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REVIEW

Alien Plant Invasions in India: Current Status and Management Challenges

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Abstract Invasive species are a major driver of global environmental change contributing to the loss of biodiversity, altering of ecosystem structure and functioning, and affecting provision of ecosystem services worldwide, including in India. In view of globalization of Indian economy and consequential increase in international travel and trade, introduction, establishment and spread of alien species is likely to escalate in India with serious ecological and socio-economic consequences. A recent study has reported the occurrence of 1,599 alien plant species belonging to 841 genera in 161 families in India, and the alien flora thus represents 8.5 % of the total Indian vascular flora. While the taxonomic inventory of alien species represents the first important step, but more detailed studies on characterization of alien species on the basis of their stage of invasion, identification of potentially invasible habitats/ecosystems, detection of introduction pathways and vectors of alien species, assessment, mapping and monitoring of invasive species using modern geo-spatial technology such as hyperspectral remote sensing, impact assessment, containment, control and restoration are still lacking in India and hence impede effective management of plant invasions in the country. It is in this context that an integrated research and policy framework for the management of alien plant invasions in India is proposed.

Keywords Invasive species · Geo-spatial technology · Mapping · Impact assessment

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Introduction

Biological invasions constitute one of the serious environmental concerns of the present times because of their high ecological and economic costs [1, 2]. The ecological impacts include displacement of native species [3], alteration of ecosystem structure by disrupting food webs and species interactions [4], alteration of ecosystem processes [5], induction of genetic and evolutionary changes in native biota [6–8]. The estimated annual economic damage from invasive alien species (IAS) worldwide totals more than US $1.4 trillion per annum—close to 5 % of GDP [2]. Annual economic losses due to IAS in various countries have been estimated to be about US $30 billion in USA [9], €12 billion in Europe [10], £1.7 billion in Great Britain (GB Non-native species Secretariat), US $14 billion in China [11]. In view of these ecological and economic impacts of IAS, parties to the convention on biological diversity, in 2010 in Nagoya, Japan, adopted the strategic plan for biodiversity 2011–2020 in which the Target 9 under the Strategic Goal B stipulates that by 2020, IAS and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment. Such initiatives have stimulated efforts to quantify patterns in the extent of biological invasion, its impact on biodiversity and policy responses [12]. The €2.4 million pan-European research project delivering alien invasive species inventories for Europe (DAISIE) funded by the European Commission was recently completed and it has far-reaching scientific, management and policy implications [13]. Likewise, a number of similar studies on the alien floras of many neighbouring Asian countries, such as China, [14–17], Singapore [18], Japan [19], Korea [20]; Taiwan [21], have also been undertaken.

Table 1 Estimates of alien flora in India

Author	Estimate of alien species
Chatterjee [27]	39 % of the flora of Indian subcontinent is alien
Maheshwari [28]	40 % of Indian flora is alien
Saxena [29]	40 % of Indian flora is alien
CBD [30] "India's 3rd National Report"	40 % of Indian flora is alien, of which 25 % is invasive
Goyal and Arora [22] "India's 4th National Report" to CBD	173 alien plant species are invasive

Table 2 Taxonomic conspectus of alien flora of India after Khuroo et al. [31]

Plant group	No. of families	No. of genera	No. of species
Angiosperms	152	825	1,552
Gymnosperms	8	16	46
Pteridophytes	1	1	1
Total	161	842	1,599

Like other parts of the world, India is also beset with the problem of alien plant invasions [22] and it is going to further exacerbate due to increasing globalization of Indian economy. In fact, the magnitude of merchandise imports is a significant determinant of the number of alien species [23–25] as well as the rate of new species introductions [26]. Since India is a mega-biodiverse country, the implications of invasive species on the conservation and sustainable use of biodiversity would be much pronounced. Hence, there is an urgent need to develop an integrated framework for the prediction, prevention, rapid response and control of alien plant invasions in India.

Current Status

Inventory of Alien and Invasive Species

India lacks a comprehensive database of alien species belonging to different taxonomic groups, though several estimates of alien flora [27–29] have been projected (Table 1). Objective analysis of these estimates reveals that such approximations are grossly speculative and are not based on authentic and reliable data.

Recently, a relatively more reliable estimate of alien flora of India (Table 2) has been provided by Khuroo et al. [31]. The percentage of alien flora according this estimate is only about 8.5 % of the total Indian vascular flora. This study, based on the systematic review of ca. includes 190 studies published over the last 120 years (1890–2010 AD) and field observations, has identified 1,599 plant alien species belonging to 842 genera in 161 families in India.

