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ASSESSING THE IMPACT OF INVASIVE ALIEN PLANT SPECIES ON ENVIRONMENT, ECOSYSTEM SERVICES AND HUMAN HEALTH

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ABSTRACT

Invasive alien plant species (IAPS) are considered to be an important driver of global change in biodiversity, community structure, and ecosystem processes of the invaded ecosystem, fundamental to human well-being (access to secure livelihoods, health, good social relations, security and freedom). There isa lack of studies on IAPS, concerning its economic quantification, livelihood considerations and human health risk assessments. In this article, we review the role of invasive alien plant species in modulating native plant species diversity, environment, ecosystem, climate change, land-use change, socio-economic security and also tried to discuss the role of IAPS on the health of humans and human well-being. We suggest some management practices and use of advance tools such as remote sensing and GIS to assess, map and monitor the vulnerability of IAPS. These advance technologies may also help in the detection of impact of IAPS on ecosystems, and its conservation and restoration.
Keywords: Biodiversity, Climate change, Human health, Invasion, Livelihood

Introduction

During the past half-century the degree of biological invasions has increased rapidly (Pysek and Richardson, 2010). Invasive species are a major driver of global change in biodiversity (via competition, predation, hybridization and indirect effects), community structure and genetic diversity, (Pyˇsek and Richardson, 2010; McGeoch *et al.*, 2010). IUCN (2000) defined invasive species as an alien species which becomes introduced in natural or semi-natural ecosystems and threatens the native biodiversity. The introduction of species beyond their native range as a direct or indirect result of human action alters ecosystem processes (Jeschke *et al.*, 2014). However, many introduced species are useful in new geographic areas because these species provide resources and other ecosystem services (Vaz *et al.*, 2017). Import, human mobility and increasing establishment rate are some important factorswhich cause increased growth of IAPS. Resource pool accessibility and increasing globalization are other factors which affect the number of IAPS (Seebens *et al.*, 2017).

Current reviews of the degree of the homogenization of the world's biota have shown that not only islands and disturbed sites are affected by IAPS but also mainland areas are affected.

After habitat destruction, the biological invasion is widely reported as the second greatest agent of endangerment and extinction of species (Pejchar and Mooney, 2009; Rai and Singh, 2020). European Environment Agency (2012) has "linked invasive species to disease, allergies, urban landscapes, and other ecosystem services which support human activity". IAPS also have a deleterious effect on the ecosystem processes, which are related to human well-being, through alteration of the natural environment, ecosystem structure as well as economic cost (Mooney, 2005; Liu *et al.*, 2005; Mazza *et al.*, 2014; Crowl *et al.*, 2008). These changes have global consequences for human well-being, including the alteration of goods (like fisheries, agricultural and forest products) and services such as clean and plentiful drinking water, climate stabilization, pollination, culture and recreation (Daily *et al.*, 2009).

Out of all flora present in Indian subcontinent 40% species are alien, in which only 25% are invasive (Singh, 2005). A total of 169 alien species have been reported in varied ecosystems of India (Kapoor and Usha, 2020). The number of invasive species in varied ecosystems such as in terrestrial ecosystem is 53, aquatic ecosystem (55), agricultural ecosystem (47) and island ecosystem (14) (Kapoor and Usha, 2020).

For understanding the consequences of invasive species, the invasion ecology is now firmly rooted in environmental management. The emergence of invasion ecology has resulted from two forces (1) development of the scientific basis for invasion biology, (2) urgency of the invasive species issue (Reichard and White, 2003). According to McGeoch *et al.* (2010), invasion ecology has exploded to embrace and borrow insights, methods, and approaches from biogeography, conservation biology, epidemiology, human history, population ecology, and many other domains.

In this review article, we tried to discuss the role of invasive alien plant species on native plant diversity, environment, ecosystem, land-use change, socio-economic security. We also tried to discuss the impact of IAPS on human health and well-being Fig 1.

