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INVASIVE EXOTIC PLANT SPECIES AND THEIR INFLUENCE ON THE ENVIRONMENT, ECOSYSTEM SERVICES, ECONOMY AND HEALTH: A SEARCH

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ABSTRACT

Invasive exotic plant species (IEPS) is recognized as threat to the native biodiversity and leads to the loss of habitat for the indigenous species on the earth. Invasions not only tear down the native plant species but have adverse impacts on economy and human health. Many documented records from Western countries connected with alien species revealed altered ecosystem services and socio-economic conditions via diverse mode of actions. Even though, the ecological impacts of alien species were documented, there is a dearth of analysis regarding their economic quantification, livelihood considerations, biotechnological aspects and human health risk assessments are the need of the hour. The noxious exotic invasive plants in India were *Ageratum conyzoides*, *Eupatorium adenophorum, Parthenium hysterophorus, Lantana camara, Mikania micrantha, Argemone mexicana* and *Eichhornia crassipes*. In this context, an attempt was made to enlist the alien species of Kerala and a review to account the impacts of invasive exotic plant species on various aspects of the environment globally. Results regarding the alien species search revealed the following species such as *Chromolaena odorata, Senna spectabilis, Hypoestes sanguinolenta, Maesopsis eminii, Eupatorium cannabinum, Mikania micrantha, Sphagneticola trilobata* and *Acacia mearnsii* were intruded in to various ecosystems of Kerala after the repeated floods. They directly affect the germination and survival of local species, damage the quality of soil and affect ground water availability. Nearly 80 species were noted as alien species in Kerala by many state level surveys. Research in the direction of impact of alien species on socio-economic cultural aspects of life and derailment of ecosystem is not yet seriously carried from Kerala. Further, there is a paucity of the ecological models/indicators to establish interrelationship among global environmental changes, biodiversity and health, warranting future researches.

Keywords: Alien species, Ecological impacts, Ecosystem, Invasion, Native species, Biodiversity.

1. INTRODUCTION

Invasive exotic plant species (IEPS) are considered to be the major direct driving force of loss of biodiversity across the earth. Management of invasive exotic plant species seems to be a challenge in the field of conservation of biological diversity. The alien species threatens the ecosystems, degrade the habitats and create issues to other indigenous species through invasion. It is treated as the second largest factor of species endangerment and extinction of biodiversity in an area. The ecological cost is often irrecoverable via loss of native species and ecosystems. It also causes high loss of economy, in terms of reduced crop yield and production of livestock, declined natural biodiversity, increased production costs and so on. Biodiversity has become one of the hottest areas at local, national and global scale. Biodiversity includes all forms of biological entities inhabiting the earth including microbes, wild plants and animals, domesticated animals and cultivated species and even genetic material like seeds and germplasm etc [1]. Invasive exotic plant species are species, native to one area or region, that have been introduced into an area outside their normal distribution, either by accidental or for on usage and

which latter gets colonized or invaded their new habitats, threatening the native biodiversity, ecosystems and habitats, and human wellbeing. Alien species invasion globally threatens biological diversity, ecosystem dynamics, resource availability, economy of an area and human health [2]. The spread of these species is considered as one of the high risk factor to the ecosystem. Accidental introductions happened via trade or travel across continents and import of various items such as timber, food grains, fodder etc.

Currently, the human centered landscapes are typically featured by intensive land-use pattern and increased scale of habitat destruction, often results in to contrasted mosaics of habitat. Fragmentation of the existing habitat is a major threat to biological diversity and ecosystem functioning. Decreasing existing habitat size and increasing isolation of habitat patches results in to decline in species richness and abundance, also changes in community structure. This process of habitat fragmentation and destruction may greatly change the landscape architecture and local ecosystem functioning. After habitat fragmentation, the surviving plant communities become more prone to invasion by non-native plant species. Many studies documented that floristic changes emerge after habitat fragmentation, which may be due to invasion by an alien weed. Forest study of Costa Rica reported that fragmented tropical dry forest were prone to invasion by weedy generalist plant species. When changes in community occur either through habitat alteration or through the invasion of alien species, local decline, and even extinction of native species may occur. The effect of fragmentation on species loss is now becoming well known in many parts of the earth. However, limited studies have viewed at the effects of fragmentation on the success of invaders and the subsequent effects of the invader on the native species resident in fragments. In this scenario, the objective of the review is to report the alien invasion of species threating to various aspects on the environment including health and economy. Further, a check list of exotic species was also prepared in this context from Kerala.

2. MATERIAL AND METHODS

Intensive floristic survey reports were screened in different areas of Kerala in such a way that each location could be studied in every season of the year. A comprehensive list of invasive exotic plant species and the information regarding the various issues of invasive exotic plant species of the area was prepared. The nativity, sources and mode of introduction of these alien invasive plants were noted from the available literatures. The native ranges of the species were recorded from published literatures. Plants were categorized according to their life forms as herb, undershrub, shrub, climber and tree. The studied habitats were wasteland, cultivated field, riverbank, pond bank, home garden, forest, roadside etc.

