Chapter 19
Challenges on Account of Invasive Alien Terrestrial Plants

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19.1 Biological Invasions: Concept, History, and Current Perspective

Human-mediated intentional or accidental migration of exotic species beyond their native geographical range leads to a well-known phenomenon, *biological invasion*. Expansion of international trade, transport, and tourism led to the breakdown of biogeographic barriers and enhanced the cross-border movement of non-indigenous species (Meyerson and Mooney 2007; Hulme 2009; Capinha et al. 2015; Bertelsmeier et al. 2017). A small proportion of these migrated species, competent enough to endure the biotic and abiotic challenges presented by the novel habitat and capable of causing apparent ecological and economic impacts are defined as *invasive species* (Richardson et al. 2000; Canning-Clode 2015; Kaur et al. 2019; Shackleton et al. 2019). Being a second leading cause (after habitat fragmentation) of global biodiversity loss (Wilcove et al. 1998; Bellard et al. 2016) and the major cause of species extinction in island ecosystems (Brockie et al. 1988; Tershy et al. 2002), the biological invasion has emerged as a gruelling challenge for the conservation managers.

Naturalists have observed the phenomenon of invasion since ages and invasive species were described by several nineteenth- and twentieth-century scientists, e.g. Charles Darwin, Alphonse De Candolle, Joseph Hooker, Charles Lyell, Frank Egler, Herbert Baker, Marston Bates, and Carl Huffaker (Richardson and Pyšek 2008; Richardson 2011). However, the precise concept of biological invasion was introduced by British ecologist, *Charles S. Elton* in 1958 in his book, *The Ecology of Invasions by Animals and Plants* (Elton 1958). He, therefore, is considered the

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S. Kaur et al. (eds.), *Biodiversity in India: Status, Issues and Challenges*,
https://doi.org/10.1007/978-981-16-9777-7_19

unofficial Father of Invasion Ecology and his book is now accepted as a landmark in the field of invasion science (Davis et al. 2001). However, it was in 1982, during the general assembly of the Scientific Committee on Problems of the Environment (SCOPE), that a project named *SCOPE Programme on the Ecology of Biological Invasions* was initiated. This step provided momentum to the notion of biological invasion, resulting in a series of publications and regional/global synthesis associated with the concept (Simberloff 2011). Later, with the participation of the International Union for Conservation of Nature (IUCN) and the Centre for Agriculture and Bioscience International (CABI), *Global Invasive Species Programme* (*GISP*) was developed in 1997 (GISP 2020). This program addressed the factors driving the phenomenon of biological invasion, suggested prevention/management strategies, and developed a database for information exchange among researchers and conservation managers (Richardson 2011; GISP 2020).

At present, the growing attention towards this global problem can be estimated from (1) increased rate of publications/books on biological invasion; (2) scientific journals exclusively dedicated to tackling problems related with the issue (e.g. *Biological Invasions*, *Aquatic Invasions*, *NeoBiota*, *Bio-Invasions Records*); (3) conferences aiming to bring together the invasion biologists on a common platform (e.g. International Conference on Marine Bio-invasions; NeoBiota—European Conference on Biological Invasions), and (4) International Research Programmes such as GISP (1997), NEOBIOTA (1999), DAISIE (2005), INVASIVES (2013), GloNAF (2015), etc. addressing this issue on a global level (Canning-Clode 2015). Further, protocols such as Invasive Species Environmental Impact Assessment (ISEIA) and Environmental Impact Classification for Alien Taxa (EICAT) allow the classification of alien and invasive species under different risk categories (Vanderhoeven et al. 2017).

Furthermore, with the development of advanced techniques, molecular approaches, and DNA tools, a better understanding of the origin, evolution, and consequences of biological invasions is being captured (Ward et al. 2008; Darling et al. 2017). Attempts have also been made to forecast the spatio-temporal distribution of non-indigenous species in future climate change scenarios. Such studies can make reliable and robust predictions about population dynamics, potential outcomes, and preventive measures of the invasive species (Gallien et al. 2010). Nevertheless, invasion science has now become an independent sub-discipline of ecology (Davis et al. 2001). It has not only embraced a full spectrum of interdisciplinary fields, e.g. sociology, economics, and risk assessment but has also attracted socio-ecological collaborations amongst researchers, government bodies, non-government organizations, conservationists, landscape managers, and stakeholders (Canning-Clode 2015; Vaz et al. 2017).

In this chapter, we addressed the concept of *plant invasion* and the challenges associated with it. Beginning with the course of establishment of an alien plant into a new geographic range and the attributes which could facilitate its successful invasion in a non-native environment, this discussion aimed at enhancing the understanding of the phenomenon of plant invasion. Later on, the current status of invasive plant species at a regional and global scales is presented along with their consequences, which highlights the issues we are dealing with at present. Finally, we concluded the chapter by focusing on the potential risks that we are needed to be prepared for in near future.

19.2 Process of Plant Invasion

The framework of the invasion process and the associated terminologies are explained by a number of biologists (Williamson and Fitter 1996; Richardson et al. 2000; Blackburn et al. 2011). However, in a botanical context, the Richardson framework fits most appropriately (Blackburn et al. 2011). Here, an overview of the invasion process is provided in a generalized manner, taking insights from the model proposed by Richardson et al. (2000).

