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Invasive plants: Unveiling the invasion process, ecological effects and management approaches

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The ecological disruptions caused by the invasive species are increasingly recognized as a significant threat to global sustainability. Invasive Alien Plant Species (IAPS) are particularly concerning due to their role in biodiversity decline and consequent changes to ecosystem functions and socio-economic conditions through various means. While the ecological impacts of IAPS are well-documented, there is a lack of research on their economic assessment, effects on livelihoods, potential biotechnological applications such as phytoremediation, bio-energy, synthesis of nano particles, biomedical and industrial uses, and human health risks associated with them. The management strategies can be strengthened by integrating geo-spatial technologies like remote sensing and GIS to map and monitor the spread of IAPS. Additionally, the scope of IAPS management should include ecological indicators, bio-security measures, and risk assessment protocols with thorough discussion. Both positive and negative impacts of IAPS on the environment, health, ecosystem services, and socio-economy are outlined to inform the development of effective policy frameworks aimed at mitigating the human health implications associated with IAPS management.

Key words: Invasion, Biodiversity, Ecological indicators, Health risk, Sustainable management

1. Introduction

Biodiversity plays a crucial role in supporting human well-being and providing essential ecosystem services, including

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food production, medicine and environmental protection (Aerts et al., 2018; Stone et al., 2018; Jones, 2019). Species which cross over their natural distribution and get introduced to new habitats are known as alien species. Despite its significance, invasive alien plant species (IAPS) pose serious threats to local biodiversity, ecosystem services, and human health (Pejchar and Mooney, 2009; Kueffer, 2017; Jones and Mc Dermott, 2018; Bartz and Kowarik, 2019). The United Nations' Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES) warns that about one fifth of the Earth's surface including biodiversity hotspots, is at risk due to biotic invaders (IPBES, 2019). High income countries, particularly in the European Union, Australasia, and North America, face a higher prevalence of IAPS, driven by increased trade and transport activities (Seebens et al., 2018).

IAPS not only threaten ecosystems but also impede advancements in biomedical sectors due to global environmental changes induced by land-use and climate change (Ebi et al.,2017). Human-mediated transport continues to spread IAPS across diverse environments, disrupting ecosystems and contributing to their negative impact on human health (Rai, 2015; Kueffer, 2017). The complex interplay between IAPS, biodiversity loss and human health requires careful consideration in socio-ecological and socio-economic perspectives. Loss of native plant diversity through IAPS can affect air quality, carbon sequestration, and indirectly impact human health (Jones and McDermott, 2018).

2. Modes of plant invasion

Introduction of the species to the new location can either be accidental or intentional. ‘Invasion ecology’ refers to the

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examination of the human-mediated introduction of invasive alien plant species (IAPS) to areas beyond their native range. This involves processes such as transportation, establishment, colonization, and the spread across landscapes. Apart from intentional introductions by humans, there are instances of alien species being introduced through natural means. For instance, *Limnocharis flava* in Kerala is thought to have been introduced by ocean currents as coconuts have been dispersed to various locations, including islands, through waves and ocean currents. As a result, the scope of invasion ecology is steadily broadening.

The term commonly referenced as alien/non-native/exotic/introduced species pertains to organisms existing in a new region, distinct from their original habitat. Human activities play a key role in facilitating IAPS to overcome various bio-geographical barriers. Notably, the invasive potential of these species varies along the naturalization-invasion continuum. In essence, IAPS are plant species characterized by efficient reproductive strategies, both vegetative and through seeds, allowing them to sustain self-replacing populations, even in remote areas. The presence of IAPS can have a significant impact on native plants in the invaded region - those species that have evolved in a specific area without human intervention, thriving through natural processes.