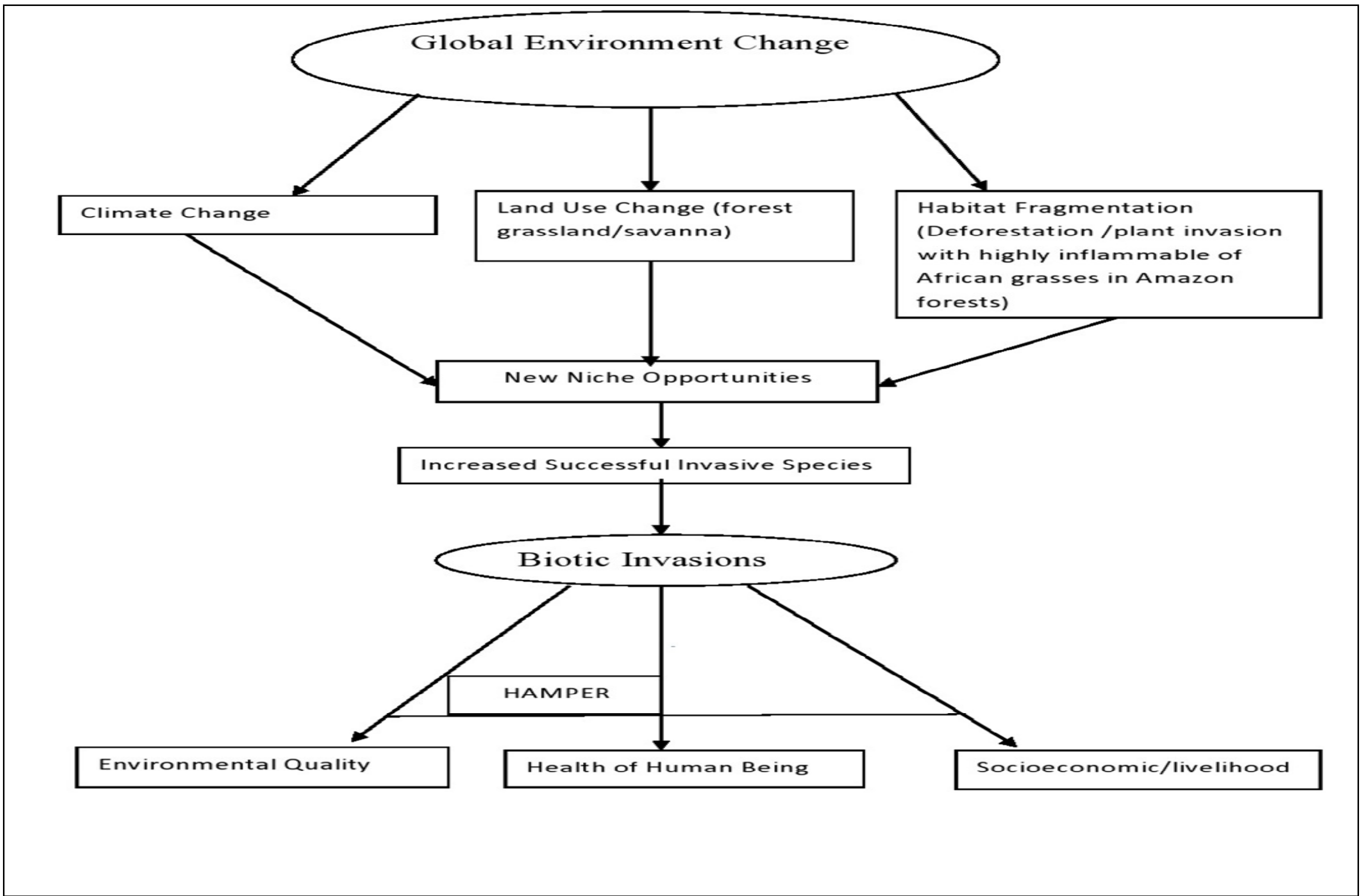

Fig. 1 : Global environmental change facilitate invasion in-turn affecting human health and socio-economic livelihood.

'Invasion ecology' is the study of the introduction of IAPS to a new area beyond their natural boundary through anthropogenic activity such as transport, and their establishment, colonization and landscape spread. There are several ways through which alien species have been introduced to a new ecosystem. For instance, (i) *Ageratina adenophora* (Sprengel) native to Mexico was introduced as an ornamental plant in Britain where it became invasive and rapidly spread throughout the world. (ii) *Limnocharisflava* and coconut introduced by the wave and ocean current and spread to different other parts of the world.

Invasive species are sometimes referred to as non-native, exotic, and alien species. However, there are conceptual differences among these terms. Non-native species are defined as the species which are introduced by humans either accidentally or intentionally to a new region outside their potential native range (Landerberger *et al.*, 2007). Exotic species isconsidered much as a broader term which includes any species (livestock, crop and garden plant) that are not native to a particular region (Landerberger *et al.*, 2007).Other confusing terminologies related to invasive alien plant species are "agricultural weeds," "revegetation species," and "aqua-cultural species" (Miawaki and Washitani, 2004). As already stated the IAPS is a dominant or codominant species and causes threats to biodiversity. However, the agricultural weeds and revegetation species reduce the productivity of crops and soil erosion, respectively through introduction in a highly disturbed area.

Characteristics of IAPS

The invasive species have the following general attributes: (Patnaik *et al.*, 2017; Willis and Blossey, 1999)

i) Tolerate a wide range of environmental conditions such as temperature, water, soil quality, humidity, etc.
ii) Produce a huge amount of seeds and have high germination success.
iii) Have a fast growth rate.
iv) Have stronger vitality, higher biomass, greater height, and a longer life span compared to native species of the invaded area
v) Allelopathic in nature (prevent the growth of neighboring plants by secreting chemicals)

According to Radosevich *et al.* (2003), the invasive alien plant species are aggressive (because of small seed size, short juvenile period, persistent seed bank long flowering and fruiting periods and replace the native plant).

Mechanisms of biological invasion

According to Levin *et al.* (2006), the biological invasion occurs when species are intentionally or accidentally introduced outside of their native or historic range, and species get successfully spread in their new environment. There are several stages through which biological invasion occurs such as introduction, establishment, spread and impact and every step is checked through several ecological attributes.

ERH (enemy release hypothesis) postulates that few IAPS those are distanced from their natural enemies like pathogens and herbivores, become more successful in the invading habitat. (Blumenthal, 2006; Rai, 2015). For example, in newly invaded areas, the seeds of *Impatiens glandulifera*, do not get affected by its natural fungal pathogens (Najberek *et al*., 2018).

The introduction of species in a new area outside of their natural range causes changes in ecosystem functioning leading to the extinction of native species (Jeschke *et al*., 2014). However, there is a paucity of literature on the consequences of such introductions on most of the non-native species (Jeschke*et al*., 2014). Establishment of IAPS outside their natural boundary is a crucial step in the process of plant invasion (di Castri, 1990). Crawely (1989) showed that the probability of successful seedling establishment would increase with the level of disturbance creating open space in a closed canopy. Spread is another process facilitating establishment. It can be dependent on the frequency and intensity of disturbance (Valentine *et al*., 2007). However, the spread is also constrained through habitat connectivity and dispersal ability (Rai, 2015).

Favourable habitats and corridors can strangely influence the distribution and abundance of IAPS. For example, roads can act as corridors for movement as well and can play a major role in the growth and dispersal of IAPS (Mortenson *et al*., 2017).

Plant biochemistry perspective to invasion ecology

Plant-plant interaction may help a species to invade and established in a new habitat by hampering the growth of native species through exudation of allelochemicals (Raizada *et al.,* 2008). Allelopathy is a proposed mechanism of biological invasion for many IAPS. It is a process in which biotic interference occurs through bio-active molecules (Rai and Singh, 2020). The term allelopathy was first given by Molisch (1937), it consists of two Greek words, allelon meaning ‘mutual’ and pathos meaning ‘to suffer’, harmful effects on each other (Yadav *et al*., 2016). It is an important strategy that increases the competitive ability of a species by releasing allelochemicals that in some way inhibits the germination and/or growth, or increases the mortality of individuals of another species (Gentle and Duggin, 1997). These are secondary metabolites; consist of mainly phenolics, terpenoids and sesquiterpenes which negatively affect the native plant species (Pinzone *et al*., 2018).