Since this comprehensive catalogue of alien plant species of India is based mostly on published studies, it would be worthwhile and prudent to undertake extensive field surveys of manageable spatial units which could be either political units (such as a state) or biogeographic units [32] to further improve this published database and have a more exhaustive inventory of alien species based on the framework provided by Khuroo et al. [33].

Characterization of Alien Species

It is important to characterize alien species on the basis of their life-form, growth-form, invasive status and other biological traits. Such characterization helps in identifying the syndrome of traits that contribute to invasiveness of alien species which in turn paves way for developing a predictive trait-based risk assessment protocols. It is for these reasons Khuroo et al. [31] also recognized alien plant species of India into different categories of invasion status (Table 3).

Categorization of alien species in terms of their invasion status, i.e. the status which a species has attained in the invasion process (introduction–naturalization–invasion continuum) assumes most importance. Usually three categories, namely casual, naturalized and invasive are recognized following Richardson et al. [34]. *Casuals* are alien species that do not form self-replacing populations and rely on repeated introductions into the area; *naturalized* are those alien species which reproduce consistently without direct human intervention but do not necessarily invade local vegetation while *invasives* are those alien species that have the potential to form large populations and spread rather quickly over a considerable area. Such a characterization, on one hand, is very useful in identifying the potential invasive species, and on the other hand, it helps in prioritizing the alien species that have already established and require immediate control and containment measures. It is for these reasons the alien plant species of India were categorized [33] and the number and proportion of species belonging to various categories are given in Table 3. However, intensive surveys throughout India need to be undertaken for more region-specific categorization of alien plant species. Another hierarchical stage-based approach to characterize alien species has been proposed by Colautti and MacIsaac [35] on the basis of spatial distribution and population abundance of alien species in their non-native range. Despite having scope in the management of alien species, it has been used only by Khuroo et al. [36] to characterize alien flora of the Kashmir Himalaya. Out of the total of 436 alien invasive plant species recorded in the region, the number of species belonging to invasion stages II, III, IVa, IVb and V was 119, 107, 56, 77 and 77 species, respectively (Table 4).

Such a hierarchical approach could be used for characterizing alien flora of India but detailed data needs to be

Table 3 Characterization of alien flora of India on the basis of invasion status

Category	Sub-category	Number of species	% Age of species
Invasion status	Cultivated un-escaped aliens	812	50.78
	Casual aliens	57	3.56
	Casual/naturalized aliens	114	7.13
	Naturalized aliens	257	16.07
	Naturalized/invasive aliens	134	8.38
	Invasive aliens	225	14.07

Table 4 Stages of invasion recognized by Colautti and MacIsaac [35] and number of invasive species belonging to each of these stages in the Kashmir Himalaya, India

S. no.	Stage of invasion	Characteristics	Number of species
1	0	Potential IAS (or their propagules) in their native range(s)	Not applied
2	I	Potential IAS (or their propagules) in the transport vector(s)	Not applied
3	II	IAS (or their propagules) released and introduced into their non-native range(s)	119
4	III	IAS that reproduce and establish their populations in the non-native range(s)	107
5	IVa	IAS become widespread in distribution but form populations with limited number of individuals	56
6	IVb	IAS remain localized in distribution but form abundant populations	77
7	V	IAS become widespread in distribution and form abundant populations	77

collected about the spatial spread (occurrence of alien species across various sites/spatial units) and abundance (number of individuals of species within sites/spatial units) of alien species. Such an approach would pave way for implementation of hierarchical strategy of prediction, prevention, control and restoration for the management of alien plant invasions in India.

Source Regions of Alien Flora

It is now a well established fact that the exchange of alien species between continents has not been a random phenomenon, instead it is significantly influenced by political history, cultural background, extent of trade and travel [37, 38] and climatic match between the target and source region [38–41]. Thus, the geographic origin of an alien species is an important trait that has been shown to play a key role in the temporal sequence of introductions into target regions [42, 43] and in predicting a species ability to naturalize [44]. It is precisely for these reasons that the biogeographic affiliations of the alien flora of India were worked out to identify the source regions of alien flora of India. Based on the study carried out by Khuroo et al. [31], it becomes evident that South America is the native region of 35 % of the total alien flora of India (Fig. 1). The percentage of alien plant species belonging to other continents is given in Fig. 1.

