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Alien weeds and their effect on Indian agriculture

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Abstract
Invasive alien plant species are among the most pressing challenges to global biodiversity, agriculture, forestry, livestock and human health. Weeds, described as unwanted plants since the dawn of civilization, cause 10-80% crop losses depending on management practices, with average losses of 36.5% in *Kharif* and 22% in *Rabi* seasons. In India, the economic burden of invasive species has exceeded $127 billion over six decades, with major weeds such as *Parthenium hysterophorus*, *Lantana camara*, *Eichhornia crassipes*, and *Salvinia molesta* severely impacting ecosystems and productivity. Their success is attributed to rapid growth, prolific reproduction, genetic variability, long seed dormancy, allelopathy, and capacity to adapt across habitats. Invasions are facilitated by ecosystem disturbances, nutrient enrichment, lack of natural enemies, and global trade, typically progressing through introduction, establishment, lag, and expansion phases. These weeds not only displace native flora but also disrupt ecosystem services, degrade soil and water quality, reduce food and fodder security, and increase risks to livestock and human health.
Biological control has emerged as an effective and eco-friendly management approach. Successful examples include *Zygogramma bicolorata* against *Parthenium hysterophorus*, *Neochetina* spp. against water hyacinth, and *Cryptobagous salviniae* against *Salvinia molesta*, which have significantly reduced weed populations without complete eradication. Such interventions alleviate economic losses, restore ecological balance, and reduce reliance on herbicides, especially as more than 270 weed species are herbicide-resistant globally. However, despite a century of progress, gaps persist in awareness, policy, and large-scale implementation. To address the ecological and socio-economic threats posed by invasive alien weeds, there is an urgent need for integrated strategies that combine prevention, early detection, biological control, habitat restoration, and strict quarantine measures. This chapter synthesizes the biology, mechanisms, impacts, and management of invasive alien weeds with special reference to India, highlighting the need for coordinated, science-based solutions.

Key words: Alien weeds, biological control, allellopathy and ecosystem

1. Introduction

Weeds, defined as undesirable plants growing where they are not wanted, were first conceptualized in an agricultural context by early agronomists such as Jethro Tull (1731) [1], and they have coexisted with cultivated crops since the advent of organized agriculture nearly 10,000 years ago. Their persistence poses a serious threat to crop productivity worldwide. Depending on the crop, weed density, and timeliness of control measures, reported yield losses range from 10% to as high as 80% (Oerke, 2006) [2]. In India, average crop losses attributable to weeds are estimated at 36.5% during kharif and 22% in rabi seasons, making weed management one of the most critical factors influencing crop production (Gharde *et al.*, 2018) [3]. In fact, weed control alone can account for nearly one-third of the total cost of cultivation in several crops (Rao, 2011) [4].

Adoption of integrated weed management (IWM) practices has the potential to significantly enhance agricultural productivity. Estimates suggest that effective IWM could contribute an additional 103 million tonnes of food grains, 15 million tonnes of pulses, 10 million tonnes of oilseeds, and over 50 million tonnes of commercial crops annually in India (Yaduraju, 2012) [5]. Such an increase would translate into economic gains comparable to current national agricultural outputs, valued at more than Rs. 1 lakh crore per annum.

However, invasive alien weeds further exacerbate this challenge. India has incurred over USD 127 billion in economic losses over the past six decades due to biological invasions, making it the second most affected nation globally after the United States (Rai *et al.*, 2021) [6]. Field demonstrations consistently show that effective weed management interventions can boost crop yields by 5-30%, depending on crop and ecosystem conditions (Rao, 2011) [4]. Parallel to these trends, herbicide usage in India has grown rapidly from less than 1,000 metric tonnes in the early 1980s to more than 6,000 MT in 2016-17, with wheat accounting for the highest share (57%), followed by rice (17%), plantation crops (9%), and soybean (4%) (Gharde *et al.*, 2018) [3]. This upward trend reflects both the increasing pressure of weed infestations and the growing reliance on chemical weed management across major cropping systems.

2. Invasive Alien Weeds

Invasive alien species are non-native plants or organisms that establish, proliferate, and spread rapidly in new environments, causing significant ecological, environmental, health, and economic damage. They disrupt natural habitats, displace native biodiversity, alter ecosystem processes, and threaten the ecological integrity of invaded landscapes (CBD, 2001). Globally, invasive alien plants have drawn the attention of ecologists, conservation biologists, forest managers, and policy makers due to their profound impacts on ecosystem functioning and the services ecosystems provide (Mack *et al.*, 2000) [8]. Their unchecked spread can be catastrophic, with far-reaching consequences for biodiversity conservation, environmental stability, and even global food security (MEA, 2005).