- The first stage of the invasion process requires the transportation of a plant or its propagule across the major geographical barrier(s) (inter-continental or intra-continental or both) through any agency (mostly humans, but there can be other factors such as wind, water, etc.). The species can be called "*alien*," "*exotic*," "*non-native*," "*non-indigenous*," and "*introduced*" (terminologies are interchangeably used by the researchers) at this step of the invasion process (Fig. 19.1).
- Upon introduction, the first and foremost challenge faced by an alien species is the novel environment (consisting of biotic/abiotic components) of the introduced habitat that a species needs to be acclimatized to for its survival (Fig. 19.1).
- Thereafter, a species needs to overcome any barrier(s) guarding the long-term and consistent production of offspring (either by vegetative or generative means). A species can be considered either "*casual*" or "*naturalized*" at this stage of the invasion process. The casuals are defined as the introduced species that can successfully survive and occasionally reproduce; however, they are incapable

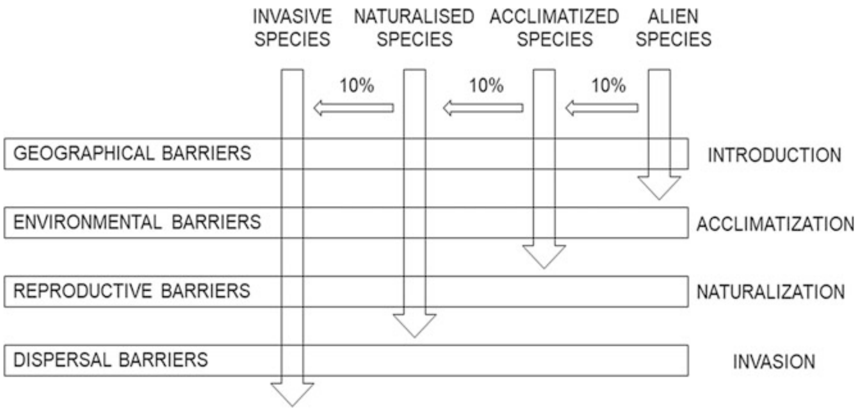

Fig. 19.1 A general scheme of the process of plant invasion (after Williamson and Fitter 1996; Richardson et al. 2000)

of producing self-replacing populations, and therefore, rely on repeated introductions for their existence within the non-native boundaries. On the contrary, naturalized plants are competent enough to reproduce on their own, freely, and for several generations (with or without human intervention) (Fig. 19.1).

- Finally, the naturalized species that produce offspring by generative means in hefty numbers and surmount the local/regional dispersal barriers, thereby spreading at considerable distances from parent plants, are called "*invasive*" (Fig. 19.1).

In addition to the given stages of invasion process, Richardson et al. (2000) further added post-dispersal environmental barriers (disturbed habitats and natural/semi-natural habitats) to include the resistance posed by various factors during disturbances and process of succession. The authors also pointed out that the process is reversible, and any ecological shift or fluctuation may augment the spread of an alien species or result in its total extinction.

The statistical rule proposed by Williamson and Fitter (1996) is also explicitly and implicitly adopted by invasion biologists regardless of the identity of the taxon. The rule (popularly known as "*Ten's rule*") states that only one-tenth of the species (i.e. 10% of the total species) survive at every step of the invasion process (Fig. 19.1). Nevertheless, ecologists also have a contradictory viewpoint in this regard that the rule undermines the negative impacts posed by alien species that are still in the process of invasion (Jarić and Cvijanović 2012).

19.3 Determinants of Successful Invasion

The introduction-naturalization-invasion continuum depends upon interactions amongst the introduced species, the invaded habitat, and the chance/timing of introduction (Pyšek and Richardson 2008; Moravcová et al. 2015). Researchers argue that apart from these factors, the species of the invaded ecosystem and their interactions with the introduced species also regulate the trend of invasion (Szabó et al. 2019). Efforts are being made to provide the best explanation of the mechanisms underlying the invasion process. Several hypotheses have been proposed in this context, a few of which even reflect contradictory opinions (Enders et al. 2018). It has also been accepted that multiple factors govern the phenomenon of invasion and success of an invasive species and does not rely on any single theory/concept (Gurevitch et al. 2011). Common hypotheses/theories proposed so far in the context of plant invasion are listed in Table 19.1.

The dominance of an invasive species can be explained by one or more of these hypotheses. However, there could be many more factors that have not been included in these assumptions and yet have a strong influence on the invasion facet of a species. Also, there are aspects that have been postulated but deserve more consideration, understanding, and pragmatic evidence.

