incentives for sustainable use of biomass from invasive species where appropriate.
- Build awareness among civil society to encourage participation, behavioural change, and stronger demand for policy action.

6. Secure dedicated funding (see Section 8.2)

- Create earmarked budget lines at central and state levels to ensure sustained financing for IAS prevention and management.

By pursuing these steps, India can move from a fragmented, reactive approach towards a coordinated, proactive strategy that safeguards biodiversity, livelihoods, and the economy.

CONCLUSION

IAS are a rapidly escalating yet under-recognised threat to India's biodiversity, economy, and human well-being. The costs of inaction are mounting: eroding ecosystems, undermining rural livelihoods, and jeopardising national conservation and development goals. Decisive, coordinated action is no longer optional but imperative. An adequately resourced, inclusive national strategy can shift India's response from fragmented firefighting to proactive management. By prioritising prevention, strengthening early-warning and rapid-response systems, and empowering communities to lead on local management, India can protect its ecosystems, bolster livelihoods, and secure a resilient, sustainable future.

PREFACE

OBJECTIVE OF DOCUMENT

India faces mounting environmental challenges as globalisation, climate change, and human activities accelerate ecological changes. Invasive alien species (IAS) have emerged as one of the most pressing threats, disrupting ecological balance, threatening native biodiversity, and impacting the livelihoods of communities dependent on natural resources.

This document serves as both a guide and a practical toolkit for policymakers, researchers, and stakeholders addressing the IAS challenge. Drawing upon the latest research, case studies, and field-tested practices, it outlines strategies to mitigate the far-reaching ecological, economic, and social impacts of IAS in India's terrestrial and freshwater ecosystems. Rooted in national policies and international frameworks, the document not only assesses the severity of the IAS issue but also presents actionable solutions to bridge critical gaps in existing knowledge and management practices.

Beyond policy and technical recommendations, this document seeks to foster collaboration among India's key stakeholders—from research institutions and NGOs to community groups and government agencies. By integrating scientific insights with local wisdom, it aims to empower conservation efforts and promote a more resilient, adaptive, and sustainable approach to IAS management across India's diverse ecosystems.

HOW THE DOCUMENT IS ORGANISED

The document begins by establishing the significance of IAS in the context of global biodiversity loss, explaining how these species disrupt native ecosystems, outcompete indigenous flora and fauna, and impact rural and forest-dependent communities. It then situates IAS within broader environmental challenges, such as biodiversity decline, land use change, and climate change, which further exacerbate their spread and establishment.

India's response to IAS is examined through the lens of both international and national policy frameworks, assessing how global agreements and domestic legislation have shaped the country's IAS management strategies. Key obstacles in enforcement and gaps in current policy implementation are explored, highlighting the need for stronger governance and biosecurity measures.

The document then shifts to practical solutions, discussing early detection systems, ecosystem-based management strategies, and the importance of cross-sector collaboration. It also emphasizes the role of scientific research, policy advocacy, and community engagement, using case studies to illustrate successful on-ground initiatives.

Finally, the document synthesises key findings and offers recommendations for improving IAS management in India by calling for strengthened biosecurity protocols, greater public awareness, and stronger regional and international cooperation.



Photo: Dr Manzoor Ahmad Shah, Department of Botany, University of Kashmir, Srinagar



A close-up photograph of a white thistle flower with spiky petals, set against a dark, blurred background. The flower is positioned on the left side of the frame, with its green base visible at the bottom.

1

**Brief overview of
Invasive Alien
Species (IAS) and
their Impacts on
Biodiversity,
Ecosystems, and
Human Well-Being**

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) defines invasive alien species (IAS) as

“Species whose introduction and/or spread by human action outside their natural distribution threatens biological diversity, food security, and human health and well-being. ‘Alien’ refers to the species having been introduced outside its natural distribution (‘exotic,’ ‘non-native,’ and ‘non-indigenous’ are synonyms for ‘alien’). ‘Invasive’ means ‘tending to expand into and modify ecosystems to which it has been introduced.’ Thus, a species may be alien without being invasive, or, in the case of a species native to a region, it may increase and become invasive, without actually being an alien species.”

IPBES estimates that around 20% of the Earth’s surface, including key biodiversity hotspots, is at risk from IAS¹, underscoring the need for urgent policy and management responses.

In developing nations like India, where a significant portion of the population rely on natural resources for their livelihoods, the impacts of IAS on both biodiversity and human well-being are particularly severe². Moreover, IAS often outcompete native flora and fauna for food, water, and space, sometimes driving indigenous species to extinction³, thereby exacerbating the ongoing global biodiversity crisis.

The spread of IAS is facilitated through multiple pathways, often linked to global trade, tourism, and transportation networks. Human-mediated movement—via aquaculture, horticulture, the pet trade, or contaminated shipping cargo—remains the primary pathway for IAS introductions⁴. Additionally, urbanisation, land-use and sea-use alterations, pollution and habitat degradation create conditions that favour the establishment and proliferation of IAS⁵. Together, these factors enable IAS to overcome natural dispersal barriers and expand across continents, with globalisation acting as a major driver⁴



A leopard makes its way through a parthenium-infested undergrowth in the Nagarhole Tiger Reserve in Karnataka, peninsular India | Photo: Aathira Perinchery.

The ecological impacts of IAS are well documented, with invasive plants and animals causing habitat degradation, reduced water quality, and loss of primary productivity and altered nutrient cycling. In India, where over 70% of the population relies directly on natural resources, the socioeconomic consequences are equally severe². IAS like *Lantana camara* (hereafter *Lantana*), *Neltuma juliflora* (hereafter *Neltuma*), *Chromolaena odorata* (hereafter *Chromolaena*), and *Parthenium hysterophorus* (hereafter *Parthenium*) have devastated agricultural systems⁶ altered cropping patterns, and disrupted rural and indigenous livelihoods⁶

These IAS compete with native plants and restrict access to non-timber forest products (NTFPs), which are vital for many marginalised communities².

A major challenge in IAS management is its intersection with climate change. Rising global temperatures and shifting precipitation patterns are making ecosystems more susceptible to invasion⁵. In the Indian Himalayas, for instance, the invasive *Ageratina adenophora* is migrating to higher altitudes, threatening endemic species in fragile ecosystems⁷. This case highlights how climate change continues to create favourable conditions for IAS, increasing the risk of biological invasions and complicating management efforts.

Despite growing concerns, large data gaps persist in India regarding invasive alien vertebrates, invertebrates, fungi, microbes, and marine organisms. Additionally, our understanding of how IAS interact with climate change is also limited. Existing research has largely focused on a few prominent IAS and terrestrial ecosystems, while the impacts on lesser-known species as well as on freshwater and marine ecosystems remain underexplored⁵.

Addressing these challenges requires a comprehensive and coordinated approach, involving both national and international policies⁸. Key priorities include developing an exclusive national policy and action plan to combat IAS, increasing awareness of the negative impacts of IAS among stakeholders and engaging them in IAS management actions, strengthening biosecurity measures (including surveillance systems), refining predictive modelling tools, and fostering global cooperation to curb the impacts of IAS on biodiversity and human well-being⁹⁻¹¹. A more nuanced understanding of the social and economic impacts, especially on rural and indigenous communities, is also essential for developing effective management strategies that safeguard both ecosystems and livelihoods².



The invasive Ageratina adenophora | Photo : Wikimedia Commons



A vertical strip on the left side of the page shows a close-up of a plant with small, bright yellow and orange flowers and green, serrated leaves. The background is a solid dark red color.

2

Importance of Understanding IAS in the Context of Global Change Factors

2.1 | Climate Change

2.2 | Influence Of Land Use Change On Invasive Species: Habitat Modification, Fragmentation, and Creation Of New Niches

2.3 | Introduction Pathways of IAS and the Role of International Trade in Species Transport

2.1 CLIMATE CHANGE

Over the past century, global mean surface temperatures have increased by approximately 0.7°C, with a sharper rise of 0.16°C per decade since 1970—particularly evident during winter months. Alongside shifts in precipitation patterns, these changes disrupt ecosystem dynamics and significantly impact biodiversity by forcing species to migrate, alter their life cycles, or develop new physiological traits¹². Moreover, rising temperatures and extreme weather events, like droughts, floods, cyclones, and sea-level rise, are making previously unsuitable habitats more favourable for IAS. Changes in land, sea, and freshwater use, triggered by climate change, may also make ecosystems more susceptible to invasion by IAS.

Projections indicate that climate change will continue to raise temperatures, intensify droughts, and exacerbate other extreme weather events. The Millennium Ecosystem Assessment identifies climate change as one of the major drivers of biodiversity loss by the end of this century¹³. These changes are likely to profoundly affect species distributions and behaviours, especially for IAS. As temperature and precipitation patterns shift, the geographic ranges of both native and non-native species may expand into new territories, while others could face increased competition or new environmental pressures. Some previously benign species could become invasive, while native species migrating into novel habitats may disrupt local ecosystems¹².

In India, for example, warming in the Ganges basin is projected to raise the mean annual temperature by 1–4°C between 2010 and 2050, potentially allowing non-native species such as common carp, Nile tilapia, and African catfish to colonise new areas and further alter local ecosystems. Such a shift is already evident in a census of Kerala's Ashtamudi Lake, which revealed that 85% of its 51 recorded species were marine, including the highly invasive charru mussel (*Mytella strigata*)—a shift attributed to reduced freshwater flow from the Kallada River due to climate change¹⁴.

Furthermore, alterations in river courses and increased flooding can accelerate the introduction and spread of IAS. Rising water temperatures can stress native species, weaken immune systems, and reduce reproductive success, while favouring more adaptable invaders. These temperature fluctuations also disrupt ecological rhythms by altering sex ratios, spawning times, and migration patterns¹⁴.

Terrestrial ecosystems face similar threats. Many IAS exhibit robust resilience to warming and can rapidly colonise new landscapes. A study by the Institute of Forest Productivity in Ranchi analysed the dispersion dynamics of two invasive plant species, *Chromolaena odorata* and *Lantana* central and eastern India. They found that both species demonstrate strong climate resilience, highlighting the need for targeted control in predicted invasion hotspots¹⁶. While *Lantana* has been widely studied, emerging evidence suggests that *Chromolaena* may be equally or more aggressive in its expansion. Similarly, *Parthenium* is expected to expand its range due to climate-induced flooding and elevated CO₂ levels¹⁷.



2.2. INFLUENCE OF LAND USE CHANGE ON INVASIVE SPECIES: HABITAT MODIFICATION, FRAGMENTATION, AND CREATION OF NEW NICHES

Land-use change, whether through habitat modification or the transformation of landscapes, can facilitate the establishment of IAS¹⁸. Fragmentation caused by linear intrusions like roads and powerlines¹⁴, combined with unsustainable biomass extraction and grazing, increases ecosystem vulnerability to invasion. Furthermore, linear intrusions often serve as dispersal routes for IAS via vehicular transport and altered microclimates resulting from increased artificial surfaces¹⁹. The interaction between land-use change, climate change, and IAS is expected to modify the drivers that facilitate biological invasions, forming new introduction pathways and enabling some IAS to overcome barriers to establishment and spread in certain habitats⁶.

Changes in land use can also subtly but significantly alter ecosystem processes. For example, altering disturbance regimes—such as suppressing fire in fire-adapted ecosystems or increasing fire in fire-sensitive ones—can elevate invasion risks^{20,21}.

Human-mediated species introductions, such as those for biocontrol of other pests, can further destabilise native species, creating new opportunities for IAS. Freshwater ecosystems are particularly at risk, as pollution, changes in water flow, and habitat disruption have allowed IAS like mosquitofish (*Gambusia affinis*) to thrive²².



2.3. INTRODUCTION PATHWAYS OF IAS & THE ROLE OF INTERNATIONAL TRADE IN SPECIES TRANSPORT

The rapid globalisation of trade has greatly accelerated the movement of goods across borders, inadvertently facilitating the spread of invasive alien species. Today, international trade is one of the primary pathways for IAS introduction. These species often “hitch a ride” as contaminants or stowaways in commodities such as clothing, livestock, or ships’ ballast water.

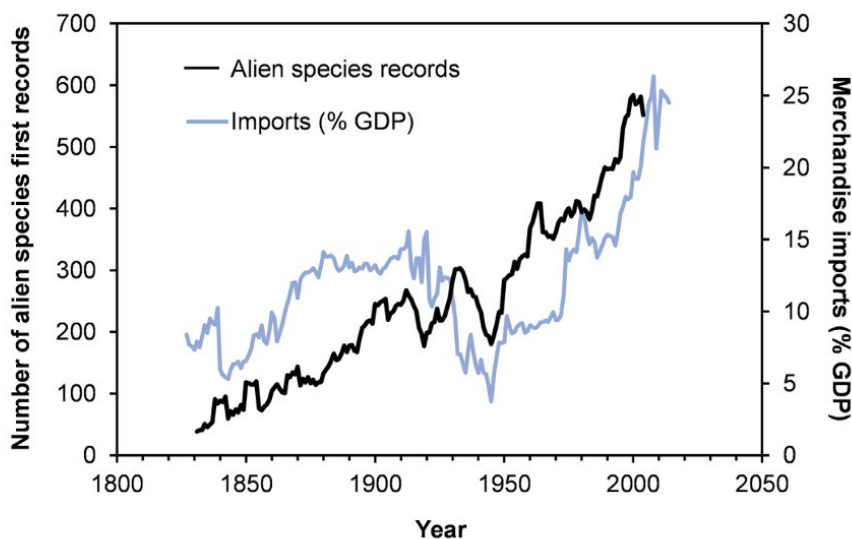


Figure 1. Temporal trends since the early 19th century in the percentage of gross domestic product (GDP) attributed to imports and the number of first recorded occurrences of alien species worldwide. First records of alien species are presented as 5-year running averages for clarity²³.

Beyond direct transport, international trade contributes to IAS spread by transforming habitats in both exporting and importing regions. Trade-driven urbanisation and resource extraction create favourable conditions for IAS establishment. Combined with climate change, these pressures intensify invasion risks, highlighting the urgent need for a comprehensive biosecurity strategy²³.

Technological advancements in trade—such as container shipping and the construction of major maritime routes like the Suez and Panama Canals—have further intensified the spread of IAS by enabling species to travel further and establish in new environments by connecting previously separate biogeographic regions. The rise of e-commerce and the emergence of new trade routes further complicate efforts to monitor and regulate the movement of potentially invasive species²³. Moreover, the global exchange of plants, planting materials, and other goods not only risks introducing alien pests but also new diseases and virulent strains, leading to severe biosecurity challenges. Host plants may harbour invasive pests, while untreated packing materials, contaminated seeds, and even unprocessed timber serve as frequent vectors. These pathways enable invasive species to bypass natural barriers and enter new ecosystems, particularly forests. Although quarantine measures aim to reduce risks associated with IAS movement, their effectiveness is often limited amid the growing complexity and scale of global trade networks¹¹. Since the liberalisation of global trade under the World Trade Organization (WTO) in 1995, the volume and speed of goods crossing international borders have surged, intensifying the risk of IAS introductions¹¹. However, biosecurity measures have not been modified to keep pace with the growth in volume, diversity, and origins of global trade and travel.

This growing risk underscores the need for a more coordinated global response. Strengthening quarantine measures, improving risk analysis, and enhancing international cooperation are essential steps toward reducing IAS introductions and ensuring safer global trade¹¹.







3

Impacts of Invasive Alien Species in India

3.1 | Ecological Impacts

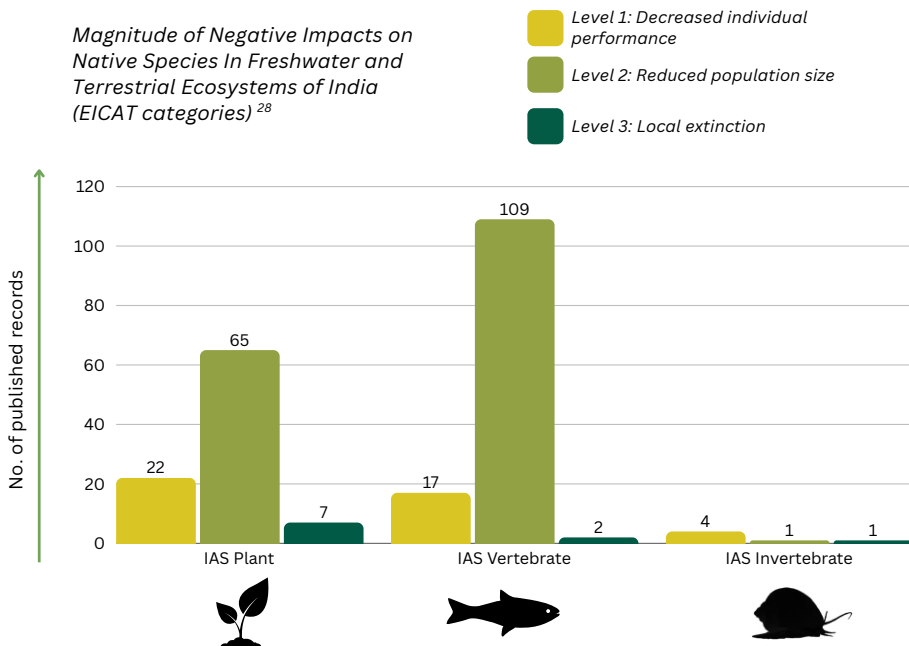
3.1.1 | IAS Negatively Impact Native Biodiversity

3.1.2 | IAS Alter Ecosystem Functioning

3.1.ECOLOGICAL IMPACTS

3.1.1. IAS NEGATIVELY IMPACT NATIVE BIODIVERSITY ACROSS ECOSYSTEMS

Biological invasions are among the leading drivers of biodiversity loss globally, implicated in 60% of global extinctions and directly responsible for 16%²⁴. IAS have a predominantly negative impact on native biodiversity (71% negative vs. 29% positive²⁴), impacting multiple levels of ecological organization—from individuals to communities—by altering ecosystem characteristics in ways that reduce native species survival^{25–28}. These changes often simplify species assemblages and shift resource availability, leading to biotic homogenisation^{29,30}. The type of impact can range from reductions in individual performance and populations of native species to global extinction²⁸. The severity of impacts often varies by IAS taxon, biogeographic context, and host ecosystem type. Vertebrate IAS typically have more pronounced effects than invertebrates or plants, and spatially isolated ecosystems such as islands and lakes are particularly vulnerable^{24,28}.



In India, over half of the IAS with recorded negative impacts are plants⁵. Invasive alien plant species (IAPS) are linked to 22–64% reductions in local species richness of native plants, as well as declines in abundance, particularly in dry and deciduous forests^{31–38}. *Lantana* is the most studied IAPS³⁹, and its invasion has been linked to the likely local extinction of several understory plants³³ (Box 3.1).



Chromolaena odorata



Lantana camara



Parthenium hysterophorus



Neltuma juliflora

Woody IAPS have extensively altered processes influencing native plant community assembly in forest understories^{33,40,41} and open natural ecosystems^{20,42,43}, promoted the dominance of annual grasses over native perennials in grasslands^{44,45}. They have reduced habitat availability for endangered fauna such as one-horned rhinoceros (*Rhinoceros unicornis*)⁴⁶, hog deer (*Axis porcinus*)⁴⁷, Nilgiri tahr (*Hemitragus hylocrius*)⁴⁸, and Nilgiri pipit (*Anthus nilghiriensis*)⁴⁹. Woody IAPS can also modify native animal behaviour, species composition, and habitat use by altering habitat structure, displacing native forage plants, and providing alternate food sources—as in the case of blackbuck (*Antilope cervicapra*)^{50–52}.

