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Impact of Exotic Pests on Agro-biodiversity and their Management: A Review

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ABSTRACT: The agricultural economy in India is vulnerable to threat from exotic pests/ diseases. Invasive species, disease vectors, and pathogens affect biodiversity, ecosystem function and services, and human health. Climate change, land use, and transport vectors interact in complex ways to determine the spread of native and non-native invasive species, pathogens, and their effects on ecosystem dynamics. Although invasive alien species have been identified as the second greatest threat to biodiversity after habitat loss, characterizing and quantifying their impacts on native species and habitats remains a fundamental problem in the conservation biology. Adopting a hypothesis-driven experimental approach to impact assessment, and to eradication efforts through adaptive management, would benefit our ecological understanding of invasive species without delaying critical management action that could reduce the spread of invasive species population. A new plant quarantine order has been approved by the Indian Government in 2003 which harmonizes the International plant protection convention with regulatory framework of India. For the management of alien species, community based approaches can be implemented with other control measures. In the present chapter the short description, their impact and control measure of Indian alien species has been discussed.

Keywords: Invasive alien species, Risk Assessment, Quarantine, Agriculture, CBD.

INTRODUCTION

In introduced, alien, exotic, non-indigenous, or non-native species, or simply an introduction, is a species living outside its native distributional range, which has arrived there by human activity, either deliberate or accidental. Non-native species can have various effects on the local ecosystem. Introduced species that have a negative effect on a local ecosystem are also known as invasive species.

Not all non-native species are considered invasive but some have no negative effect. The International Plant Protection Convention (1952) also contains provisions applicable to invasive alien species when the concerned species are plants or plant products pests. The main aim of IPPC is to prevent the introduction of plants and plant products pests as well as to promote requisite measures for their management.

According to the IPPC, a quarantine pest considered as an invasive alien species under the CBD and causes the significant damage in plants. The IPPC covers the protection of all the crops found in natural habitat and sometimes it is confined to the protection of agricultural and forestry plants. The Convention on biodiversity (1992) has a major role to take action on invasive alien species (Vitousek *et al.,* 2006). The major goals of the convention are the conservation and sustainable utilization of biodiversity and reasonable sharing of benefits arising out of the genetic resource utilization. CBD requires contracting parties to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species. Convention on Biological Diversity uses the term "alien and visualize “after habitat destruction the biological invasion of alien species as the second worst threat “Invasive alien species are plants, animals, pathogens and other organisms that are non-native to an ecosystem, and which may cause economic or environmental harm or adversely affect human health (Anonymous, 2002). For establishment and growth of the alien species takes the right conditions. In fact, most introduced species do not become permanently established in their newly found environment. They either find the wrong type of conditions for survival, or there they are unable to produce enough offspring to maintain a viable population. For those species that are able to reproduce and survive, most never cause significant problems. For the Canada’s economic point of view, although they survive, spread and reproduce in the environment, but generally do not found to pose a risk to the environment or society (Herbold and Moyle, 1986). However, some introduced species are able to boom at the new location. They have the favorable biological properties which allow them to flourish in more numbers quickly. Often out-competing native plant and animal species for food water and space, they are usually able to reproduce and spread quickly. In particular, they impact adversely upon biodiversity, including decline or elimination of native species through competition, predation, or transmission of pathogens and the disruption of local ecosystems and ecosystem functions (Bryan, 1996). Invasive alien species affect agriculture, forestry, and human health, and are also widely recognized as the second largest global threat (after direct habitat destruction) to the conservation of biodiversity (Ghate, 1991; Walker and Steffen, 1999). These species can dominate a wide range of habitats, where they alter the functioning, structure, and composition of these habitats, often with serious consequences (Wilcove *et al.,* 1998). Several species of commercially important trees that are used in plantation forestry are also invasive. Other species include ornamental plants. Alien species are found to invade the native species in the natural habitat which affect the natural ecosystems that are reported to be problems for managers of protected areas and hence the adjective "invasive" is commonly used to describe these kinds of organisms (Perrings *et al.,* 2005). Invasive alien causes significant impact on agriculture, forestry, fisheries and natural systems which are an important basis of people’s livelihoods in developing countries. With the rapidly increasing global commerce the chances of introduction of alien species accidentally will be more (White *et al.,* 1993; Mooney and Cleland, 2001).