There are some important invasive alien plant species like *Prosopis juliflora* Swartz, *Leucaena leucocephala*, *Lantana camara* L., *Parthenium hysterophorus*, *Ageratum conyzoides* that secrete allelochemicals and are commonly released from its leaves, roots as well as fruits. According to Patnaik and Abbasi, 2017, allelochemicals (secondary metabolites) like syringing, L-tryptophan, juliprosopine, juliprosine and juliprosopinal are identified in *Prosopis juliflora* and it also displays autotoxicity: its chelates suppress the germination of its own seeds (Warreng, 1994, 1995).

Allelochemicals are often referred to as novel weapon (NW), that eventually repress the native species and remove the obstruction from the way for IAPS colonization in a new environment (Pinzone *et al*., 2018). For example, *Prosopis juliflora* releases allelochemicals from its root, leaves as well as fruits (Noor *et al.,* 1995). It is known to inhibit germination of seeds of other species of plants that lie in its vicinity (Muturi *et al.,* 2017). Al-Humaid *et al.,* (1998) recorded the suppression of seed germination and early growth of Bermuda grass (*Cynodon dactylon*). *P. juliflora* foliage may contain water-soluble allelochemicals and these chemicals identified as syringin, (-) - lariciresinol, L-tryptophan, juliprosopine, juliprosine, and juliprosopinal. Among these, juloprosine derivatives exhibited the most pronounced allelopathy.

Various common ecological hypotheses have been given by ecologists for the reason behind why few plant invaders show huge dominance in their naturalized range in comparison to the native range (Inderjit *et al*., 2006). A biochemical explanation was recently proposed as the 'novel weapons hypothesis' based on the findings that *Centaurea diffuse* (diffuse knapweed) and *Centaurea maculosa* (spotted knapweed) release bioactive compounds (weapons) showing much activeness against native species in invaded area than the species present in their native range.

(Inderjit *et al*. 2006, Callaway and Ridenour, 2006). The novel weapons hypothesis (NWH) was presented to describe observed results revealing that *Centaurea diffusa* and *Centaurea maculosa* compete more strongly with species present in their invaded range as compared with the ones in their native ranges. Studies suggested that the mechanism behind this competitive advantage is allelopathy (Bais *et al*., 2002, Vivanco *et al*., 2004).

The root exudates of *C. maculosa* shows stronger allelopathic effects than *Festuca idahoensis* although no biogeographic comparisons were found (Ridenour and Callaway, 2001). Subsequent reports have been found that the roots of *C. maculosa* secrete a racemic mixture of (+) and (-) catechin (Bais *et al*., 2002). (+)- Catechin shows some antimicrobial behaviour against few microbes and later it was found that it possesses average phytotoxicity (Veluri, *et al*., 2004). Catechin was also reported to possess distinct phytotoxic activity against several plants. Relying on the developmental phases of the plant; *C. maculosa*, the root exudates release many phytotoxic substances other than catechin.

Plants come up with an abundance of chemicals with distinct bioactivities at various phases of growth and responding to specific stresses, indicates that one compound cannot have the sole responsibility for any biological mechanism (Inderjit *et al*., 2006). Methyl jasmonate, is a minor component that releases from sagebrush (*Artemisia tridentata* spp. tridentata), subdues the seed germination of *Nicotiana attenuata* in field situations. Although the allelopathic impacts of methyl jasmonate on *N. attenuata* seed banks were confirmed, the chances of other anonymous compounds in the allelopathic suppression of *N. attenuate* seeds are not excluded. Allelopathic activities of root exudates are likely to be caused by a mixture of a similar compound, for example, catechin as discusses above, investigated because they are sometimes present in higher amounts, and unknown chemicals present in smaller (or larger) quantities (Inderjit *et al.,* 2006).The biotic and abiotic soil factors can be affected by root-exuded chemicals that can indirectly inhibit plant growth.

Impacts of IAPS on Environment and ecosystem services

Biotic invaders affect the ecosystem by altering the ecosystem processes such as nutrient cycling, primary productivity, hydrology, and geomorphology and also change the rules of existence for all species (Higgins and Richardson, 1996). There are so many invaders that can affect the ecosystem processes; for example, invader *Myrica faya* (nitrogen-fixing tree) in the young volcanic site of National Park of Hawaii spread through birds, altered the community composition of plant species and soil organisms, by facilitating the dominance of non-native species (Vitousek and Walker, 1889).

The IAPS can greatly influence the ecosystem services by altering ecosystem processes. The ecosystem services affected by the IAPS are, provisioning (e.g. food, timber, fibreand water), regulating (e.g. climate mitigation, flood control, disease, pollination and water purification) and cultural (e.g. recreation, tourism, aesthetics and spirituality) (Pejchar and Mooney, 2009). The effect of IAPS on ecosystem structure and function are well known but there is a lack of information about the mechanisms linking IAS to ecosystem services (Pejchar and Mooney, 2009). Moreover, the economic impact of IAPS on the ecosystem services is also neither quantified nor incorporated into economic impact assessments. As such, the impacts of IAS can result in an 'invisible tax' on ecosystem services that are rarely included in decision making.

Here, we try to put some light on the costs and benefits of IAPS for provisioning, regulating and cultural services, for the proper understanding of synergies and trade-offs associated with these impacts. There have been several attempts made to quantify the economic impact of IAPS(Pimentel *et al*., 2005; Xu *et al*., 2006; Office of Technology Assessment, US Congress 1993). The impacts shown in these assessments are staggering (e.g. US$14.45 billion in China) but largely anecdotal and wide-ranging (Xu *et al*., 2006). For example, figures for the total cost of IAS in the USA range from US$131 billion cumulative to US$128 billion annually (Pimentel *et al*., 2005; Office of Technology Assessment, US Congress, 1993). Besides, they have not used the systematic empirical methods of estimating costs and have not considered the benefits (Perrings *et al*., 2000; Born *et al.,* 2005). In addition, many effects of IAPS on ecosystem services that are difficult to convert into monetary terms are regularly overlooked.