On islands, IAS impacts are particularly severe due to the insular characteristics of native species, including lower abundances, restricted ranges, and limited behavioural or physiological defences against novel predators and competitors^{53,54}. In the Andaman archipelago, invasions by spotted deer (*Axis axis*)⁵⁵, common myna (*Acridotheres tristis*)^{56,57}, Indian bullfrog (*Hoplobatrachus tigerinus*)⁵⁸, and giant African snail (*Lissachatina fulica*)⁵⁶ have already been documented. Several other species are likely to be in initial stages of invasion (e.g., tilapia and common garden lizard). Based on the few impact studies of IAS on Indian islands, mammalian herbivores have reduced seedling density, vegetation cover, and altered plant community composition^{55,59,60}. Deer herbivory, for example, is likely responsible for declines in forest floor lizard populations due to loss of understory cover⁶¹. Similarly, Indian bullfrogs have negatively impacted native island anuran populations as their tadpoles cause high mortality in endemic tadpoles, while adult bullfrogs prey on several endemic centipedes, amphibians, and reptiles⁶².



In freshwater ecosystems, invasive alien fish such as common carp, tilapias, suckermouth catfishes, and African catfish have caused population declines in native species^{63–66} and disrupted food webs, particularly in the upper Gangetic plains^{67,68} (see Box 3.4) and in culture-based fisheries of Andhra Pradesh⁶⁹. At the community level, IAS fish have shifted the trophic composition of open water systems towards lower trophic levels, as most are detritivorous, herbivorous, or omnivorous⁷⁰. A review of 26 IAS fish species using the IUCN EICAT framework⁷¹ identified interspecific competition as the dominant pathway of impact (20/26 species), followed by predation (15/26) and herbivory (10/26). Invasive molluscs like *Pomacea bridgesii* and *Physella acuta*, tend to occur in high abundance, and have been documented to threaten native species through direct predation and competition owing to their wide-ranging food preferences^{72–74}.

Invasive aquatic plants have significantly altered plant community composition in lacustrine ecosystems and have led to the decline of native species such as lotuses (*Nelumbo sp.*) in Jammu and Kashmir⁷⁵. IAPS like *Eichhornia crassipes*, *Salvinia molesta*, *Alternanthera philoxeroides*, and *Ipomoea sp.* have also contributed to significant reductions in fish and bird biodiversity across several aquatic and wetland ecosystems^{76–78}.



A river covered in water hyacinth | Wikimedia Commons

Direct impacts of IAPS include suppressed growth and recruitment of native flora through altered microclimates and increased interspecific competition^{33,36,79,80}. Many IAPS also exhibit allelopathic effects that hinder native species, affecting individual performance and recruitment rates^{68,81–83}. Additionally, some disrupt plant-soil feedback mechanisms by affecting plant-mycorrhizal associations and soil microbial communities^{84–87}.

Further, IAPS can also indirectly impact native communities by altering biotic interactions⁵². Fleshy-fruited IAPS, for example, often form novel mutualistic associations with resident, generalist vertebrate frugivores, potentially reshaping native plant-frugivore networks^{88–90}. These associations may increase competition for dispersers and reduce visitation rates, ultimately affecting native plant population dynamics^{91–93}. In India, *Lantana* is dispersed by bulbuls^{94–96} and even large mammals like sloth bears⁹⁷, while *Neltuma* is dispersed by blackbuck⁵¹.



3.1.2. IAS ALTER ECOSYSTEM FUNCTIONING

IAS affect energy flow, nutrient cycling, biomass distribution, ecohydrology, and disturbance regimes. In both terrestrial and freshwater ecosystems, IAS have altered nitrogen and phosphorus cycling, carbon cycling and storage, and water flow patterns. For instance, in grassland, riparian, and forest ecosystems, they alter biomass, evapotranspiration rates and fire regimes.

Globally, IAS affect soil nutrient dynamics through indirect mechanisms (e.g., by influencing the abundance of other macro- and micro-organisms, and substrate characteristics), and direct ones (e.g., Nitrogen-fixing plants alter nitrogen and phosphorus cycling). In arid and semiarid regions of India, soils invaded by the nitrogen (N)-fixing *Neltuma* show greater amounts of total and mineral N, available phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), and soil organic carbon (C)^{98,99}. Similarly, in montane grasslands, invasion by the N-fixing tree *Acacia mearnsii* is associated with an increase in soil N availability and nitrification rates¹⁰⁰. Such increases in mineral inputs can disrupt natural ecosystems by altering soil properties and nutrient dynamics, negatively impacting native plant communities^{101,102}. Overall, Indian studies broadly support global findings that IAP effects on nutrient cycling are variable and context-dependent.



Forest understory covered in Lantana | Photo : Wikimedia Commons

For example, soils collected under *Lantana* show greater pools and fluxes of N compared to soil under native dry forests in Central India²⁹, with the opposite observed in the Western Himalayas¹⁰³. Other studies have found both positive^{99,101} and negative effects of IAPs on nutrient cycling¹⁰⁴. These differences—especially for non-N-fixing IAPs—may relate to their influence on biomass and organic inputs, which in turn affect nitrogen fluxes and soil carbon^{98,99,101–104}.

Invasive plant biomass directly influences ecosystem carbon budgets. For instance, *Lantana* can store up to 6 T/ha of carbon in degraded subtropical forest understories¹⁰⁵, and woody IAPS in grasslands substantially increase aboveground carbon—though often at excessive cost to biodiversity and other ecological functions¹⁰⁶. IAPS also influence soil carbon through litter and root exudate inputs^{29,68}.

Indirectly, IAPS alter key ecological processes such as primary productivity, nutrient cycling, and vegetation dynamics, changes that can have longer-lasting impacts on carbon dynamics than direct biomass accumulation^{107–109}. Understorey IAPs such as *Lantana*, *Mikania micrantha*, and *Chromolaena* reduce carbon storage by altering native plant composition^{40,79,110} and fire regimes¹¹¹. Some IAPs also influence soil microbial and mineral properties, further disrupting carbon cycling^{19,108}. For example, *A. mearnsii* invasion in montane grasslands is associated with decreased respiration of CO₂ from soil¹¹². Such invasions by woody plants in grasslands can reduce below ground carbon storage^{113,114}, but these impacts remain poorly studied in the Indian context. Similarly, not much is known about the impacts of IAS animals on ecosystem carbon budgets but studies from other places highlight potential impacts. While impacts of invasive animal species on carbon cycling remain understudied in India, international research such as those on invasive insects in European forests¹¹⁵, suggests they may also significantly affect ecosystem carbon dynamics—highlighting the need for further investigation.



Invasive Wattle plantations surround a reservoir in the Nilgiris, Tamil Nadu. | Photo : Anand Osuri

Furthermore, IAPS, particularly trees, can strongly influence hydrologic dynamics by replacing native vegetation over large spatial scales, especially in grasslands, riparian zones, and catchments¹¹⁶. IAPS like *A. mearnsii* in the Nilgiris increase evapotranspiration, reduce soil moisture and reservoir storage, and heighten flood risks during extreme rainfall^{117,118}.

High water use by invasive trees in riparian zones (Fig. 2) can lower dry-season base flows sustained by groundwater^{119–121}, impacting native aquatic plants and potentially facilitating the spread of other IAPS through altered biogeochemical processes^{122–124}. For instance, terrestrial nitrogen-fixing IAPS can alter the nitrogen cycle and budget in catchment soils and riparian zones, leading to increased nitrogen export in streams¹⁰⁰. However, such feedback patterns between terrestrial and aquatic IAPS remain understudied in India.

In freshwater ecosystems, invasive benthic and floating IAPS reduce light penetration, alter water temperatures, and limit oxygen availability, promoting eutrophic conditions. Their high biomass provides food for IAS fish, which in turn affects nutrient cycling and increases turbidity. Similarly, invasive molluscs alter nutrient cycles through grazing and bio-erosion²⁴.

While some aquatic IAPS contribute to carbon sequestration and pollutant absorption^{125,126}, these potential benefits are often outweighed by their negative impacts, such as sedimentation and hypoxia in wetlands. For example, *E. crassipes* (water hyacinth) obstructs flow in irrigation canals—reducing discharge by 40–95%¹²⁷—and lowers open water surface area due to its high transpiration rates.

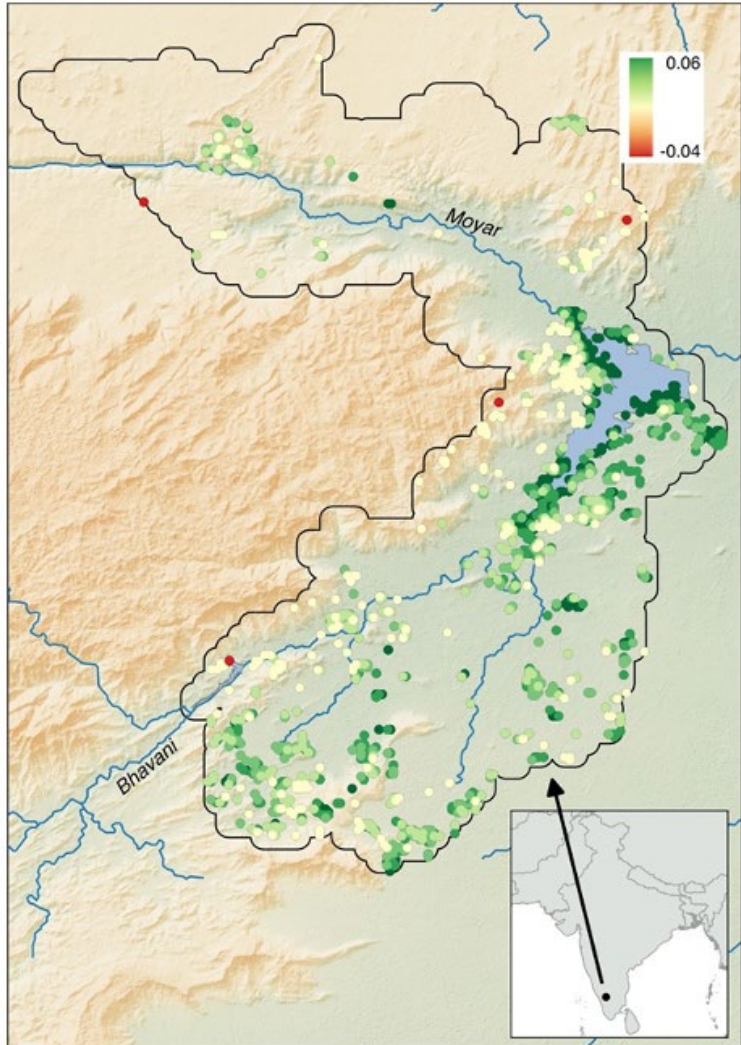


Figure 2. A Map of greening (greener shades) and browning trends in the Moyar–Bhavani Sagar riparian zone and reservoir shore, primarily associated with the proliferation of *Neltuma juliflora*.





4

Socio-Economic Impacts

4.1 | Economic Impacts of IAS in India

4.2 | Social and Cultural Impacts of IAS in India

4.2.1 | IAS Impacts On Cultural Relationships Between Local Communities and Their Landscapes

4.3 | IAS Impact on Traditional Practices and Knowledge

4.4 | IAS impacts on Human Health and Well-Being

4.1 | ECONOMIC IMPACTS

IAS have a complex impact on nature's material contributions to human livelihoods and food production in India, imposing significant economic costs while also offering some benefits as local communities adapt to their presence.

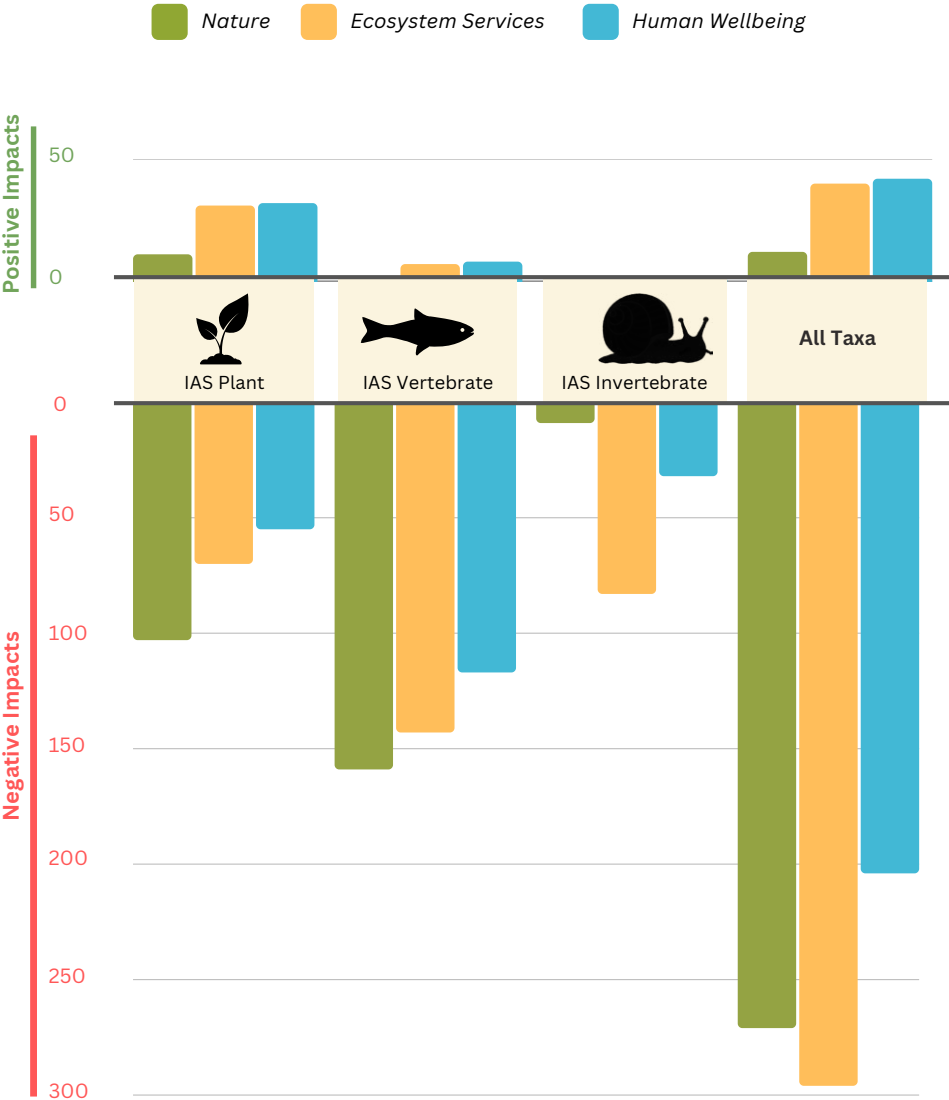
IAS affect livelihoods by disrupting the supply and exchange of key economic goods from natural ecosystems, limiting access to bioresources, reducing productivity in agriculture, plantations, horticulture, fisheries, and animal husbandry. They also impact the cultural and aesthetic value of landscapes and pose risks to human health^{128,129}. For instance, in districts like Mirzapur, Uttar Pradesh, invasive species such as *Ipomea carnea* have diminished soil fertility and reduced crop yields, directly threatening food security. In response, farmers are often left with difficult choices: either abandoning agricultural land or investing in expensive chemical interventions to manage the invasions¹³⁰.

The global economic cost of biological invasions from 1970–2017 is estimated at a minimum of \$1.288 trillion, with an annual mean of \$26.8 billion¹³¹. IAS-related costs in India between 1960–2020 are estimated at \$127.3–182.6 billion (₹8.3–11.9 trillion), though these figures are likely underestimates¹³² (Fig.3).

In agriculture alone, economic losses from crop weeds—both native and exotic—are estimated at over \$11 billion annually, with yield losses ranging from 13.8% in rice to over 35% in groundnut¹³³. These estimates often exclude biodiversity loss, human health impacts, and long-term ecological degradation (J.S. Mishra, Pers. Comm).

While global assessments often focus on monetary valuations, IAS impacts in India are more acutely felt as losses to livelihoods—especially among rural populations that depend directly on natural resources. These losses are compounded by extreme poverty levels, limited management resources, and insufficient preparedness to address IAS-driven challenges^{134,135}.

Documented positive and negative impacts by IAS taxa on nature, ecosystem services and human wellbeing in India* | Data sourced from Bacher et al. 2025 ²⁸



* In Terrestrial and Freshwater Ecosystems

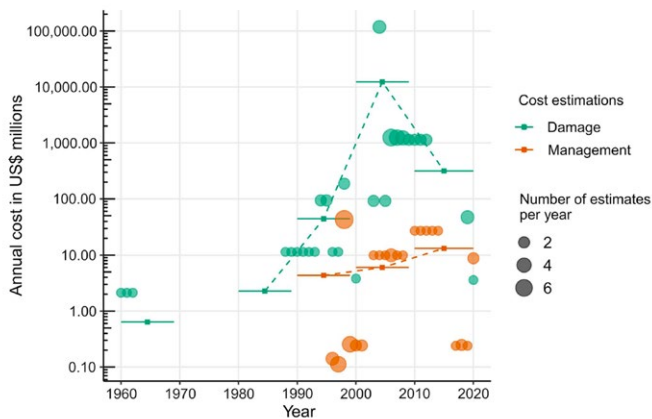
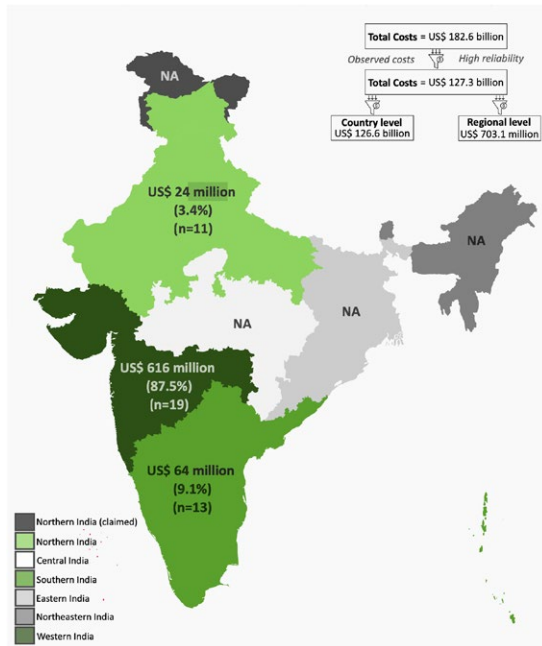


Figure 3. Regional distribution of reported economic costs from biological invasion in India. Percentages in parentheses indicate each region's share of total reported costs. Four regions are listed as NA due to a lack of cost entries, though this does not imply that costs were absent. Right: Temporal trends in damage and management costs from IAS in India. Bars represent 10-year averages; points indicate annual totals, scaled by the numbers of cost entries per year; dashed lines show the trends between bars. No data was available for 1970–1980. Note: Y-axis is presented on a $\log_{10}$ scale. | Figure reproduced from Bang et al. 2022¹³²

IAS pose a major threat to agriculture, nutritional security, and livelihoods in India, where over 50% of the population depends on farming—mostly small and medium farmers with land holdings <2 ha¹³⁶. IAS plants and insects reduce crop yield and quality by competing for resources, harbouring pests, disrupting irrigation, and increasing the cost of production^{17,137}. Managing *Parthenium* alone costs over ₹12,000 crore annually¹³⁸, with studies from other countries reporting yield losses of up to 50% in maize and 69–97% in sorghum^{139,140}. Similarly, the invasion of *Neltuma* across arable lands and water catchments in Tamil Nadu reduces agricultural productivity and increases water stress and siltation¹⁴¹. In agroforestry systems of Kerala, *M. micrantha* has reduced farm earnings by ₹4,000 per ha annually and decreased profits in teak plantations by over ₹6,000 per ha, often disproportionately affecting marginal and smallholder farmers¹⁴².