3. RESULTS AND DISCUSSION

3.1. Invasions of species by anthropogenic activities and natural means

The introduced invasive exotic plant species (IEPS) by human beings threaten the ecosystems, biodiversity and replaced many economically unique native plant species and thereby creating issues in agriculture and silviculture practices, upsetting the vegetation dynamics and nutrient recycling. Introductions of alien plants by human activities in the native habitats are the major reason for the drastic changes recorded within the indigenous native plant communities of the area [3]. Trade connected with commerce (especially imports) and extensive travel by people magnified the intensity of invasive alien species across the world. Current scenarios of transport have directly/indirectly increased the inadvertent migration of species, often resulted in to disastrous consequences [4]. Introduced or indirectly carried species reports like *Eucalyptus citriodora*, *Lantana camara, Acacia auriculiformis* and *Senna spectabilis* were the examples substantiating the degradation of natural ecosystems [5].

The natural invasion mainly depends upon the dispersal ability of the invading species. The time scale for natural invasion usually ranges from few to many years. Birds, animals, water and wind forms the agents for natural invasion. *Ageratum conyzoides* and *Parthenium hysterophorus* were examples for natural invasion [6]. After migration of an exotic plant species, there is a lag phase before an exponential phase of its fast spread. The species like *P. hysterophorus* that at a given period may seems to be non-invasive but suddenly spread vigorously.

3.2. Various types of environmental impacts by the invasive exotic plant species (IEPS)

3.2.1. Impacts of exotic species invasions on indigenous species

Study reports of past introduced plants illustrated that the impacts of invasive species are complex and may permanently alter the vegetation and community structures. Invasive exotic plant species inducts more

stress especially where communities are disturbed. Limited data was available on alien plant species threatened the undisturbed local indigenous plant communities. In Kerala, *Chromolaena odorata*, *Senna spectabilis*, *Hypoestes sanguinolenta, Maesopsis eminii, Eupatorium cannabinum, Mikania micrantha, Sphagneticola trilobata* and *Acacia mearnsii* were well recognized alien invaders which posed threat to indigenous plant communities including the protected areas under conservation and also the habitats from planes to hilly tracts (Table 1).

Table 1: List of alien invaders which posed threat to indigenous plant communities in Kerala

Sl. No	Plant name	Family, habit & origin	Threatens
1.	*Chromolaena odorata* (L.) R.M. King & H. Rob	Asteraceae, Climber South America and Central America	Threatens the species like *Sida cordifolia*
2.	*Senna spectabilis* (DC.) Irwin & Barneby	Caesalpinioideae, Tree, South and Central America	Intruded in to wildlife sanctuaries as well as in plantations
3.	*Hypoestes sanguinolenta* Hook.	Acanthaceae, Herb, Madagascar	High risk species to native plants
4.	*Maesopsis eminii* Engl.	Tree, Rhamnaceae, Africa	Inhibits the undergrowth of native species
5.	*Eupatorium cannabinum* L.	Herb, Asteraceae, Europe to Central Asia	High nuisance value around water ways
6.	*Mikania micrantha* Kunth.	Asteraceae, Climber, America	Herbivores face food scarcity as the native plant species
7.	*Sphagneticola trilobata* (L.) Pruski	Asteraceae, Runner, Mexico	Garden plant threatened
8.	*Acacia mearnsii* De Wild	Mimosoideae, Tree, south-eastern Australia	Ground water threatened

Disturbed and unattended habitats are more prone to the invasion when compared to the well-managed ecosystems and habitats. The habitats which have more diverse plant communities were highly competitive and resist invasion. Schmitz et al., [7] reported that the invasive trees of Florida such as *Schinus terebinthifolius*, *Melaleuca quinquenrvia* and *Casuarina* spp resulted in to major threats to the native vegetation. Similarly, the introduced different pine species created issues to natural habitats in Australia, New Zealand, and South Africa. It was reported that in Christmas Island at Australia 52.70% species have been found to be exotic like *Leucaena leucocephala, Muntingia calabura, Ricinis communis, Carica papaya* and *Psidium guajava* and most of them were confined to disturbed regions such as minefields, overburden dumps, and road sides [8].

The alien terrestrial species introduced in to the natural habitats are responsible for the extensive and unpredictable irreversible changes in those areas (Table 2). Many countries initiated techniques to utilize the exotic tree species for commercial, economic uses and for ornamental landscapes which further intensified more noxious invaders growth. These tree species have impacted the natural above-ground herbal and other native vegetation. Sometimes, under the alien conditions or in new invaded ecosystems, such type of species become naturalized and expands over other native ecosystems. Richardson et al., [9] reported that introduced pines in the Southern Hemisphere have affected large areas of natural grasses and thickets. It brought a lot of change in the dominant annual and perennial herbals and decreased the species composition and modified vegetation patterns and the nutrient cycles. The disturbed forest understories are more prone to invasion as compared to the undisturbed zones. Dogra et al., [10] reviewed that there are many species such as *Alliaria petiolata*, *Acer platanoides*, *Lonicera bella, Rhamnus cathartica* and *Berberies thunbergii* that established and dominated the low light forest understories in the Northwestern USA. The invasive species survive under the shade because rapid growth takes place in the microhabitats than exposed conditions.