Table 19.1 Common hypotheses/theories proposed in context of plant invasion

Theory/hypothesis	Postulations	References
Disturbance	Disturbed ecosystems are more likely to attract invasions by alien species compared with the undisturbed ecosystems	Elton (1958), Hobbs and Huenneke (1992)
Diversity, Invasion Potential, or biotic resistance	The communities rich in biodiversity limit invasion By alien species compared with the communities where diversity is sparse	Elton (1958), Levine and D'Antonio (1999)
Enemy release	The absence of natural enemies (pests, pathogens, and predators) in the introduced region facilitates unchecked proliferation of the alien species	Elton (1958), Keane and Crawley (2002)
Ideal weed	Specific traits possessed by an alien species define its success in the non-native range	Elton (1958), Rejmánek and Richardson (1996)
Limiting similarity	Greater the difference between native and exotic species, greater will be the chances of invasion by the species	MacArthur and Levins (1967)
Empty niche or opportunity windows	Available resources or empty niches attract invaders to establish and propagate	MacArthur (1970), Johnstone (1986)
Dynamic equilibrium	Dynamic conditions of a habitat alter the competition of resident species and give way to the opportunistic alien invasive species	Hutson (1979)
Evolution of increased competitive ability	In case of reduced herbivory (due to the absence of natural enemies) in the introduced region, invasive plants tend to allocate their resources towards higher growth rate and better competitive ability rather than defence purposes	Blossey and Nötzold (1995)
Phenotypic plasticity	Alteration of phenotypic characteristics in response to environmental factors enables invasive plant species to perform better in a wide range of novel habitats	Williams et al. (1995)
Propagule pressure	Ability of an invasive species to produce long-lasting viable seeds provides it with a competitive advantage over the natives	Williamson (1996), Lockwood et al. (2013)
Invasional meltdown	Invaders affect ecosystem in a way to facilitate invasion by other alien species	Simberloff and von Holle (1999), Sax et al. (2007)
Sampling	A large number of different alien species in an area exert more interspecific competition for the natives, and hence tend to become more successful	Crawley et al. (1999)
Fluctuating resource	A decrease in native population due to any natural/anthropogenic disturbance opens up wealth of resources, and hence paves the way for invasion	Davis et al. (2000)
Adaptation	Alien species pre-adapted to ecological conditions of the invaded habitat or alien species closely related to the native species are more likely to become invasive	Duncan and Williams (2002)

(continued)

Table 19.1 (continued)

Theory/hypothesis	Postulations	References
Enemy inversion	Natural enemies of an invasive species introduced in the exotic ranges as biocontrol agents may not be as effective as they are in native ranges due to the novel ecological conditions of the invaded ecosystem	Colautti et al. (2004)
Increased susceptibility	The probability of exotic species with the lower genetic diversity to become invasive is low	Colautti et al. (2004)
Novel weapon	Allelochemicals released by an invasive plant species mediate new plant–plant and plant–microbial interactions, thus altering ecosystem functions	Callaway and Ridenour (2004)
Reckless invader	An alien species that become invasive soon after its introduction has a short success story and gets eliminated sooner or later	Simberloff and Gibbons (2004)
Specialist–generalist	Ecosystems, where local pests and predators are specialists and local mutualists are generalists, are more prone to invasion	Callaway et al. (2004)
Biotic acceptance	Despite being occupied by rich and diverse native communities, an invaded ecosystem tends to accept and accommodate the population of alien species	Stohlgren et al. (2006)
Enemy of my enemy	Natural enemies of an invasive species introduced in the exotic ranges as biocontrol agents are more harmful to native diversity of invaded ecosystem	Eppinga et al. (2006)
Human commensalism	Humans are not only responsible for introduction of alien species but also for their spread to long distances, thus facilitating the invasion process	Jeschke and Strayer (2006)
Environmental heterogeneity	Invasion by any alien species depends on heterogeneity of the host environment	Melbourne et al. (2007)
Island susceptibility	Island ecosystems are more prone to the attack and impacts of alien invasive species compared with the continental ecosystems	Jeschke (2008)
Community ecology	Introduced species with advanced phenologies are more likely to get adapted to the novel habitats, especially in view of seasonal shifts	Wolkovich and Cleland (2011)

19.4 Data on Invasive Alien Plants

Invasive alien plants are present in every part of the world; however, the numbers vary from region to region (Inderjit et al. 2018). The highest numbers of naturalized alien plants are documented from North America (~6000) and Europe (~4000); whereas, the lowest numbers are reported from Antarctica (~160), followed by temperate Asia (~2200) and tropical Asia (~2000 species) (van Kleunen et al. 2015). However, considering the fact that the majority of the global biodiversity is yet to be explored, it is expected that the actual number of the alien or invasive species are far more different than our current speculations (Jarić et al. 2019). This is particularly true for the emerging economies, where there is a lack of research opportunities and facilities.

19.4.1 International Statistics

Nearly one-sixth of the world's geographical area, including 16% of the global biodiversity hotspots, is predicted to be susceptible to invasion (Early et al. 2016). A global study by van Kleunen et al. (2015) anticipated that a total of 13,168 vascular plant species (approximately 3.9% of the world's total extant flora) have naturalized in 843 continental and island regions. The authors also stated that North America held the maximum naturalized flora, whereas Pacific Islands showed the maximum rate of accumulation of alien species (van Kleunen et al. 2015). Another report on naturalized alien flora of the world corroborated this study stating that California, North America, is the world's richest region in terms of naturalized alien flora with 1753 alien plant species (Pyšek et al. 2017).