Meanwhile, IAS insects damage crops, prompting increased pesticide use, which harms agroecosystem and human health, while often failing to resolve the problem^{143–146}. They also indirectly impact crop production by affecting populations of beneficial insects such as pollinators and natural enemies of crop pests^{147–149}.

Negative impacts of IAS often extend beyond agriculture. For instance, IAS fish like suckermouth catfish reduce yields of commercially valuable Indian carps^{69,150}, while aquatic IAPS obstruct irrigation systems, reduce water availability, and impair transportation and hydroelectric generation^{125,151}. In some cases, communities have abandoned traditional livelihoods due to aquatic IAS invasions, as seen among fisherfolk in Wular Lake¹⁵¹. Despite the high economic costs, very few studies from India have addressed the impacts of aquatic invasions¹⁵² (Fig. 4).

While IAS have negatively impacted livelihoods, in some cases, local communities have adapted by finding productive uses for them as fuelwood, fodder, food, and value-added products. *Lantana*, for instance, contributes up to 46% of household income in some parts of South India through furniture-making and value-added product sales¹⁵³. Water hyacinth handicrafts in Assam generate an average annual net profit of ₹66,000 per 10-member unit¹⁵⁴. Similarly, *Neltuma* is valued by communities in Tamil Nadu and Gujarat as a source of high-quality charcoal¹⁵⁵ and class 'A' medicinal honey¹⁵⁶ (see also Box 3.2). It also meets 80–90% of the firewood requirement in some arid areas¹⁵⁷. *Azolla*, an aquatic IAPS, is used as poultry feed and bio-fertilizer¹⁵⁸. *Nymphaea mexicana* and *Hydrocharis dubia* are also used as a fodder by communities in Dal Lake, Kashmir¹⁵⁹.

Similarly, although IAS fish species displace native species, they now dominate local fisheries due to their year-round availability and affordability. Of the 26 IAS fish species assessed for this report, 23 were found to have commercial value, even though 20 also negatively impacted traditional fisheries.

Thus, IAS impacts on livelihoods are complex, often involving trade-offs between benefits and losses. Notably, these impacts are not evenly distributed across social strata, causing perceptions of their impacts to vary across different stakeholder groups (e.g., farmers, pastoralists, urban communities) and to shift over time, depending on livelihood dependence¹⁶⁰. Effective IAS management must therefore account for these dynamics in local perceptions and values¹⁶¹.

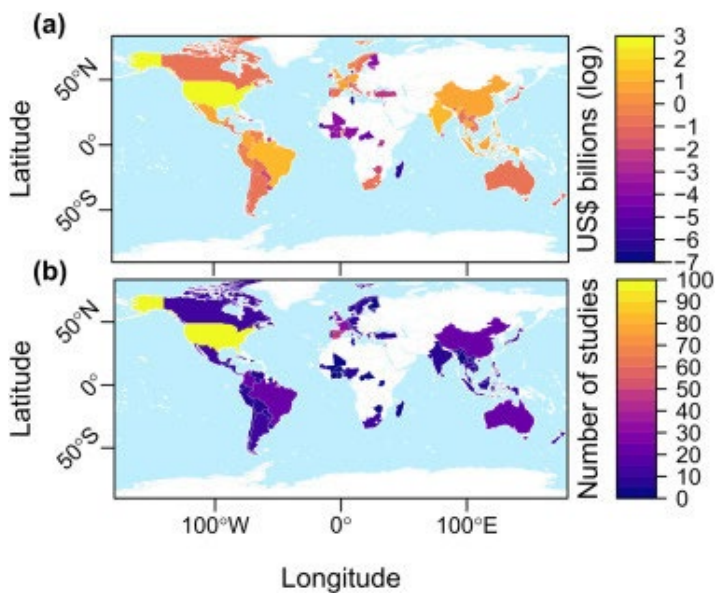
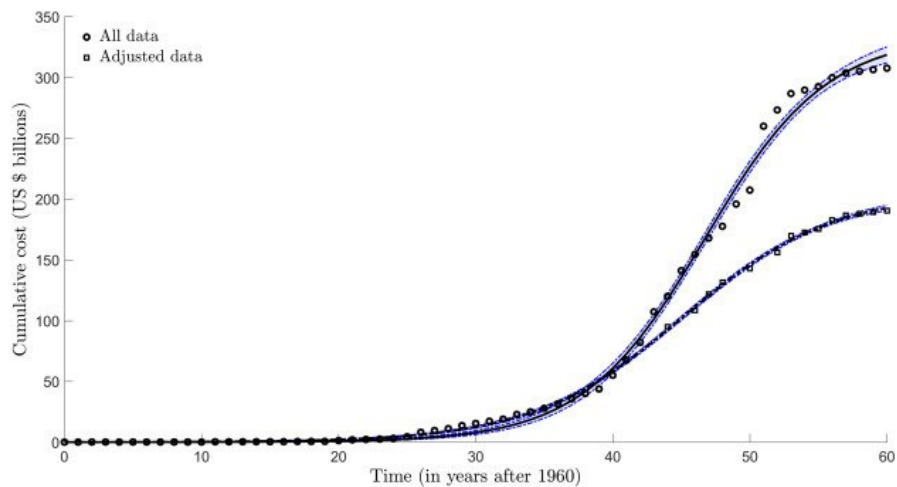


Figure 4: Rising economic cost of aquatic IAS globally (1960–2020). Left: Temporal trends Right: Global distribution of (a) total reported economic costs and (b) number of studies (i.e., unique documents) on aquatic IAS | Figure reproduced from Keller RP et al. ¹⁵¹.



Soligas in their landscape | Photo :Wikimedia Commons



Lantana crafts being made | Photo : The Shola Trust

4.2 | SOCIAL AND CULTURAL IMPACTS OF IAS

4.2.1 | IAS IMPACTS ON CULTURAL RELATIONSHIPS BETWEEN LOCAL COMMUNITIES AND THEIR LANDSCAPES

Invasive species can profoundly alter how communities relate to their landscapes. In southern India, dense *Lantana* thickets obstruct access to sacred sites and other culturally significant locations, disrupting the spiritual connections indigenous communities hold with their environment. These communities perceive invaded landscapes as “unkempt and dirty,” reflecting a perceived loss of cultural and aesthetic value^{79,162}. In the Nilgiris, *A. mearnsii* (wattle) has transformed the native shola-grassland landscape into darker, enclosed environments, weakening the cultural ties of Toda pastoralists with their surroundings, with many describing the wattle-invaded grasslands as dark and foreboding¹⁶³.

IAS also displace native plants used in traditional medicine, rituals, and daily life, contributing to the erosion of cultural knowledge systems¹³⁴. This loss of biodiversity further jeopardizes food security, as rural populations must adapt to degraded ecosystems that can no longer sustain traditional agriculture and subsistence farming^{2,164}. These shifts disproportionately affect women, who must often travel farther to collect firewood, water, and wild foods as ecosystems degrade, increasing their daily workloads and reducing their time to engage with other economic opportunities¹³⁴.

4.3 | IAS IMPACT ON TRADITIONAL PRACTICES AND KNOWLEDGE

In various regions of India, traditional livelihoods such as agriculture and livestock grazing are increasingly threatened by the spread of IAS. In the Himalayas, for example, IAS outcompete indigenous vegetation like Banj oak (*Quercus leucotrichophora*) and Chir pine (*Pinus roxburghii*), which have long been used as livestock fodder and fuel respectively, by local communities. As a result, many households experience a decline in forest-based livelihoods, often forcing people to seek alternative income sources or migrate for work¹⁶⁵.

Traditional knowledge systems, built on generations of interaction with native ecosystems, are also being eroded by the spread of IAS. Indigenous knowledge about the use of native plants for medicine, food, and cultural purposes is deeply embedded in rural communities. However, IAS displace these native species, diminishing the availability of culturally and medicinally significant flora¹⁶⁵. In the Kailash Sacred Landscape (KSL), for instance, local communities have observed the decline of medicinal plants due to the spread of invasive species like *Lantana*, which have no recognized cultural or medicinal value.

This loss of indigenous knowledge impacts livelihoods and diminishes cultural heritage. Younger generations, in particular, are less likely to inherit traditional knowledge about native species when these are replaced by non-native species that do not serve the same ecological or cultural functions. The displacement of species used in cultural rituals, traditional medicine, and food systems weakens the cultural identity of affected communities¹³⁰.

Although many communities recognise the threats posed by IAS, they lack the means to respond. In the Chandak-Aunla Ghat region (a watershed of the KSL), for instance, local communities acknowledge the damage caused by IAS but are constrained by limited technical capacity and financial resources. Consequently, they frequently depend on external interventions, which can further erode traditional ecosystem management practices¹⁶⁵.

Despite the challenges, some communities have adapted by finding new uses for invasive species. For example, *A. adenophora* is used in certain areas for bedding materials or as a blood clotting agent, illustrating how traditional knowledge systems can evolve to accommodate environmental changes¹⁶⁵. However, such adaptations rarely compensate for the broader ecological and economic losses caused by IAS, and the negative impacts generally outweigh the benefits.



Ipomea carnea | Photo : Wikimedia Commons

4.4 | NEGATIVE IAS IMPACTS ON HUMAN HEALTH AND WELL-BEING

IAS pose several health risks to humans, including disease transmission, allergic reactions, and physical injuries, and indirect impacts on livelihoods¹⁶⁶. In India, *Lantana* is known to cause contact dermatitis¹⁶⁷, while *Parthenium* pollen triggers bronchial congestion¹⁶⁸. Certain invasive molluscs, such as *Physella acuta*, *Lissachatina fulica*, and *Planorbella duryi*, coexist with species that serve as intermediate hosts for certain diseases in humans and livestock. Additionally, *P. acuta* can host trematodes responsible for ‘swimmer's itch’ in humans¹⁶⁹. Some invasive fish, such as the alligator gar (*Atractosteus spatula*), may cause physical injuries to humans due to their size or aggressive behaviour.

Indirectly, IAS can increase injury risks by degrading landscapes. Dense *Lantana* thickets obstruct visibility and access to paths, often forcing herders to navigate hazardous terrain, leading to injuries for both humans and animals^{79,162,170,171}. Similarly, in the Rann of Kutch, Neltuma invasion has disrupted pastoral routes and access to water, increasing conflict over grazing lands¹⁷². Furthermore, IAPS have also been reported to affect human-wildlife coexistence in various parts of India. For instance, the invasion of *Mimosa diplotricha* into one-horned rhinoceros’ habitats may be contributing to increased crop depredation and negative human-rhino interactions in Kaziranga national park in Assam¹⁷³.



Below | Neltuma juliflora, seen here as the green vegetation, has extensively encroached upon the communal grazing lands of the Banni grasslands, posing significant ecological and livelihood challenges. Reproduced from Perinchery, A. The complex life of Banni¹⁷³.



5

Case Studies of Invasive Alien Species in India

5.1 | *Lantana camara*: Ecological Impacts and Control Measures

5.1.1 | Genetic Underpinnings

5.1.2 | Ecological Impacts

5.1.3 | Control and Management

5.1.4 | Socio-ecological and cultural impacts

5.1.5 | Alternative livelihoods from *Lantana*

5.2 | *Neltuma juliflora*: Spread and management strategies

5.2.1 | Introduction

5.3 | Invasive Insects in Agroecosystems

5.4 | Impacts of Invasive Alien Aquatic Species on India's Freshwater and Marine Ecosystems

5.1. LANTANA CAMARA: ECOLOGICAL IMPACTS AND CONTROL MEASURES

Lantana, a woody shrub native to South America, is listed among the world's top 10 worst invasive plants^{175,176}. Introduced to India in the 1800s as a hedge and ornamental plant, various *Lantana* species have since hybridised into forms now referred to as *Lantana camara* (sensu lato)^{153,177,178}. Today, it is one of the most widespread invasive species in India, colonising both forest and agricultural landscapes¹⁷⁹.

Using a combination of field data and ecological niche models like MaxEnt, it was estimated that *Lantana* now occupies over 154,800 sq. km of forested land and threatens more than 3 million km²—nearly 44% of India's total forest area¹⁸.

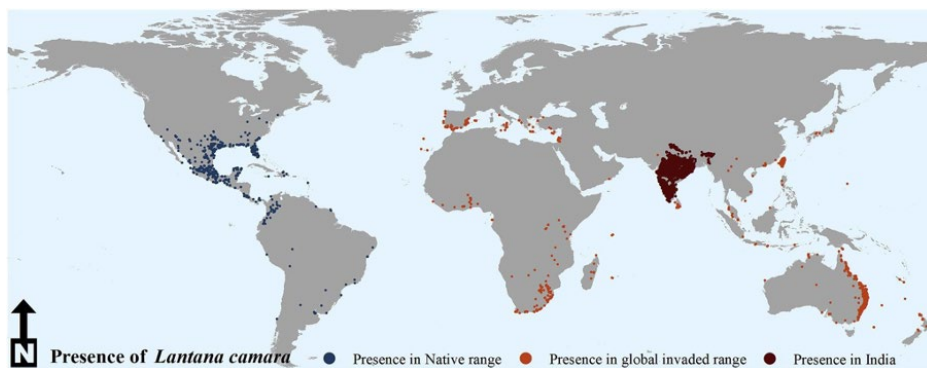


Fig. 1. *Lantana camara* presence locations in its native range in tropical America (blue) and invaded regions (orange: GBIF data; maroon: India-specific field sampling data)¹⁸.

5.1.1 | GENETIC UNDERPINNINGS

Lantana has spread extensively across India due to multiple introductions, gene flow between populations, and rapid adaptation to diverse habitats. However, its genetic structure remains poorly understood, and there is emerging evidence to suggest that it may represent a complex of hybrid species^{153,178,181}. Unfortunately, these uncertainties limit the effectiveness of control strategies. Therefore, targeted investment in genetic and ecological research is critical to inform more precise, region-specific *Lantana* management policies.



5.1.2 | ECOLOGICAL IMPACTS

Lantana invasion causes biodiversity loss, alters species composition, affects soil properties, and hampers forest recovery across multiple forest landscapes in India¹⁸², for instance:

- In Mudumalai, *Lantana* invasion reduces the frequency of mammal-dispersed species, such as *Phyllanthus emblica* and *Kydia calycina*, and slows the growth rates of native species, effects likely influenced by rainfall seasonality⁸⁰. Similar declines in native species richness and tree regeneration have been observed in Bandipur^{40,183}, Achanakmar¹⁸⁴, the Vindhya³³, and Biligiriranga (BRT) Hills¹⁸⁵.
- In Kanha, *Lantana* invasion has reduced species diversity, altered understory plant composition, and changed soil chemistry. Native species like *Bauhinia malabarica* and *Asparagus racemosus* were absent in invaded areas, which instead had more *Flemingia sp.*¹⁸⁶.
- In the Vindhya, *Lantana* leaf litter, characterized by low lignin and high nitrogen content, decomposes rapidly, altering soil nutrient dynamics and contributing to the local extinction of several native herbs³³.
- In the degraded forests of the Himalayan foothills, *Lantana* also affects carbon budgets through both direct and indirect pathways^{105,107}.
- At BRT Hills, *Lantana* has significantly reduced tree sapling density, limiting native tree seedlings from recruiting into larger size classes³⁵.

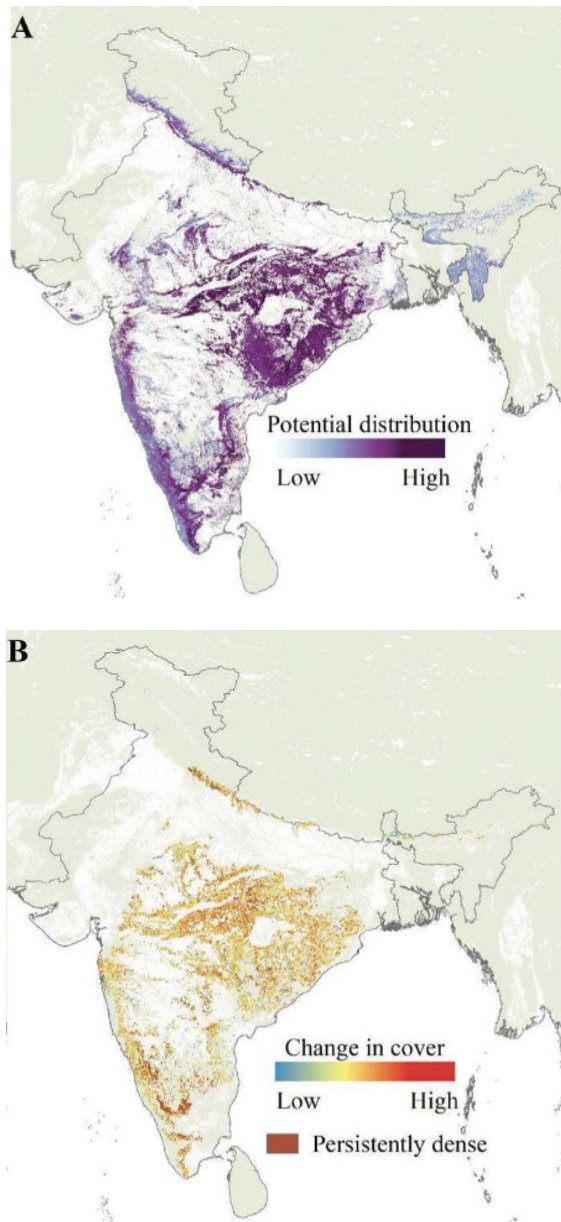


Fig. 2. Potential distribution (A) and rate of invasion (B) of *Lantana camara* in India | Figure reproduced from Bhagwat et al.¹⁷⁹

5.1.3 | CONTROL AND MANAGEMENT

Lantana management costs an estimated \$18,700 per km² in India¹⁸⁷. Most efforts rely on mechanical removal, especially uprooting of the whole plant, though this has shown limited long-term success¹⁷⁹. Newer techniques that target the meristematic (growth) tissue have proven more effective¹⁸⁷.

Lantana colonises through various recruitment strategies, including seed dispersal by birds and mammals^{188,189}, emergence from the soil seed bank after disturbance¹⁸⁷, and regrowth from persistent root stock¹⁹⁰. Therefore, effective management must involve habitat prioritisation, phased removal, and rapid ecological restoration to prevent re-establishment^{187,190}.

Grasslands, too, are increasingly encroached upon by *Lantana* and other woody invasives and must be prioritised alongside forests in management efforts¹⁹⁰. Fire plays a complex role in *Lantana* dynamics. Some evidence links its spread to the suppression of traditional cool-season fires, while others suggest it thrives under high-intensity dry-season fires that reach the canopy¹¹¹. However, more research is needed to understand how fire regimes influence invasive spread and to guide landscape-level fire and invasion management.