In India, many invasive weeds entered inadvertently through contaminated agricultural imports particularly food grains during the mid-20th century. Since then, species such as *Lantana camara*, *Parthenium hysterophorus*, *Salvinia molesta*, and *Eichhornia crassipes* have spread aggressively across agricultural landscapes, forests, and wetlands. These invasives reduce crop productivity, suppress native flora, alter soil microbial communities, and pose severe health hazards to humans and livestock (Rai *et al.*, 2021). Among the various management strategies, classical biological control has emerged as one of the most effective, sustainable, and environmentally benign approaches for controlling invasive weeds, outperforming mechanical or chemical methods in long-term suppression and ecosystem restoration (Julien & Griffiths, 1998) [10].

3. Biological Control of Weeds

Biological control of weeds involves the deliberate use of natural enemies such as insects, mites, and pathogens to suppress invasive plant populations and reduce their harmful ecological and economic impacts. Unlike chemical herbicides, classical biocontrol does not aim to eradicate weeds but seeks to restore ecological balance by keeping weed populations below damaging thresholds. With more than a century of global successes, biological control has demonstrated its effectiveness in managing numerous invasive weeds worldwide (Julien & Griffiths, 1998) [10]. However, despite its proven potential, many countries affected by serious infestations have adopted biological control only to a limited extent, leaving substantial room for expansion through improved international collaboration and knowledge sharing (McFadyen, 1998) [11].

The need for sustainable weed management is further underscored by the rapid rise of herbicide resistance, with more than 270 weed species worldwide evolving resistance to one or more herbicide modes of action (Heap, 2023). In this context, biological control offers a robust, long-term alternative. Introducing multiple natural enemies against a single weed species has often enhanced suppression levels. A prominent example is Australia, where nine different biocontrol agents were introduced against *Parthenium hysterophorus*, resulting in substantial reductions in its density and competitiveness across seasons and regions (Dhileepan & McFadyen, 2012) [13]. A similar integrated multi-agent strategy holds promise for India, particularly against widespread invasive weeds such as *Parthenium hysterophorus*, *Chromolaena odorata*, *Mikania micrantha*, *Eichhornia crassipes*, *Pistia stratiotes*, and *Alternanthera philoxeroides*.

The following are well-documented biological control agents along with their respective target weed species

Insect	Scientific name	Family / Order	Target weed
Leaf-feeding beetle	*Zygogramma bicolorata*	Chrysomelidae, Coleoptera	*Parthenium hysterophorus*
Flea beetle	*Agasicles hygrophila*	Chrysomelidae, Coleoptera	Alligator weed (*Alternanthera philoxeroides*)
Stem-boring moth	*Niphograpta albiguttalis*	Crambidae, Lepidoptera	*Eichhornia crassipes* (Water hyacinth)

Case Studies of Successful Weed Biocontrol in India

4.1 Water Hyacinth (*Eichhornia crassipes*)

Water hyacinth, first reported in India in 1896, has become one of the most destructive aquatic weeds, severely affecting water bodies, fisheries, irrigation systems and biodiversity. Classical biological control has been a major strategy for its management. Two weevil species *Neochetina eichhorniae and Neochetina bruchi* (Coleoptera: Curculionidae) were introduced and established successfully in several parts of India, where they substantially reduced plant vigour and biomass by continuous feeding and oviposition damage (Jayanth, 1987; Jayanth & Visalakshy, 1994) [14, 15]. Additional agents such as Orthogalumna terebrantis (Acarina: Galumnidae) were released in limited areas, while Cornops aquaticum was later evaluated under controlled conditions for its potential use (Baloch *et al.*, 2008) [16]. One of the most successful biocontrol demonstrations occurred in Hebbal Tank, Bengaluru, where the introduction of Neochetina spp. resulted in nearly 95% reduction of water hyacinth within two years, leading to significant ecological recovery and economic savings (Jayanth, 1988) [17].