Effect of selected IAPS on soil processes

Ecology of invasive species, alteration in community structure and economic deprivation are some points that are inscribed in the majority of the research papers that focus on the harmful effects of invasive plant species. Themes like, alteration in soil processes after the invasion of plant species often affect the development and involvement of native as well as alien species; are often disregarded (Raizada *et al*., 2008). Soil processes which change in response to plant invasion, in turn, affect the recruitment and growth of both native as well as invasive species, are often ignored.

Basic alterations in soil mechanisms, such as nitrogen and carbon dynamics are frequently accompanied by exotic plant species, for instance, invasions into the eastern deciduous forest (Kourtev*et al*., 2001), cheatgrass invasions into desert grasslands (Sperry *et al*., 2016) hawkweed (*Hieracium* spp.) invasions into New Zealand pastures and perennial grass invasions into dry forests in Hawaii (Mack and D' Antonio, 1998). Although, these studies stated that alterations in the dispersal and chemistry of litter, occasionally affects barberry species and have no effects on stilt grass and hawkweed nitrogen cycling. Moreover, changes in microclimate among sites (Scott *et al*., 2010) or alteration in the fire regime (cheatgrass invasions, Hawaiian grasses) may have varying impacts on nitrogen and carbon cycling. Eventually, few invasions are likely to cause an increment in nitrification rate by magnifying the losses of nitrogen and leaching (barberry, stilt grass) and/or reduced plant intake (Hawaiian grasses). Especially, in the decayed plot, they may further report for an overall expansion of the ecosystem's nitrogen pool (hawkweed invasions into heavily grazed pastures).

Parthenium hysterophorus (Asteraceae) is regarded as one of the major invasive species throughout the globe. Elevated concentrations of soil nitrogen and organic matter were notable in the transitional and invaded plots, unlike the non-invaded ones. Highest levels of soil pH, potassium and phosphorus were seen in the invaded plots, whereas the mentioned factors were noted to be moderate in transitional and lowest in the non-invaded plots. Management of the *P. hysterophorus* is essential to restrict future troubles, as it shows an overall negative impact on the working of the whole ecosystem by changing the below-ground soil nutrient contents and above-ground vegetation (Timsina *et al*., 2010).

The impact of invasive species onmicrobial biomass, nitrogen availability and mineralization, carbon and enzymatic activities of soil. It is clear that there is no consistent pattern regarding the effect of invaders on soil nutrients pools and fluxes. Nevertheless, due to plant invasion, the majority of studies show increased mineralization and availability of soil nitrogen and phosphorus, increased soil carbon and decline in microbial enzymatic activities (Raizada *et al*., 2008). Few studies are also shown in Table.1.

Table 1: The impact of invasive plant species on soil processes

Study area	Studied species	Studied soil properties	Impact	Affected species	References
Hawaii	*Myrica and Accacia*	Available nitrogen	+	-	Sharma *et al*., 2005 Vitousek and Walker, 1989
New Zealand grassland	*Bromus tectorum*	Nitrogen mineralisation	-_	*Hieracium spp.*	Belnap and Phillips, 2001
Costa Rica	*Hyparrhenia rufa*	Nitrogen cycling	-	-	

United States and the Maritime provinces of Canada Colorado Plateau (USA) arid grassland	*Rhamnus cathartica* *Bromus tectorum*	Carbon content Nitrogen mineralization	+	Woodlands *(Quercus alba L., Quercus rubra L. and Tilia Americana L.)* *Hilaria jamessi Stipa spp.*	Raizada *et al*., 2008
Varanasi, India	*Hyptis suaveolens*	Soil pH Total inorganic N and N-mineralisation Soil moisture Microbial biomass carbon (MBC) Microbial Biomass Nitrogen (MBN)	+ + _ _ _	-	Afreen *et al*., 2020
Basel, Switzerland	*Prunuslauocerasus*	Soil moisture Metabolic activity of soil microbial community	_ +	-	Rusterholz *et al*.,2018
Fujairah Emirate, UAE	*Prosopis juliflora*	Values of K, N, organic C% and P beneath the canopy EC, Na, HCO_3 beneath the canopy	+ +	*Arnebia hispidissima*	Keblawy and Abdelfatah., 2014
Zurich, Switzerland	*Solidago gigantea*	Bacterial biomass Fungal biomass Fungal to bacterial ratio	_ + +	*Molinia caerulea* , *Moench carexpanacea Anthoxanthium oradatum*	Scharfy *et al*., 2010
North-east Scotland	*Mimulus guttatus*	Total C Total N Soil moisture	+ + +	Riparian plant communities	Truscott *et al*., 2008
Southwest Yunnan Province, China	*Ageratinaadenophora*	Soil pH C content N content K content NO_3-N,NH_4^+-N	_ + + _ +	*Lolium perenne Eupatorium fortune Medicago sativa*	Niu *et al*., 2007
Mediterranean Basin islands	*Ailanthus altissima Carpobrotus spp. Oxalis pes-caprae*	C/N ratio Organic C Acid soil Acification of soil	_ + + +	Therophytes	Vilà *et al*., 2006
Colorado Plateau (USA) arid grassland	*Bromus tectorum*	Porosity Nitrogen mineralisation	+ _	*Hilaria jamesii* (Torr.) Benth. *Stipa comota* Trin. & Rupr. and *Stipa hymeniodes* (R&S) Ricker	Evans *et al*., 2001
Central Himalaya (sub-tropical zone)	*Eucalyptus tereticornis* Smith	Proportion of finer particles Water holding capacity Organic matter Nutrient concentration	_ _ _ _	-	Baragali *et al*., 1993

Impact of IAPS on aquatic ecosystem

There are even limited studies which deal with the impact of IAS on the aquatic ecosystem (Levine *et al*., 2003). IAPS can have important consequences on the aquatic food chain (Lovell *et al*., 2006). For example, in Victoria lake, the introduction of water hyacinth (*Eichhornia crassipes*) has caused the several consequences such as a reduction in the production as well as the quality of fish, blockage in the water and boat movement, impair water supply and spread of many water-borne diseases (Pejchar and Mooney, 2017).