5.1.4 | SOCIO-ECOLOGICAL AND CULTURAL IMPACTS

Indigenous and forest-dependent communities perceive *Lantana* as detrimental to both humans and animals¹⁶². Its spread reduces access to non-timber forest products, forcing people—particularly women—to walk longer distances and invest more time in resource collection. Furthermore, shrinking grazing grounds have changed cattle herding practices, with herders and livestock having to increasingly navigate dangerous terrain to avoid dense thickets, often resulting in injury¹⁷⁰.

5.1.5 | ALTERNATIVE LIVELIHOODS FROM LANTANA

Some initiatives have sought to turn *Lantana* into a livelihood opportunity. Notably, The Real Elephant Collective (TREC), engages local communities and artisans in the Nilgiri Biosphere to harvest *Lantana* and create life-sized elephant replicas that promote awareness of human-wildlife coexistence. Emerging applications like biochar production from *Lantana* are also being explored for carbon storage and soil fertilisation.

Right and Below | Local communities engaged to craft Lantana elephants by the The Real Elephant Collective | Photo : The Real Elephant Collective

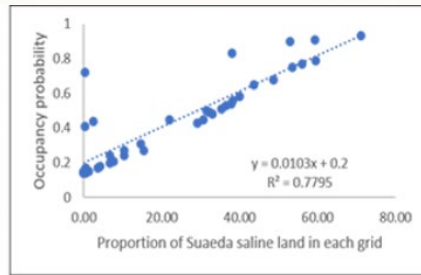


5.2 | *NELTUMA JULIFLORA*: SPREAD AND MANAGEMENT STRATEGIES

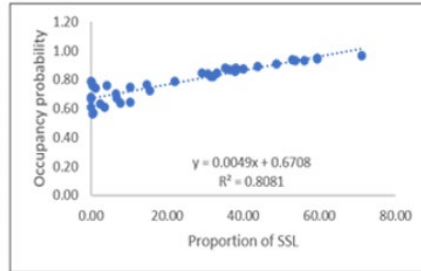
5.2.1 | INTRODUCTION

Neltuma (formerly known as *Prosopis juliflora*) is a small tree or shrub native to Mexico, South America, and the Caribbean. It is considered one among the world's most invasive plant species, especially in Africa, Asia, and Australia¹⁶⁰. In India, it is widespread across arid zones and is valued for its wood, resin, and pods. However, despite some benefits, *Neltuma* invasion has caused significant ecological harm, including biodiversity loss and ecosystem disruption, and efforts to remove it have been largely unsuccessful.

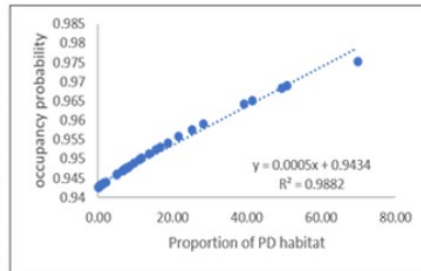




Suaeda saline land
(Native habitat)

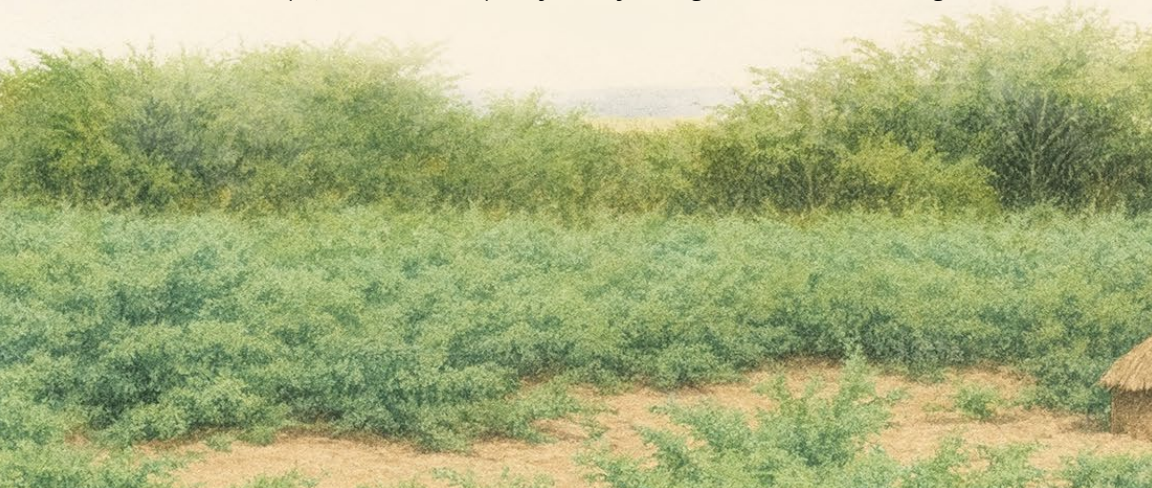


Suaeda saline land
(Native habitat)



Prosopis cover
(Invaded habitat)

Figure 1. Habitat relationships of the desert fox (*Vulpes pussilla*; top), Indian fox (*Vulpes bengalensis*; middle), and Golden jackal (*Canis aureus*; bottom) across the Banni landscape, based on occupancy surveys using direct and indirect signs.



Managing *Neltuma* is especially challenging in human-dominated landscapes across several Indian states, where its ecological impacts often conflict with its socio-economic benefits. For instance, in the Banni grasslands of Kutch, *Neltuma* has both supported and disrupted local livelihoods². On one hand, it provides benefits such as shade, timber, fuelwood, and seasonal income through charcoal production and the collection of pods, resin, and honey—especially valuable during drought years. It also acts as a windbreak and supports household construction needs. However, native livestock breeds show varying responses to *Neltuma*. While the Banni buffalo, bred by the Maldhari community, is relatively tolerant and can consume the pods, the indigenous Kankrej cow is more sensitive to them. This has contributed to shifts in herd composition, alongside broader factors such as agricultural mechanization reducing demand for Kankrej bulls, and dairy intensification favouring the high milk-yielding Banni buffalo.

However, the negative consequences of *Neltuma* invasion are significant. It now occupies about 60% of former grassland areas (Niphadkar et al., unpublished), reducing access to traditional grazing routes, altering landcover, impacting fodder availability and diminishing incomes from pastoralism². This has degraded habitat quality for native flora and fauna, increased groundwater salinity, and reduced fodder availability for both wild herbivores and livestock¹⁹¹. *Neltuma* also poses a risk to livestock health through injuries and toxic effects from pod consumption (e.g., Kankrej cows). The expansion of *Neltuma* thickets reduces suitable habitat for the Indian desert fox, a habitat specialist. In contrast, generalists like the Indian jackal benefit from the altered habitat and show increased occupancy. The elevated presence of jackals may further suppress desert fox populations through competitive exclusion or intra-guild predation^{192,193}. Additionally, *Neltuma* colonization alters rodent communities, increasing populations of pest species and disrupting local food webs^{193,194}. Furthermore, *Neltuma* invasion has contributed to increased land privatization, undermining traditional common property regimes critical to pastoralist cultures.

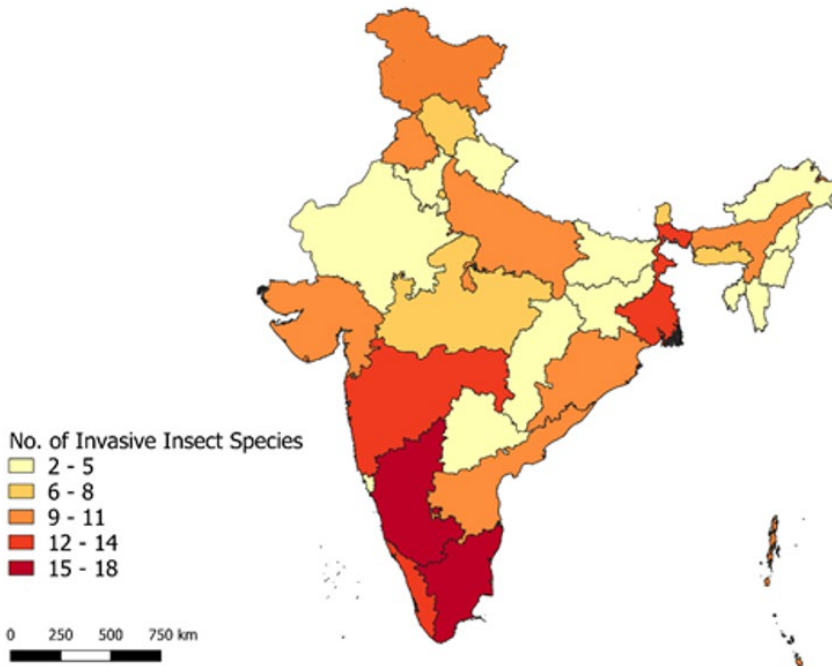


Figure 2. Neltuma-based charcoal production has become a critical livelihood strategy in the drought-prone Banni region, with 60–70% of residents now dependent on this economy. Among 147 respondents, 70% supported a mixed landscape of Neltuma and native grasses to cope with climatic variability.

Despite the loss of grassland and changes in faunal communities (Fig 1), local adaptations to *Neltuma* have helped decrease income inequality and improve resilience to economic shocks in the Banni region (Fig 2). These trade-offs underscore the complexity of *Neltuma* management. Its spread has reshaped not only the region's ecology but also the livelihoods of Banni's people—highlighting the importance of developing future management strategies in close partnership with local communities.

5.3 | INVASIVE ALIEN INSECTS IN AGROSYSTEMS

India has reported 21 invasive alien insects¹¹⁵, most of which affect agroecosystems across the country by damaging crops such as cotton, maize, fruits, and vegetables. States including Karnataka, Tamil Nadu, Kerala, Maharashtra, and West Bengal report the highest incidences (Fig. 1; Centre for Agriculture and Bioscience International (CABI, 2021)). Beyond direct yield losses, invasive insects can also disrupt crop production by affecting beneficial insects such as pollinators. Infestations frequently prompt indiscriminate insecticide use, which not only fails to address the issue effectively but also damages beneficial insect populations, builds toxic residues in crops, and poses health risks to both farmers and consumers.



*Figure 1. Number of invasive alien insect species recorded in agroecosystems across Indian states¹⁹⁵.
Disclaimer: this map is for illustrative purposes only and does not imply the expression of any opinion on the part of the Biodiversity Collaborative concerning the delimitation political boundaries*



*Damage to maize by the fall armyworm (*Spodoptera frugiperda*) | Photo : Wikimedia Commons*



Papaya mealybug (*Paracoccus marginatus*)

An invasive mealybug, native to Central America and known to feed on multiple crops, invaded farms in Coimbatore, Tamil Nadu in 2008. The pest infested around 100 different host plants posing a great threat to papaya cultivation in India.

Tomato pinworm (*Tuta absoluta*)

The South American tomato pinworm, *Tuta absoluta* was first reported infesting tomato fields in Pune, Maharashtra and subsequently in other districts, viz. Ahmednagar, Dhule, Jalgaon, Nashik and Satara during November 2014¹⁹⁶. It can cause 100% damage to the crop under favourable conditions¹⁹⁷ and has spread to all the tomato growing regions in India.



Rugose spiralling whitefly
(*Aleurodicus rugioperculatus*)

A highly invasive polyphagous sap sucking insect, was first reported in India from coconut growing regions of Pollachi, Tamil Nadu in 2016¹⁹⁸. It is estimated to have caused damage to 1,19,764 ha of agricultural land across India, and is currently distributed in Andhra Pradesh¹⁹⁹, Assam, Goa, Gujarat, Kerala²⁰⁰, Maharashtra, Telangana, and West Bengal²⁰¹.

The fall armyworm (*Spodoptera frugiperda*)

First detected in maize fields in Karnataka²⁰², rapidly spread to Maharashtra, Gujarat, Tamil Nadu, Kerala, Assam, Arunachal Pradesh, Mizoram, Rajasthan, and Odisha.





The coconut mite (*Aceria guerreronis*)

Affected almost all major coconut producing states by 2012²⁰³, leading to an estimated 20–30% loss in crop yield²⁰⁴.

The Red Palm Weevil
(*Rhynchophorus ferrugineus*)

A major pest of palms and sugar cane, has caused severe damage in different palm species across Karnataka, Kerala, Goa, Punjab and has even spread to Meghalaya²⁰⁵.



The cotton mealybug (*Phenacoccus solenopsis*)

Has caused up to 40% losses in cotton production. In addition, the added cost of pesticide made cotton cultivation almost unaffordable for small landholders²⁰⁶.

The Cassava mealybug (*P. manihoti*)

One of the most destructive pests of cassava, was accidentally introduced and documented in Thrissur, Kerala in April 2020²⁰⁷. It has spread to cassava growing districts of Tamil Nadu, damaging 7.0–86.7% of plants²⁰⁸.



CASE STUDY

5.4 IMPACTS OF INVASIVE ALIEN AQUATIC SPECIES ON INDIA'S FRESHWATER AND MARINE ECOSYSTEMS

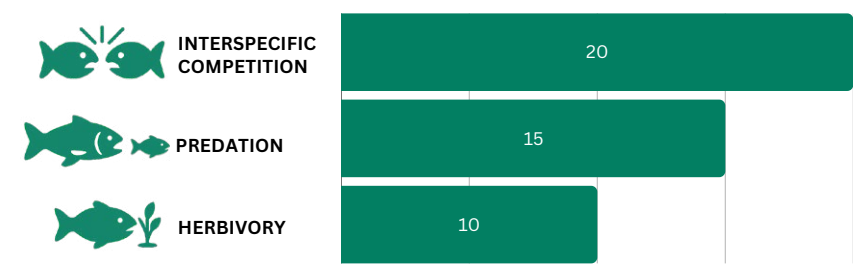
In India's freshwater, estuarine, and marine ecosystems, over 200 IAPS, over 56 invasive alien fish species, 5 species of molluscs, 3–4 turtle species, and lower invertebrate taxa such as flatworms, annelids, cladocerans, echinoderms, cnidarians, corals (1 species), and even red algae and bacteria have been reported. While hundreds of introduced species have been documented, not all are currently invasive, though many hold the potential to become so in the future.

Key global and regional databases, including CABI, India Biodiversity Portal, FishBase, and the Global Register of Introduced and Invasive Species (GRIIS), provide information on introduced and potentially invasive fish species in India.



Water hyacinth (Eichhornia crassipes) is the most widespread aquatic invasive plant across India's wetlands. Photo: Wikimedia Commons.

Globally, the economic cost of aquatic IAS is estimated at around \$345 billion, with India recording the third-highest national cost, after the USA and Brazil. Despite some isolated studies and reports highlighting invasions and related threats, India currently lacks a coordinated, nationwide system for monitoring and managing aquatic IAS.



How IAS fish impact native aquatic fauna. Based on a review of 26 IAS fish species using the IUCN EICAT framework.



Tilapia, native to Africa, have become the mainstay of fisheries in rivers and wetlands across India | Photo: Nachiket Kelkar.

PATHWAYS OF INTRODUCTIONS AND INVASION

The major intended and accidental pathways of spread of invasive species are through systematic introductions for freshwater aquaculture for food (e.g., tilapia), aquarium trade in ornamental plants and fishes, deliberate introductions (e.g., in botanical gardens), pollution mitigation (e.g., water hyacinth), disease control (e.g., malaria control by guppy fishes), shipping (e.g., ballast water leading to mollusc introductions), and industrial culture (e.g., *Kappaphycus* algae for cola production).

Fish introductions into India began as early as the 1870s, with new species added nearly every decade. Despite legal restrictions, illegal and accidental introductions continue due to inadequate quarantine protocols and weak ecosystem monitoring.



Brown trout, native to Europe, were introduced to high-altitude streams and rivers of the Himalayas and the Western Ghats for sport fishing. | Photo: Wikimedia commons.

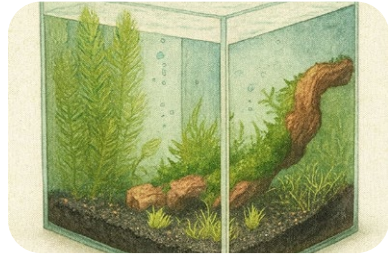
INVASIVE ALIEN FRESHWATER FISH SPECIES

A total of 626 non-native fish species has been reported in India, of which 16 have been clearly identified as invasive²⁰⁹. Estimates of exotic or non-native fish species vary substantially across global and national databases; here, we are citing the highest reported numbers. Similarly, information on the number of invasive species and the extent of their impact differs across studies. The primary pathways of introduction are:



AQUACULTURE

- species introduced as food fish (e.g., Nile tilapia, African catfish)



AQUARIUM TRADE

- ornamental species released into the wild (e.g., Amazonian suckermouth catfishes)



SPORT AND RECREATIONAL FISHING

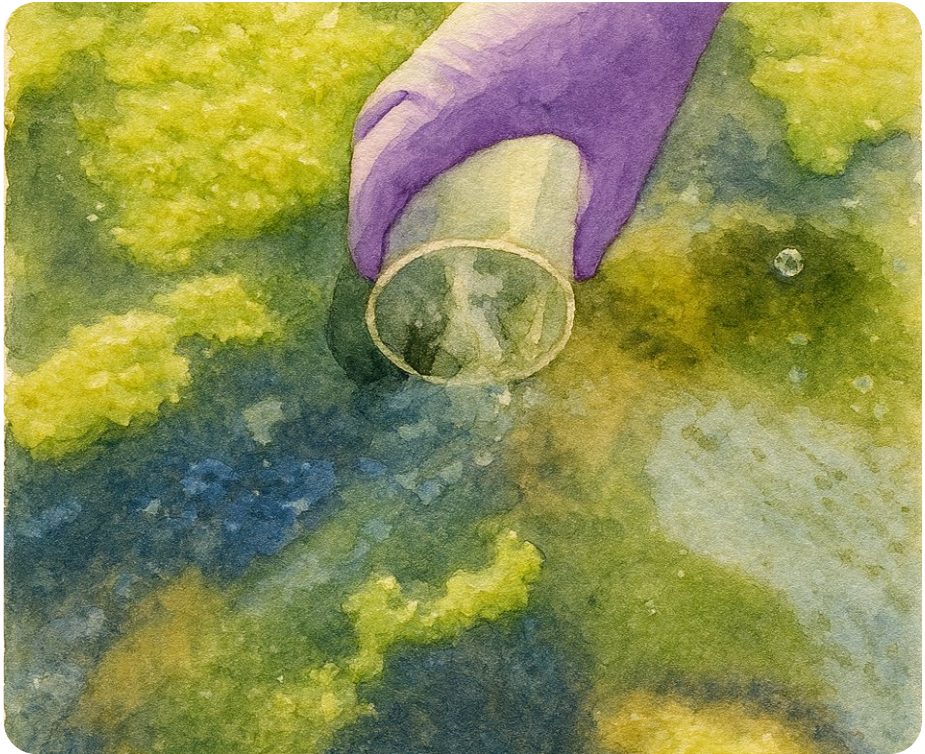
- game species introductions (e.g., trout, mahseer)



LARVICIDAL USE

- species like guppies introduced for mosquito control

Additionally, some fish native to parts of India, such as Indian major carps, have been translocated nationwide for aquaculture. Others, like the red-bellied pacu, have entered through both aquaculture and aquarium trade. The Western Ghats, peninsular South India, and eastern and northeastern states are hotspots for non-native fish introductions, followed by the Himalayan and sub-Himalayan regions, and finally, Central and Western India. Invasive species like Nile tilapia (*Oreochromis nilotica*) and common carp (*Cyprinus carpio*) are reported to aggressively establish themselves by outcompeting native fish species and inducing hypoxic conditions in aquatic systems. The African catfish is known to be a voracious predator of native fish, invertebrates, birds, and even small mammals. Another notable emerging threat is the Amazonian suckermouth catfish (*Pterygoplichthys* sp.), whose burrowing habits not only degrades aquatic habitats but also pose risks to urban infrastructure



Hypoxic conditions in an aquatic system

INVASIVE ALIEN AQUATIC PLANT SPECIES

Freshwater ecosystems in India have been significantly impacted by invasive alien aquatic plants, notably *Eichornia crassipes*, *Salvinia molesta*, *Pistia stratiotes*, and *Alternanthera philoxeroides*. These species cause profound ecological disruptions and impose major socio-economic costs, affecting livelihoods, infrastructure, and ecosystem health. A state-wise assessment found that about 2.4% of India's naturalized alien flora is aquatic²¹⁰. The Kashmir Himalaya stands out as a hotspot for aquatic plant introductions, with around 129 alien plant species posing significant threats to wetland ecosystems and the communities that depend on them.