A. Some important report on invasive alien species

A total of 173 invasive alien species comprises of 117 genera (44 families) were found to be noticed. The maximum proportions of alien flora in India are contributed from Tropical America (74%) and Africa (11%) (Drake *et al.,* 1989). US Congress based office of Technology Assessment (1993) estimated that since 1906, about 70 most harmful invasive species had caused damage of US$ 97 billion in the USA. In Australia the annual looses is estimated at US$ 6.24 billion (Reddy, 2008). During each year the insect pests damage about 13% of potential crop production at a cost of about $33 billion in U.S. crops. Among 40% of the pests introduced, it has been estimated that about $13 billion of crop loss each year is due to these alien pests. Approximately 1000 of indigenous mite and insect species include pests in stored food commodities, crops as well as structures. Hawaii has about 5200 identified native species of insect, and 2600 additional introduced insect species (Babbitt1998). Avian malaria was introduced to Hawai in exotic birds kept by settlers. This was made possible following the introduction of the southern house mosquito (*Culex quiquefasciatus*) in the water barrels of a sailing ship in 1826 (Howarth, 1990). Hawaii’s unique native birds succumbed quickly because, unlike non- native birds, they have no resistance to avian malaria. In the forests woody plants are found to attack by more than 20 non-indigenous species of plant pathogens (Liebold *et al.,* 1995).

Two of the most serious plant pathogens are the chestnut blight fungus (*Cryphonectria parasitica*) and Dutch elm disease (*Ophiostoma ulmi*). Before the accidental introduction of chestnut blight, approximately 25% of eastern U.S. deciduous forest consisted of American chestnut trees (Campbell and Schlarbaum, 1994). Alien plant pathogens which introduced into India are listed in Table 1.

Table 1: Alien plant pathogens which introduced into India.

Pathogens	Disease	Introduced	Year
Hemileia vastatrix	Coffee rust	Sri Lanka	1879
Phytophthora infestans	Potato late blight	UK	1883
Urocystis tritici	Wheat flag smut	Australia	1906
Erysiphe cichoracearum	Cucurbit powdery mildew	Sri Lanka	1910
Plasmopara viticola	Grape downy mildew	Europe	1910
Sclerospora phillipinensis	Maize downy mildew	Java	1912
Pyricularia oryzae	Blast of paddy	SE Asia	1918
Xanthomonas campestris pv. campestris	Crucifer black rot	Java	1929
Oidium heavea	Rubber powdery mildew	Malaya	1938
Phytophthora nicotianae	Tobacco black shank	Holland	1938
Virus	Banana bunchy top	Sri Lanka	1940
Virus	Hairy root of apple	England	1940
Synchytrium endobioticum	Potato wart	Netherlands	1953
Urocystis cepulae	Onion Smut	Europe	1958
Xanthomona campestris	Rice bacterial leaf blight	Philippines	1959
Globodera rostochiensis	Potato golden nematode	Europe	1961

Sources: Alien plant pathogens in India. In: Biological Invasions

Coffee leaf rust was first reported in 1861 by a British explorer on uncultivated coffee in the Lake Victoria region of Kenya in East Africa. During the latter half of the 18th century the coffee rust (*Hemelia vastatrix*) epidemic that found over different parts of South India and Sri Lanka resulted in the planting of tea in place of coffee and losses due to this disease are believed to be about 15% annually (Baillie *et al.,* 2004). The severity of the white woolly aphid infestation, recorded in 2002 in over 200 000 ha of sugarcane is another example. The invasion outcome is influenced by invading species and the habitants they invade. For example, according to Weed Science Society of America (1992) annual crop losses due to invasive alien weeds are estimated in between $2 billion and $3 billion and for the management of the cost given the current levels of herbicide use, was estimated to be between $1.5 billion and $2.3 billion (Monaco, 1977). Annual cost of invasive weed species at $23.4 billion is incorporating other values, such as yield reduction due to weeds. This variability indicates that an approach to cost estimates still needs work. The crop loss due to weeds are found to be 30% amounting to US$90 billion dollar per year (Pimentel, 2000). *Lantana* itself is found to cause the significant loss which is estimated to be US$924 million per year.

This variability indicates that an approach to cost estimates still need**s** work.