The majority of the world's worst invasive plants belong to a relatively few families (Asteraceae, Poaceae) and genera (*Acacia*, *Mimosa*, *Cyperus*) (Mack et al. 2000). A recent study also confirmed the maximum contribution of Asteraceae (1343 species) to the global naturalized alien flora, followed by Poaceae (1267 species) and Fabaceae (1189 species) (Pyšek et al. 2017). On the contrary, this new report suggests *Solanum* (112 species), *Euphorbia* (108 species) and *Carex* (106 species) to be the most representative genera of the world's naturalized alien plant community (Pyšek et al. 2017). It has also been ascertained that horticulture and nursery trade are the main pathways for intentional plant introductions, whereas ignorant possessions and transportation are accounted for the maximum unintentional introductions (Turbelin et al. 2017). GISD (2020) lists 100 worst invasive species of the world, of which 36 are invasive plant species (Table 19.2).

19.4.2 National Statistics

Estimations about the share of alien or invasive species in the Indian vegetation over the last ten years have varied to a great extent. In an earlier report, Reddy (2008) described 173 species consisting of 117 genera and 44 families to be invasive in India. Later on, another study revealed that exotic species constitute 8.5% (1599 species) of the net extant vascular flora of the country with 14% (225 species) being invasive (Khuroo et al. 2012). Of late, a total of 471 naturalized alien species were reported in India, representing 2.6% of the total flora of India (Inderjit et al. 2018).

Table 19.2 Worst invasive plant species of the world (source: CABI 2020; GISD 2020; GRIN 2020; Plant List 2020)

Plant species	Family	Habit	Nativity	Distribution
Terrestrial plants				
Acacia mearnsii De Wlid.	Fabaceae	Shrub/tree	Aus	Afr; Eur; Pac; S Am
Ardisia elliptica Thunb.	Primulaceae	Shrub	Asia temp; Asia trop	Afr; N Am; Pac; S Am
Arundo donax L.	Poaceae	Grass	Asia temp; Asia trop	Afr; Aus; Eur; N Am; Pac; S Am
Cecropia peltata L.	Urticaceae	Tree	N Am; S Am	Afr; Asia trop; Pac
Chromolaena odorata (L.) R.M. King and H. Rob.	Asteraceae	Herb	N Am; S Am	Afr; Asia temp; Asia trop; Aus
Cinchona pubescens Vahl	Rubiaceae	Tree	S Am	Afr; Pac
Clidemia hirta (L.) D. Don	Melastomataceae	Shrub	N Am; S Am	Paleotropics
Euphorbia esula L.	Euphorbiaceae	Herb	Afr; Asia temp; Asia Trop	N Am; Eur
Hedychium gardnerianum Sheppard ex Ker Gawl.	Zingiberaceae	Herb	Asia trop	Afr; Aus; Pac; S Am
Hiptage benghalensis (L.) Kurz	Malpighiaceae	Shrub	Asia temp; Asia trop	Afr; Aus; Pac; N Am
Imperata cylindrica (L.) Raeusch.	Poaceae	Grass	Afr; Asia temp; Asia trop; Aus; Eur	Pac; N Am; S Am
Lantana camara L.	Verbenaceae	Shrub	N Am; S Am	Neotropics
Leucaena leucocephala (Lam.) de Wit	Fabaceae	Tree	N Am; S Am	Afr; Asia trop; Asia temp; Aus; Eur; Pac
Ligustrum robustum (Roxb.) Blume	Oleaceae	Shrub/tree	Asia trop; Asia temp	Afr; N Am
Lythrum salicaria L.	Lythraceae	Herb	Afr; Asia temp; Eur	Aus; N Am; S Am
Melaleuca quinquenervia (Cav.) S.T.Blake	Myrtaceae	Tree	Asia trop; Aus; Pac	Afr; N Am; S Am
Miconia calvescens DC.	Melastomataceae	Tree	N Am; S Am	Asia trop; Aus; Pac
Mikania micrantha Kunth	Asteraceae	Climber	N Am; S Am	Afr; Asia trop; Asia temp; Aus; Pac
Mimosa pigra L.	Fabaceae	Shrub	Afr; N Am; S Am	Asia trop; Aus; Pac
Myrica faya Dryand.	Myricaceae	Tree	Afr	Pac

(continued)

Table 19.2 (continued)