3.3. Impact on the soil structure and its dynamics

Invasion by exotic plant species affects the dynamics and structure of the soil on a holistic scale and have immense impact on ecosystem functions like soil-mineral recycling. Since these effects result from differences in the mode of behavioural patterns between the exotic and native species, novel physiological characters such as nitrogen, phosphorus cycling may cause maximal alterations in the ecosystem function [11].

Table 2: List of Invasive Alien plant species in India

Plant species	Family, Habit & origin	Impacts
Acacia mearnsii De Wild.	Mimosoideae, Tree, South-eastern Australia	It rapidly grows to forms dense thickets and destroys the grazing lands.
Acanthospermum hispidum DC.	Asteraceae, Herb, Brazil	Troublesome annual weed of annual and perennial crops.
Aerva javanica (Burm.f.) Juss. ex Schult.	Amaranthaceae, Herb, Trop. America	It has only recently come to be regarded as a serious environmental weed.
Ageratum conyzoides L.	Asteraceae, Herb, Trop. America	Allelopathic, highly invasive, threat to croplands
Alternanthera tenella Colla.	Amaranthaceae, Herb, Trop. America	Rapid colonizer and harmful to forest ecosystem.
Alternanthera philoxeroides Mart.) Griseb	Amaranthaceae, Herb South America	By forming dense mats of interwoven stems over water or land, this invasive weed may threaten the native flora and fauna, reduce crops yields, block ships, and promote flooding
Argemone mexicana L.	Papaveraceae, Herb, Trop. Central & South America	Harm native flora through allelopathy
Asclepias curassavica L.	Asclepiadaceae, Herb, Trop. America	It is prolific in disturbed sites and competes with agricultural crops and indigenous species. This plant contaminates crop seed.
Blainvillea acmella (L.) Philipson.	Asteraceae, Herb, Trop. America	It is a common weed in cultivated fields, degraded forests.
Bidens pilosa L.	Asteraceae, Herb, Trop. America	The plant is thought to produce allelopathic toxins that affect a number of crops.
Blumea obliqua (L.) Druce	Asteraceae, Herb, Trop. America	The extinction of native species and has negative impact on crop production
Calotropis procera (Ait.) R.Br.	Asclepiadaceae, Shrub, Trop. Africa	It is noxious weed; hence it is controlled within the area. Establishing the weed has been advocated for environmental protection and as a nurse crop for more valuable species
Cardamine hirsuta L.	Brassicaceae, Herb, Trop. America	It is a fast-growing herb that often behaves as a weed in both disturbed and undisturbed sites
Cassia alata L.	Caesalpiniaceae, Shrub, West Indies	Introduced as an ornamental and became threat to local flora
Celosia argentea L	Amaranthaceae, Herb, Trop. Africa	It is a common weed of cultivated fields and scrub lands.
Chromolaena odorata (L.) King & Robinson	Asteraceae, Herb, Trop. America	Its foliage is reportedly flammable (contains essential oils), making it a threat to indigenous coastal forest patches, which are not resilient to fire.
Cleome viscosa L.	Cleomaceae, Herb, Trop. America	This species produces large numbers of sticky seeds that can be easily dispersed by wind and has the potential to spread much further into new habitats.
Chrozophora rottleri (Geis.) Spreng.	Euphorbiaceae, Herb, Trop. Africa	This plant species act as the main cause for threat to the native biological diversity.
Cleome gynandra L.	Cleomaceae, Herb, Trop. America	It is aggressive colonizer and is weed of village wastelands, dumping grounds, crop lands
Crotalaria retusa L.	Papilionaceae, Herb, Trop. America	The risk of new introductions as well as the probability of escape from cultivation is high
Croton bonplandianum Boil.	Euphorbiaceae, Herb, Temperate South America	Became threat to endemic flora and gradually destroys.
Cryptostegia grandiflora R.Br.	Asclepiadaceae, Herb, Madagascar	A threat to native biodiversity.
Cuscuta chinensis Lam.	Cuscutaceae, Herb, Mediterranean	It has proved locally invasive and damaging to fruit and ornamental trees.