Weeds cause an estimated 30% loss in crop production which worth about US$90 billion per year (Singh, 1996). The economic loss from Lantana is estimated to be US$924 million per year. In India, about 50 alien diseases of livestock and wildlife including foot and mouth disease cause significant loss (Khera and Sharma, 1967). In Kerala, *Alvinia molesta* is considered as serious weed in paddy field. *Eichornia*, commonly called as water hyacinth, is introduced as an ornamental pond plant from the Amazon Basin; now it has become a menace in the backwaters. Efficiency of managing *Salvinia* and *Eichornia* with biocontrol agents such as *Neochetina eichhorniae* (curculionid weevil) and *N. bruchi*, natives of South America were introduced to India in 1982 as control agents against *Eichornia* and established in many places (Alexander and Parsons, 1986). *Mikania micrantha* has been a serious problem in the southern states and also in the northeastern states. The spread of this weed has found to be suppressed the growth of many economically important plants like forest and agricultural crops (Joy *et al.*, 1985). In coconut and cashewnut plantations, an introduced weed such as *Mimosa pudica* has become a serious problem.

Chromolaena odorata is a perennial shrub, native to South and Central America, and capable of establishing in a wide variety of agro-ecological conditions. In Southern and Northern India it is a serious problem in pastures, forests, orchards and commercial plantations (Wang *et al.*, 1994). The spread of *Heteropsylla cubana* is a good example of exotic insects on exotic tree species. The occurrence of the spiraling whitefly, *Aleyrodicus disperses*, is an example of an exotic insect invading native crops. It is a native of Central America and spread westward across the Pacific, Southeast Asia and entered India through Sri Lanka in 1994 (Singh, 1998). Rhinoceros beetle is an established pest of coconut palms in India. Beetles were also collected from natural forest areas-decaying logs served as breeding grounds and the adult beetles later migrated to susceptible crops like oil palms and coconut. There are several cases of invasion of indigenous insect pests on indigenous tree crops in forest plantations (Varma *et al.,* 2001). *Helicoverpa armigera*, a very important agricultural pest is found to feed on the terminal shoots of young teak in Tamil Nadu (Varma *et al.,* 2001). Over 1,20,000 non-native species of plants, animals and microbes have invaded just six countries - the US, UK, Australia, South Africa, Brazil and India. Annual environmental losses caused by introduced pests in the United States, United Kingdom, Australia, South Africa, India and Brazil have been calculated at over US$ 100 billion (Varma *et al.,* 2001). In some region of America, Australia and Dominica and Montserrat in the Caribbean, a fungus i.e. *Batrachochytrium dendrobatidis* which found to cause Chytridiomycosis, pushed populations of amphibian species to decline and even go extinct. In some amphibian population, this fungus was found to cause sporadic death with 100% mortality. A total of 80% of the threatened species in South Africa are endangered due to invasions by alien species. Invasive species are one of the leading threats to native wildlife. Approximately 42% of Threatened or Endangered species are at risk primarily due to invasive species. The total economic losses caused by invasive alien species to China were to the time of USD 14.45 billion, with direct and indirect economic losses accounting for 16.59% and 83.41% of total economic losses, respectively (Xu and Ding, 2003; Oerke *et al.,* 1994).

The frequency of invasion by alien species including plants, animals and microbes recorded in six countries namely the US, UK, Australia, South Africa, Brazil and India can be judged by the number 1,20,000 which is quite high and has significant impact on the economy and environment. Soybean rust caused by the fungus *Phakopsora pachyrhizi* cause yield reductions of 10 to 30% on a regional basis are typical in areas where the Asiatic strain is found, and yield reductions of over 90% (relative to attainable yields) have been reported for individual fields. Canker has now spread to about 1000 square miles of southern Florida. The eradication effort has cost over $200 million and the disease is still spreading because tree destruction programs have been successfully challenged (Schubert *et al.,* 2001). The Erysiphales members have also major role in the biological invasions.