Lantana (*Lantana camara*): Lantana camara is among the most widespread invasive alien plant species in India, infesting an estimated 13 million hectares of forest and wasteland (GISIN, 2012). Over the past century, several biological control agents have been introduced globally and in India to manage this weed, including Epinotia lantanae (Lepidoptera: Tortricidae), *Lantanophaga pusillidactyla* (Lepidoptera: Pterophoridae), *Octotoma scabripennis* (Coleoptera: Chrysomelidae), *Ophiomyia lantanae* (Diptera: Agromyzidae), and *Orthezia insignis* (Hemiptera: Ortheziidae). Many of these agents established but exhibited only limited or localized impact, similar to global experiences (Julien & Griffiths, 1998; Day *et al.*, 2003) [10, 19].

One of the most notable introductions in India was the tingid bug Teleonemia scrupulosa (Hemiptera: Tingidae), released by the Forest Research Institute (FRI) during the 1940s. Although it caused significant defoliation of Lantana initially, its impact later diminished, and concerns were raised when the insect was found feeding on teak (*Tectona grandis*) flowers, leading to discontinuation of official releases (Sankaran *et al.*, 1989) [20]. Despite this, T. scrupulosa escaped containment and is now naturalized across several Indian states, where it continues to feed on Lantana but provides only moderate suppression (Sankaran *et al.*, 1989; Sharma *et al.*, 2005) [20, 21]. These experiences highlight the complexity of Lantana biocontrol and the need for integrated management strategies.

4.3. Water Fern (*Salvinia molesta*): *Salvinia molesta*, native to southern Brazil, is a highly invasive aquatic fern that rapidly clogs water bodies, disrupting irrigation, fisheries, and local biodiversity. It was first reported in India from Vole Lake, Kerala, in 1955 (Center *et al.*, 2002) [22]. To manage this weed, the weevil Cyrtobagous salviniae (Coleoptera: Curculionidae) was imported from Australia in 1982 and released in Bengaluru during 1983-84. The biological control program was highly successful: within three years, previously abandoned canals became navigable due to substantial reduction in *Salvinia* biomass (Jayanth, 1987) [14]. By 1988, the use of this agent alone was estimated to save approximately Rs. 68 lakh annually in paddy cultivation costs in Kerala, demonstrating the economic and ecological benefits of classical biocontrol.

4.4Carrot Weed (*Parthenium hysterophorus*): *Parthenium hysterophorus*, commonly known as carrot weed, was introduced into India in 1955 through contaminated food grain imports from the USA and rapidly spread to nearly 35 million hectares, although effective control has now been achieved in about 7 million hectares (~20%) (Evans, 1997) [24]. Initial biological control efforts began in 1983 with the introduction of three Australian insects: a defoliating beetle, a flower-feeding weevil, and a stem-boring moth. Of these, only the leaf-feeding beetle *Zygogramma bicolorata* (Coleoptera: Chrysomelidae) passed host-specificity tests, while the other agents were rejected due to non-target risks (Jayanth & Bali, 1993) [25].

Controversy arose when *Z. bicolorata* was reported feeding occasionally on sunflower, prompting the Government of India to temporarily ban its release in 1991. A subsequent evaluation by a government-appointed Fact-Finding Committee confirmed the beetle's safety, and the ban was lifted in 1999 (Dhileepan, 2001) [26]. The first official release occurred in Bengaluru in 1984, after which the beetle spread naturally to neighboring countries, including Nepal and Pakistan (Shabbir *et al.*, 2013) [27].

In addition to exotic agents, native insects such as *Nupserha* sp. (Cerambycidae) were observed feeding on Parthenium, reducing flowering and seed set (Kumar, 2009) [28]. Overall, the introduction and establishment of *Z. bicolorata* remains one of the most successful and well-documented examples of classical weed biocontrol in India, demonstrating both ecological and economic benefits.

Mechanism of Invasion: The invasive process of alien plant species generally follows a sequence of four distinct phases explaining how a species progresses from accidental or deliberate introduction to large-scale dominance in a new habitat (Richardson *et al.*, 2000) [29].

5.1 Introduction: Species introductions occur either through natural agents such as birds, animals, wind, or water, or through human-mediated pathways. In the modern era, increasing globalization, international trade, and enhanced human mobility have greatly accelerated the unintentional transfer of invasive species across continents (Mack *et al.*, 2000) [8]. Contaminated food grains, nursery trade, timber imports, ballast water discharge, and ornamental plant introductions are among the most common pathways that facilitate the entry of alien weeds into new ecosystems.