Cytisus scoparius (L.) Link	Papilionaceae, Herb, Europe	It displaces native understorey vegetation and grasses, finally forming monospecific stands.
Crassocephalum crepidioides (Benth) S. Moore	Asteraceae, Herb, Africa	The plants pose a serious threat to flora and fauna.
Datura innoxia Mill.	Solanaceae, Shrub, Trop. America	It has the capacity to invade natural habitats and can be considered as potential threat for natural biodiversity.
Digera muricata (L.) Mart.	Amaranthaceae, Herb, SW Asia	Common weed of irrigated dry cultivated fields.
Echinops echinatus Roxb.	Asteraceae, Herb, Afghanistan	Serious aquatic weed, allelopathic in nature, causes hindrance in navigation, reduces water quality and algal growth
Eclipta prostrata (L.) Mant.	Asteraceae, Herb, Trop. America	It has never been reported as a serious weed but it is troublesome in several crops.
Eupatorium cannabinum L.	Asteraceae, Herb, Europe to Central Asia	Allelopatic effect causes serious threats to native flora
Euphorbia heterophylla L.	Convolvulaceae,:Herb, Trop. America	It is reported as an emerging weed in cotton and processing tomato.
Evolvulus nummularius (L.) L.	Convolvulaceae, Herb, Trop. America	It is found both in agricultural land and waste and fallow lands mainly as noxious weeds.
Gomphrena serrata L.	Amaranthaceae, Herb, Trop. America	Occasional weed of cultivated fields, habitation and forest openings.
Gnaphalium polycaulon Pers.	Asteraceae, Herb, Trop. America	It is a noxious species found in tanks, ditches and margins of river banks.
Hyptis suaveolens (L.) Poit.	Lamiaceae, Herb, Trop. South America	It is a major threat to native biodiversity, ecosystems and livelihoods.
Hypoestes sanguinolenta Hook.	Acanthaceae, Herb, Madagascar	It competes with the native flora and reduces its population.
Indigofera linifolia (L.f.) Retz.	Papilionaceae, Herb Trop. America	Invasion of the species threat natural habitat
Ipomoea carnea Jacq.	Convolvulaceae, Shrub Trop. America	The invasions of the species cause ecological disturbances that threaten native biodiversity.
Ipomoea obscura (L.) Ker.-Gawl.	Convolvulaceae, Herb Trop. Africa	Common weed in moist places of degraded forests and hedges.
Lantana camara L.	Verbenaceae, Herb Trop. America	Strongly allelopathic, serious threat to medicinal plants, responsible for forest fire
Lagascea mollis Cav.	Asteraceae, Herb, Trop. Central America	Common weed of forests, plantations, habitation, waste lands and scrub lands
Leucaena leucocephala (Lam.) de Wit	Mimosacceae, Herb, Trop. America	Runs wild in waste lands, scrub lands and fringes of plantations.
Macroptilium atropupureum (DC.) Urban	Papilionaceae, Climber, Trop. America	It is a weed species quite common but often scarce in crops.
Maesopsis eminii Engl.	Rhamnaceae, Tree, Africa	A threat to tropical forest conservation.
Malvastrum coromandelianum (L.) Garcke	Malvaceae, Herb, Trop. America	Common weed of cultivated fields, forest openings and habitation.
Merremia aegyptia (L.) Urban.	Convolvulaceae, Herb, Trop. America	A very good website detailing weed species
Melochia corchorifolia L.	Sterculiaceae, Herb, Trop. America	Common weed of moist places.
Mikania micrantha Kunth.	Asteraceae, Climber, Trop. America	Known for its allelopathic potential, highly invaded forest areas
Mimosa pigra L.	Mimosacceae, Shrub, Trop. North America	It has the potential to harm a wide number and variety of different types of primary production
Ocimum americanum L.	Lamiaceae, Herb, Trop. America	Common weed of waste lands and scrub lands.
Ocimum gratissimum L.	Lamiaceae, Herb, Africa	Species prefers wet and fertile conditions, but can tolerate drought after flowering and influence the natural habitat.
Oxalis corniculata L.	Oxalidaceae, Herb, Europe	Common winter season weed.
Parthenium hysterophorus L.	Asteraceae, Herb, Trop. North	Aggressive colonizer, highly allelopathic,