The introduction and spread of powdery mildew pathogen of grapes in Europe from North America include a good example for invasions caused by powdery mildew fungi. Recently, some other powdery mildew species previously not recorded in Europe have also appeared in some European countries. The threat possessed by the invasive alien microbes in Indian agriculture is reduced crop and livestock yield. The Bengal famine of 1943 is one amongst the several famines that occurred in India and caused by the invasive fungus *Cochliobolus miyabeanus* (formerly *Helminthosporium oryzae*), from Japan in about 1919. Nearly, 2 million people were died and several millions were affected. USA indicated damage costs of $137 billion per year from a subset of invasive species (Pimentel, 2000). The invasion of Banana Bunchy Top Virus is also found to cause economic losses in Southern India. *P. nigronervosa* colonies collected directly from the pseudostem of injected plants date (42 DAI) tested positive for BBTV and infected 9.5% of the healthy banana plants. The findings indicate that banana plants may remain a potential source of virus inoculums 6 week after injection with a bananacide. Potato leaf blight pathogen (*Phytophthora infestans*) of Europian origin is another important invasive pathogen of India. In all the potato growing areas of India it is a common problem causing nearly 70% losses to the potato growers every year (Murphy and McKay, 1933). 8% loss from this disease has been estimated recently (Copeland *et al.,* 1990).

Precise estimates of grain yield losses owing to BLB are not available in tropical Asian countries although the disease has been studied extensively in Japan. In tropical Asia, more virulent populations of the pathogen are present and losses are thought to be higher than in Japan. Estimated yield losses in tropical Asia vary from 2 to 74% depending on location, season, weather conditions, and cultivars. Worldwide stem rust of wheat is the most destructive disease of wheat and barley and found to cause severe losses. Rustin the Great Plains of North America caused yield losses of up to 14 percent. These losses can exceed 50 percent locally depending on favorable environmental conditions for disease development, onset of disease early in the growing season, and cultivar susceptibility. Since the 1950s, resistance genes bred into wheat varieties have held truly devastating stem rust epidemics in check. In East Africa (1998) a new race Ug99 of stem rust that overcomes the resistance in wheat cultivars grown in the United States and other parts of the world. Currently, seven races of the Ug99 lineage have been identified and have spread to different countries in Africa and the Middle East. Introduced mammal species include cats, dogs, burros, horses, sheep, pigs, cattle, goats, deer and monkeys which promote and intensifying soil erosion (Layne, 1997). Of the 97 bird species introduced into the India only 5% are considered beneficial a majority (56%) is pests (Temple, 1992). In United state several number of indigenous bird species, including chickens and pigeons, are introduced for agricultural purposes. Thus, if we assume $800 million per year in economic losses from starlings, $1.1 billion per year from pigeons, and $200 million for house sparrows and other birds. Some of the pests intercepted in quarantine in Table 2.

Table 2: **Examples of different categories of pests intercepted in quarantine.**

Unknown in India	*Peronospora manschurica*/ Soybean/ USA *Uromyces betae*/ sugarbeet/ USA and Italy *Fusarium nivale*/ wheat/ UK Cowpea mottle virus/ Cowpea/ Philippines Tomato black ring virus/ French bean/ CIAT *Heterodera schactii* Sugarbeet/ Denmark *Anthonomus grandis*/ Cotton/ USA *Helminthosporium maydis* / race T/ Sorghum/ USA
Known to occur but the race/biotype/strain intercepted is not known to occur	Pea seed -borne mosaic virus/ Broad bean *Burholderia solanacearum*/ biovar 3/ Groundnut/ Australia

Source: Mandal (2001)

Place to place movement of invasive species: Invasive species reach new areas outside of their home range in one of two ways

(i) Self-introduction of species into new areas is not a new phenomenon. The rate of happening of this process is very slow for millions of years and close neighbors introductions of species occur.

(ii) Humans have greatly altered the speed at which species are moved around the world and species introductions are occurring between areas that are separated by vast distances and across natural barriers (e.g., oceans and mountains) that had previously prevented the long-distance movement of species.

Establishment of invasive species: At least four different factors can affect the successful invasion, establishment, and spread of the invasive species.

(i) **Propagule pressure**: This refers to the number and frequency of introductions of an organism (or propagules) into a new area. Typically, the larger the number of individuals that are introduced, and if the introductions are spread out over a long time interval, together these two things will likely increase the chances of the organism establishing.

(ii) **Minimum viable population size:** In a new area the introduction results in the population establishment of new organisms. To sustain the population and to help it grow a minimum number of individuals are needed.