Human-induced disruptions have not only caused the worldwide proliferation of IAPS, but have also significantly influenced the mechanisms of invasion (Kueffer, 2017). A comprehensive understanding of the fundamental mechanisms driving the success and impacts of IAPS is crucial for ecological and health risk assessments (Stohlgren and Schnase, 2006). The complexity of why IAPS succeed in diverse environments necessitates investigation within the context of specific IAPS. To achieve this, exploring species-specific mechanisms is essential, considering their varying invasive potential aligned with ecosystem attributes (Ehrenfeld, 2008). Several hypotheses, such as enemy release (ERH), novel weapon (NWH) and empty niche (EN), have been suggested to elucidate the invasion of IAPS into new environments. However, no single hypothesis is adequate to comprehensively explain IAPS invasions. Sharma et al. (2005) argue that the most relevant hypothesis is always specific to the particular IAPS under consideration. In this context, the ERH hypothesis suggests that certain IAPS thrive in new habitats due to the absence of natural enemies, such as pathogens and herbivores, present in their native environments (Blumenthal, 2006). For example, *Impatiens glandulifera* seeds in newly invaded regions are devoid of fungal pathogens (Najberek et al., 2018).

Allelopathy constitutes an ecological process involving biotic interference through bioactive molecules. Remarkably, allelochemicals are recognized as novel weapons (NW) that significantly suppress native species, facilitating the colonization of IAPS in new habitats. These allelochemicals, which are secondary metabolites like phenolics, terpenoids, and sesquiterpenes, exert adverse effects on native plant species (Pinzone et al., 2018). Phenolic compounds, among these allelochemicals, are widespread and often contribute to allelopathy. Certain IAPS, such as *Fallopia japonica* (Japanese knot weed) in the United Kingdom, release

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allelochemicals acting as novel weapons that profoundly alter food webs (Abgrall et al., 2018). Similarly, *Chromolaena odorata* secretes odoratin, a novel allelochemical, conferring the ability to defend against enemies, particularly soil-borne pathogens, thereby granting the IAPS a competitive advantage over native species (Zheng et al., 2015).

Moreover, a comprehensive understanding of plant-microbe and insect interactions, encompassing both mutualistic and antagonistic relationships, is crucial for unraveling the mechanisms of IAPS spread (Jack et al., 2017). Nutrient enrichment, both in terrestrial and aquatic ecosystems, plays a pivotal role in the success of IAPS in new habitats (Aragon et al., 2014). For instance, elevated nitrogen levels in soils are identified as a factor aiding *Bromus tectorum* (Cheat grass) in outcompeting native flora (Morris et al., 2016). Additionally, intriguing research reveals that the impact of IAPS on soil carbon pools and local climate correlates with differences in the traits of the IAPS and native species (Martin et al., 2017).

3. List of invasive alien plant species (IAPS)

According to the study conducted by Sajeev et al. (2012) under Kerala Forest Research Institute, 38 invasive alien plant species are found in the forests of Kerala. Of these, 10 are high risk, 12 pose medium risk, 10 pose low risk and the rest 6, are insignificant. High risk species represents a severe threat to native species and ecological communities. Medium risk species causes moderate threat while low risk species represents relatively low threat. Insignificant species represents an insignificant threat to native species and ecological communities. Further information regarding

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invasive alien plant species found in Kerala is given in Table 1.

3.1 High risk IAPS

3.1.1 *Acacia mearnsii* De Wild.

Identified as exceedingly invasive in Mannavanshola, Pambadumshola and Eravikulam National Park, this variety is a rapidly expanding, evergreen, nitrogen-fixing tree introduced to Kerala during the 1980s to reforest high-altitude grasslands. Its cultivation primarily targets the tannin-rich bark. Demonstrating aggressive colonization tendencies, especially in moist tropical environments resembling warm temperate climates, these trees generate copious long-lasting seeds that germinate massively post-fire events. Additionally, through the release of potent allelochemicals, they impede the establishment of native flora nearby. Invading neighboring grasslands, they heighten the risk of forest fires due to their tannin-laden bark. Consequences of their proliferation includes reduced stream flow, biodiversity decline, heightened soil erosion, and increased riverbank instability.