	America	allergic to animals and human being, threat cause to crops and other native flora
Passiflora foetida L.	Passifloraceae, Herb, Trop. South America	Common weed of forest fringes and bunds of cultivated fields.
Pedalium murex L.	Pedaliaceae, Herb, Trop. America	Occasional weed of waste lands, road sides and cultivated fields.
Pennisetum purpureum Schum.	Poaceae, Herb Trop. America	Posing a threat to the native species
Peristrophe paniculata (Forssk.) Brummitt	Acanthaceae, Herb, Trop. America	The native flora is facing severe threats from this species.
Peperomia pellucida (L.) Kunth.	Piperaceae, Herb, Trop. South America	Common winter season weed in gardens and on moist rocks near by habitation.
Pilea microphylla (L.) Liebm.	Urticaceae, Herb, Trop. South America	Pilea microphylla also known as rockweed, common weed of gardens and often as a pot weed.
Physalis pruinosa L..	Solanaceae, Herb, Trop. America	This alien invasive species is a serious threat to indigenous flora.
Portulaca oleracea L..	Portulacaceae, Herb, Trop. South America	Weed of moist fields and gardens.
Prosopis juliflora (Sw.) DC.	Mimosacceae, Shrub, Mexico	Aggressive and has not only successfully invaded several habitats but has also caused substratum degradation in these by causing loss of finer soil particles
Rhynchelytrum repens (Willd.) C.E. Hubb.	Poaceae, Herb, Trop. America	Occasional weed of disturbed places.
Senna spectabilis (DC.) Irwin & Barneby	Caesalpinioideae, Tree, South and Central America	The plant is posing a threat to wildlife and indigenous plants in the forest areas.
Sesbania bispinosa (Jacq.) Wight	Papilionaceae, Shrub, Trop. America	It has a tendency to naturalize and thus poses a threat of local dispersal.
Solanum americanum Mill.	Solanaceae, Herb, Trop. America	Occasional weed of cultivated fields and often found in forest fringes.
Sida acuta Burm.f.	Malvaceae, Herb, Trop. America	This plant has a pantropical distribution and is considered a weed.
Solanum torvum Sw.	Solanaceae, Shrub, West Indies	It is considered to be a serious threat to the productivity and sustainability of pasture.
Solanum seaforthianum Andrews.	Solanaceae, Climber, Brazil	This species is an aggressive invasive vine that has been widely cultivated as an ornamental.
Spermacoce hispida L.	Rubiaceae, Herb, Trop. America	Common weed of degraded forests, scrub and cultivated fields.
Spilanthes radicans Jacq.	Asteraceae, Herb, Trop. South America	Common weed of gardens and occasionally found in cultivated fields and forest fringes.
Sphagneticola trilobata (L.) Pruski	Asteraceae, Runner, Mexico	Plant is belongs to the top 100 of most alien invasive species in the world, which seriously threatens the biodiversity of its indigenous congener.
Stachytarpheta cayennensis (Rich) Vahl.	Verbenaceae, Herb, America	According to a risk assessment this species is regarded as being highly invasive and is a casual weed, a "garden thug", with effects on the local plant.
Synedrella nodiflora (L.) Gaertn.	Asteraceae, Herb, West Indies	Common weed of waste lands and gardens.
Tridax procumbens L.	Asteraceae, Herb, Trop. Central America	Common weed, along railway tracks, road sides, in cultivated fields and degraded forests.
Tribulus terrestris L.	Zygophyllaceae, Herb, Trop. America	Plants invade roadsides, pastures, fields, grasslands and degraded forests.
Triumfetta rhomboidea Jacq.	Tiliaceae, Herb, Trop. America	Common weed of forest openings, scrub and waste lands.
Turnera ulmifolia L.	Turneraceae Herb, Trop. America	Occasional weed of habitation and disturbed lands.
Urena lobata L.	Malvaceae, Shrub, Trop. Africa	It invades disturbed areas, pastures, eroded areas, and perennial crop plantations.

		Tolerates salt spray but does not grow in saturated soils.
Ulex europaeus L.	Papilionaceae, Shrub, Western Europe	It is an invasive shrub deemed as one of the most invasive species in the world.
Waltheria indica L.	Sterculiaceae, Herb, Trop. America	Abundant along railway tracks, road sides and in degraded forests.
Xanthium strumarium L.	Asteraceae, Herb, Trop. America	Occasional weed of cultivated fields and scrub lands.
Youngia japonica (L.) DC	Asteraceae Herb, Trop. South America	Occasional weed of cultivated fields and scrub lands.

(Source:C. Sudhakar Reddy, G. Bagyanarayana, K.N. Reddy & Vatsavaya S. Raju. 2008. Invasive Alien Flora of India. National Biological Information Infrastructure, Usgs, USA)

Kourtev et al., [12] studied the differences in earthworm densities and nitrogen dynamics in soils under exotic and native plant species. The invasion of *Berberis thunbergii* and *Microstegium vimineum* in hardwood forests of New Jersey, Europe has showed significant increase of pH in soils under the invasive plants when compared to soils under native shrubs (*Vaccinium* spp.). In addition, the available nitrate and net potential nitrification were remarkably higher in soils under the two exotic species. Sharma and Dakshini [13] reported the integration of plant and soil features and the ecological success of *Prosopis* species. The introduced *P. juliflora* was fast growing, highly aggressive and invasive, and causes substratum degradation in the semi-arid and arid areas of North and North-west India as compared to native species *P. cineraria*. This lack of integration amongst plant and soil characteristics and the ability to meet its nutrient requirements in all situations could be the basis of the phenomenal spread of *P. juliflora* across varying environmental conditions, in contrast to *P. cineraria* [13]. Correlations between habitats with contrasting levels of soil resource availabilities suggest that an increase in resource availability tends to increase invasion of non-native grassland communities than native plants. For example, nutrient enrichment has been consistently shown to increase the abundance of alien plant species and decrease the abundance of native ones.

3.4. Impact on economy due to invasion

Many introduced alien species for human welfare around the world are known to create environmental and economic havoc [14]. Therefore, people's views about alien spp. and their local ecological knowledge can be an effective mode to classify the exotic impacts. For example, *Acacia mangium*, an exotic species in northern Brazilian Amazon, is noted for its harmful effects to economy, environment and indigenous people through alteration of the water quality [14]. Similar reports were also noticed from India.