(iii) **Lag period:** The population is highly localized when a new species establishes in a new area. The numbers of organisms is not particularly high. This condition may endure for a long time, sometimes years, before exponential growth is reported. Then, for reasons often not well understood, the lag or "incubation" period ends, and the population explodes in size and the area occupied.

(iv) **Climate and environment:** The survival of introduced species is always found in suitable climate. (e.g., nice temperatures, adequate water), and if there are sufficient resources available for growth and reproduction (e.g., food availability, diseases or predators free environment, and scarcity of competitors) all year round.

Invasive species a problem: (i) World Conservation Union, states that the impacts of alien invasive species are immense, insidious, and usually irreversible. They may be as damaging to native species and ecosystems on a global scale as the loss and degradation of habitats.

(ii) A wide diversity of economic and environmental problems is caused by invasive species. This is almost always arising from growth of uncontrolled population and spread in the invaded area.

(iii) In the agricultural system and urban areas these economic impacts are most severe where livelihoods are or life qualities of people are affected.

(iv) For example, successful invasions by agricultural pests results in greater costs to farmers who must control the new pest, often with pesticides. Consequently, food costs more to produce because of increased pest management expenses, and the risk to the environment, such as accidental pollution of water and air with pesticides, increases too.

(v) Urban problems can be caused by invasive ant and termite species that create trouble in homes, and also tree pests that kill ornamental trees.

(vi) Invasive species cause several environmental problems resulted the extinction of native animals (e.g., the brown tree snake in Guam has caused the extinction of native bird species).

Spread of invasive species: The primary spreads of invasive species are found by the various activities of human. People, and the goods we use, travel around the world very quickly, and they often carry uninvited species with them.

Ships: It carries aquatic organisms in their ballast water.

Wood products: Insects can get into wood, shipping palettes and crates that are shipped around the world.

Ornamental plants: Few ornamental plants can flee into the wild and become invasive.

Pet trade: Some invasive species are intentionally or accidentally released pests. In the Everglades Burmese pythons are becoming a big problem.

Invasive species pose such a threat: Invasive species cause harm to wildlife in many ways. When a new and aggressive species is introduced into an ecosystem, it might not have any natural predators or controls. It can breed and spread quickly, taking over an area. Native wildlife may not have evolved defenses against the invader or they cannot compete with a species that has no predators.

The direct threats of invasive species:

(i) Native species praying

(ii) Out-competing native species for food or other resources

(iii) Causing or carrying disease

Preventing native species from reproducing or killing their young

The indirect threats of invasive species:

(i) **Changing food webs:** Invasive species can change the food web in an ecosystem by destroying or replacing native food sources. For wildlife, the invasive species may provide little to no food value.

(ii) **Decreasing biodiversity:** Alteration in the abundance and diversity by the invasive species are reported that are important habitat for native wildlife.

(iii) **Altering ecosystem conditions:** In an ecosystem, some invasive species are capable of changing the conditions like soil chemistry or the intensity of wildfires.

Characteristics of Invasive species:

(i) Rapid growth rate

(ii) Rapid reproduction rate

(iii) High adaptability

(iv) Eminent dispersal ability

(v) Ability to survive on various foods

(vi) Ability to survive in various environmental conditions (like in water, on land, in air, marshy areas.

Impacts of invasive alien species on biodiversity: Various biomes and ecosystems are found to affect by the IAS slowly of rapidly as shown in Table 3.

Table 3: World worst Invasive alien species.