Plant species	Family	Habit	Nativity	Distribution
Opuntia stricta (Haw.) Haw.	Cactaceae	Shrub	N Am; S Am	Afr; Asia temp; Aus; Eur; Pac
Pinus pinaster Aiton	Pinaceae	Tree	Afr; Eur	Afr; Aus; Pac; S Am
Prosopis glandulosa Torr.	Fabaceae	Tree	N Am	Afr; Aus; S Am
Psidium cattleianum Afzel. ex Sabine	Myrtaceae	Shrub	S Am	Afr; Aus; N Am; Pac
Pueraria montana var. lobata (Willd.) Sanjappa & Pradeep	Fabaceae	Climber	Asia temp; Asia trop; Pac	Afr; Aus; Eur; N Am; S Am
Reynoutria japonica Houtt.	Polygonaceae	Herb	Asia temp	Aus; Eur; N Am; S Am
Rubus ellipticus Sm.	Rosaceae	Shrub	Asia temp; Asia trop	Afr; Aus; Pac; S Am
Schinus terebinthifolia Raddi	Anacardiaceae	Shrub/ tree	S Am	Afr; Aus; Eur; N Am; Pac
Spathodea campanulata P. Beauv.	Bignoniaceae	Tree	Afr	Asia trop; Aus; Pac; S Am
Sphagneticola trilobata (L.) Pruski	Asteraceae	Herb	N Am; S Am	Afr; Asia temp; Asia trop; Aus; Pac
Tamarix ramosissima Ledeb.	Tamaricaceae	Shrub/ tree	Asia temp; Asia trop	Afr; N Am; S Am
Ulex europaeus L.	Fabaceae	Shrub	Eur	Afr; Asia temp; Asia trop; Aus; N Am; S Am
Aquatic plants				
Caulerpa taxifolia (M. Vahl) C.Agardh	Caulerpaceae	Green Macro-alga	Tropical waters of the Indian, Pacific and Atlantic Oceans	The Mediterra-nean Sea
Eichhornia crassipes (Mart.) Solms	Pontederiaceae	Herb	S Am	Tropics and subtropics
Spartina anglica C.E. Hubb.	Poaceae	Grass	Eur	Asia temp; Aus; N Am
Undaria pinnatifida (Harvey) Suringar	Alariaceae	Kelp	Asia temp; Asia trop	Eur; N Am; S Am; Aus

Nativity: *Afr* Africa, *Asia trop* Asia tropical, *Asia temp* Asia temperate, *Aus* Australia, *Eur* Europe, *S Am* South America, *N Am* North America, *Pac* Pacific Islands

This report also stated that lower altitudinal regions lying in tropical/subtropical areas have greater number of alien flora with the maximum figures being recorded from Tamil Nadu (332 species) and the minimum being recorded from the Lakshadweep Islands (17 species) (Inderjit et al. 2018).

A survey of the Indian Himalayan Region showed the presence of 571 alien species, of which 21% (96 species) were invasive (Khuroo et al. 2007). Another study described a total of 190 invasive alien species from the Indian Himalayas representing 112 genera and 47 families (Sekar 2012). On the other hand, a study of the Srinagar city revealed a higher percentage of alien species (58%) rather than natives (48%) in the local vegetation (Mehraj et al. 2018). It has also been observed that the richness of alien species plunged rapidly above an altitude of 2000 m asl (Khuroo et al. 2011). In an attempt to identify the invasion hotspots in India using the approach of Ecological Niche Modelling, it was predicted that nearly 49% of the total geographical area and 19 of the total 47 eco-regions of the country are susceptible to invasion with biodiversity hotspots and coastal areas being the most sensitive regions (Adhikari et al. 2015).

Similar to the data reported at the global scale, the most representative families of naturalized Indian flora are Asteraceae, Fabaceae, and Poaceae (Khuroo et al. 2012; Inderjit et al. 2018). However, the Indian Himalayan region is also dominated by Solanaceae, Convolvulaceae, and Brassicaceae (Khuroo et al. 2007; Sekar 2012). As per the previous findings of Khuroo et al. (2012), the three most species-rich genera were *Eucalyptus*, *Ipomoea*, and *Senna*; whereas according to the recent data, *Solanum*, *Ipomoea*, and *Euphorbia* are the dominating genera of the alien flora of India (Inderjit et al. 2018). The most obnoxious alien invasive species of the country include *Parthenium hysterophorus*, *Ageratum conyzoides* L., *Lantana camara* L., *Chromolaena odorata* (L.) R.M.King & H.Rob., *Ageratina adenophora* (Spreng.) R.M.King & H.Rob., *Leucaena leucocephala* (Lam.) de Wit, *Prosopis juliflora* (Sw.) DC. and *Mikania micrantha* Kunth among the terrestrial exotics and *Eichhornia crassipes* (Mart.) Solms and *Pistia stratiotes* L. among the aquatic exotics (Sharma and Raghubanshi 2012). Some of the alien plants, notably, *Tagetes minuta* L., *Anthemis cotula* L., *Sapium sebiferum* (L.) Roxb. and *Broussonetia papyrifera* (L.) L'Hér. ex Vent. are in the process of establishment and hold the potential to become invasive in future (Kohli et al. 2012). Biogeographically, the majority of the alien flora of the country is native of the USA (Khuroo et al. 2012; Sekar 2012; Inderjit et al. 2018). A list of troublesome invasive alien plant species of India is presented in Table 19.3.