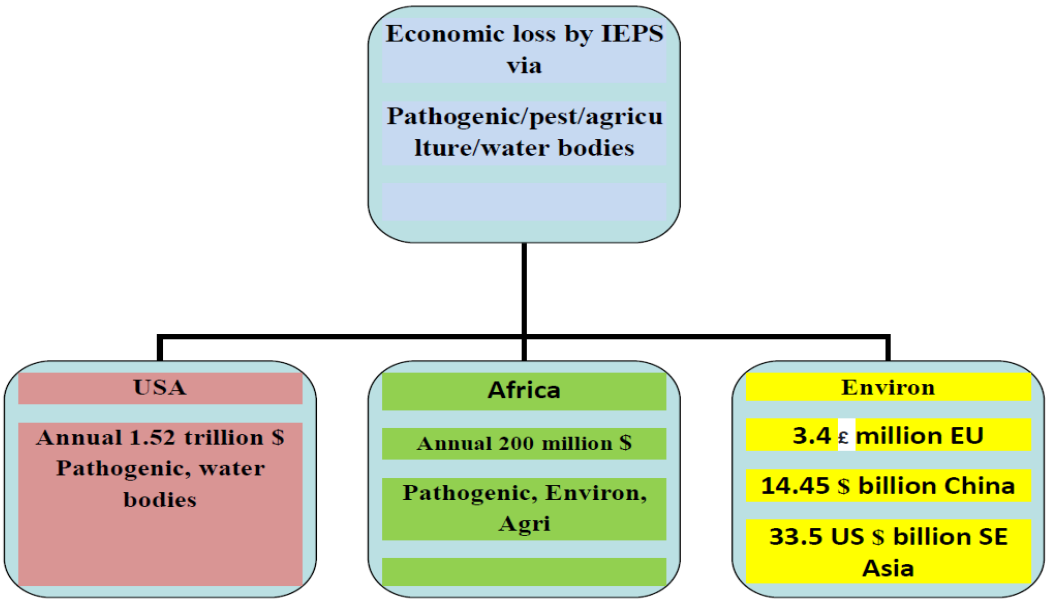
The invasion of aquatic species like *Eichhornia crassipes* in Lake Victoria has become a disaster for human welfare as it reduces fish growth and eco-tourism of the area [15]. Furthermore, the ecological niche models, and Global Climate Models have predicted a shift of water hyacinth, under climate change regime, towards European and Mediterranean regions indicating the serious economic implications of such invasion. Farming in Kuttanad depends on the entry of water into the fields. It has become routine for us to remove water hyacinth, locally known as *pola* or *kulavazha,* before preparing the fields for cultivation. The removal of weeds is labour and cost-intensive. The government provides us Rs. 4,880, but sometimes it is too meager an amount given the degree of infestation. The farmers also face difficulty in transporting machineries and harvested grains in boats through the weed-infested water channels in Kainakary. The plant chokes the life out of the freshwater ecosystem by preventing penetration of sunlight, required for the survival of underwater fauna. It also provides a breeding ground for mosquitoes, insects and disease pathogens. In Alappuzha, its overgrowth in Vembanad Lake, a designated Ramsar site, has affected the movement of passenger boats and houseboats. It causes damage to boats' engine. Fishing is another sector hit hard with large swathes of water bodies remaining carpeted with the plant. Efforts to remove the weeds from water bodies using various methods including physical, mechanical, chemical and biological have so far failed. In fact, the problem has virtually multiplied over the years. A sum of Rs. 30 crore earmarked under the first Kuttanad Package was "wasted" owing to the unscientific approach adopted. The locals in the area meet the major part of this expense by utilizing these weeds for making value-added products and thereby generating employment. Kottapuram, a village in

Thrissur district of Kerala, residents has found an innovative way to use the water weed to create jobs for poor underprivileged women.

In USA, the invaded *Tamarix ramosissima* plants has resulted in huge loss of water (1.4-3.0 billion cubic meters worth US$ 26.3-67.8 million) that deprives various human needs [15]. Similarly, *Melaleuca quinquenervia* in Florida, and *Eucalyptus* species in California, with their deep tap roots, use a huge quantity of the ground water.

In Southeast Asian context, human health sector alone suffered economic loss of US $1.85 bill ion from disease-spreading alien invaders. Negi et al., [16] attempted a long-term ecological monitoring on forest ecosystems in Indian Himalayan Region. The agriculture and health sectors together suffered an economic loss of US$33.5 billion due to the invasive species. Thus economic loss due to invaders was more pronounced in agriculture (approximately 90 % of monetary loss) than human health sector.