Pistia stratiotes, native to East Africa, is an emerging invasive weed in India's waterscapes | Photo: Wikimedia commons

INVASIVE FRESHWATER TURTLES

The red-eared slider (*Trachemys scripta elegans*), a semi-aquatic turtle native to the Southern USA and northern Mexico, has been increasingly reported across several water bodies in India—including Maharashtra, Gujarat, Delhi, Assam, and even remote parts of Mizoram—largely due to releases from the aquarium trade.



Red-eared slider turtles, native to southern USA and northern Mexico, in a wetland in Ahmedabad. | Photo: Wikimedia commons

These turtles are highly aggressive, outcompeting native turtles for food and basking space, while also posing disease transmission risks. Their early maturity and high fecundity make them successful invaders. More recently, juvenile Chinese softshell turtles (*Pelodiscus sinensis*) have appeared in pet shops in metro cities and have even been reported from the Chambal River, posing risks to the highly endangered native turtle species in this critical habitat.

5.5 | CAUSES AND IMPACTS OF AQUATIC INVASIONS

Aquatic invasions in India are driven by the same factors that threaten native species—habitat alteration, infrastructure expansion, and species introductions. India is the second largest dam-building nation in the world, dependent heavily on surface water infrastructure for irrigation, power, industrial supply, and energy generation, and is also the second largest producer of freshwater aquaculture fish in the world, both of which have contributed to the spread of invasive species. Several introduced food fish species, including African catfish and tilapia (*Oreochromis spp.*), have become invasive in reservoirs and wetlands. These species alter ecosystems through intense predation or by increasing water turbidity via detritus processing.



African catfish in an Indian reservoir | Photo: getarchive.net

Hydrological changes, such as damming and flow regulation, create conditions that mimic the native habitats of invasive species—e.g., deep, cool, and vegetation-rich oligotrophic waters that favour species like common carp. In areas like the Gangetic plains, where invasive fish dominate, fisher communities now depend on them for income and food security, complicating efforts to manage or replace them.

Below | The degradation of rivers and wetlands has promoted ecosystem invasions | Photo: Wikimedia commons.



Similarly, declining water quality in the rivers and wetlands has facilitated invasions by exotic fishes and plants. For instance, the heavily polluted and regulated Yamuna River in Uttar Pradesh hosts the highest number of invasive species in the Gangetic plains. Large-scale projects, such as river interlinking, could exacerbate these invasions. In contrast, less hydrologically modified rivers in the central Western Ghats report fewer instances of invasive fish species. Continued unregulated stocking of exotic fish and introductions via the aquarium trade remain key pathways. This underlines the urgent need for improved monitoring, restoration, and interdisciplinary research to safeguard India's freshwater ecosystems.





6

Management and Control Strategies

6.1 | Early Detection and Rapid Response

6.1.1 | Importance of early intervention

6.1.2 | Tools and techniques for IAS detection

6.2 | Prevention

6.2.1 | Measures to prevent introduction

6.2.2 | Quarantine and biosecurity measure

6.3 | Eradication, Containment, and Control

6.3.1 | Need for Integration of Spatial and Molecular Technology for IAS Surveillance and Management

6.3.2 | Integrated Pest Management (IPM) Approaches

6.3.3 | Facilitation of Classical Biological Control of IAS in Agroecosystems Would Enable a More Rapid and Effective Response to Emerging Invasive Plant and Insect Threats

6.3.4 | Managing Trade-Offs between IAS Impact

6.3.5 | Importance of Ecosystem-Based Approaches to Habitat Management

6.3.6 | Need for Ecosystem Restoration

6.3.7 | Consideration Of Emerging Ecological Perspectives

6.4 | Knowledge Gaps

6.4.1 | Need For An Open National Database On IAS

6.4.2 | Lack of Research on Certain Invasive Species and Ecosystems

6.4.3 | Studies on the Human Dimensions of Biological Invasions

6.4.4 | Standardized Research Methodologies to Evaluate Trade-Offs in Impacts

6.4.5 | Long Term Monitoring and Multispecies Studies

6.4.6 | The Interaction Between IAS and Climate Change

The IPBES Report on IAS and their control (2023) outlines these context-specific management options to prevent and mitigate the negative impacts of IAS:

- **When a species is absent:** Prevention of entry is the most cost-effective and efficient strategy. This includes managing introduction pathways through import controls and biosecurity regulations. It is applicable across ecosystems and remains the only feasible approach for managing invasions in marine environments.
- **During the establishment phase:** If prevention fails, management efforts should focus on surveillance and preparedness, including early detection, rapid response, and eradication measures. Eradication using physical and chemical methods can be an effective strategy when the IAS population is small and slow-spreading, especially on islands. However, its success depends on sustained surveillance and the complete removal of all individuals. Most successful vertebrate eradications have been reported from islands.
- **When a species has spread:** If eradication is no longer feasible, IAS should be managed through containment or control. For instance, physical and mechanical control, including pulling, cutting, and manual removal, is widely practiced by farmers and plantation workers in India but is often unsustainable due to the need for repeated interventions. Chemical control, involving pesticides and herbicides, is also common and locally effective, but its broader use is constrained by short-term efficacy, non-target effects, and environmental concerns
- **When the species is widespread:** At this stage, ecosystem-based approaches involving adaptive management using integrated methods and site restoration become necessary.

Species- and site-based methods have shown success and cost-effectiveness, particularly in terrestrial and enclosed freshwater ecosystems²¹¹.

6.1 | EARLY DETECTION AND RAPID RESPONSE

Early Detection and Rapid Response (EDRR) is key to stopping IAS before they establish, spread or take hold in new areas. India currently lacks a comprehensive surveillance system to track and manage IAS. In its absence, monitoring key entry points and conducting regular presence-absence surveys can serve as early warning systems. While early detection helps assess invasion risks, a rapid response system is equally important to contain and manage outbreaks. However, an effective response requires a national-level database that systematically tracks IAS occurrences, their spread across ecosystems, and past management efforts, both attempted and successful. India has no successful cases of early detection and management of any IAS so far.

6.1.1 | IMPORTANCE OF EARLY INTERVENTION

Effective early intervention requires tracking introduction pathways, monitoring both potential and known IAS, enforcing border surveillance, implementing strict regulations, and rapid response measures to contain threats. These efforts are especially critical in marine and freshwater ecosystems, such as rivers, where IAS can spread rapidly. Although India is a signatory to the Convention on Biological Diversity (CBD) and the Cartagena Protocol on Biosafety, it lacks structured early warning systems and standardized IAS surveillance and tracking mechanisms. In contrast, many countries have nationwide documentation programs for early observations of IAS. One example is the PlantwisePlus programme, implemented in parts of Africa, Asia, and Latin America, which assists smallholder farmers identify pests and crop damage, contributing to early detection of IAS outbreaks²¹².

Beyond early detection, long-term monitoring is also essential for detecting re-introduction, particularly when previously eradicated species reappear. This requires comprehensive national IAS databases, digital repositories, or atlases to support border management and control efforts. While some ecosystems in India, such as freshwater systems, have species databases categorized along the introduction-invasion continuum, such records are largely absent for most other ecosystems²¹³.

6.1.2 | TOOLS AND TECHNIQUES FOR IAS DETECTION

A range of advanced tools and technologies are now available for early IAS detection and management. For instance, environmental DNA (eDNA) helps identify species in water and soil, while remote sensing with satellite imagery and aerial photography utilizing unmanned aerial vehicles (UAVs) enables large-scale mapping. Predictive models, such as niche modelling (see Section 4.3A), help forecast potential IAS spread. Additionally, citizen science initiatives aid early detection through crowd-sourced data.

eDNA

eDNA is a powerful, non-invasive tool for detecting and mapping IAS across large extents of aquatic and terrestrial ecosystems^{214,215}. It works by amplifying genetic material from environmental samples such as soil, water, feathers, leaves, scent marks, pollen, or eggshells^{216,217}. With advancements in molecular techniques such as RT-PCR (reverse transcription polymerase chain reaction), qPCR (qualitative PCR), ddPCR (droplet digital PCR), and high-throughput sequencing, researchers can now detect IAS from even trace amounts of eDNA^{218–220}.

Notably, eDNA monitoring has been particularly effective in lentic and lotic water bodies, enabling early IAS detection without harming native fish populations^{220–223}. This approach has been applied successfully in marine ecosystems, notably in Eastern Canada for multiple IAS²²⁴. In terrestrial habitats, eDNA has proven to outperform camera trapping in detecting IAS²²⁵ and has facilitated the early detection of alien microbes and invasive insects in croplands and forest soils^{226–228}.

In India, eDNA techniques have been applied to both species' conservation and IAS monitoring^{229,230}. While the standardization of eDNA sampling methods is necessary for accuracy, it remains a reliable tool for validating IAS distributions predicted through ecological niche models.

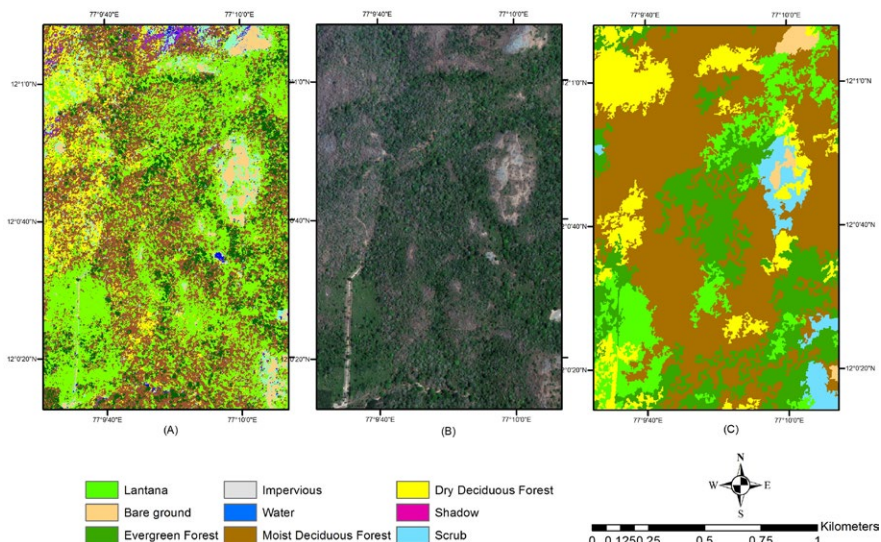
Right | Landcover classification map with understory invasive species Lantana camara mapped from very high resolution satellite image A. Pixel-based classification B. Satellite image from World View C. Object-based classification.

SATELLITE IMAGE- BASED MAPPING

Satellite imagery and remote sensing platforms, including UAVs or drones, are valuable tools for large-scale IAS mapping in both densely forested and open habitats. These techniques enable rapid, repeatable assessments in large areas, allowing researchers to track invasion patterns, identify species, and measure plant traits^{231,232}.

In India, high-resolution imagery has been used to document the loss of tropical montane grasslands to invasive timber species (acacia, pine, and eucalyptus) in the shola-grasslands of the Western Ghats and to identify areas for potential conservation and restoration^{233,234}. Similarly, medium- and high-resolution imagery has been used to monitor *Neltuma* invasion in the Kachchh Biosphere Reserve²³⁵.

Mapping understorey IAS or invasion fronts benefits from high-resolution satellite imagery, advanced classification algorithms, and airborne hyperspectral imaging^{150,151}. Using interpolated presence-absence data, researchers and state forest departments have produced hectare-scale distribution maps of *Lantana* in tiger reserves across the Western Ghats and Central India^{186,236,237}, providing critical baselines for tracking invasion dynamics and guiding targeted management strategies.



CITIZEN SCIENCE

The European Commission Green Paper defines citizen science as “general public engagement in scientific research activities where citizens actively contribute to science either with their intellectual effort, or surrounding knowledge, or their tools and resources”²³⁸. This public engagement can aid in IAS detection, mapping IAS, generating research questions, and awareness-building at minimal cost²³⁹, while raising momentum among the public for contribution to science.

Initiatives like the SPAIS (Spotting Alien Invasive Species) group on the India Biodiversity Portal, launched in 2014, have collected over 3,400 reports to date²⁴⁰. More recently, PARDESI (Participatory Assessment of the Regional Distribution of Exotic Species in India) was launched to map 27 IAPS in the Nilgiris district of Tamil Nadu using smartphones. By collecting presence-absence data, PARDESI (now known as the MIAP initiative) combines the rigour of grid-based sampling with the broad reach of citizen science (The Hindu, Jul 4, 2021; <http://miap.atree.org>).

Citizen science further strengthens large-scale IAS monitoring by leveraging social media, online databases, and AI-powered species identification tools, particularly in areas with limited institutional or individual data resources^{241,242}. Additionally, the integration of mobile mapping and AI-driven identification has further streamlined IAS documentation, expanding the scope of citizen-driven efforts in management strategies.

Other pathway surveillance tools include sentinel surveillance and monitoring, volatile detection techniques, pheromone and semiochemical lures, track-and-trace next-generation sequencing, and meta barcoding to identify IAS. Several modern technologies are also under development²¹¹.

Right | SPAIS (Spotting Alien Invasive Species) group on the India Biodiversity Portal

Spotting Alien Invasive Species [SPAIS] - LIST



We are not yet sure how many invasive animals (both vertebrates and non-vertebrates) and pathogens there are – their estimates vary. The best estimate to date puts the number of alien invasive plants in India at 225. The SPAIS campaign has selected a subset of known, and easily identifiable alien invasive species listed below to begin with. For detailed species information please visit - http://indiabiodiversity.org/group/spotting_alien_invasive_species/species

2. *Ageratina adenophora* (Spreng.) R.M.King & H.Rob. [Crofton weed (E), Osadi (H)]



Habit: Perennial herb/ sub-shrub
Occurrence: Disturbed forests, open areas; moist to wet tropics, subtropics

3. *Anthemis cotula* [Stinking Chamomile (E)]



Habit: Annual herb
Occurrence: Temperate regions

4. *Conium maculatum* [Poison Hemlock (H)]



Habit: Perennial herb
Occurrence: Temperate regions

6. *Lantana camara* L. [Lantana weed (E), Raimuniya (H)]



Habit: Shrub (can behave like a climber)
Occurrence: Wide variety of habitats; semi-arid to wet tropics, subtropics

7. *Mikania micrantha* [Climbing Hempweed (E)]



Habit: Perennial herbaceous climber
Occurrence: Wide variety of habitats; moist to wet tropics

8. *Mimosa diplotricha* Sauvage [Giant false sensitive plant (E), Shiah-kanta (H)]



Habit: Large sprawling/climbing shrub
Occurrence: Moist to wet tropics

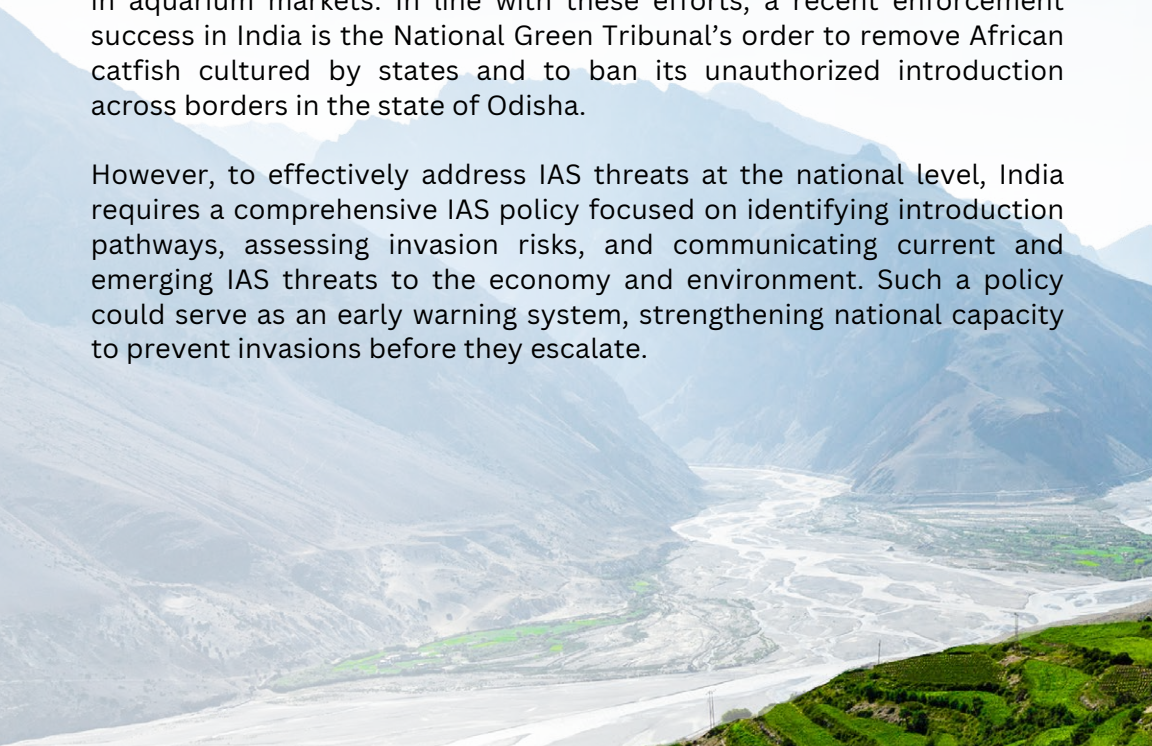
6.2 | PREVENTION

The most effective way to prevent IAS entry is to block their introduction pathways, conduct periodic monitoring, and promptly remove any newly detected arrivals. Thus, prevention measures fall into two key categories: (1) identifying new invasions and their pathways and (2) preventing the spread of known IAS, including re-invasion.

6.2.1 | MEASURES TO PREVENT INTRODUCTION

As a signatory to the CBD, India must align with international regulations governing the introduction of fish and plant species, including compliance with the CBD (2002), IPCC/UNEP/CBD/SBSTTA (the United Nations Environment Programme/Convention on Biological Diversity/Subsidiary Body on Scientific, Technical and Technological Advice) (2003), the FAO (Food and Agriculture Organization) Code of Conduct on Responsible Fisheries (2012), and CITES (Convention on International Trade in Endangered Species) approvals for species traded in aquarium markets. In line with these efforts, a recent enforcement success in India is the National Green Tribunal's order to remove African catfish cultured by states and to ban its unauthorized introduction across borders in the state of Odisha.