Table 1. Invasive alien plant species in Kerala

Sl. No.	Species	Family	Risk category	Native place
	Acacia mearnsii De Wild.	Mimosaceae	High	Australia
	Ageratina adenophora (Spreng.) King & Robins.	Asteraceae	Medium	Central America
	Ageratum conyzoides L.	Asteraceae	Low	Central America
	Alternanthera bettzickiana (Regel) G.	Amaranthaceae	Insignificant	America

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	Nichols.			
	Alternanthera brasiliana (L.) Kuntze	Amaranthaceae	Low	Central and South America
	Alternanthera philoxeroides (Mart.) Griseb.	Amaranthaceae	Insignificant	South America
	Amaranthus spinosus L.	Amaranthaceae	Low	Central and South America
	Asclepias curasavica L.	Asclepiadaceae	Insignificant	America
	Centrosema molle Benth.	Fabaceae	Low	America
	Cestrum aurantiacum Lindl.	Solanaceae	Medium	Central America
	Chromalaena odorata (L.) King & H. Rob.	Asteraceae	High	America
	Clidemia hirta (L.) D. Don	Melastomataceae	Low	Central and South America
	Erigeron karvinskianus DC.	Asteraceae	Low	South America
	Hyptis capitata Jacq.	Lamiaceae	Medium	Central America
	Hyptis suaveolens (L.) Poit.	Lamiaceae	Medium	America
	Ipomea purpurea (L.) Roth	Convolvulaceae	Medium	Central America
	Jatropha gossypifolia L.	Euphorbiaceae	Insignificant	South America
	Lantana camara L.	Verbanaceae	High	Central and South America
	Leucaena leucocephala (Lam.) de Wit	Mimosaceae	Low	America
	Merremia vitifolia (Burm.f.) Hallier f.	Convolvulaceae	High	Asia
	Mikania micrantha Kunth	Asteraceae	High	South America
	Mimosa diplotricha C.	Fabaceae	High	South

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	Wight ex Sauvalle var. diplotricha C. wight ex Sauvalle			America
	Mimosa diplotricha C. Wight ex Sauvalle var. inermis (Adelb.) Veldk.	Fabaceae	Low	South America
	Mimosa pudica L.	Fabaceae	Low	South America
	Mucuna breacteata DC. ex Kurz	Fabaceae	High	Asia
	Parthenium hysterophorus L.	Asteraceae	Medium	South America
	Pennisetum polystachyon (L.) Schult.	Poaceae	Medium	Africa
	Phytolacca octandra L.	Phytolaccaceae	Insignificant	America
	Prosopis juliflora (Sw.) DC.	Mimosaceae	High	South America
	Pueraria phaseoloides (Roxb.) Benth.	Fabaceae	High	Asia
	Senna hirsuta (L.) Irwin & Barneby	Ceasalpiniaceae	Medium	America
	Senna occidentalis (L.) Link	Ceasalpiniaceae	Low	South America
	Senna spectabilis (DC.) Irwin & Barneby	Ceasalpiniaceae	Medium	America
	Senna tora (L.) Roxb.	Ceasalpiniaceae	Medium	America
	Sphagneticola trilobata (L.) Pruski	Asteraceae	High	America
	Synedrella nodiflora (L.) Gaertn.	Asteraceae	Insignificant	West Indies
	Tithonia diversifolia (Hemsl.) A. Gray	Asteraceae	Medium	Central America
	Measopsis eminii Engl.	Asteraceae	Medium	West and Central Africa

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3.1.2 *Chromolaena odorata* (L.) King & H

Unintentionally introduced from Assam in the 1940s, this rapidly growing, erect or sprawling perennial shrub is widely distributed across most forests in Kerala. Despite naturalizing in numerous areas, it still forms dense thickets capable of over topping plants up to 20 meters in height due to its phenotypic adaptability. The species exhibits high reproductive efficiency and its seeds are dispersed by wind, rendering its management challenging. Addressing this species necessitates re-establishment strategies where eradicating it is complemented by facilitating the regeneration of native plants to phase out the invasive species.

3.1.3 *Lantana camara* L.

Initially introduced for decorative purposes, this compact, upright, and robust shrub densely populates open, sunlit environments. It dominates as an undergrowth species, disrupting natural progression and diminishing indigenous biodiversity. The persistent growth of this shrub can effectively halt rainforest regeneration for extended periods. It represents a significant menace to disturbed forests, where vast swaths of land are overtaken by this singular species. Adopting mechanical eradication methods followed by the reintroduction of native plants is imperative to rehabilitate habitats and prevent these sites from serving as launching points for further incursions deep into the forest.