Shackleton et al., [17] documented in African region related with the alien species as high risk i.e. *Opuntia stricta*, was evaluated to cause the economic loss of US$ 500–1000 per household per year through participatory rural appraisal technique. Further, Sileshi et al., [18] reported that in the agriculture sector of African countries, alien invaders were evaluated to result in an economic annual loss of US$ 1 billion by causing damage to agriculture crops. Pejchar and Mooney, [15] evaluated *Myriophyllum spicatum*, an aquatic plant, in Lake Tahoe of Sierra Nevada (US), caused a recreational loss by 1%, which in monetary terms amounts to US$500 000 annually. Similarly, *Euphorbia esula* and pathogenic *Xanthomonas campestris* (citus canker) were known to cause economic loss of nearly US $200 million dollar annually [1]. It has been estimated that about US $ 600 million goes to minimize the loss caused by alien species to environment and agriculture (Fig.1).



Source [(Office of Technology Assessment.

Fig. 1: Quantification of alien species impacts in terms of economic loss driven by environmental alterations in terms of socio-ecological/economic aspects of human wellbeing of different countries - United states, China, Africa European Union, South East (SE) Asia

3.5. Impacts on the ecosystem services

Many alien/introduced exotic species are well known for their impacts on ecosystem services *viz,* aesthetic, recreational, cultural and regulatory [15]. Eiswerth et al., [19] recorded the adverse effect of alien species such as obstruction of the water navigation, they by the recreation and tourism services. Restrictions on trade of ornamental exotic species to avoid their harmful effects on environment have been reported to impact the aesthetic services of ecosystems [15]. Many alien species are also known to impact the regulatory ecosystem services i.e., hazards mitigation (e.g. landslide), water

treatment, pest management, pollination, climate change, etc., which are inextricably linked with agriculture and forestry [15].

The invasion of *Opuntia stricta* in African region adversely affected the environment and economy. It has also affected the livelihood of local people through reduction in fodder and livestock health [17]. Since the cultural values are confined to a specific community, their economic quantification is difficult [15]. The cultivation of multi-purpose trees and shrubs is encouraged widely in order to boost bioenergy and industrial sectors [20]. Although, multi-purpose plants provide several benefits to humans, the introduction of alien species as a multipurpose species like *Prosopis* sp. (mesquite) in South Africa can profoundly affect the ecosystem services [21].

3.6. Impact on invasion in diverse environment, protected areas and diversity hotspots

Hughes and Convey [22] reviewed the possible mechanism of protection of Antarctic terrestrial ecosystems from inter- and intra-continental transfer of non-indigenous species by human activities. Alien invasion of microbes, plants and animals may be occurred due to scientific explorations, industrial activities, tourism and cargo oriented travel of people [23]. Frenot et al., [24] reported the biological invasions in the Antarctic area and its impacts and implications. The red quinine tree was introduced in the treeless ecosystems of Galapagos highland, but recently it turned as invasive; thereby reduced the incoming solar radiation which in turn affected the endemic herbaceous species more adversely than non-endemic native species [25].

Foxcroft et al., [26] assumed that the well-managed protected areas, particularly those located on mountain hotspots, are resistant to plant invasion as evident from Kruger Natonal Park of South Africa. Now there is growing literature which reveals that the plant invasion is a major threat to forest biodiversity in protected areas also as is demonstrated in Gros Morne National Park in boreal Canada [26]. Najar et al., [27] analyzed the shola tree regeneration is lower under *Lantana camara* thickets in the upper Nilgiris plateau. Kannan et al., [28] warned on playing with the forest:invasive alien plant species, policy and protected areas in India.

Ecosystem functioning is derailed due to alien species to a greater extent in the geographically isolated islands than in the main lands [29]. It has been documented that such species affect the ecosystem functioning through (a) reduction in the diversity of native species and animals, (b) remarkable changes in physico-chemical soil features (mostly through allelopathy), and (c) enhancement in ecosystems response towards altered fire regimes [29]. Schindler et al., [30] and Heshmati et al., [31] documented the impacts of alien species to reduce the biodiversity of native plants, which may have adverse implications for environment functioning, ecosystem services and global climate change.

However, their proposed role in extinction was argued by invasion biologists and in order to invalidate it or ascertain it uniform dataset across the diverse habitats especially in the isolated islands are needed. Arya et al., [32] documented the ecological impact of planting indigenous plants instead of exotic Acacia trees in Anchal. Jones [33] studied the changes in cropping patterns, resilience and invasive plants of the home gardens of Kerala. Mangla et al., [34], recorded the impacts of exotic invasive plant accumulates native soil pathogens which inhibit native plants growth.

Competition between alien species vs native flora for resources regulating ecosystem functioning may lead to the invasion melt down. Simberloff and Von Holle, [35] meltdown hypothesis states that the establishment of one invasive species in a new environment makes it easier for other nonnative species to invade. The first impact of alien species is the reduction in biodiversity is common across the earth. Alien invaders are also affect the wildlife for example, Gan et al., [36] reported that the alien species *Spartina alterniflora* replaces native *Phragmites australis* and *Scirpus mariqueter* in wetlands of China, which eventually leads to the decline in avian populations due to the movement and feeding restrictions.

Eutrophication in the oligotrophic water bodies leads to intensify the strength of alien species. Similarly, alien species tend to spread at a faster rate, consequent upon the expansion of natural fire regime, which may also have adverse impacts on the ecosystem functioning. Pejchar and Mooney, [15] recorded that many alien species were found to alter the fire regimes in several terrestrial ecosystems that result in a huge socio-economic loss.