Impact of IAPS on human health

Invasive species have an indirect effect on human health through changes in environmental quality (air, water and soil quality) and ecosystem structure (biodiversity, food availability and land-use change) and can facilitate exposure to toxin and allergens leading to cause disease, injury and even death (Jones and McDermott., 2018). There is a growing appreciation for research on the negative health externalities of invasive species. The WHO warns that the continuing spreading of invasive species worldwide can cause significant impacts on public health (Jones and McDermott, 2018). Biodiversity and its changes are positively as well as negatively related tohuman health (Stone *et al*., 2018; Aerts *et al*., 2018). Pyšek and Richardson (2010), suggests that millions of people around the world face disease, injury and even death due to invasive species.

The continuing increase in the event of invasionmay be due to changes in climatic condition and continued globalization (Jones and McDermott, 2018.). There are several studies which indicate that the IAS may enhance the population of mosquito by providing them suitable habitat. Invasive species may significantly influence the biology and malaria-transmitting ability of *Anopheles spp* (Stone *et al*., 2018).

Certain IAPS may act as an ecological indicator of environmental pollution (Rai and Singh2020). Ash tree is one of the examples of invasive species which can act as a sink for air pollutant (Rai and Singh, 2020). It can reduce mortality and morbidity rates in heavily polluted areas by removing harmful air pollutants. Nowak *et al.* (2013) estimated annual improvements in air quality ranging from 0.05% in San Francisco to 0.24% in Atlanta, because of tree cover, leading to mortality reductions of 0.6 person/year in San Francisco and 1.2 persons/year in Atlanta. Donovan *et al.* (2013) found that Emerald ash borer (EAB) detection was associated with 21,193 excess cardio-respiratory deaths in the US years between 2002 and 2007.

Socio-economicimpacts of IAPS

IAPS can also have a beneficial impact on poor people in rural areas as for them livelihood is an issue of paramount importance, especially in economically poor landscapes (Pejchar and Mooney, 2017). Certain invasive species can act as a source of food while some other adversely affect the productivity of agricultural food crops. For example, the *Prosopis* species such as *Prosopis glandulosa, Prosopis juliflora* and *Prosopis pubescens* are considered as a beneficial invader; and used for timber, medicine, charcoal and firewood by local communities (De Wit *et al*., 2001; de Neergaard *et al*., 2005). The wood of *P. granudulosa* used as fuelwood in Africa and South-east Asia while *P. juliflora* serves as food and fodder in their invaded landscapes (Shackleton *et al*., 2006). The economic value of the firewood (*Acacia* and *Pinus*) alone is US$2.8 million (Turpie *et al*., 2003). In contrast to *Prosopis* species, the *Opuntia stricta* has an adverse effect on environment and economy, it affects the livelihood of local communities by reducing the fodder and livestock. Because introduced species are often incorporated into local livelihoods, it is difficult to assume that harmful impacts on biodiversity or other ecosystem goods and services automatically translate into negative effects on human well-being (Shackleton *et al*., 2007).

IAPS and Climate change

Climate change is a global environmental problem that will alter distributions and abundances of many species, by increasing the ranges and establishment opportunities of IAPS. In addition, IAS, climate change, land-use change and alterations in the nitrogen and carbon cycles, are identified as the top four drivers of global biodiversity loss. The impact of IAPS may increase or decrease under several scenarios of global climatic change driven by greenhouse-gas (GHG, N deposition and altered disturbance regimes (Dukes and Mooney, 1999).Climate change can facilitate IAPS as (i) newly introduced species in the regions may become invasive due to the climate change, (ii) altering the species hierarchies in the ecosystems that may produce new dominants with invasive tendencies, (iii) Climate-induced stress in an ecosystem may stimulate invasive pathways.

Climate change can influence the spread, behavior, distribution and harm caused by invasive species and also the effectiveness of control methods. Climate change also can modify the nature of invasive species and the tools used to manage them by greatly altering their behavior and interactions with other organisms, which leads to further difficulty in invasion management (Runyon *et al*., 2012).

The rise in average temperature with increase in variability of rainfall (frequency; intensity), atmospheric GHG concentrations, frequency and severity of storms and rising sea level, as a result of climate change will affect the invading species and its potential to invade the host ecosystem (native or derived). The greatest impacts of climate change on invasive species may arise from changes in the frequency and intensity of extreme climatic events that disturb ecosystems, making them vulnerable to invasions, thus providing exceptional opportunities for their dispersal and growth (Masters and Norgrove, 2010).

Managing IAPS

There are several management practices which are essential for the improvement of environment and livelihood security (Climate Change Resource Center, USDA)

- Eradication of existing populations through physical/mechanical, chemical, or biological treatments.
- By maintaining closed-canopy conditions to prevent light-loving invasive species to enter the understory.
- By Setting- up artificial barriers in connected migration areas to prevent the spread of invasive species.
- By increasing proper monitoring and mapping via integration of remote sensing and GIS (used historically in mapping plants and vegetation distribution) for known invasive species, to ensure early detection.
- Remote sensing can prove a promising tool for the detection of IAPS which would help decision-makers to manage alien plant invasion.
- By developing appropriate research strategies, funding mechanisms, and policies for IAPS at the local and national level.