However, to effectively address IAS threats at the national level, India requires a comprehensive IAS policy focused on identifying introduction pathways, assessing invasion risks, and communicating current and emerging IAS threats to the economy and environment. Such a policy could serve as an early warning system, strengthening national capacity to prevent invasions before they escalate.



To prevent the introduction and spread of IAS, vigilant screening at ports of entry by trained officials is essential. Airports, seaports, and land borders should display clear information on prohibited materials and legal consequences, while airlines must prohibit the transport of plants, animals, and related products without proper phytosanitary certificates and import permits. Additionally, airports should provide information on invasive pests already present in the country to prevent further spread. To strengthen biosecurity measures, nurseries and seed companies involved in importing and exporting seed and plant material must submit annual certifications confirming they have not introduced any invasive species.

Monitoring efforts should also focus on potential invasion hotspots through coordinated efforts involving Agricultural Universities, ICAR research organisations, Central Integrated Pest Management (IPM) centres, Forestry Research institutes, and Fisheries Training and Research institutes. A structured system should also be in place for consulting taxonomists from research organisations when identifying potential IAS. Furthermore, long-term research should monitor rare introduction pathways, such as those associated with migratory birds or laboratory model organisms.



6.2.2 | QUARANTINE AND BIOSECURITY MEASURE

Beyond entry point inspections, a robust quarantine system is essential to contain potential IAS threats. Biosecurity measures, such as quarantines and risk assessments play a vital role in preventing introductions, with quarantine facilities at ports of entry serving as key barriers against accidental arrivals. While the World Trade Organization discourages quarantine laws to reduce trade barriers²⁴³, such regulations are crucial for controlling IAS spread via global trade.

Comprehensive pre- and post-border quarantine approaches are necessary at airports, seaports, and land border crossings to minimize invasion risk. Mandatory inspections of imported material further strengthen containment efforts, particularly by holding live materials in designated quarantine facilities for a stipulated period. For example, India's quarantine system for fungal pathogens has proven effective, intercepting 15 invasive fungal species between 2015–2020 before they could establish. Only one new alien fungal pathogen, *Puccinia horiana* (causal agent of chrysanthemum white rust), has been recorded in the last five years, highlighting the success of these strategies^{244,245}. To reinforce preventive measures, a centralized tracking facility should be established, linked to Governmental institutions like the ICAR–National Bureau of Agricultural Insect Resources (NBAIR), which operates the QC-2 quarantine facility for invasive insect pests. Establishing similar facilities for other taxa would enhance IAS identification and information dissemination.

Furthermore, the MoEF-CC must enforce stronger quarantine regulations and direct control measures, particularly in freshwater aquaculture and the aquarium trade. Given the risks posed by unregulated trade, grey markets, such as online aquarium fish trade, must be closely monitored and strictly regulated²⁴⁶.

Quarantine officials at ports of entry must be professionally trained and equipped to identify non-indigenous pests, particularly potential IAS near border regions. The use of simple taxonomic keys and AI-based identification tools—already in use globally—could significantly improve detection efficacy in India²⁴⁷. Additionally, raising awareness of phytosanitary protocols is essential to prevent the entry of uncertified plant and animal materials through cargo or baggage.

While national quarantine systems are crucial, establishing holding mechanisms at state borders within the country is equally important. Increasing awareness among police personnel and port authorities to recognise and restrict IAS movement domestically would further strengthen India's internal biosecurity.

In addition to quarantine, horizon scanning and Pest Risk analysis (PRA) are important biosecurity tools to identify the impending threats of IAS and to assess whether an organism is a potential pest, further determining the necessary precautionary measures. Effective PRA requires comprehensive knowledge of an organisms' life history, particularly its life cycle²²⁰. Additionally, robust risk assessments must consider the potential unintended ecological impacts of biological control agents, including their effects on non-target species and broader ecosystems. Despite its usefulness, PRAs have sometimes failed to identify pests before they spread beyond their native ranges²⁴⁸. Therefore, PRAs must be conducted by trained personnel using up-to-date protocols to ensure accurate risk assessments and prevent costly oversights. Once an organism is confirmed to pose minimal risk, it can be removed from the quarantine list.



6.3 | ERADICATION, CONTAINMENT, AND CONTROL

6.3.1 | NEED FOR INTEGRATION OF SPATIAL AND MOLECULAR TECHNOLOGY FOR IAS SURVEILLANCE AND MANAGEMENT

Effective surveillance mechanisms are vital for detecting invasive species at all stages of establishment. While vigilance and preventive measures form the first line of defence, integrating advanced spatial and molecular technologies can greatly enhance IAS management.

Walsh²⁴⁹ provides a comprehensive overview of remote sensing approaches for mapping invasive species at multiple scales, both on the ground and via sensors, highlighting their potential for IAS monitoring. Similarly, Padalia and Bahuguna¹⁶³ highlight the effectiveness of spatial modelling in identifying potential invasion hotspots in India's forested areas, aiding conservation planning. Modelling also helps bridge existing knowledge gaps in IAS research and evaluate the presence of pseudo-absent pests based on factors such as host diversity, host presence, per capita gross domestic product (GDP), global prevalence, and proximity to coastlines²⁵⁰. Additionally, it can help estimate time lags between introduction and invasion, facilitating proactive management.

One such model, CLIMEX²⁵¹, is a powerful tool for predicting the emergence and spread of new invasives. However, due to limited data, India currently lacks an effective predictive framework for early invasion detection, limiting rapid response capabilities. Niche modelling—an approach that predicts potential species distribution based on their current geographic spread—offers a promising alternative^{252,253}. This approach enables large-scale predictive mapping, aiding early detection and response strategies^{254,255}. Niche modelling is also valuable for risk assessments, helping evaluate the likelihood and impact of IAS through predictive modelling and prioritization. Notably, climate change can influence IAS pathways, impact mechanisms, and even alter control measures (Hellmann 2008). A recent study by Nobinraja et al.²⁵⁶ used predictive modelling to illustrate how invasive alien fishes can expand their range due to climatic change and human interventions such large-scale projects like river inter-linking, which connect vulnerable habitats of native and endangered species to invasive hotspots.

Risk analysis models are also essential for assessing potential threats posed by newly introduced species²⁵⁷. For instance, Banerjee et al.²⁵⁸ combined genetic data with niche modelling to predict potential distribution of *M. micrantha* in South and Southeast Asia. Such integrative approaches are crucial for developing effective invasion management strategies.

Furthermore, modelling approaches provide analytical solutions for complex ecological challenges, particularly in assessing the cumulative impacts of multiple IAS taxa—such as plants, fish, algae, and molluscs—on freshwater ecosystems. These studies help disentangle IAS interactions within the habitat and track their spread across ecosystems based on introduction pathways, native ranges, and the ecological status of water bodies^{257,259}. For example, Sreekanth et al.²⁶⁰ used modelling to examine the intricate interactions between IAS and native species in an Indian freshwater pond, highlighting the ecosystem's vulnerabilities. Additionally, modelling can predict habitat degradation scenarios and assess climate change impacts on hydrology and society, such as increased flood risk in low-lying areas and IAS spread through introduced food fish species^{260,261}. Thus, by employing predictive methods such as niche modelling and simulations, researchers can predict future scenarios of IAS spread and vulnerabilities, facilitating proactive management and mitigation strategies in both terrestrial and aquatic systems.



Genetic studies are also essential for understanding the evolutionary dynamics of IAS and their success in invaded ranges. Phylogeographic analyses provide insights into founding populations, genetic variability, source populations, hybridization events, and introduction pathways²⁶²⁻²⁶⁴. Integrating such information with PRA schemes can enhance IAS management strategies. However, despite its potential for predicting and controlling agricultural pests, the molecular taxonomy of many IAS remains relatively unstudied. This gap underscores the value of molecular keys and genetic barcodes, which offer a significant advantage over morphological identification by enabling early pest detection before outbreaks occur²⁶⁵. For instance, barnacle scales (*Ceroplastes cirripediformis*), identified as an IAS by the CABI in 2017, were first recorded in India in 2021²⁶⁶. Their identity was confirmed through molecular methods by the Nodal Centre for Biological Invasions, Kerala Forest Research Institute, facilitating rapid containment²⁶⁷.



Barnacle scales (Ceroplastes cirripediformis) | Photo: Wikimedia Commons

PRA can also help develop a priority list of ‘risk-prone’ species, especially for planned introductions in agriculture or fisheries. However, this list may change with projected climate change, as some IAS are expected to shift their ranges, introducing new threats to previously unaffected regions. Thus, identifying range-shifting invasive plant species is crucial for proactive monitoring and management. Conversely, some currently invaded areas may become climatically unsuitable for IAS, creating potential retreat zones that offer opportunities for ecological restoration. In this context, an ensemble of species distribution models can predict future IAS distributions, guiding management efforts^{101,268}. Integrating such advanced modelling techniques into large-scale data collection is vital for improving rapid assessment surveys and informing management strategies.

Adaptive IAS management requires comprehensive information on their spatial distribution, ecological interactions, and societal impacts. Strengthening capacity in genetic, GIS/RS, and data science tools will enhance detection and monitoring efforts. Building expertise within research institutions and government agencies tasked with natural resource management is essential for leveraging modern technologies for IAS prevention and control. Recent advances in genetics (e.g., eDNA^{214,215,229,230}), remote sensing (e.g., high-resolution, hyperspectral imagery, and LiDAR^{269,270}), and data-driven modelling techniques (e.g., machine learning techniques) have significantly improved our ability to detect, track, and predict IAS. To maximize these benefits, technical training programs should be developed for graduate students and mid-career professionals, focusing on molecular, advanced RS, and statistical tools for IAS management. Such programs should emphasise the integration of multiple techniques; for instance, applying genetic tools to trace introduction routes and validate species distribution models, while very high-resolution or hyperspectral satellite data can be used to forecast IAS spread under future climate scenarios and to identify currently uninvaded but vulnerable areas.

6.3.2 | INTEGRATED PEST MANAGEMENT (IPM) APPROACHES

The spread of invasive pests like the fall armyworm, rugose spiralling whitefly, and black thrips have increased pesticide use in Indian agroecosystems¹⁴³. These pests reproduce quickly, spread widely, and attack multiple crops, making chemical control ineffective over time²⁷¹. Repeated insecticide use can lead to the insect pest developing resistance to the insecticide, while also creating a build-up of chemical residues on crops and in the environment, negatively impacting farmers and consumers health¹⁴⁵, and harming native pollinators and beneficial natural enemies of crop pests.

For instance, fall armyworm (*Spodoptera frugiperda*) attack maize during the tasseling and cob formation stage²⁰², a period crucial for pollinators. To control this pest, farmers use insecticides like chlorantraniliprole, emamectin benzoate, and spinetoram, which are deleterious to bee pollinators^{144,146}. In some cases, such as papaya mealybug infestation on mulberry²⁷², pesticide use is not feasible due to risks to the sericulture industry. These challenges highlight the urgent need to adopt IPM approaches.



Corn damaged by fall armyworm being sold in a local market | Photo : Sandilyan)

IPM involves the strategic combination of physical, chemical, biological, and cultural or traditional practices to control pests, while minimizing risks to human, animal, and environmental health, in the most economically sustainable manner²⁷³. Adaptive and context-specific, IPM is especially useful for managing IAS in freshwater habitats and agroecosystems. For instance, in Sub-Saharan Africa, a combination of early warning systems, community-led monitoring (using pheromone traps), early planting, planting resistant varieties, weeding, crop rotation, and strategic pesticide use effectively contained fall armyworm invasions²¹¹. In India, ICAR-National Bureau of Agricultural Insect Resources has developed a nationally recommended, pesticide-free, bio-intensive IPM module for managing fall armyworm. It includes the use of pheromone traps, parasitoids, and microbial biopesticides (Ballal et al 2021). In Kerala, baiting and point chemical treatments have helped manage the giant African land snail (*Lissachatina fulica*) invasion, while minimizing ecological harm²¹¹.

Implementation of IPM in India can be supported through existing Government schemes that focus on the sustainable development of the agricultural economy, such as the Mahatma Gandhi National Rural Employment Guarantee Scheme (MNREGA), which employs small and marginal farmers who can participate in pest monitoring, early warning, and control. Additionally, State Biodiversity Boards (SBBs) and Biodiversity Management Committees (BMCs), supported by the National Biodiversity Authority (NBA), can integrate IAS surveillance into People's Biodiversity Registers (PBR) to strengthen early detection and monitoring.

6.3.3 | FACILITATION OF CLASSICAL BIOLOGICAL CONTROL OF IAS IN AGROECOSYSTEMS WOULD ENABLE A MORE RAPID AND EFFECTIVE RESPONSE TO EMERGING INVASIVE PLANT AND INSECT THREATS

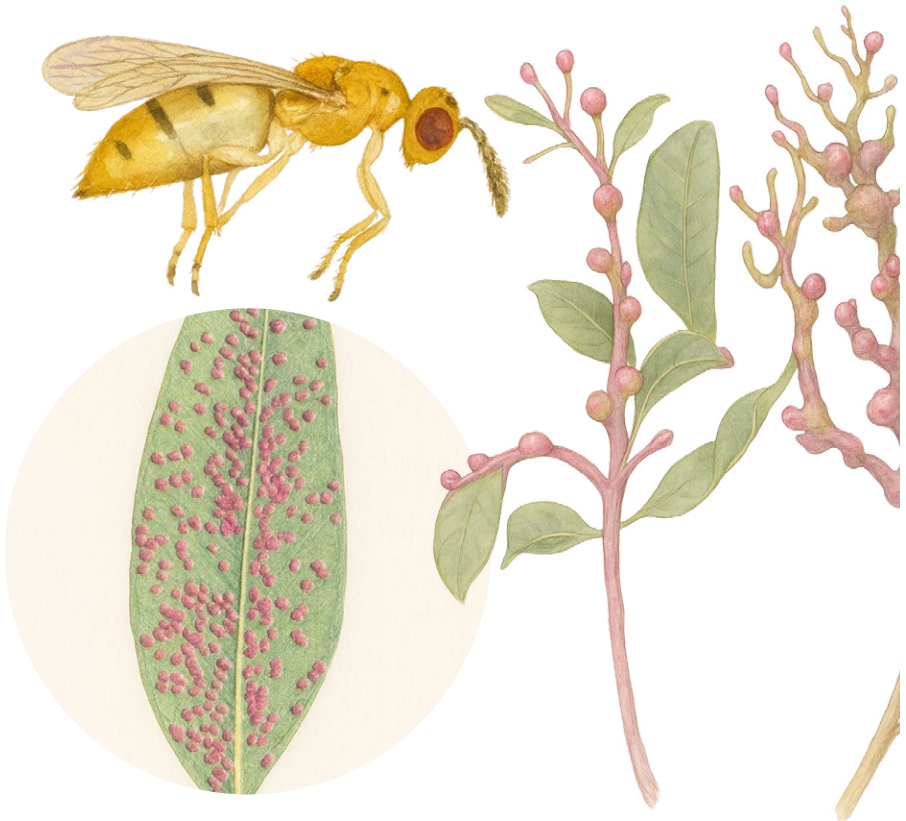
Classical biological control involves introducing natural enemies (parasitoids, predators, or pathogens) of the IAS pest from its native range to control its spread. It is especially effective during initial stages of invasion and has been mainly used to tackle plant and invertebrate IAS. However, it carries ecological risks, particularly to non-target native species, making rigorous risk assessment essential²¹¹. Long-term effects of biocontrol agents on native ecosystems are also difficult to predict.

Globally, only about half of all biocontrol efforts have succeeded, but the economic benefits of successful cases surpass the costs of failed ones²¹¹. Countries like Australia and South Africa have shown that biocontrol of invasive plants can yield high long-term returns, particularly when integrated with IPM and backed by strong research investment²¹¹. One example from India is the successful biocontrol of the water fern (*Salvinia molesta*) in aquatic systems using a weevil (*Cyrtobagous salviniae*)²⁷⁴. In another instance, the rust fungus (*Puccinia spegazzinii*) was introduced in India and seven other countries in the Asia-Pacific region to control the spread of *M. micrantha*. While the pathogen successfully established and effectively controlled *M. micrantha* in five countries²⁷⁵, it failed to establish in India, likely due to the quantity and timing of its release.



A leaf damaged by the rust fungus (*Puccinia spegazzinii*) | Photo: Wikimedia Commons

There are several successful examples of the use of classical biological control against IAS insects in agroecosystems, both globally and in India. Of the 169 species of insect biocontrol agents introduced in India, 71 established post-release, with 13 providing effective control and 4 offering partial success. One notable example is the parasitoid *Acerophagus papayae*, which effectively controlled the papaya mealybug within five months, delivering economic benefits of \$121–309 million annually across five major crops. In Tamil Nadu alone, farmers saved \$7.5 million in insecticide costs²⁷⁷. Other successes include *Quadrastichus mendeli* and *Selitrichodes kryseri*, which controlled eucalyptus gall wasp infestations across an estimated 8000 ha, saving the paper industry, and the release of *Dipha aphidivora* and *Micromus igorotus*, natural predators of the woolly aphid, which helped save ₹365 crore worth of sugarcane (Business today, March 20, 2011).



Quadrastichus mendeli, a parasitoid of the Eucalyptus gall wasp

Despite its proven effectiveness against insect pests and invasive plants, classical biological control remains underutilized due to regulatory hurdles, fear of non-target effects, limited access to biocontrol agents, and poor communication with stakeholders, including farmers and policymakers^{211,278}. In India, alongside efforts to prevent the entry of alien insects, there is a pressing need to strengthen taxonomic collaboration to facilitate rapid detection, documentation, and identification of new invasive species. To facilitate early-stage uptake of biocontrol—when it is most effective—national and international collaboration must be enhanced. Effective implementation will require the following actions:



Valuation: Assessing the financial, environmental, social, and cultural benefits of biological control for managing IAS pests.



Research support: Increasing funding for biological control research and development.



Regulatory reform: Streamlining and time-bound approvals for import and release of exotic biocontrol agents for rapid response.



Global cooperation: Facilitating bilateral projects between research institutions and regulatory agencies to enable faster exchange of specimens and control agents.



Biopesticide registration: Fast-tracking approval of indigenous biopesticides developed by national research labs to ensure quick adoption by commercial producers and farmers.

6.3.4 | MANAGING TRADE-OFFS BETWEEN IAS IMPACTS

While many introduced species provide valuable ecosystem services for which they were originally brought in, a small but significant proportion become invasive, causing unintended harm to native biodiversity, ecosystem functioning, and human well-being and affecting the provisioning of other ecosystem services. This can result in complex trade-offs between biodiversity and ecosystem services, or among different ecosystem services themselves.

Freshwater aquaculture illustrates this tension well. In the upper Gangetic plains of Uttar Pradesh, for example, IAS fish such as tilapia and common carp dominate catches, especially during the dry season. For local fishing communities, these species are now key to food security and income. Removing them, by means other than fishing, without a timely recovery of native species could disproportionately harm already vulnerable groups.

To help navigate such trade-offs, Zengeya et al.²⁷⁹ proposed a typology of introduced species based on both their benefits (such as ecosystem services) and negative impacts (on biodiversity, ecosystems, or human well-being).