A similar analysis of the alien flora of the Kashmir Himalaya [45] revealed that Europe was the major source region for the alien flora of this region. Thus, such analyses need to be undertaken at various spatial scales in a country like India where different regions vary in cultural, geographic, climatic and socio-economic conditions and hence in the extent of alien plant invasions and composition and source of invasive species.

Pathways and Vectors of Introduction and Spread of Alien Species

Pathways are defined as a suite of processes that result in the introduction of an alien species from one geographical location to another, and vectors include dispersal mechanisms and means of introduction [46]. Pathways and vectors for alien species are numerous and can be the result of a diverse array of human activities operating over a range of scales in time and space. Good knowledge of both these categories provides options for limiting contamination of vectors, monitoring pathways for target pests, and generic management measures. Such interventions have the potential for reducing propagule pressure and thus the likelihood of establishment and spread of potential invasive species. Elucidation of introduction pathways is also crucial for informing various facets of post-incursion management [47]. Fundamental to this effort is an understanding of the diversity and patterns of the human-assisted transport mechanisms that serve to move alien species across their natural barriers.

In India, limited information exists about the pathways and vectors that are involved in the introduction and spread of alien species. However, preliminary observations and perusal of literature gives an idea about the likely pathways and vectors of transport of alien species in India. For instance, majority of intentionally introduced alien species are imported for ornamental purposes (e.g. *Lantana camara*) which then escape cultivation and spreads through seed contaminants along with introduced crop species (*Parthenium hysterophorus*).

Impact Assessment

Assessment of impact due to IAS on ecological processes, such as carbon and nitrogen cycling [48, 49], hydrological

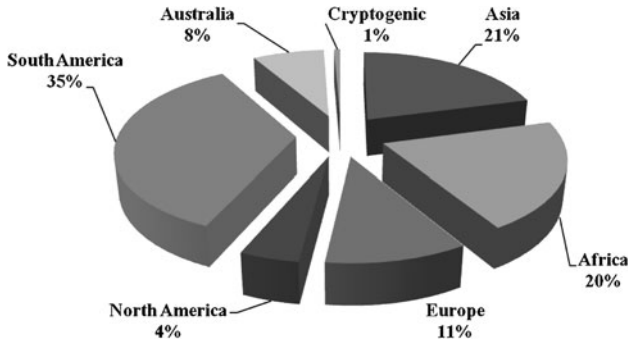

Fig. 1 Percentage contribution of various source regions to the alien flora of India

cycles [50], frequency and/or intensity of fire, normal disturbance regimes in the native communities [51, 52] and native biodiversity [53] have revealed that both the structural organization and the functional integrity of ecosystems are affected due to invasion by alien species. Recent global meta-analysis of 199 research studies dealing with 1,041 field studies involving 135 alien plant taxa revealed that abundance and diversity of resident (i.e. native) species decreased in invaded sites, whereas primary production and several ecosystem processes were enhanced [1] due to invasion by different plant species.

Although a large number of alien species have become naturalized and are now spreading as invasives in India, still only a few have been investigated with respect to their impact on native ecosystems [54] such as *L. camara* [55–59], *Chromelaena odorata* [55], *Centaurea iberica* [60], *Leucanthemum vulgare* [61], *Anthemis cotula*, *Conyza canadensis* and *Sisymbrium loeselii* [62, 63], *Prosopis juliflora* [64], *Ageratum conyzoides* [65], *Eupatorium adenophorum* [66], *Phalaris minor* [67], while economic impact of invasive species has been quantified in several countries and for several species, no such information exists for India. Thus, it is high time that studies documenting economic impact of IAS in India are undertaken to quantify the losses incurred due to their biological invasions.

Priority Invasive Species and Priority Invaded Ecosystems

In view of limited resources available for control of IAS, it is necessary to identify priority IAS following rational and objective approaches. One such rational approach could be stage-based characterization of alien species as discussed earlier. The species that are widespread as well as abundant (Stage V) could be prioritized for management.

Likewise, priority ecosystems need to be identified on the basis of their level of invasions, and two indices, namely relative alien species richness and relative alien species abundance have been proposed [68] to quantify levels of biological invasion in different ecosystems. Since this approach would guide ecosystem restoration and management, it is necessary to undertake such studies in different ecosystems of India and identify those ecosystems that are more vulnerable to alien invasions. A study carried out by Dar [69] in the Kashmir Himalaya brought out the importance of such an approach by quantifying the levels of plant invasions in different habitats (Table 5).