Micro-organisms	**Aquatic invertebrates**
Avian malaria (*Plasmodium relictum*)	Comb jelly *(Mnemiopsis leidyi)*
Banana bunchy top virus (Banana bunchy top virus)	Fish hook flea *(Cercopagis pengoi)*
Rinderpest virus (Rinderpest virus)	Golden apple snail *(Pomacea canaliculata)*
Macro-fungi	Green crab *(Carcinus maenas)*
Chestnut blight (*Cryphonectria parasitica*)	Marine clam *(Potamocorbula amurensis)*
Crayfish plague (*Aphanomyces astaci*)	Mediterranean mussel *(Mytilus galloprovincialis)*
Dutch elm disease (*Ophiostoma ulmi*)	Northern Pacific seastar *(Asterias amurensis)*
Frog chytrid fungus (*Batrachochytrium dendrobatidis*)	Zebra mussel *(Dreissena polymorpha)*
Phytophthora root rot (*Phytophthora cinnamomi*	**Land invertebrates**
Land plants	Argentine ant *(Linepithema humile)*
African tulip tree (*Spathodea campanulata*)	Common wasp *(Vespula vulgaris)*
Black wattle (*Acacia mearnsii*)	Giant African snail *(Achatina fulica)*
Brazilian pepper tree (*Schinus terebinthifolius*)	Gypsy moth *(Lymantria dispar)*
Cogon grass (*Imperata cylindrica*)	Khapra beetle *(Trogoderma granarium)*
Cluster pine (*Pinus pinaster*)	Little fire ant *(Wasmannia auropunctata)*
Erect pricklypear (*Opuntia stricta*)	Red imported fire ant *(Solenopsis invicta)*
Fire tree (*Myrica faya*)	Rosy wolf snail *(Euglandina rosea)*
Giant reed (*Arundo donax*)	Sweet potato whitefly *(Bemisia tabaci)*
Gorse (*Ulex europaeus*)	**Amphibian bullfrog *(Rana catesbeiana)***
Hiptage (*Hiptage benghalensis*)	Cane toad *(Bufo marinus)*
Japanese knotweed (*Fallopia japonica*)	Caribbean tree frog *(Eleutherodactylus coqui)*
Kahili ginger (*Hedychium gardnerianum*)	**Reptile**
Koster's curse (*Clidemia hirta*)	Brown tree snake (*Boiga irregularis*)
Kudzu (*Pueraria montana var. lobata*)	Red-eared slider (*Trachemys scripta*)
Lantana (*Lantana camara*)	**Mammals**
Leafy spurge (*Euphorbia esula*)	Brush tail possum (*Trichosurus vulpecula*)
Leucaena (*Leucaena leucocephala*)	Domestic cat (*Felis catus*)
Melaleuca (*Melaleuca quinquenervia*)	Goat (*Capra hircus*)
Mosquite (*Prosopis glandulosa*)	Grey squirrel (*Sciurus carolinensis*)
Miconia (*Miconia calvescens*)	Macaque monkey (*Macaca fascicularis*)
Mile-a-minute weed (*Mikania micrantha*)	Mouse (*Mus musculus*)
Mimosa (*Mimosa pigra*)	Nutria *(Myocastor coypus*)
Privet (*Ligustrum robustum*)	Pig (*Sus scrofa*)
Pumpwood (*Cecropia peltata*)	**Birds**
Purple loosestrife (*Lythrum salicaria*)	Indian myna bird (*Acridotheres tristis*)
Quinine tree (*Cinchona pubescens*)	Red-vented bulbul (*Pycnonotus cafer*)
Shoebutton ardisia (Ardisia elliptica	Starling (*Sturnus vulgaris*)
Siam weed *(Chromolaena odorata)*	**Fish (Continued)**
Strawberry guava *(Psidium cattleianum)*	Mozambique tilapia (*Oreochromis mossambicus*)
Tamarisk *(Tamarix ramosissima)*	Nile perch (*Lates niloticus*)
Wedelia *(Sphagneticola trilobata)*	Rainbow trout (*Oncorhynchus mykiss*)
Red-vented bulbul (*Pycnonotus cafer*)	Walking catfish (*Clarias batrachus*)
	Western mosquito fish (*Gambusia affinis)*

Source: Global Invasive Species Database

The global economy, with increased transport of goods and travels has facilitated the movement of live species over long distances and beyond natural boundaries while transported organisms become invasive are in small percentage, and on the health of the plants, animals and human they have a tremendous impact -threatening lives and affecting food security and ecosystem health.