3.1.4 *Merremia vitifolia* (Burm. f.) Hallier f.

Frequently encountered along the edges and openings of forests, this perennial vine possesses the capacity to overwhelm indigenous vegetation entirely, obstructing

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sunlight access to the native species below. It spreads vigorously and reproduces asexually, proving exceedingly challenging to manually uproot, especially as the plant matures and its stem thickens over time. In instances where it ascends to the forest canopy, severing the main stem could desiccate the plant and heighten the risk of canopy fires by increasing the fuel load. Hence, any encroachment by this plant should be promptly addressed to prevent suppression of native flora.

3.1.5 *Mikania micrantha* Kunth

An expeditiously growing perennial vine deliberately introduced from South America as a ground cover for rubber plantations, exhibits extensive distribution throughout Kerala. It possesses the ability to ascend to the forest canopy from forest edges and spread across it, adversely affecting tree growth within the forest as well as the vegetation underneath. It aggressively occupies gaps created by fallen trees in natural forests. Numerous young teak plantations in moist environments suffer heavy infestations by *Mikania*. Reproduction occurs through both sexual and vegetative means; vegetative propagation from fragmented foliage thrives particularly in moist soil and air conditions. During flowering, it attracts a plethora of pollinators, including butterflies, thereby exerting competitive pressure on the regeneration of native species. As the foliage dries, it also poses a risk of canopy fires and should be eradicated upon establishment to mitigate this danger.

3.1.6 *Mimosa diplotricha* var. diplotricha

Originally introduced as a nitrogen-fixing ground cover for coffee plantations, this rapid-growing trailing plant can aggressively overrun native vegetation. Both spiny and non-spiny variants exist, with the former displaying the highest level of aggression. It scrambles vigorously over indigenous plants, forming dense, tangled thickets reaching heights of up to 3 meters, inhibiting the regeneration, reproduction, and growth of native species. Due to its thorn presence, herbicide application is favored over mechanical removal. The species proliferates in non-forest areas, posing a significant risk of invasion into forests. Early detection and swift eradication are imperative to safeguard forests from this species.

3.1.7 *Mucuna bracteata* DC. ex Kurz

A swiftly proliferating perennial vine, creeping and vigorously climbing, deliberately introduced as a nitrogen-fixing ground cover that exhibits drought and shade tolerance. It has the capacity to suffocate, overwhelm, and stunt native trees through its prolific growth and climbing behavior. Reproduction primarily occurs through seeds and fibrous roots originating from nodes. This species has breached plantation borders and commenced aggressive incursions into forests from their perimeters. Once established, it becomes exceedingly challenging to eradicate. Stringent legislation is necessary to prevent its usage in plantations adjacent to forests.

3.1.8 *Prosopis juliflora* (Sw.) DC.

A thorny, rapid-growing, small to medium-sized evergreen tree with a squat, twisted trunk and expansive canopy has been a subject of extensive debate in India. While many view it as a species that fulfills the fuel requirements of communities in arid regions, it is also recognized as a formidable invasive species due to its capacity to diminish habitat carrying capacities. In Kerala, it is prevalent in the dry deciduous forests of Chinnar Wildlife Sanctuary. Left unchecked, it can establish dense, impenetrable thickets that pose significant threats to indigenous flora and fauna. Moreover, it can desiccate the soil and vie with other plants for water, particularly in arid regions. Given the context of global climate change, careful monitoring of this species is essential as it may compromise the resilience of native species.

3.1.9 *Pueraria phaseoloides* (Roxb.) Benth.

Introduced for utilization as a ground cover in rubber plantations owing to its nitrogen-fixing abilities and shade tolerance, this vigorous, deeply rooted, twining, and climbing legume thrives in various soil types. It proliferates abundantly in vacant lands and forest edges, with the capability to ascend to the canopy and envelop medium-sized trees completely. Legislative measures are warranted to regulate its deployment in plantations neighboring other plantations.