Table 5 Level of plant invasion in different habitats of Kashmir Himalaya

Habitat type	Level of invasion as the proportion of alien to all plant species (%)	Level of invasion as the proportion of invasive species to all alien plant species (%)
Forests	44	37
Grasslands	71	44
Roadsides	69	41

Management Challenges

The harmful effects of IAS are now widely recognized, and multiscale (local, regional, national, and international) programmes are in practice in many parts of the world to reduce current and potential future impacts. Particularly important are risk assessment, pathway management, early detection, rapid response, mitigation and restoration.

Risk Assessment

It is the first step in the risk management process. Historically, while the formal risk assessment procedures were initially developed in areas such as public health, banking, engineering, and pollution control, but now much work has been carried out in developing risk assessment frameworks for biosecurity concerns [70, 71] because preventing the introduction of species with a high risk of becoming invasive is, in theory, the most cost effective management strategy.

Predictive Modelling and Risk Assessment

Not only it is possible to predict potentially invasive species through use of various pre-introduction risk assessment schemes and prevent their introduction into non-native regions but it is also likely to identify the already introduced species that in course of time could become invasive and hence warrant rapid response. Trait-based risk assessment aims to discriminate IAS from non-invasive alien species [72–77]. There are two types of trait-based

risk assessment models, namely pre-introduction (predictive) and post-introduction (prioritization) models [78] and most attention has been focused on organism-based protocols. Besides, screening procedures with good accuracy rates (>80 % in many cases) are now available for diverse regions and taxa [79]. The development of various modelling tools for predicting species distributions and availability of fine-scale environmental data have significantly helped in predicting the risk of IAS even at a global scale [38, 80].

Early Detection and Rapid Response

The huge volume of traded commodities and multiple pathways of their transport make the interception of all potentially IAS impractical. Therefore, early detection and rapid response initiatives are a crucial ingredient of management programmes developed for invasive species. Though the rapid response must be triggered by early detection [81], but an obvious problem is that emerging invaders are rare and in many cases, such low occurrence fundamentally limits their detection. The problem is further compounded when the organisms are small, inconspicuous, or otherwise difficult to see, identify, and map. Consequently research has focused on improving protocols and technologies such as remote sensing etc. have been developed for their use in monitoring [82] and mapping [83] alien species. There is an urgent need to utilize these newly emerging technologies and approaches in India for management of biological invasions.

Eradication

For many invasive species, biological control has become and will remain the most suitable option for sustainable control. However, there is renewed interest in eradication, after Simberloff [84] argued that pessimism about the prospects of eradicating invasive species was fostered by the widespread publicity of failures and hence eradication should be attempted more often. Thus, in India also eradication of certain priority invasive species needs to be considered.

Mitigation and Restoration

Much effort has been spent on developing strategies and approaches for restoring ecosystems following degradation caused by invasive species. Interventions range from low-impact practices, involving only the removal or reductions in numbers of invasive species through many treatments that bring about reduction in the presence, abundance, or impacts of invasive species and promote the growth of native species, to massive and expensive exercises, involving engineering, reintroduction of native species, and various attempts to direct succession. Many restoration efforts have succeeded in mitigating negative impacts of invasive species with huge benefits and hence such interventions need to be considered for implementation in India as well.

Conclusions and Way Forward

Based on the above review of the current status of alien species invasions and their management in India, it becomes apparent that the necessary knowledge about the extent and impact of such species is far from complete and hence warrants immediate remedial measures. Following are the recommendations that need to be implemented for effective management of biological invasions in India.

i. A comprehensive inventory of alien species (including all taxa) growing in different biogeographical provinces of India is need of the hour in view of increase in anthropogenic activities that promote introduction, establishment and spread of alien species. To achieve this goal, an All India Coordinated Project for preparing an inventory of alien species needs to be formulated and launched. It is also imperative in view of recognition of IAS as the Target 9 of the 20 Targets of the Strategic Plan on Biodiversity (2011–2020).
ii. Identification of priority invasive species on the basis of objective criteria followed by their mapping using GIS and remote sensing tools, their impact assessment and identification of habitats/areas likely to be invaded by such invasive species in near future employing niche modelling approach needs to be undertaken.
iii. Major introduction pathways and vectors of alien species need to be detected and plugged in order to prevent further introduction of alien species that are likely to become invasive over a period of time.
iv. An institutional, legal and specific national policy framework to deal with IAS in India needs to be evolved.
v. A national alien invasive species information network with regional nodes interconnected through a web-based network is an immediate priority for quicker and easier dissemination of information about invasive species necessary for prevention and rapid response measures.

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