		BENEFITS (ecosystem services)	
		Low	High
NEGATIVE IMPACTS (biodiversity, ecosystem services, human wellbeing)	Low	Inconsequential species	Beneficial species (e.g., Tamarind, Chinara)
	High	Destructive species (e.g., Parthenium, Lantana)	Conflict-generating species (e.g., Common carp, Neltuma)

Of these four types of species, the first two require no management. In the case of the third, the necessary management is clear, and calls for eradication, or at least control. The fourth and final type of species presents the greatest difficulty, as any management approach must navigate the associated trade-offs.

One of the key challenges with conflict-generating IAS is the time lag between their introduction and the manifestation of their negative impacts. A species may offer short-term benefits before its ecological costs become apparent much later²⁸⁰.



Pre-introduction risk assessments²⁸¹ and strong regulatory mechanisms are essential to prevent the entry of species already known to be invasive elsewhere. However, exceptions persist, such as the introduction of the seaweed, *Kappaphycus alvarezii*, to the Gulf of Mannar in India, despite its documented invasiveness in Hawaii²⁸².

Another challenge with conflict-generating IAS lies in differing stakeholder perceptions. A species viewed as valuable for livelihoods may simultaneously be seen as ecologically damaging, creating difficulties in integrating goals of biodiversity conservation and human well-being and complicating management decisions. In such cases, management strategies may need to vary by context. For instance, *Neltuma* could be eradicated in protected areas of high conservation value²⁸³, but retained in human-dominated landscapes where it supports rural livelihoods (see Case Study 3.2).

Finally, efforts to evaluate these trade-offs are constrained by limited research. While IAS impacts on native species are relatively well-studied in India and across the globe, their effects on ecosystem services²⁸⁴, livelihoods, and human well-being—especially from a local perspective—remain underexplored¹³⁴.



Kappaphycus alvarezii seaweed

6.3.5 | IMPORTANCE OF ECOSYSTEM-BASED APPROACHES TO HABITAT MANAGEMENT

In India, invasive species management is often limited to one-off removal efforts, with little published data on the methods, outcomes, or long-term impacts. Such sporadic approaches—especially when not informed by species biology or ecology—can often do more harm than good. For many common IAS, research indicates that repeated interventions are required for effective control^{5,187,285}. Ecosystem-based management approaches, i.e., tailored management interventions for wetlands, grasslands, forests, and agricultural systems, can greatly improve the success of IAS control. Similarly, species-specific approaches that consider the invasion stage (e.g., containment, spread, or restoration) improve outcomes. Adaptive management frameworks that include robust documentation and monitoring help identify habitat vulnerabilities (e.g., lack of native competitors) and support effective restoration²⁸⁶.

While total eradication is often unrealistic, targeted efforts to reduce IAS abundance and spread in key habitats may be more feasible and cost-effective²⁸⁷. Achieving this requires scientific understanding of how different habitats respond to invasion based on their specific abiotic and biotic contexts and disturbance histories^{18,40,80}. Standard control methods—mechanical, chemical, biological, or engineering—must be tailored to site-specific conditions for optimal results^{288–290}.



Photo: Ramya Ravi

6.3.6 | NEED FOR ECOSYSTEM RESTORATION

The UN Decade on Ecosystem Restoration (2021–2030) highlights the urgency of restoring ecosystems degraded by IAS. To prevent re-invasion, removal of IAS must be followed by long-term restoration efforts aimed at re-establishing native species and ecosystem functions. Wherever possible, legacy satellite imagery and historical records can help reconstruct pre-invasion landscapes and aid restoration efforts²³⁵. Identifying clear indicators of healthy, resilient ecosystems is essential for measuring restoration success. In-depth studies on the impacts of IAPS on functional diversity will also help guide the restoration of ecosystem functioning, and therefore, the provisioning of desired ecosystem services. However, setting pre-invasion baselines can be challenging, especially in landscapes already shaped by long-term human impacts. In such contexts, adaptive, site-specific strategies may be more practical.

Restoration is often costly, complex, and dependent on the regeneration potential of the invaded ecosystem. It requires technical support from international and national research cells, sustained labour, and resource availability. Continued monitoring of the area is essential to check re-invasions. It may be noted that some of the management methods such as chemical control of invasive alien plants affects regeneration potential of native species and use of prescribed fire increases biomass of invasive plants compared to native species²⁹¹. Treating invaded areas as entire landscapes (e.g., working plans in forested areas) or waterscapes (e.g., entire watersheds for smaller river systems) enable collaboration across agencies and support functionally resilient ecosystems.

Restoration plans must also consider impacts on native flora and fauna²⁹². In terrestrial ecosystems, interactions between woody IAS and native animals can influence restoration outcomes and should be studied further¹¹¹. Notably, the impacts of invasive plants on ecosystem processes and functions can persist as ‘legacy effects’ even after their removal¹⁰². Understanding these effects on native plant–soil interactions is essential for informing effective ecological restoration. One major impediment to measuring the efficacy of ecosystem restoration in alien plant invaded ecosystems is the lack of data on the initial status of native plants²¹¹.

In aquatic ecosystems, complete eradication of IAS is often unfeasible. Instead, “functional eradication”—reducing invasive populations below ecologically harmful thresholds in high-priority areas—offers a more practical strategy²⁹³. Functional eradication refers to suppressing invader populations below levels that cause unacceptable ecological effects—within high-priority locations. Bio-control agents (e.g., parasites, introduction of predators) have shown some success in controlling some invasive carp species. Restoration efforts should prioritize the reintroduction of native species into modified fish assemblages, using a long-term, phased approach.

In parallel, some communities have adapted to IAS by utilizing them for livelihoods, which can support containment and reduce ecological pressure. For example, charcoal production from *Neltuma* is a major livelihood activity in many parts of India, and complete removal may be unacceptable to local communities^{2,294}. Similarly, many aquatic plant species can be harvested for industrial applications such as fodder, biofuels, mats, paper products, or cordage¹⁵⁹. However, attention is warranted to avoid spread of the species while harvesting and utilizing these for different purposes. Systematic harvesting could help manage invasions while supporting livelihoods and water body restoration. However, India currently lacks coordinated efforts to evaluate this potential. Nonetheless, integrating aquatic IAS control with public welfare schemes such as MNREGA could enable scalable, community-supported restoration efforts. An integrated framework of aquatic plant invasion in India, linking these various aspects, is presented in Fig. 3.

Thus, restoration of ecosystems through holistic interventions grounded in ecological understanding of landscapes and waterscapes, supported by repeated management efforts, native species nurseries, adaptive strategies, and inclusive approaches that account for human-ecosystem interactions, would reduce the vulnerability of native ecosystems to biological invasion. Adopting a landscape-scale restoration approach, backed by coordinated action across government departments, can improve IAS management while also advancing broader goals such as employment generation, social welfare, and integrated landscape planning.



Figure 3: An integrated framework for managing aquatic plant invasions in India. Systematic documentation of invasion status is essential for identifying knowledge gaps, assessing ecological and socio-economic impacts, and guiding appropriate management strategies.

6.3.7 | CONSIDERATION OF EMERGING ECOLOGICAL PERSPECTIVES (E.G., NOVEL ECOSYSTEMS)

The novel ecosystems concept has gained relevance in the Anthropocene, where human-driven changes are rapidly transforming species assemblages, interactions, and ecosystem processes in unprecedented ways. Defined as ecosystems shaped by human activity that have crossed ecological thresholds—resulting in new, self-sustaining trajectories—novel ecosystems differ fundamentally in composition and function from their historical baselines²⁹⁵. Such ecosystems are characterized by a change in species composition relative to those previously found in the same biome prior to crossing a threshold.

Across peninsular India, widespread invasions by *Lantana*, *Neltuma*, and *Acacia* (wattle) have transformed terrestrial landscapes. Similarly, in aquatic habitats, invasions by common carp and tilapia in the upper Gangetic plains, and water hyacinth in wetlands, have altered species composition and ecosystem function. For example, oxygen-depleting hyacinth shifts fish communities from surface-dwelling “whitefish” to hypoxia-tolerant “blackfish” species. These shifts restructure the invaded ecosystems into novel ecosystems by fundamentally transforming their ecological dynamics and resident species⁴².

In such cases of intense invasion, restoration to historical baselines is no longer feasible due to altered abiotic conditions and entrenched ecological and social dependencies. For example, removing *Lantana* alone is likely to cause soil desiccation or erosion. Similarly, eradicating *Neltuma*, which has become an important livelihood source for impoverished communities, could result in socio-economic hardship^{296,297}. In such contexts, managing rather than eradicating these transformed systems may be more pragmatic, aligning with the idea of ‘rambunctious gardens,’ where our role is that of a constant gardener²⁹⁸.



Black wattle (Acacia mearnsii) | Photo: Wikimedia Commons

6.4 | KNOWLEDGE GAPS

Critical information gaps on the distributions and impacts of most IAS on native biodiversity and human well-being persist, hampering the development of effective management strategies and policies to tackle them.

6.4.1 | NEED FOR AN OPEN NATIONAL DATABASE ON IAS

An open national database on IAS, with a strong spatial and mapping component, is essential for detecting and preventing new invasions, the development of effective management and control strategies, and for raising awareness among civil society about IAS and their impacts.

Such a database should be built on uniform, scientific criteria consistent with global standards and international frameworks (e.g., CBD and IPBES). Species should be classified using ecological and biogeographic data—including traits, native range, spread, invasion stage, and known impacts—rather than purely political boundaries, which may become increasingly fluid with changing climates. These criteria must be peer-reviewed, expert-led, and regularly revised to reflect new data and insights.

An annotated, regularly updated national database on IAS would enable:



Identification of high-risk species and priority introduction pathways for prevention action



Assessment of socio-economic and ecological impacts of IAS



Prioritization of species for management action



Building public **awareness** about IAS and their impacts.

Developing a dynamic, spatially explicit, value-added national IAS database using the latest networking and information technology is a critical priority²⁹⁹. A hub-and-spokes model—with a central coordinating system linked to taxon-specific hubs—could enable efficient management of diverse data streams. Existing national^{213,300–302} and global initiatives, such as the Global Naturalized Alien Flora (GloNAF) project and Europe’s DAISIE (Delivering Alien Invasive Species Inventories for Europe)³⁰³, serve as useful templates. The European Invasive Alien Species Information System, for example, a “one stop-shop” for information on the 100 most invasive alien species in Europe, assesses their ecological and socio-economic risks and impacts, helps raise public awareness, supports applied research, and informs management decisions^{284,304}.

Although several government and academic institutions in India have compiled IAS datasets, many are incomplete, unpublished, or inaccessible. A national IAS database must prioritize open access to spatial and environmental data to support coordinated action by researchers, managers, and civil society.



6.4.2 | LACK OF RESEARCH ON CERTAIN INVASIVE SPECIES AND ECOSYSTEMS

IAS research in India remains taxonomically narrow, largely focused on a few invasive plants and their impacts on a single trophic level or a single taxon^{7,39}. There is a clear need to expand studies to include invasive vertebrates, invertebrates, fungi, and microbes, as well as their interactions across multiple trophic levels.

Further, research is especially lacking in high-conservation-value ecosystems such as islands, marine and freshwater systems, wetlands, grasslands, savannas, protected areas, and biodiversity hotspots like the Western Ghats and the Western and Northeastern Himalayas³⁰⁵. For example, Indian grasslands and wetlands, which are highly vulnerable to invasions, remain under-studied despite their socio-ecological importance. Similarly, islands, given their small geographic area, may be experiencing unquantified ecological and socio-economic impacts of human influence and synanthropic IAS⁵⁶.

Despite widespread IAS presence, only 12% of all IAPS studies in India focus on the Indian Himalayas, with particularly limited data from the terrestrial and freshwater ecosystems of Northeastern Himalayas⁷.



6.4.3 | NEED FOR STUDIES ON THE HUMAN DIMENSIONS OF BIOLOGICAL INVASIONS

Globally, the Asia-Pacific region is reported to experience the highest level of impact on health due to IAS⁶. Yet, only 20% of studies on IAPS impacts in India examine their effects on human well-being; most focus exclusively on their ecological consequences². However, the social impacts of IAS are highly context-specific, shaped by local governance, policy, and stakeholder perspectives^{2,134}.

The same IAS can be perceived very differently across regions. For instance, while the Soliga community of BRT experience adverse effects from *Lantana camara*, communities in MM Hills have developed diverse livelihoods around its use². These differing perceptions underscore the need for research that accounts for local context, especially the voices of indigenous and local communities, to better assess well-being impacts and inform inclusive, effective management policies³⁰⁶. This will require moving beyond studies of individual species and including interdisciplinary methods, both quantitative and qualitative, to understand the complex relationships between people, invasive species, and their habitats².



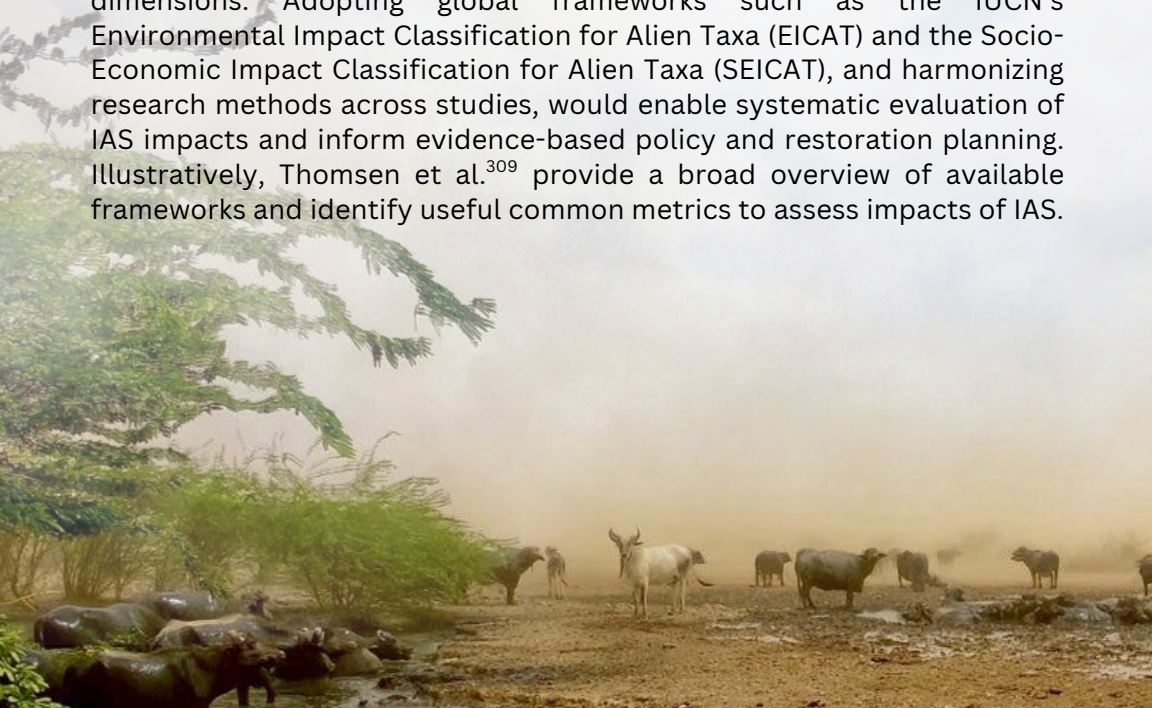
Photo: Getty Image

6.4.4 | NEED FOR STANDARDIZED RESEARCH METHODOLOGIES TO EVALUATE TRADE-OFFS IN IMPACTS

Many IAS were originally introduced for well-intentioned purposes—such as food production, carbon sequestration, landscape restoration, or as ornamentals—but have since become entrenched in their respective social-ecological systems, complicating assessments of their net impact. For example, freshwater fish species introduced for aquaculture or escaped from aquariums have now become invasive, disrupting native ecosystems³⁰⁷.

In some instances, invasive species support new livelihoods or benefit certain native species, complicating both management practices and the broader discourse on regulation and control². Ironically, large-scale restoration back to native grassland could compromise climate resilience provided by *Neltuma*-based livelihoods³⁰⁸.

Such trade-offs between ecological harm and socio-economic benefits highlight the need for long-term, spatially explicit data and standardized research frameworks that assess impacts across ecological and social dimensions. Adopting global frameworks such as the IUCN's Environmental Impact Classification for Alien Taxa (EICAT) and the Socio-Economic Impact Classification for Alien Taxa (SEICAT), and harmonizing research methods across studies, would enable systematic evaluation of IAS impacts and inform evidence-based policy and restoration planning. Illustratively, Thomsen et al.³⁰⁹ provide a broad overview of available frameworks and identify useful common metrics to assess impacts of IAS.



6.4.5 | NEED FOR LONG-TERM MONITORING AND MULTISPECIES STUDIES

Long-term monitoring of IAS in India remains limited but is crucial for establishing baselines and tracking trends in their spread and impact across regions. Large-scale and long-term monitoring and inventorying efforts, combined with ecological niche modelling or species distribution modelling, can help develop effective frameworks to predict future invasions by and spread of introduced species. This is especially important in the context of climate change impacts on biodiversity, hydrology (e.g., by increasing the vulnerability of the region's hydrological balance), and human well-being. (e.g., elevated flood risk in low-lying areas and the potential spread of introduced food fish species). The lack of sufficient resources remains an impediment affecting long-term monitoring of alien species invasions and restoration efforts in India.

In addition to monitoring, systematic documentation of native dispersers and pollinators of IAPS is also crucial, as these interactions often facilitate the long-distance spread of invasives. Such data can improve predictions of range expansion and inform strategies to prevent reinvasion of managed areas. For example, blackbuck feeding on *Neltuma* pods⁵⁰ or birds dispersing *Lantana*^{95,190} illustrate how animal-IAPS interactions can complicate control and restoration efforts.

Many of India's terrestrial, freshwater, and agroecosystems are invaded by multiple IAS, whose combined impacts can disrupt native communities³¹⁰. Multi-species and multi-scale studies that examine effects across individual, population, and community levels—such as mutualisms, competition, or facilitation—are needed to identify broad ecological patterns and invasion consequences^{311,312}. When it is not feasible to study IAS species, a practical alternative is to group IAS with similar traits, pathways, and impacts using an “invasion syndrome” approach³¹³.



Photo: Ramya Ravi

6.4.6 | STUDYING THE INTERACTION BETWEEN IAS AND CLIMATE CHANGE

The interaction between IAS and climate change remains underexplored, hindering effective management⁵. While climate change accelerates the spread of IAS by creating more favourable environments for non-native species and reducing the competitive ability of native species the broader ecological impacts and long-term consequences of these interactions have not been studied. For instance, the extent to which climate change amplifies the effects of IAS on ecosystem dynamics, including biodiversity loss, and habitat degradation, is not adequately studied.

One critical challenge in addressing these gaps is the lack of region-specific data, particularly in developing nations like India, where research on IAS is constrained by limited funding and expertise. Most studies focus on well-documented IAS such as *Lantana* and *A. adenophora*, while lesser-known species remain understudied. Moreover, studies have primarily concentrated on terrestrial ecosystems, leaving the impacts of IAS on freshwater and marine ecosystems underexplored, especially in the context of climate change. This imbalance limits understanding of how these ecosystems respond to the combined pressures of biological invasions and shifting climate patterns^{5,7}.