3.1.10 *Sphagneticola trilobata* (L.) Pruski

A creeping, mat-forming perennial herb indigenous to the tropical regions of Central America, this species is extensively cultivated for its aesthetic appeal, often erroneously utilized even in gardens adjacent to forest offices due to its striking yellow blooms juxtaposed against lush green foliage. Exhibiting a broad ecological adaptability, it thrives equally well in both sunlit and shaded environments. It effectively outcompetes native species, including numerous medicinal

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plants. Despite producing minimal viable seeds, its flowers are abundant in nectar, attracting pollinators away from indigenous species. Public awareness regarding the threat posed by this species must be disseminated widely to prevent its introduction into forests, as its removal necessitates long-term restoration strategies.

4. Impacts of plant invasion

4.1 Environmental impacts of IAPS

The impact of invasive alien plant species (IAPS) on ecosystem functioning is more pronounced in islands compared to the mainland. IAPS influence ecosystem functioning through three fundamental mechanisms: (a) diminishing the diversity of native plants and animals, (b) inducing significant alterations in the physico-chemical attributes of soils, primarily through allelopathy, and (c) amplifying ecosystems' responsiveness to modified fire regimes (Pysek et al., 2012). A well-documented consequence of IAPS is the reduction in the biodiversity of native plants, carrying potential adverse implications for environmental functioning, ecosystem services, and global climate change (Heshmati et al., 2019). The recognized role of IAPS in native biodiversity loss is widely acknowledged; however, their presumed contribution to extinction is a subject of debate among invasion ecologists. To either refute or confirm this, a consistent dataset across diverse habitats, especially in islands, is essential (Sax and Gaines, 2008). Intense competition for crucial resources regulating ecosystem functioning between IAPS and native flora may result in the phenomenon termed 'invasion meltdown'. According to the invasion meltdown hypothesis, the establishment of one invasive species in a new

environment facilitates the invasion of other non-native species (Simberloff and Von Holle, 1999). It is noteworthy that the initial impact of IAPS, namely the reduction in biodiversity, is consistently observed globally.
Moreover, alien invaders have detrimental effects on wildlife. For example, *Spartina alterniflora* displaces native macrophytes (*Phragmites australis* and *Scirpus mariqueter*) in Chinese wetlands, leading to declines in avian populations due to movement and feeding restrictions (Gan et al., 2009). In aquatic systems, IAPS can invade through unique physiological characteristics such as high biomass and deep roots, hindering water flow and rendering it unsuitable for drinking and irrigation (Pejchar and Mooney, 2009). IAPS also contribute to increased flood frequency by narrowing stream channels and altering soil attributes like decreased water holding capacity and increased soil erosion, ultimately harming native plant communities and posing human health risks. Lizarralde (1993) reported that the IAPS, *Castor canadensis*, also disrupt water quality and increase flood risk.

IAPS further impact the quantity of surface and ground water (Shackleton et al., 2019). *Prosopis pallida*, a nitrogen-fixing IAPS in arid regions of Hawaii Island, exploits groundwater resources to an extent that alters the soil environment (Dudley et al., 2014). Some IAPS consume substantial amounts of water, exacerbating water scarcity impacts and causing shifts in socio-ecological regimes (Shackleton et al., 2019). Reports indicate that IAPS alter soil stability, leading to soil erosion (Pejchar and Mooney, 2009). Invasions by noxious IAPS, such as spotted knapweed (*Centaurea stoebe*), leafy spurge (*Euphorbia esula*), and cheat grass (*Bromus tectorum*), can

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profoundly impact the soil quality of grassland ecosystems (Gibbons et al., 2017). *Acacia dealbata*, an IAPS in the Mediterranean ecosystem, reduces native plant diversity by negatively affecting soil chemistry and microbial functioning (Lazzaro et al., 2014).