Conclusions

Although the consequences of invasive alien species on native biodiversity and ecosystem services are well documented, however, their role in species extinction is still a matter of discussion among the invasion biologists. Extreme climatic conditions (intense heatwave, hurricanes, floods, droughts, etc.) may promote biological invasions, however, anthropogenic disturbances (intentional invasion) play a vital role in driving the same. Millennium Ecosystem Assessment, 2005 confirmed that human-mediated disturbances are the prime factors responsible for the biotic invasion and global environmental change. If such anthropogenic disturbances will continue for the long term, there may be an appearance of new IAPS disastrous to environmental and human health. Nevertheless, with the precise understanding of various stages of invasion process such as; introduction, establishment, spread and impact, we can sustainably administer the IAPS. Those alien species that are likely to become invasive due to climate change need to be identified and eradicated or controlled before they spread and become invasive. Cooperation among countries in data acquisition and sharing will be necessary.

The current literature review indicates that most research papers lack the understanding of the true reasons behind the dispersal of alien species, at the same time, there is no clear understanding regarding invasion processes. To create a promising environment in which researches on biological invasion can be promoted and funded, there should be a widespread concern for the development of a sustainable system of land use and have to be combined with the awareness of the effects of invasive species on the system. Besides, there is a lack of an ecological framework to establish interrelationship among global environmental degradation and health, promising future researches. Further, it is a long-term process to completely eradicate and control over invasive alien flora. However, a proper management and time to time screening can help to overcome this problem in India as well as on a global scale. We suggest that there should be a serious focus on the investigation and research in the field of invasion ecology to generate sufficient data and a clear picture.

References

Aerts, R., O, Honnay and Van Nieuwenhuyse, A (2018). Biodiversity and human health: mechanisms and evidence of the positive health effects of diversity in nature and green spaces. *British medical bulletin*, 127(1): 5-22.

Afreen, T., Singh, V., Yadav, V.K., Singh, R.P. and Singh, H., 2020. Impact of rainfall variability on the ecophysiology of Hyptis suaveolens: a study in the constructed tropical grassland. *Environmental Monitoring and Assessment*, 192:1-11.

Al-Humaid, A. I. and M. O. A. Warrag (1998). Allelopathic effects of mesquite (*Prosopis juliflora*) foliage on seed germination and seedling growth of bermudagrass (*Cynodon dactylon*). *Journal of Arid Environments* 38: 237–243.

Bargali, S.S., Singh, R.P. and Joshi, M., 1993. Changes in soil characteristics in eucalypt plantations replacing natural broad-leaved forests. *Journal of Vegetation Science*, 4(1): 25-28.

Born, W., Rauschmayer, F. and Bräuer, I., 2005. Economic evaluation of biological invasions—a survey. *Ecological Economics*, 55(3): 321-336.

Blumenthal, D.M., 2006. Interactions between resource availability and enemy release in plant invasion. *Ecology Letters*, 9(7): 887-895.

Callaway, R.M. and W.M, Ridenour (2006). Novel weapons: invasive success and the evolution of increased competitive ability. Front. *Ecol. Environ.*2: 436–443

Crawley, M.J. (1989). Chance and timing in biological invasions. In: Drake, J.A., H.A. Mooney, F. di Castri., R.H. Groves., F.J. Kruger., M. Rejmlnek and M. Williamson (eds.) *Biological invasions: A global perspective*, 407-423, John Wiley and Sons, Chichester.

Crowl, T.A., T.O, Crist., R.R, Parmenter., G, Belovsky. And A.E, Lugo (2008). The spread of invasive species and infectious disease as drivers of ecosystem change. *Frontiers in Ecology and the Environment*, 6(5): 238-246.

De Wit, M.P., Crookes, D.J. and Van Wilgen, B.W., 2001. Conflicts of interest in environmental management: estimating the costs and benefits of a tree invasion. *Biological invasions*, 3(2):167-178.

de Neergaard, A., Saarnak, C., Hill, T., Khanyile, M., Berzosa, A.M. and Birch-Thomsen, T., 2005. Australian wattle species in the Drakensberg region of South Africa–An invasive alien or a natural resource?. *Agricultural systems*, 85(3): 216-233.

Daily, G.C., S, Polasky., J, Goldstein., P.M, Kareiva., H.A, Mooney., L, Pejchar., T.H, Ricketts., J, Salzman. and R, Shallenberger (2009). Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment*, 7(1): 21-28.

di Castri, F. (1990). On invading species and invaded ecosystems: the interplay of historical chance and biological necessity. In: di Castri, F., A.J. Hansen and M. Debussche, (eds.) Biological invasions in Europe and the Mediterranean Basin. 3-16, *Kluwer Academic Publ.*, Dordrecht.

Dukes, J.S. and Mooney, H.A., 1999. Does global change increase the success of biological invaders?. *Trends in Ecology & Evolution*, 14(4):135-139.

Ehrenfeld, J.G (2003). Effects of exotic plant invasions on soil nutrient cycling processes. *Ecosystems*, 6(6): 503-523.

El-Keblawy, A. and Abdelfatah, M.A., 2014. Impacts of native and invasive exotic Prosopis congeners on soil properties and associated flora in the arid United Arab Emirates. *Journal of arid environments*, 100, 1-8.

European Environment Agency [EEA] (2012) the impacts of invasive alien species in Europe. Technical report No 16/2012. Copenhagen, Denmark.

Gentle, C.B. And J.A, Duggin (1997). Allelopathy as a competitive strategy in persistent thickets of Lantana camara L. in three Australian forest communities. *Plant Ecology*, 132(1): 85-95.

Higgins, S.I. and D.M, Richardson (1996). A review of models of alien plant spread. *Ecological modelling*, 87(1-3): 249-265.

Jeschke, J.M., Bacher, S., Blackburn, T.M., Dick, J.T., Essl, F., Evans, T., Gaertner, M., Hulme, P.E., Kühn, I., Mrugała, A. and Pergl, J., 2014. Defining the impact of non-native species. *Conservation Biology*, 28(5): 1188-1194.