5.2 Establishment: Following introduction, only a fraction of species manage to establish successfully. Establishment depends on the species' ability to overcome ecological barriers, adapt to local climatic and edaphic conditions, and compete with native vegetation. Traits such as prolific seed production, vegetative reproduction, allelopathic potential, and escape from natural enemies often give invasive weeds a competitive advantage (Rejmánek & Richardson, 1996).

5.3 Lag Period: Many invasive weeds exhibit a lag phase characterized by little or no visible population growth. This period allows the species to undergo genetic or ecological adaptation before rapid spread begins. The lag phase may last from a few years to several decades, with most invasive plants displaying an average lag period of 20-30 years, while around 4% of species globally exceed 40-year lag phases (Crooks, 2005) [31]. During this silent phase, weeds remain largely unnoticed, complicating early detection and management.

5.4 Expansion Phase: After the lag phase, the weed enters the expansion phase, marked by rapid increase in population density and spatial spread. This is typically the most destructive stage, during which invasive species displace native vegetation, disrupt ecological processes, and cause significant economic losses in agriculture and forestry (Lockwood *et al.*, 2013) [32]. Most management efforts are concentrated in this stage, although eradication is rarely feasible, shifting the focus instead to containment and suppression.

6. Major Invasive Alien Weeds in India

India hosts a diverse range of ecosystems that are increasingly threatened by the spread of invasive alien weeds. These species, introduced intentionally or accidentally from other regions, often possess aggressive growth habits, strong allelopathic effects, and high ecological adaptability. As a result, they out compete native flora, reduce agricultural productivity, degrade rangelands, and disrupt hydrological systems. Understanding their botanical traits, origin, and associated threats is essential for designing effective management strategies. Table 1 provides a consolidated overview of major invasive alien weeds prevalent in India, highlighting their native range, growth habit, ecological impacts, and key references documenting their invasiveness.

Table 1: Major Invasive Alien Weeds in India

S.No.	Species and Common name	Family and Habit	Native	Threats	References
1	*Ageratum conyzoides* (Goat weed)	Asteraceae-Herb	Tropical America	Allelopathic, highly invasive, threat to croplands of Himalayan region.	Dogra *et al.*, 2009; Roder *et al.*, 1998[33, 34]
2	*Eupatorium adenophorum* (Crofton weed)	Asteraceae - Shrub	Mexico	Allelopathic effect causes serious threats to native flora.	He & Liu 1990
3	*Eichhornia crassipes* (Water hyacinth)	Pontederiaceae - Aquatic herb	Tropical South America	Serious aquatic weed, allelopathic in nature, causes hindrance in navigation, reduces water quality and algal growth.	Raghubanshi *et al.*, 2005; Sun *et al.*, 1988[36, 37]
4	*Lantana camara* (Lantana)	Verbenaceae - Shrub	Tropical America	Strongly allelopathic, serious threat to medicinal plants, responsible for forest fire.	Sharma *et al.* 2005; Raghubanshi *et al.*, 2005[21, 36]
5	*Mikania micrantha* (Mile-a-minute)	Asteraceae- Herb	Sub-tropical zones of America	Known for its allelopathic potential, highly invaded forest areas.	Raghubanshi *et al.*, 2005; Zhang *et al.*, 2002[36, 38]
6	*Parthenium hysterophorus* (Congress Grass or Carrot Grass)	Asteraceae- Herb	Tropical America	Aggressive colonizer, highly allelopathic, allergic to animals and humans, threat to crops and other native flora.	Kohli & Rani 1994; Kanchan & Chandra 1980; Kohli & Batish 1994[39, 40]
7	*Argemone mexicana* (Mexican Prickly Poppy)	Papaveraceae - Herb	Tropical Central & South America	Harms native flora through allelopathy.	Reddy 2008[42]