The interaction between climate change and IAS in aquatic and terrestrial ecosystems, particularly in biodiversity hotspots like the Western Ghats, further illustrates the complex feedback loops at play. For example, the 2018 and 2019 floods in Kerala released several alien fish species, including alligator gar, from illegal aquaculture farms into natural water bodies. This flood-driven dispersal highlights the urgent need for better policies to address the risks posed by IAS during extreme climate events³¹⁴. Similarly, the invasion of native montane grasslands of the Upper Nilgiris by *A. mearnsii* (black wattle) has been associated with altered eco-hydrological processes and increased flooding risk during extreme rainfall events^{117,118}. Finally, climate change and associated extreme weather events could also trigger range expansions of IAS, threatening endemic species in biodiversity hotspots like the Indian Himalayas, as evidenced by the expansion of *A. adenophora* to higher elevations in the Western Himalayas. However, the lack of data on species distributions, ecological interactions, and life histories limits predictive modelling and proactive management⁷. Initial studies, however, strongly underscore the need to integrate climate change considerations into IAS management strategies.

Another critical issue lies in current management approaches, which tend to treat IAS and climate change as separate concerns. This fragmented approach overlooks how climate change exacerbates the spread and impact of IAS, reducing the effectiveness of existing mitigation strategies. Integrated management strategies that consider IAS and climate change as interconnected threats are urgently needed. For instance, species like *Chromolaena* and *Parthenium* thrive in disturbed environments, and their spread is often facilitated by urbanisation and land-use changes—both of which are influenced by climate change⁵.

Addressing these gaps effectively requires a multidisciplinary approach that brings together ecologists, climate scientists, policymakers, and local communities. Cross-sectoral collaborative efforts can support the development of comprehensive, adaptive strategies to tackle the compounded threats posed by IAS and climate change. For instance, biosecurity measures need to be updated to consider extreme weather events, such as floods, which can release IAS into new environments. Additionally, stronger international cooperation and better enforcement of environmental regulations are also essential to protect vulnerable ecosystems from compounded threats³¹⁴.



Photo : Lantana Craft Centre



7

POLICY AND GOVERNANCE

7.1 | National and International Frameworks

7.1.1 | Role of CBD, IPBES, and Other International Agreements

7.1.2 | National Policies and Legislation on IAS Management

7.1.3 | Institutional Framework: Role of Community Organisations, NGOs, and Research Institutions in IAS Management

7.2 | Integrating Social and Economic Impacts of IAS into Research and Management Frameworks

7.3 | Bridging Knowledge Gaps: Ameliorating Data Collection and Analysis

7.4 | Community-Led Management and Restoration Efforts

7.1 | NATIONAL AND INTERNATIONAL FRAMEWORKS

7.1.1 | ROLE OF CBD, IPBES, AND OTHER INTERNATIONAL AGREEMENTS

India, despite being a global biodiversity hotspot with over 11% of the world's plant species, still lacks a unified national policy and national plan for managing IAS. While environmental protection laws exist, specific regulations for IAS remain fragmented and underdeveloped, limiting the country's capacity to address their growing impact.

Effective IAS governance demands coordinated action across national and international levels. Since global trade, travel, and land-use changes are key drivers of IAS introduction, managing these pathways is critical. International treaties and scientific platforms help harmonize national efforts and foster cooperation to prevent and control IAS.



A display at the Convention on Biological Diversity in Hyderabad, India

The Convention on Biological Diversity (CBD), established during the 1992 Earth Summit in Rio de Janeiro, is the foremost international treaty addressing biodiversity loss, recognizing IAS as a key driver. Its objectives—biodiversity conservation, sustainable use, and equitable benefit-sharing—incorporate IAS management through instruments such as the Aichi Biodiversity Targets, which call for identifying and controlling IAS and managing their pathways.

In particular, Aichi Target 9 (under the CBD’s Strategic Plan for Biodiversity 2011–2020) called on member states to identify, prioritise, and manage IAS and their pathways, and to integrate IAS control into national biodiversity strategies. Despite this, rising global trade and travel have intensified the risk of new invasions, underscoring the need for stricter measures and updated targets³.

The CBD plays a pivotal role in facilitating cooperation between countries to manage IAS through collaboration with organisations like the World Health Organization and the International Plant Protection Convention helping to strengthen biosecurity frameworks and reduce IAS risks from trade and transport. Recent CBD meetings, including COP15, have further emphasised early detection, rapid response, and regional collaboration as key pillars of IAS management³¹⁵.

The CBD also promotes inclusive governance by encouraging the integration of traditional knowledge with scientific approaches. Local and indigenous community engagement is now a key part of IAS management strategies. The post-2020 global biodiversity framework builds on these commitments, proposing more ambitious IAS targets with improved monitoring and reporting mechanisms^{3,315}.

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) plays a pivotal role in bridging science and policy, offering evidence-based assessments that guide global biodiversity and governance. Recognising IAS as a major driver of biodiversity loss, IPBES has underscored their far-reaching impacts on ecosystems, economies, and human well-being. Its 2019 Global Assessment highlighted how climate change is accelerating the spread of IAS into ecologically vulnerable regions³¹⁶.

A key contribution is its thematic assessment on IAS³¹⁶, which provides a comprehensive understanding of the scale and consequences of biological invasions. The assessment supports global policy efforts, including the CBD, by promoting adaptive and science-led approaches to IAS management. IPBES emphasises the need for coordinated, multi-stakeholder action; urging governments, international bodies and civil societies to strategies and build capacity, especially in the developing world. Additionally, IPBES identifies several key impediments to the successful management of IAS, particularly in the developing world, including gaps in knowledge and information, inadequate legislation, weak enforcement, low awareness, limited capacity and resources, and conflicting interests. Through advocating predictive tools to assess the risk of IAS under future climate scenarios, IPBES strengthens global preparedness and enhances the integration of IAS into broader biodiversity frameworks. Its work reinforces the importance of collaborative governance in confronting one the most complex and urgent environmental threats of our time.

7.1.2 | NATIONAL POLICIES AND LEGISLATION ON IAS MANAGEMENT

India's legal framework for managing IAS remains fragmented and insufficient, despite the country's biodiversity richness and growing vulnerability to biological invasions. The primary legislation addressing biological introductions is the **Plant Quarantine (regulation of import into India) Order, 2003**, which mandates pest risk analysis for all imported plant material. However, this framework includes only a limited number of recognised IAS, offering inadequate coverage, especially for invasive plants.

Other laws such as the **Destructive Insects and Pests Act of 1914**, regulate pest movement but overlook invasive animals and plants. Broader conservation legislations, including the **National Forest Policy of 1988 and the Wildlife (Protection) Act, 1972**, prioritise wildlife and habitat protection but lack specific provisions to address IAS³¹⁷.

The **Integrated Forest Management Scheme (IFM)**, introduced in 2009, targets the control of IAS in forested areas. However, its implementation has been hindered by limited awareness, resource constraints, and legal contradictions. For instance, the Wildlife Act, which prohibits removal of any life form, including invasive species, from protected areas, poses a barrier to active IAS management³¹⁷.

India's commitments under international agreements such as the **Convention on Biological Diversity (CBD)** and the **Aichi Biodiversity Targets**, has encouraged the development of national strategies aligned with global standards. These include identifying and managing priority IAS. However, progress has been limited due to data gaps, weak institutional coordination, and divergent stakeholder interests. For example, the **National Biodiversity Authority (NBA)** and the **ENVIS Centre on Floral Diversity**—operating under the Ministry of Environment, Forest, and Climate Change (MoEFCC)—maintain separate lists of recognised IAS, underscoring the absence of a unified national database³¹⁷. Without standardised data and inter-agency alignment, effective national monitoring, early detection, and rapid response remain constrained.

In this regard, the **Non-Native Risk Management (NNRM)** scheme offers a promising model. It applies a structured multi-parameter scoring system to evaluate IAS, factoring in ecological, economic, and social risks, along with expert judgement and confidence scoring-aligned with risk-assessment frameworks proposed by Reshi & Rashid³¹⁸.

Another governance gap lies in the unregulated domestic trade of potentially invasive plants. Online nurseries actively market species like *Lantana* and *Mimosa pudica*, both ranked among the world's worst invasives, with little oversight, enabling their widespread proliferation across India³¹⁷.

To address these persistent issues, experts have proposed a **National Invasive Species Strategy and Action Plan (NISSAP)**. The plan would establish a coordinated response across government departments, trade bodies, and local communities. It would include a risk assessment framework to categorise species into “blacklisted” (prohibited) and “whitelisted” (permitted). Additionally, consumer and trader awareness campaigns would also aim to reduce reliance on invasive species in sectors handicrafts and biofuel production³¹⁷.

Ultimately, while India has policies that touch on IAS, and in the case of Tamil Nadu, there exists a state-level sectoral policy on IAPS management and restoration (TN PIPER), the absence of an integrated enforceable national strategy continues to undermine effective management. Strengthening biosecurity protocols, harmonising legislation, building institutional capacity, and improving public awareness are critical to creating a coherent and proactive national IAS response.

7.1.3 | INSTITUTIONAL FRAMEWORK: ROLE OF COMMUNITY ORGANISATIONS, NGOS, AND RESEARCH INSTITUTIONS IN IAS MANAGEMENT

Managing IAS in India requires a coordinated approach involving research institutions, NGOs, and local communities, especially as globalisation climate change and intensive land and sea use change accelerate the arrival and spread of invasive species^{4,319}.

Key organisations, such as the Indian Council of Agricultural Research (ICAR), Zoological Survey of India (ZSI), and Kerala Forest Research Institute (KFRI), have led efforts to identify, assess, and manage IAS across agricultural, forest, and aquatic ecosystems. ICAR focuses on invasive pests, weeds, and diseases affecting crops and livestock³¹⁹, while KFRI has conducted extensive research on invasive plants like *Mikania micrantha*, *Senna spectabilis*, *Acacia mearnsii*, and *Lantana* in forested landscapes.

Institutions like the National Biodiversity Authority (NBA), particularly through its Centre for Biodiversity Policy and Law (CEBPOL), have compiled national lists of invasive species and developed criteria for species designation. Additionally, universities like Banaras Hindu University (BHU) and the University of Kashmir contribute to ecological and genetic studies, helping predict future invasions and their impact in the context of climate change³¹⁹.

Despite these efforts, institutional capacity remains limited. The number of IAS-focused researchers in India is relatively small, and studies tend to be species-specific or site-limited, hindering a national understanding of invasion dynamics and their socio-ecological impacts.

In the non-governmental sector, organisations such as CABI run campaigns to educate the public, farmers, and forestry workers about the ecological and economic threats posed by IAS. These NGOs provide critical knowledge on identifying and controlling IAS and often serve as intermediaries between research institutions, government agencies, and local communities.

Some NGOs also engage in policy advocacy and ecosystem-level planning. For instance, Wetland International South Asia and IORA Ecological Solutions work with governmental bodies to develop conservation strategies aimed at preventing the spread of IAS in vulnerable ecosystems. Others, like the Salim Ali Centre for Ornithology and Natural History, contribute to national databases on invasive species and support the development of control strategies. Many have also led successful on-ground efforts, such as the removal of *Neltuma* in Keoladeo National Park, which helped restore the wetland's ecological balance³¹⁹.

Community organisations and local groups are often the first responders to IAS threats, particularly in rural and remote regions where state intervention is limited. They support early detection, rapid response, and habitat restoration through activities such as manual removal of invasives and replanting of native species³¹⁹. Their local knowledge and involvement are vital for ensuring sustained management efforts, especially in agriculture, forestry, and fisheries, where invasive species cause the most damage. After invasive species removal, community organisations often lead restoration efforts, which include replanting native species and rehabilitating degraded land. Additionally, these groups conduct workshops and training sessions to build capacity for IAS management.

National parks and protected areas have benefited from integrated efforts combining scientific research, policy support, and local engagement. The management of *Lantana camara* in the Western Ghats, for example, showcases how collaborative approaches involving local forest departments, NGOs, and community groups can effectively address invasive species challenges³¹⁹.

However, major challenges persist: fragmented research, limited data, lack of resources, and reactive strategies remain barriers to effective IAS control. Proactive biosecurity measures are often underprioritized. Moving forward, India needs a more integrated approach—one that boosts research funding, strengthens cross-sector partnerships, and promotes restoration and public awareness—to better tackle the expanding threat of biological invasions^{11,319}.

7.2 | INTEGRATING SOCIAL AND ECONOMIC IMPACTS OF IAS INTO RESEARCH AND MANAGEMENT FRAMEWORKS

The management of IAS in India demands an integrated approach that considers not only the ecological impacts but also the economic and social consequences of these invasions. The rising financial burden of IAS is often underestimated due to gaps in impact data and limited reporting on control and restoration costs, which underscores the need for more robust research frameworks capable of accurately quantifying these impacts⁷⁵. Moreover, rural, and indigenous communities, particularly those reliant on natural resources, are disproportionately affected by IAS.

Despite this, the human dimensions of invasive species, i.e., how IAS affect livelihoods and human wellbeing and how these impacts are perceived by people¹³⁴, remain poorly understood. Most impact assessments are led by natural scientists, with little integration of socio-economic perspectives. This can result in the systematic underestimation of certain types of impacts and the overall magnitude of impact, particularly for conflict-generating species, as well as limit our ability to evaluate trade-offs across ecological, economic, and social outcomes²⁷⁹.

Addressing these gaps requires greater support for interdisciplinary research that aims to quantify or assess the social, economic, cultural, and public health impacts of IAS. In addition, collaborative projects between natural and social scientists to assess impacts of IAS on livelihoods could lead to the evolution of suitable inter-disciplinary frameworks for impact assessment and importantly, enabling more inclusive and effective management strategies.

7.3 | BRIDGING KNOWLEDGE GAPS: AMELIORATING DATA COLLECTION AND ANALYSIS

Despite the widespread social and economic impacts of IAS, India still lacks comprehensive, nation-wide assessments. Most studies remain limited to specific regions or species, hindering the development of targeted, region-specific strategies across the country's diverse ecosystems¹³².

To address this, research frameworks must prioritise the collection of more comprehensive data, including the indirect costs of IAS, such as health impacts and loss of ecosystem services. Establishing a dedicated national biological invasion research programme would help centralise data, standardise methodologies, and enable more consistent evaluation of IAS impacts¹³².

In parallel, predictive modelling should integrate climate change scenarios to forecast future invasion patterns. As climate change makes more regions hospitable to IAS, early warning systems based on these models will be essential for protecting vulnerable ecosystems and communities^{2,5}.

7.4 | COMMUNITY-LED MANAGEMENT AND RESTORATION EFFORTS

Community participation is critical to effective IAS management, especially in areas with limited government capacity. Local knowledge and involvement in activities such as manual removal and habitat restoration have led to successful outcomes¹³⁴. For example, in the Western Ghats, community-driven efforts to remove *Lantana* have led to the regeneration of native forests and the restoration of local biodiversity. Such participatory approaches ensure that IAS management strategies are culturally appropriate and tailored to the specific needs of the affected communities^{2,164}.



Lantana removal in the Western Ghats | Photo: Wikimedia Commons





8

SYNTHESIS AND CALL FOR ACTION

8.1 | Key messages

8.2 | Call for further
research and action to
address the IAS challenge

8.1 | KEY MESSAGES



The unmitigated spread of invasive alien species (IAS) in every major habitat and ecosystem throughout the country has imposed vast and ever-increasing costs on major sectors of the Indian economy, civil society, and natural ecosystems. [Section 3 & 4]



Critical information gaps on the distributions and impacts of most IAS on native biodiversity and human well-being in India persist, hampering the development of effective management strategies and policies. [Section 6.4]



In the case of a few, widespread IAS, particularly those that were introduced to provide resources (e.g., food, fuel), there are complex trade-offs between positive and negative impacts on biodiversity, ecosystem services and human well-being that need to be better understood and accounted for in development of management strategies. [Section 6.3.4]



There is limited understanding of how ongoing habitat degradation, pollution, land cover change, and climate change are affecting the spread of IAS in India. [Section 6.4]



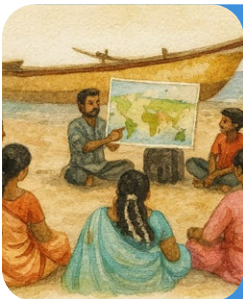
There is an urgent need to strengthen national capacity for the prevention of IAS introductions, risk assessment, and effective detection, monitoring, and management in India. [Sections 6.1 ,6.2, 6.3]



Resource allocation for IAS prevention and management must be significantly enhanced. [Section 7]



An exclusive national policy and action plan are needed to address IAS. Effective governance requires coordination across multiple government departments to prevent new invasions and manage existing IAS in both natural and human-dominated landscapes. [Section 7.1.2]



Awareness of the spread and negative impacts of IAS remains limited among government agencies and across sectors of civil society. Targeted outreach and education efforts are needed to bridge this gap. [Section 7.1.3]

8.2 | CALL FOR FURTHER RESEARCH AND ACTION TO ADDRESS THE IAS CHALLENGE

By enhancing data collection, involving local communities, and adopting an interdisciplinary and multidisciplinary approach to research and management, India can mitigate the far-reaching consequences of biological invasions on its biodiversity and people. Incorporating these dimensions will enable policymakers to develop more comprehensive strategies that protect both ecosystems and communities.

Specific actions that should be undertaken include:

- Creating a national database on IAS, with a strong spatial and mapping component, which will enhance our capacity to detect and prevent new invasions, develop effective management, and control strategies.
- Prevention of new IAS introductions is a critical priority. This underscores the need for improved surveillance and screening at ports of entry, supported by stronger biosecurity regulations. Enhancing these systems will also strengthen early warning mechanisms. Additionally, establishing and enforcing domestic quarantine measures is essential to curb the spread of IAS within the country.
- Promoting risk assessment, early detection, rapid response, eradication, and containment. Additionally, invest in the development of robust diagnostic tools and techniques to identify and prevent invasions.
- Strengthening the capacity of government agencies and other stakeholders in research, prevention, and management to effectively intercept new introductions and manage established IAS.

- Improving coordination across government departments involved in natural resource management to enable integrated IAS management and reduce the risk of new introductions.
- Facilitating collaborations between government departments, researchers, and civil society organizations, to compile ecological and social data on IAS. These collaborations can support long-term monitoring and adaptive management plans.
- Implementing tailored management strategies for different ecosystems (wetlands, inland waters, islands, grasslands, forests, agricultural systems), that account for the presence of multiple IAS and incorporate species-specific interventions based on the biological stage of invasion.
- Broadening the scope of existing research efforts to consider a wider range of species and impacts (including trade-offs between different kinds of impacts), to better understand the full extent of IAS effects and the consequences of different management approaches.
- Prioritising building awareness about IAS and their impacts across all sectors of civil society through public campaigns using various media. Integrating IAS-related content into school and college curricula.
- Promoting regional and international collaboration to share information on impending threats of invasion and to facilitate adoption of new tools and techniques for IAS surveillance and control.
- Establishing a federal agency with a mandate to coordinate information generation, create periodic monitoring mechanisms, institute management and developing a policy and action plan to address IAS.





9

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Cover Image : Ramya Ravi
Buffaloes and other livestock in the region often rest beneath expansive groves of *Neltuma juliflora* - a widespread invasive alien species, locally known as vatthans, which provide much-needed shade in the arid landscape. These vatthans are deliberately nurtured and maintained by the Maldharis, the pastoralist communities of Banni