Kapoor, L. and S, Usha (2020). Biodiversity and Conservation: India's Panoramic View. In *Socio-economic and Eco-biological Dimensions in Resource use and Conservation*. *Springer, Cham.* 313-332

Singh, K.P., 2005. Invasive alien species and biodiversity in India. *Current Science*, 88(4), 539.

Knight, K.S., Kurylo, J.S., Endress, A.G., Stewart, J.R. and Reich, P.B., 2007. Ecology and ecosystem impacts of common buckthorn (Rhamnus cathartica): a review. *Biological Invasions*, 9(8):925-937.

Landenberger, R.E., N.L, Kota. And J.B, McGraw (2007). Seed dispersal of the non-native invasive tree *Ailanthus altissima* into contrasting environments. *Plant Ecology*, 192(1): 55-70.

Levine, J.M., Vila, M., Antonio, C.M.D., Dukes, J.S., Grigulis, K. and Lavorel, S., 2003. Mechanisms underlying the impacts of exotic plant invasions. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 270(1517): 775-781.

Levine, J.M., E, Pachepsky., B.E, Kendall., S.G, Yelenik. and J.H.R, Lambers (2006). Plant–soil feedbacks and invasive spread. *Ecology letters*, 9(9): 1005-1014.

Liu, J., S.C, Liang, F.H, Liu., R.Q, Wang. And M, Dong (2005). Invasive alien plant species in China: regional distribution patterns. *Diversity and distributions*, 11(4): 341-347.

Jones, B.A. and McDermott, S.M., 2018. Health impacts of invasive species through an altered natural environment: Assessing air pollution sinks as a causal pathway. *Environmental and Resource Economics*, 71(1): 23-43.

Lovell, S.J., S.F, Stone. And L, Fernandez (2006). The economic impacts of aquatic invasive species: *a review of the literature. Agricultural and resource economics review*, 35(1): 195-208.

Luque, G.M., C, Bellard., C, Bertelsmeier., E, Bonnaud., P, Genovesi., D, Simberloff. and F, Courchamp (2014).

The 100th of the world's worst invasive alien species. *Biological invasions*, 16(5): 981-985.

Marchetti, M.P., P.B, Moyle. and R, Levine (2004). Invasive species profiling? Exploring the characteristics of non-native fishes across invasion stages in California. *Freshwater biology*, 49(5): 646-661.

Masters, G. and L, Norgrov (2010). Climate change and invasive alien species. *UK: CABI Working Paper*, 1.

Mazza, G., E, Tricarico, P, Genovesi. And F, Gherardi (2014). Biological invaders are threats to human health: an overview. *Ethology Ecology & Evolution*, 26(2-3): 112-129.

McGeoch, M.A., S.H, Butchart., D, Spear., E, Marais., E.J, Kleynhans., A, Symes., J, Chanson. and M, Hoffmann (2010). Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. *Diversity and Distributions*, 16(1): 95-108.

Miyawaki, S. and I. Washitani (2004). Invasive alien plant species in riparian areas of Japan: the contribution of agricultural weeds, revegetation species and aquacultural species. *Global Environmental Research-English Edition-*, 8(1): 89-101.

Mooney, H.A (2005). Invasive alien species: the nature of the problem. *Scope-Scientific Committee on Problems of the Environment International Council of Scientific Unions*, 63: 1.

Mooney, H.A (2005). *Invasive alien species: a new synthesis* (Vol. 63). Island press.

Mortensen, D.A., E.S. Rauschert, A.N. Nord and B.P. Jones (2009). Forest roads facilitate the spread of invasive plants. *Invasive Plant Science and Management*, 2(3): 191-199.

Muturi, G. M., G. M. J. Mohren and J. N. Kinani (2009). Prediction of *Prosopis* species invasion in Kenya using geographical information system techniques. *African Journal of Ecology* 48: 628–636.

Nakano, H., (2010). Plant growth inhibitors from mesquite (Prosopis juliflora). *In Desert Plants,Springer, Berlin, Heidelberg*, 341-352

Najberek, K., Pusz, W., Solarz, W. and Olejniczak, P., 2018. The seeds of success: release from fungal attack on seeds may influence the invasiveness of alien Impatiens. *Plant Ecology*, 219(10): 1197-1207.

Noor, M., U. Salam and M. A. Khan (1995). Allelopathic effects of *Prosopis juliflora* Swartz, *Journal of Arid Environments* 31: 83–90.

Patnaik, P., T. Abbasi and S.A. Abbasi (2017). Prosopis (Prosopis juliflora): blessing and bane. *Tropical Ecology*, 58(3):455-483.

Pejchar, L. and H.A. Mooney (2009). Invasive species, ecosystem services and human well-being. *Trends in ecology & evolution*, 24(9), 497-504.

Perrings, C., M. Williamson, E.B. Barbier, D. Delfino., S. Dalmazzone, J. Shogren, P. Simmons and A. Watkinson, (2002). Biological invasion risks and the public good: an economic perspective. *Conservation Ecology*, 6(1).

Pimentel D, Lach L, Zuniga R, and Morrison D. Environmental and economic costs of nonindigenous species in the United States. *BioScience* 2000; 50: 53-65.

Pinzone, P., D. Potts, G. Pettibone and R. Warren (2018). Do novel weapons that degrade mycorrhizal mutualisms promote species invasion?. *Plant ecology*, 219(5):539-548.

Pyšek, P. and D.M.Richardson (2010). Invasive species, environmental change and management, and health. *Annual review of environment and resources*, 35.

Rusterholz, H.P., Schneuwly, J. and Baur, B., 2018. Invasion of the alien shrub Prunus laurocerasus in suburban deciduous forests: Effects on native vegetation and soil properties. *Acta Oecologica*, *92*44-51.

Radosevich, S.R., M.M. Stubbs and C.M. Ghersa (2003). Plant invasions: process and patterns. *Weed Science*, 254-259.

Rai, P.K. and J.S. Singh (2020). Invasive alien plant species: Their impact on environment, ecosystem services and human health. *Ecological Indicators*, 111:106020.