3.7. Impacts of the alien species on human health

Biodiversity and its changes are inextricably linked with the human health, both in positive and negative sense like malaria transmission, positive health effects of diversity in nature and green spaces etc [37, 2]. Positive

implications include their applications in vector borne control and ethno-medicinal uses. For instance, a mosquito repellent was extracted from *Lantana camara* [37]. *Ambrosia artemisiifolia, Parthenium hysterophorus, Ailanthus altissima, Acacia, Acer, Casuarina, Eucalyptus, Helianthus, Platanus and Xanthium* were some of the alien species which cause allergy in human beings.

Lake et al., [38] tried to prioritize the impacts of alien species on human health, through direct exposure, as vectors or through transfer of toxins in edibles. *Lantana camara* provides a favourable habitat to tse-tse fly which causes sleeping sickness. Likewise, brush tail possum transmits bovine tuberculosis to live-stock and deer in New Zealand, affecting human health indirectly through food-chain; whereas *Parthenium hysterophorus* serves as a vector of Malaria. Similarly, *Ixodes scapularis* is a vector of *Borrelia burgdorferi*, which causes the Lyme disease in humans.

The prominent aquatic alien species like *Phragmites australis* and *Typha* assist in the colonization and multiplication of vector-borne pathogens, particularly West Nile virus [39]. *Eichhornia crassipes* is a high risk alien species, helping in the spread of schistosomiasis [37]. *Arundo donax* another top ranked alien species posing severe threats to the global environment and health. Trade of such aquatic plants facilitates the spread of disease causing vectors and increases the health risks from vector borne diseases [37]. Water blooms like cyanobacteria that release the cyano-toxins like microcystin, hepatotoxins, saxitoxins, lynbyatoxin and anatoxins are teratogenic (embryotoxic), carcinogenic, and promote tumours. These bio-toxins enter into food chain through the edible species of aquatic ecosystems like water chestnut, fishes etc. Besides the bacterial invaders, there are several other alien species which release diverse chemical toxins for example, grayanotoxins of *Rhododendron ponticum*, which contaminates honey with hazardous toxins. Similarly, the sap of *Ailanthus altissima* upon direct contact effectuates myocarditis, glochids of *Opuntia stricta* cause the eye irritations, retrorsine, an alkaloid of pyrrolizidine group from *Senecio inaequidens, Cortaderia selloana*, *Spartina anglica*, *Caesalpinia decapetala,* and *Rosa rugosa* causes skin cuts and injuries owing to their sharp edge and silicate crystal depositions on leaves. Several ornamental alien species also pose health issues as they emit toxins in the environment. For example, Allergen-specific immunotherapy is considered the most effective tool for managing human health issues due to such allergic species, whereas the adoption of ecological breeding measures like cross-breeding, and understanding the invasion biology of the may be useful for reducing their health impacts. However, species specific focused studies are needed to provide an insight of health hazards, emanating from the exposure alien species for developing better mitigation strategies [40].

3.8. Invasion is it a nuisance? The quest of management implications

Biologists in the field of invasion of alien species are now realizing that not all the alien species impose threats to environment [41]. Pejchar and Mooney [15] reported that 99% of the selected alien species were used globally as food crops directly or indirectly. Even, certain species like *Lantana camara* and *Ageratum conyzoides* were reported to have some ethno medicinal roles in primary health care [20].

IUCN's (2003) clearly states that management of alien species is a priority issue and must be mainstreamed into all aspects of managements of forests and protected areas. Both positive as well as negative ecosystem services must be clearly identified to elucidate their cost-benefit to guide the stakeholders and policy makers [17]. In biodiversity conservation, identifying/ prioritizing alien species has been given the top priority. In this respect, 10% of coastal/ marine areas and 17% of terrestrial and inland water areas are conserved through the diverse targets/action plans. Further, attention is needed for the management of global protected areas, which cover the 14.9 %, of the terrestrial realm.

4. CONCLUSION

The invasion of exotic species is the major concern throughout the earth and has adverse impact on vegetation and agricultural system. There are multiple features which influence the invasion process of alien species. Various mechanisms of invasion of alien species have been proposed. Studies highlighted that antibiosis has major role in establishment and rapid invasion of alien species. Studies documented that the allelochemicals leached from the exotic species are the major factor to compete them with habitat and environment for successful invasion. Similarly, different strategies have been also discussed regarding control of the invasive plant species including biological, cultural and chemical practices. The consequences of invasion are, diverse across the states. Public awareness related to environmental change and biodiversity loss related to alien invasion is mandatory. Sustainable utilization of

land and to counter the invasive species on the native flora and biodiversity is to be designed. The rate of spread of alien species in each of the climatic zones is different. There is also a need to give adequate resources and strategies through which ideal management can be done to control the invasion process in future.

Conflict of interest

The authors report no conflict of interest

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