Why Invasive Species Gain Advantage over Native Biota

Invasive plant species often gain a competitive advantage over native vegetation due to a suite of biological and ecological traits (Rejmánek & Richardson, 1996). They typically show rapid growth rates and short life cycles, enabling fast colonization of new habitats. High resource-use efficiency, prolific flowering, and large seed output provide abundant propagules for dispersal (van Kleunen *et al.*, 2010) [43]. Many invasive weeds succeed across diverse environments because of high genetic variability and strong adaptive evolutionary responses (Sakai *et al.*, 2001) [44]. Traits such as long seed dormancy, staggered germination, and effective dispersal further enhance persistence. Invasive plants often reproduce via both sexual and asexual means, increasing their resilience to control efforts (Baker, 1965) [45]. Their ability to utilize local pollinators and adopt distinct phenological patterns helps them avoid direct competition with native species (Pyšek & Richardson, 2007). Some invasive species modify habitat conditions by altering soil chemistry, nutrient dynamics, or microclimate, while others form dense canopies that suppress native vegetation (Ehrenfeld, 2003) [48]. Additionally, many invasive plants suffer reduced herbivore and pathogen pressure a pattern explained by the well-supported "enemy release hypothesis" (Keane & Crawley, 2002) [47] allowing them to thrive even in ecosystems where native species decline.

Role of Ecosystems in Facilitating Biological Invasion

The susceptibility of an ecosystem to invasion is strongly influenced by its ecological characteristics and level of disturbance. Habitats disturbed by natural events such as fire or flood, or by anthropogenic activities such as land clearing, overgrazing, and urban expansion, often provide entry points for alien species (Elton, 1958) [50]**.** Similarly, newly established or recovering vegetation is particularly vulnerable to invasion. Ecosystems with geographical or historical isolation and inherently low native diversity tend to offer limited biotic resistance, thereby facilitating the establishment of invasive plants. The addition of fertilizers can create nutrient-rich conditions favorable to invasive species, while pesticide use often reduces natural competition from native flora and fauna. Moderately moist habitats are more susceptible to invasion than extremely arid or waterlogged environments. Furthermore, ecosystems with fertile soils, slow recovery rates after disturbance, and a lack of natural enemies such as competitors, herbivores, or pathogens provide ideal conditions for invasive plants to establish and spread (Davis *et al.*, 2000 & Richardson and Pysek, 2006) [49, 46, 51].

Allelopathy and its Role in Plant Invasion

Allelopathy is defined as the adverse effect of one plant on another through the release of secondary metabolites into the environment (Rice, 1984) [52]. This phenomenon plays a significant role in the success of alien invasive plants, where allelopathic interference helps suppress native vegetation and enhances invader dominance (Hierro & Callaway, 2003) [53]. Among the secondary metabolites, phenolic acids and terpenoid compounds are the most common allelochemicals produced by invasive weeds. These compounds inhibit nutrient uptake, disturb cell division, and suppress root and shoot elongation in native species (Inderjit & Callaway, 2003) [54]**.** Additionally, allelochemicals may alter membrane permeability, inhibit chlorophyll formation and protein synthesis, and even inactivate certain hormones and enzymes. Some allelochemicals directly disrupt photosynthesis by interfering with photosystem II. Through these mechanisms, invasive species create unfavorable conditions for native plants, thereby gaining a competitive advantage and spreading rapidly in new habitats (Inderjit *et al.*, 2005) [55].

Environmental and Economic Impacts of Invasive Plant Species: Invasive alien plants exert profound negative impacts on biodiversity, ecosystem functioning, agriculture, forestry, livestock production, human health, and tourism. They destroy native biodiversity by decreasing the density and frequency of indigenous flora and, in some cases, driving species to extinction. The Millennium Ecosystem Assessment identified invasive alien species as one of the major drivers of biodiversity loss in the last 50-100 years

(MEA, 2005). For example, *Psidium cattleianum* forms monocultures in Mauritius, while *Parthenium hysterophorus* has invaded large tracts of agricultural land in India and Australia. Dense covers of *Lantana camara* reduce light penetration, thereby preventing the natural regeneration of tree seedlings (Sharma & Raghubanshi, 2009) [56].

Agricultural productivity and food security are also severely threatened. Invasive weeds like *Lantana camara*, *Parthenium hysterophorus*, *Argemone mexicana*, and *Eupatorium odoratum* (now *Chromolaena odorata*) compete with crops for nutrients and water, while simultaneously reducing the availability of native fodder species for livestock. Certain species such as *Lantana* are highly toxic to cattle, and their seeds remain viable for decades, making eradication extremely difficult (Sharma *et al.*, 2005) [21]. Similarly, *Parthenium* poses health hazards to livestock and humans, causing dermatitis and respiratory disorders (Lakshmi & Srinivas, 2007) [57].