4.2 Impacts of the IAPS on ecosystem services

Numerous IAPS are recognized for their impact on various ecosystem services including aesthetic, recreational, cultural, and regulatory aspects (Pejchar and Mooney, 2009). As IAPS often obstruct water navigation, they can negatively influence recreation and tourism services (Eiswerth et al., 2005). Restrictions on the sale of ornamental IAPS to mitigate environmental harm have been reported to impact the aesthetic services of ecosystems. Many IAPS also affect regulatory ecosystem services linked to agriculture and forestry such as hazards mitigation, water treatment, pest management, pollination, and climate change (Pejchar and Mooney, 2009). The invasion of *Opuntia stricta* in the African region has adverse effects on the environment and economy, impacting the livelihoods of local people by reducing fodder and livestock health (Shackleton et al., 2017). The widespread cultivation of multi-purpose trees and shrubs is promoted to enhance bioenergy and industrial sectors (Rai et al., 2018). However, the introduction of IAPS as multi-purpose species, for example, the introduction of *Prosopis* sp. in South Africa, can significantly impact ecosystem services (Shiferaw et al., 2019).

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4.3 Economic impacts of the IAPS

Several IAPS introduced for human welfare, are recognized for causing environmental and economic havoc. Therefore, understanding people's perceptions of IAPS and their local ecological knowledge becomes an effective approach to categorize the impacts of IAPS. In this context, *Acacia mangium*, an IAPS in the northern Brazilian Amazon, is noteworthy for its detrimental effects on the economy, environment, and indigenous people through alterations in water quality (Souza et al., 2018). The invasion of aquatic macrophytes such as *Eichhornia crassipes* (Water hyacinth) in Lake Victoria has become a menace for human welfare, reducing fish production and eco-tourism potential (Pejchar and Mooney, 2009). The invasion of *Tamarix ramossissima* has resulted in a substantial loss of water (1.4-3.0 billion cubic meters) in the USA, depriving various human needs (Zavaleta, 2000). Similarly, *Melaleuca quinquenervia* in Florida and *Eucalyptus* species in California, with their deep tap roots, utilize a significant quantity of groundwater (Schmitz et al., 1997).

4.4 Impacts of the IAPS on human health

Biodiversity and its fluctuations are intricately intertwined with human health, both positively and negatively. Positive impacts of IAPS include their applications in vector-borne control and ethno-medicinal uses. For example, a mosquito repellent is derived from *Lantana camara* (Mngong et al., 2011). Certain biotic invasive species affect human health through environmental contamination. For example, invasive plant pathogens like the emerald ash borer, causing massive devastation to ash trees in the United States, which previously acted as a sink for air pollutants (Jones and McDermott, 2018). Elevated levels of air pollutants can increase regional losses in tree diversity, resulting in severe health implications, including mortality (Jones and McDermott, 2018). Losses of host plants are known to spur the growth of pathogen populations, facilitating outbreaks of diseases like Tick-borne diseases, Tuberculosis, severe acute respiratory syndrome (SARS), acquired immunodeficiency syndrome (AIDS), and virulent Malaria (Hulme, 2014; Young et al., 2017; Stone et al., 2018). These severe human diseases and their sudden outbreaks across continents are reminiscent of biotic invasions themselves. An increase in the pathogen population due to host loss caused by land use change or global warming has led to the emergence of new diseases like Dengue and Yellow fever by *Aedes aegypti*, Lyme disease, African horse sickness, Chikungunya fever, Nipah virus disease etc (Hulme, 2014; Young et al., 2017; Stone et al., 2018).

Beyond public health, IAPS also affect the health of plants (Young et al., 2017). Several IAPS like cheat grass increase the outbreak of fungal pathogens, adversely affecting the health of native plants (Beckstead et al., 2010). In certain instances, pathogenic IAPS (blight fungus, *Cryphonectria parasitica*) completely eliminate existing dominant native life forms (*Castanea dentate* or American chestnut in the eastern deciduous forest of the US) (Parker et al., 1999). Furthermore, a high-risk plant invader *Parthenium hysterophorus* is demonstrated to spread phytoplasmas, a vegetable pathogen, characterized using molecular tools (16S rRNA and lineage-specific immune-dominant membrane protein genes). Interestingly, Cai et al. (2016) observed that phytoplasmas infecting vegetables belong to the same genetic lineage as

Parthenium. Ambrosia artemisiifolia, Parthenium hysterophorus, Ailanthus altissima, Acacia, Acer, Casuarina, Eucalyptus, Helianthus, Platanus and *Xanthium* are some of the IAPS causing allergies in humans (Belmonte and Vila, 2004; Mazza et al., 2014; Stone et al., 2018).