19.5 Ecological and Socio-economic Implications of Plant Invasion

The establishment of invasive plants not only poses a threat to the ecosystem processes and natural biodiversity but also affect important socio-economic assets (Lazzaro et al. 2020). Exact estimates of the damage imposed by invasive plants on the invaded habitat are difficult to gauge; however, monetary losses via disruption of ecosystem services and socio-economic provisions, and imposition of management efforts may be determined. Furthermore, invasion dynamics are rapidly changing

Table 19.3 A list of major invasive alien plant species of India (source: CABI 2020; GRIN 2020; NBA-MoEF & CC 2020; Plant List 2020)

Plant species	Family	Habit
Terrestrial plants		
Acacia auriculiformis Benth.	Fabaceae	Tree
Acacia dealbata Link	Fabaceae	Shrub/tree
Acacia mearnsii De Wlid.	Fabaceae	Shrub/tree
Ageratina adenophora (Spreng.) R.M.King and H.Rob.	Asteraceae	Herb
Ageratina riparia (Regel) R.M.King and H.Rob.	Asteraceae	Herb/shrub
Ageratum conyzoides L.	Asteraceae	Herb
Alternanthera bettzickiana (Regel) G.Nicholson	Amaranthaceae	Herb
Alternanthera brasiliana (L.) Kuntze	Amaranthaceae	Herb
Alternanthera ficoidea (L.) Sm.	Amaranthaceae	Herb
Alternanthera paronychioides A.St.-Hil.	Amaranthaceae	Herb
Alternanthera pungens Kunth	Amaranthaceae	Herb
Antigonon leptopus Hook. and Arn.	Polygonaceae	Climber
Argemone mexicana L.	Papaveraceae	Herb
Bidens pilosa L.	Asteraceae	Herb
Cannabis sativa L.	Cannabaceae	Herb
Centrosema molle Benth.	Fabaceae	Herb
Cestrum aurantiacum Lindl.	Solanaceae	Shrub
Chromolaena odorata (L.) R.M.King and H.Rob.	Asteraceae	Herb
Cirsium arvense (L.) Scop.	Asteraceae	Herb
Cryptostegia grandiflora Roxb. ex R.Br.	Apocynaceae	Climber
Cuscuta chinensis Lam.	Convolvulaceae	Climber
Cytisus scoparius (L.) Link	Fabaceae	Shrub
Dactyliandra welwitschii Hook.f.	Cucurbitaceae	Climber
Dinebra retroflexa (Vahl) Panz.	Poaceae	Grass
Dysphania ambrosioides (L.) Mosyakin and Clemants	Amaranthaceae	Herb
Erigeron bonariensis L.	Asteraceae	Herb
Erigeron canadensis L.	Asteraceae	Herb
Evolvulus nummularius (L.) L.	Convolvulaceae	Herb
Herissantia crispa (L.) Brizicky	Malvaceae	Herb
Hyptis suaveolens (L.) Poit.	Lamiaceae	Herb
Ipomoea eriocarpa R. Br.	Convolvulaceae	Climber
Ipomoea fistulosa Mart. ex Choisy	Convolvulaceae	Climber
Lantana camara L.	Verbenaceae	Shrub
Lepidium didymum L.	Brassicaceae	Herb
Leptochloa fusca (L.) Kunth	Poaceae	Grass
Leucaena leucocephala (Lam.) de Wit	Fabaceae	Tree
Maesopsis eminii Engl.	Rhamnaceae	Tree
Mikania micrantha Kunth	Asteraceae	Climber
Mimosa diplotricha Sauvalle	Fabaceae	Shrub
Mimosa pigra L.	Fabaceae	Shrub
Muntingia calabura L.	Mutingiaceae	Tree

(continued)

Table 19.3 (continued)

Plant species	Family	Habit
Opuntia dillenii (Ker Gawl.) Haw.	Cactaceae	Shrub
Opuntia elatior Mill.	Cactaceae	Shrub
Parthenium hysterophorus L.	Asteraceae	Herb
Pennisetum purpureum Schumach.	Poaceae	Grass
Prosopis juliflora (Sw.) DC.	Fabaceae	Tree
Pueraria montana var. lobata (Willd.) Sanjappa and Pradeep	Fabaceae	Climber
Senna spectabilis (DC.) H.S.Irwin & Barneby	Fabaceae	Tree
Solanum elaeagnifolium Cav.	Solanaceae	Herb
Solanum mauritianum Scop.	Solanaceae	Shrub/tree
Sphagneticola trilobata (L.) Pruski	Asteraceae	Herb
Ulex europaeus L.	Fabaceae	Shrub
Aquatic plants		
Alternanthera philoxeroides (Mart.) Griseb.	Amaranthaceae	Herb
Cabomba caroliniana A.Gray	Cabombaceae	Herb
Eichhornia crassipes (Mart.) Solms	Pontederiaceae	Herb
Ipomoea carnea Jacq.	Convolvulaceae	Shrub
Lemna perpusilla Torr.	Araceae	Herb
Lythrum salicaria L.	Lythraceae	Herb
Marsilea quadrifolia L.	Marsileaceae	Herb
Myriophyllum aquaticum (Vell.) Verdc.	Haloragaceae	Herb
Salvinia adnata Desv.	Salviniaceae	Herb
Typha angustifolia L.	Typhaceae	Herb

over time due to globalization (Meyerson and Mooney 2007). Thus, it is even more complicated to predict the ecological and economic costs of invasion in the future scenario.