In forest ecosystems, invasion by alien species can be catastrophic. For instance, *Tamarix ramosissima* and *T. chinensis* (salt cedar) introduced in the western United States have spread over hundreds of thousands of hectares, leading to reduced water tables, increased fire hazards, and displacement of native vegetation (Zavaleta, 2000; Di Tomaso, 1998) [58]. Invasive species also impact ecosystem services such as water purification, pollination, nutrient cycling, and soil fertility. Watersheds dominated by invasive plants exhibit reduced runoff and altered hydrology, often resulting in flooding (Pejchar & Mooney, 2009) [60]. Furthermore, invasive plants can alter soil microbial communities and nutrient dynamics, making soils less suitable for native flora while favoring their own persistence (Ehrenfeld, 2003) [48].

From a socio-economic perspective, the costs of invasive species are enormous, with global estimates exceeding US $400 billion annually (Pimentel *et al.*, 2005) [61]. Rural livelihoods are particularly affected as invasives reduce forest product availability, which many communities rely upon. Human health is another domain of concern: *Echium plantagineum* contains toxic pyrrolizidine alkaloids harmful to grazing animals, while the sap of *Heracleum mantegazzianum* causes severe phytophotodermatitis in humans (Nielsen *et al.*, 2005) [62]. *Parthenium* pollen is known to cause allergic rhinitis and asthma. Aquatic invasives like *Eichhornia crassipes* pollute water bodies, deplete oxygen levels, and create breeding habitats for mosquitoes, increasing the incidence of vector-borne diseases (Villamagna & Murphy, 2010) [63].

Tourism also suffers when landscapes and water bodies become dominated by invasive plants. Dense thickets of *Lantana camara* block access to protected forests and diminish landscape aesthetics (Sharma *et al.*, 2005) [21]. In the Galápagos Islands, the invasion of *Lantana* has contributed to the decline of endemic plant species, threatening ecological uniqueness and affecting educational tourism (Tye, 2001) [64]. Aquatic invasives such as *Eichhornia crassipes* and *Alternanthera philoxeroides* disrupt boating, swimming, and other recreational activities, reducing the appeal of ecotourism destinations (Villamagna & Murphy, 2010) [63].

Conclusion

The menace of invasive alien plant species has been intensifying in recent decades, largely accelerated by globalization, international trade, and human mobility. These species pose a formidable challenge to ecosystems by altering natural processes and displacing native flora and fauna. Their impacts are multidimensional ranging from reducing agricultural, livestock, and forest productivity to altering soil properties, promoting land degradation and disturbing essential ecosystem functions. Invasive weeds influence fundamental ecological processes such as species composition, nutrient cycling, food webs, hydrology and fire regimes, thereby destabilizing ecosystems that have evolved over centuries.

Beyond ecological consequences, invasive alien plants also present enormous socio-economic and human health concerns. They compromise food security by competing with crops for nutrients and water, decrease fodder availability for livestock, and in many cases, poison animals and humans. The invasion of forest ecosystems threatens not only biodiversity but also the livelihoods of rural communities dependent on forest products. Furthermore, their role in spreading human and livestock diseases, as well as their impact on tourism and recreation, underlines the extent of their far-reaching consequences. Collectively, these effects represent massive ecological and economic losses on a global scale.

While considerable research has documented the biology, ecology, and harmful effects of invasive species, a substantial gap remains between scientific awareness and effective decision-making. Policy frameworks and management strategies often lag behind the rapid pace of invasion, leading to delayed responses that allow alien plants to establish, spread, and become nearly irreversible problems. Current evidence highlights the urgent need for updated monitoring systems and comprehensive data collection to track invasions more effectively.

Moving forward, a multidisciplinary approach is crucial integrating ecological research, socio-economic assessments, public awareness, and strong administrative support. Effective management and eradication require collaboration among scientists, policymakers, local communities, and international agencies. Preventive measures such as strict quarantine regulations, early detection, and rapid response programs should be prioritized. Simultaneously, restoration of invaded ecosystems and promotion of native biodiversity are essential to counteract long-term impacts.

In conclusion, invasive alien plant species represent one of the greatest challenges to global biodiversity conservation and sustainable development. Addressing this issue requires urgent, coordinated, and science-based action. Only through holistic and collaborative strategies can we safeguard native biodiversity, secure ecosystem services, and mitigate the economic and ecological costs associated with biological invasions.

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