5. Management of invasive plants

An essential aspect of addressing the threats posed by IAPS and formulating effective action plans for their management and biodiversity restoration is the economic evaluation. The Generic Impact Scoring System (GISS), a significant assessment protocol, identified 149 plants as the worst invaders among the 486 investigated IAPS in Europe (Vila et al., 2019). While scoring methods for impact quantification are valuable, they often focus on local and regional aspects, and the occurrence of cryptogenic/cryptic alien species presents a challenge in protocol formulations (Ricciardi et al., 2013). The risk analysis of IAPS remains incomplete due to insufficient data on ecological impacts, transparency/repeatability, and the inclusion of uncertainty factors in assessments (Vanderhoeven et al., 2017). Therefore, there is a need for concrete impact assessment protocols to quantify the environmental and socio-economic impacts of IAPS (Vila et al., 2019). Considering the negative implications of many IAPS, there is an urgent need to prioritize and formulate cost-effective and environmentally feasible strategies for their management. 'Biosecurity' emerges as a management strategy to minimize the harmful environmental, economic and human health impacts of IAPS (Pyšek and Richardson, 2010). Integrating biosecurity into biodiversity conservation policies, as closely linked to food security, is crucial for protecting crops from IAPS and insect invaders (Sileshi et al., 2019). Sustainable bio-control programs should be implemented for IAPS management in both natural and agro-ecosystems. The international community should unite for an integrated approach to safeguard global biodiversity from IAPS and emerging infectious diseases (Zhou et al., 2019). Thus, we can follow certain guidelines as follows:

- Rigorous monitoring of all plants and soil entering forests for construction purposes, nursery saplings, etc. to detect any presence of IAPS in saplings, plant parts, or propagules
- Implementing quarantine procedures for imported cover crops for plantations to prevent further introductions of IAPS
- Restricting the movement of soil and plant parts from IAPS infested areas to other parts of the forest
- Regular surveillance of tourist and pilgrimage routes and areas within forests to promptly identify and eradicate new IAPS
- Managing weed-infested areas during the reproductive phase of AIS to prevent seed dispersal to uninfected areas.
- Simultaneously implementing both eradication and restoration programs in a time-bound manner.

An optimized and effective biosecurity surveillance of invaders can facilitate the implementation of mitigation measures at the initial invasion stage (Poland and Rassati, 2019). Further, optimizing biosecurity surveillance can prevent economic losses by managing insect invaders at an early stage of establishment (Yemshanov et al., 2019). Additionally, international and national biosecurity policies (International Standards for Phytosanitary Measures - ISPMs; CBD) incorporate risk assessment as an integral component of overall plant/human health risk analysis (Lindgren, 2012). However, ranking the invaders, impacting the agriculture/human health biosecurity by predicting their risk is still inadequate. This must be prioritized by each nation for the effective threat analysis (Yemshanov et al., 2019).

6. Conclusion

Although invasive alien plant species (IAPS) often have negative effects on native biodiversity and ecosystem services, their exact role in species extinctions is a topic of debate among invasion ecologists. However, the UN-IPBES recently recognized biotic invaders as significant contributors to biodiversity decline. Human-induced disturbances are the primary factors driving biotic invasions. Continued anthropogenic disruptions may lead to the emergence of new IAPS, posing risks to both the environment and human health. However, by gaining a comprehensive understanding of the various mechanisms involved in the arrival, spread, and establishment of IAPS, we can effectively manage them in a sustainable manner. In invasion ecology, greater attention should be directed towards studying the chemical ecology of interactions between native and invasive plant species to better understand the mechanisms underlying biodiversity loss. It is essential to delve deeply into emerging global issues such as biodiversity loss, climate change, unsustainable agriculture, and environmental disturbances to comprehend their interconnected impacts on human health.

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