19.5.1 Ecological Impacts

The impact of invasive plant species on community structure (via an effect on plant communities and higher trophic levels) and ecosystem processes (via interference in natural biotic/abiotic interactions, soil chemistry, nutrient cycling, hydrology, fire regimes, and other microclimatic conditions) is quite evident (Mack et al. 2000; Levine et al. 2003). Invasive alien plants have altered the ecological landscapes, degraded the ecosystem services, threatened the existence of native species, and triggered the homogenization of the world's biota, both in terrestrial and aquatic ecosystems (Vilà et al. 2011). In the forest ecosystems, certain additional threats are experienced such as the risk of hybridization, the transmission of diseases, and interference with forest regeneration (Langmaier and Lapin 2020). However, these impacts are strongly context-dependent and vary depending upon the characteristics

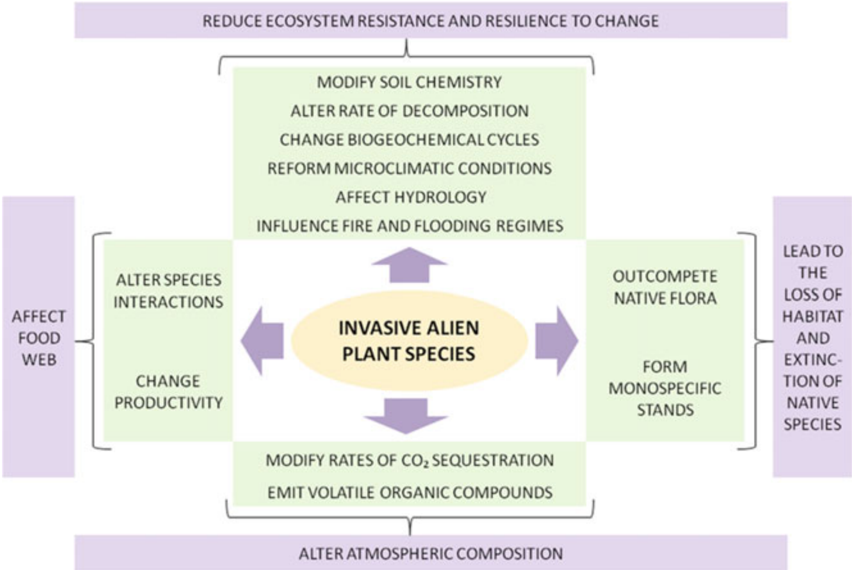

Fig. 19.2 Diagrammatic representation of the ecological impact of invasive alien plants

of invasive species and invaded habitat (Pyšek et al. 2012). A diagrammatic representation provided in Fig. 19.2 describes the multitude of ecological impacts inflicted by invasive alien species on an invaded landscape.

Statistical figures representing the extent to which invasive plant species pose a threat to the native biodiversity are severely lacking; however, some regional examinations provide interesting insights. Researchers argue that alien plants are more likely to cause displacement and community change rather than species extinctions. However, allying with natural/anthropogenic disturbances, these declined the population of 410 of the 602 plant species and 19 of the 68 bird species in the USA (Gurevitch and Padilla 2004). Threatened by the continuous spread of alien plants, nearly 166 and 113 indigenous plant species of New South Wales are listed as Endangered and Vulnerable, respectively, which together represent 49% (279 of 565) of the indigenous flora of the region (Coutts-Smith and Downey 2006). A recent study suggested that alien invasive species (here, both plant and animal invasions were taken into consideration) are responsible for 27% of the Extinct (EX)/Extinct in wild (EW) plant taxa (as per IUCN Red List 2015), all of which were island endemic species (Bellard et al. 2016). Downey and Richardson (2016) suggested that interventions of alien flora may not directly lead to extinction, but is evidently responsible for altering the extinction trajectory of species, and conservation managers should take into account the issue of alien invasions before further extinctions happen.

19.5.2 Socio-economic Impacts

Invasive plants pose a significant threat to agriculture, forestry, fisheries, and other human enterprises (Bhowmik 2005). Many invasive plants are noxious weeds of important food and cash crop species such as *P. hysterophorus*, *A. conyzoides*, *Echinochloa crus-galli* (L.) P.Beauv., *Striga hermonthica* (Delile) Benth., *Datura ferox* L., *Pennisetum* spp., *Amaranthus* spp., *Chromolaena* spp., *Cyperus* spp., and *Digitaria* spp., etc. Invasive weeds are usually more adaptable, capable of generating a large propagule pressure, tolerant to different biotic/abiotic stresses, and extremely competitive for resources (Bhowmik 2005). As a result, they compete aggressively with the crop species and cause substantial yield loss.

Similarly, invasive plant species may also lead to enormous economic losses by jeopardizing ecosystem services (Szabó et al. 2019). The habitats drifted towards invasion and were found to lose the native species, which used to provide basic food, fodder, fuel, and medicinal services to the locals (Kohli et al. 2006). Invasion of rangelands by exotic plant species reduces the availability of grasses and forbs for the livestock which has affected the practice of animal husbandry (O'Connor and van Wilgen 2020). Several other provisions substantial to human life, such as water resources, pollination services, wildlife-based tourism, and recreational activities are directly or indirectly influenced by the spread of exotic plant species (O'Connor and van Wilgen 2020). In addition, various human health hazards could also be a possible outcome of plant invasion. Some of the invasive plants have direct implications on human health (allergies, skin diseases, respiratory problems, etc.), while others influence indirectly via transmission of pests that cause diseases in humans (Allan et al. 2010).