Sperry, L.J., Belnap, J. and Evans, R.D., 2006. Bromus tectorum invasion alters nitrogen dynamics in an undisturbed arid grassland ecosystem. *Ecology*, 87(3): 603-615.

Rai, P.K., 2015. What makes the plant invasion possible? Paradigm of invasion mechanisms, theories and attributes. *Environmental Skeptics and Critics*, 4(2):36.

Raizada, P., A.S. Raghubanshi and J.S.Singh (2008). Impact ofinvasive alien plant species on soil processes: A review.

Kourtev, P.S., Huang, W.Z. and Ehrenfeld, J.G., 1999. Differences in earthworm densities and nitrogen dynamics in soils under exotic and native plant species. *Biological Invasions*, 1(2-3):237-245.

Reichard, R.R., C.L. White Iii, C.L. Hladik and D. Dolinak (2003). Beta-amyloid precursor protein staining of nonaccidental central nervous system injury in pediatric autopsies. *Journal of neurotrauma*, 20(4):347-355.

Ridenour, W.M. and Callaway, R.M., 2001. The relative importance of allelopathy in interference: the effects of an invasive weed on a native bunchgrass. *Oecologia*, 126(3):444-450.

Shackleton, C.M., McGarry, D., Fourie, S., Gambiza, J., Shackleton, S.E. and Fabricius, C., 2007. Assessing the effects of invasive alien species on rural livelihoods: case examples and a framework from South Africa. *Human Ecology*, 35(1): 113-127.

Seebens, H., T.M. Blackburn., E.E. Dyer., P. Genovesi., P.E. Hulme., J.M. Jeschke., S. Pagad., P. Pyšek., M. Winter., M. Arianoutsou and S. Bacher (2017). No saturation in the accumulation of alien species worldwide. *Nature communications*, 8(1):1-9.

Shackleton, R.T., C.M. Shackleton and C.A. Kull (2019). The role of invasive alien species in shaping local livelihoods and human well-being: A review. *Journal of environmental management*, 229:145-157.

Stone, C.M., A.B. Witt., G.C. Walsh., W.A. Foster and S.T. Murphy (2018). Would the control of invasive alien plants reduce malaria transmission? A review. *Parasites & vectors*, 11(1):1-18.

Timsina, B., B.B. Shrestha., M.B. Rokaya and Z.Münzbergová (2011). Impact of Parthenium hysterophorus L. invasion on plant species composition and soil properties of grassland communities in Nepal. *Flora-Morphology, Distribution, Functional Ecology of Plants*, 206(3):233-240.

Turpie, J.K., Heydenrych, B.J. and Lamberth, S.J., 2003. Economic value of terrestrial and marine biodiversity in the Cape Floristic Region: implications for defining effective and socially optimal conservation strategies. *Biological conservation*, 112(1-2): 233-251.

Rutty, M. and Scott, D., 2014. Thermal range of coastal tourism resort microclimates. *Tourism Geographies*, 16(3): 346-363.

Runyon, Justin B., Jack L. Butler, Megan M. Friggens, Susan E. Meyer, and Sharlene E. Sing. "Invasive species and climate change (Chapter 7)." *In: Finch, Deborah M., ed. Climate change in grasslands, shrublands, and deserts of the interior American West: a review and needs assessment. Gen. Tech. Rep. RMRS-GTR-285. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 97-115.* 285 (2012): 97-115.

D'Antonio, C.M., Hughes, R.F., Mack, M., Hitchcock, D. and Vitousek, P.M., 1998. The response of native species to removal of invasive exotic grasses in a seasonally dry Hawaiian woodland. *Journal of Vegetation science*, 9(5): 699-712.

Valentine, J.P., R.H. Magierowski., and C.R. Johnson (2007). Mechanisms of invasion: establishment, spread and persistence of introduced seaweed populations. *Botanica marina*, *50*(5-6):351-360.

Veluri, R., T.L Weir., H.P. Bais., F.R. Stermitz and J.M. Vivanco, (2004). Phytotoxic and antimicrobial activities of catechin derivatives. *Journal of Agricultural and Food Chemistry*, 52(5):1077-1082.

Vilà, M., Tessier, M., Suehs, C.M., Brundu, G., Carta, L., Galanidis, A., Lambdon, P., Manca, M., Médail, F., Moragues, E. and Traveset, A., (2006). Local and regional assessments of the impacts of plant invaders on vegetation structure and soil properties of Mediterranean islands. *Journal of Biogeography*, *33*(5), pp.853-861.

Vivanco, J.M., H.P. Bais., F.R. Stermitz., G.C. Thelen and R.M. Callaway (2004). Biogeographical variation in community response to root allelochemistry: novel weapons and exotic invasion. *Ecology letters*, 7(4):285-292.

Vitousek, P.M. and Walker, L.R., (1989). Biological invasion by Myrica faya in Hawai'i: plant demography, nitrogen fixation, ecosystem effects. *Ecological monographs*, 59(3): 247-265.

Warrag, M. O. A. (1994). Autotoxicity of mesquite (*Prosopis juliflora*) pericarps on seed germination and seedling growth. *Journal of Arid Environments* 27: 79–84.

Warrag, M. O. A. (1995). Autotoxic potential of foliage on seed germination and early growth of mesquite (*Prosopis juliflora*). *Journal of Arid Environments* 31: 415–421.

Willis, A.J. and B. Blossey (1999). Benign environments do not explain the increased vigour of non-indigenous plants: a cross-continental transplant experiment. *Biocontrol Science and Technology*, 9(4):567-577.

Xu, H., H. Ding., M. Li., S. Qiang., J. Guo., Z. Han., Z. Huang., H. Sun., S. He., H. Wu and H. Wan (2006). The distribution and economic losses of alien species invasion to China. *Biological Invasions*, 8(7):1495-1500.

Yadav, V., N.B. Singh, H. Singh., A. Singh and I. Hussain (2016). Allelopathic invasion of alien plant species in India and their management strategies: a review. *Tropical Plant Research*, 3(1):87-101.