Thereafter, the management of invasive species attracts huge finances that sometimes may not even fit in the budget of countries with low economies. The United States inhabits nearly 5000 invasive plants incurring annual monetary losses of up to $35 billion (Pimentel et al. 2005). A report from South Africa stated that an amount of nearly $38 million was spent to control alien plants in the protected areas of the Cape Floristic Region and $11–$175 million will be required in the future to address the issue (van Wilgen et al. 2016). Data on the expenditure required to control invasive plants are largely unavailable and close estimations are nearly impossible to draw. However, considering the current situation and future environmental challenges, it can be safely predicted that these figures are going to be raised exponentially to keep invasive plants in check in the near future.

19.6 Potential Risks and Future Challenges Associated with Invasive Alien Plants

Invasion dynamics are shifting at a much faster pace because of various natural and anthropogenic factors, namely, climate warming, enhanced nitrogen deposition, increased carbon dioxide concentrations, deforestation, habitat fragmentation, changes in land use pattern, population explosion, and rapid economic development (Hobbs 2000; Lin et al. 2007; Meyerson and Mooney 2007; He et al. 2011; Carboni et al. 2018). Consequently, the risks and challenges associated with the invasive alien plants are also multiplying. From the increased aggressiveness of the established invasive species to the constant emergence of new invasive species, the issues in invasion science are getting gruelling and worrisome.

The leading challenge in front of conservation ecologists, both from present and future perspective is the management of invasive plant species. Although the management strategies depend largely on the characteristics of invasive species and the invaded habitat, yet there are certain key points applicable in general. It has been well established that multiple factors govern the invasion success of an alien species and understanding these factors is a pre-requisite for designing any management program (Pyšek et al. 2012; Szabó et al. 2019). Thus, there is a strong need to bridge the knowledge gaps that persist in the understanding of invasion mechanisms. Apart from that, the choice of a strategy should take into consideration the long-term implications, involvement of a wide range of participants (from researchers to government and non-governmental organizations to local people), a suitable and balanced budgeting, and an assured consistency of efforts. Integrated weed management, a strategy that uses a combination of different control methods in an appropriate fashion, is the best approach to monitoring and regulating any invasive plant. Researchers also suggest utilizing the invasive species for ecological and economic purposes instead of the native flora (Huang et al. 2014; Carson et al. 2018). This is a relatively new and better alternative that can attract the involvement of diverse groups, industries, and the general public. Awareness among local people is another important issue that should be duly considered. Although most people do not oppose the management of invasive species, such actions are, however, not perceived as a high priority and sometimes may even be opposed (if an invasive species is providing ecosystem services or is of ornamental value) (Potgieter et al. 2019). Greater environmental awareness among people, particularly the youngsters, is of utmost importance, as this will not only aid the implementation of control strategies but will also ensure the success of the program.

Another crucial challenge is to identify the naturalized species which hold the potential to become invasive in the near future. Such species may already be in their lag phase and preparing to turn invasive or may get triggered by climate warming, seasonal shifts, or any other disturbances in the ecosystem to become invasive. In this case, identification of alien flora and constant monitoring of the species, which are either close relatives of the established invasive species or characteristically identical to them, might be helpful. Species that have a history of invasion in other parts of the world should also be targeted. At the same time, it is important to identify the geographic ranges and habitats which are more susceptible to invasion, so that appropriate preventive measures can be undertaken for their protection. Prior knowledge of the traits of most successful invasive species can also have long-term implications such as understanding of universal invasive attributes, prediction of prospective niches for an invasive species, and identification of potential invaders (Gallagher et al. 2015).

Last but not the least, it is crucial to establish strong quarantine measures to restrict the unintentional introduction of alien plants from one geographic region to another. Food and Agriculture Organization (FAO) introduced an intergovernmental treaty *International Plant Protection Convention (IPPC)* signed by 180 member countries in 1951, with an objective to "protect world's plant resources from the spread and introduction of pests and promote safe trade" (FAO 2020). The treaty is governed by certain guidelines to prevent the entry, establishment, and spread of exotic plant pests (including weeds). Although the plant quarantine measures are followed by most of the member countries, they are not stringent enough to completely restrain the unintentional transport of plant/plant parts/seeds. On the other hand, the intentional introduction should only be allowed when absolutely necessary, and the species should undergo a well-established risk assessment protocol. Policymaking should involve both government officials and researchers so that the risk assessment system should be scientifically sound and unambiguous. Only the combined efforts in research and policymaking, and strict actions at legislative, technical, and administrative levels can facilitate the containment of potentially invasive plant species.

Acknowledgments Amarpreet Kaur is thankful to NMHS, MoEF & CC, New Delhi for the financial assistance. Ravinder Kumar Kohli is thankful to the DST-SERB for JC Bose National Fellowship.

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