They may indirectly transform the structure and species composition of the ecosystem by changing the way in which nutrients are cycled through the ecosystem (McLean *et al.,* 2001). Biodiversity loss will have major consequences on human well-being. This includes the decline of food diversity, leading to malnutrition, famine and disease, especially in developing countries. The issue of invasive alien species is caused by human activities associated with international movement, but measures have to be taken at national and local levels. International cooperation can assist it**.** Biological invasions by non-native species constitute one of the major threats on livestock (Wittenberg and Cock, 2001). Invasive Alien Species may cause changes in environmental services, such as water supply, flood control, water assimilation, and nutrient recycling, conservation and regeneration of soils. The impacts of Parthenium are numerous and are most profound on livestock and grain cropping productivity, and on human health. Parthenium is highly toxic to domestic animals and animals avoid eating it. If eaten, however, the meat gets tainted and this causes direct economic losses. This could include altering geomorphic processes (soil erosion rates, for instance, or sediment accretion), biogeochemical cycling, hydrological cycles, or fire or light regimes (Levine *et al.,* 2003). In agriculture and forestry economic costs from invasive species can be separated into direct costs through production loss and management costs of invasive species. The economic loss is also through the loss of recreational and tourism revenues. Economic costs of invasions, when calculated as production loss and management costs, are low because they do not usually consider environmental damages (Richardson, 1998). If monetary values could be assigned to the extinction of species, loss in biodiversity, and loss of ecosystem services, costs from impacts of invasive species would drastically increase. In the native ecosystem, invasive plants can alter the nutrient cycling, fire regime and hydrology. Closely related and rare invasive species have the potential to hybridize with the native species which resulted in extinction and decline of native species (Mooney and Cleland, 2001). Through the process of genetic pollution, natural, wild species can be threatened with extinction. Invasive species are primary drivers of ecological change-they create and modify habitat; eat or and their diverse and widespread impacts on ecosystem (Strayer *et al.,* 2006; Marshall *et al.*, 2008). The invasive alien species are ready colonizers in disturbed areas and cause considerable ecological damage to India's natural areas, speed the disappearance of threatened and endemic species, reduce the carrying capacity of pastures, increase the maintenance costs of crop lands, and interfere with our enjoyment of the outdoors (Sharma *et al.,* 1981). A change in the climate pattern also favors the diffusion of invasive alien species. For accepting the climate change there are ample reasons will favor invasive alien species because they can tolerate a broad range of climatic conditions and can extend their ranges quickly? Invasive alien species have capacity to conquer new territories when changed eco-climatic zones become favorable for their breeding. Alien invasive plants often replicate faster by vegetative means (roots, stolons etc) and are usually more responsive to increases in atmospheric CO_2 concentrations. Changing climate is favoring spread and survival of IAS. The common Indian invasive species are originally native of South and Central America has extended and it has replaced several high medicinal and potential plant species from the high altitudes area. *Lantana camara* L. is known to produce secondary compounds toxic to ungulates and also to suppress regeneration of native species (Ricciardi *et al.,* 2000). Invasive alien species has potential to compete for scarce nutrients, it uptakes and uses nutrients from highly impoverished soil and low fertility environment (Grimm *et al.,* 2008). Invasive pathogens are particularly troublesome to human health in situations of environmental change and ecological disturbance, but the type, scale and tempo of change in health risk is accelerating under the contemporary conditions of global change. Devastating effect on the health of local people occur by the Irish potato famine in the 1840s which was caused by a fungus introduced from North America. The Asian tiger mosquito has been linked to more than 20 diseases, including yellow fever and chikungunya fever. Climate change is also enabling the spread northward of the common ragweed (Lee, 2002).

The plant is originally from North America, the seeds first coming to Europe in mixes of grain intended as bird feed. It is a powerful trigger of hay fever and other allergies. Changing landscapes are another result of invasive alien species. For example, the red palm weevil is destroying large numbers of palms in the Mediterranean region, transforming the green spaces in cities. There are also effects on ecosystems which indirectly affect humans. In some cases ecosystems altered by IAS may be less able to provide important 'ecosystem services' which support human activity.

B. Management

The Convention on Biological Diversity and its members distinguish that there is a vital need to tackle the impact of invasive alien species. The CBD sets global priorities, guidelines, collects information and helps to coordinate international action on invasive alien species. The CBD has adopted guidance on prevention, introduction and mitigation of impacts of alien species that threaten ecosystems, habitats or species**.** Global invasive species program (GISP) proposes 3 major management options, prevention, early detection, and eradication for alien species management. Prevention of introductions is mostly a cost-effective option.

(i) For a specific situation considering the ecology of target species species-specific surveys are designed and adapted.

(ii) Eradication aims to reduce the density of IAS below the acceptable threshold level.

(iii) For developing suitable management strategies examining the ecology and genetic make-up of the IAS is required (Shah, 2008).

(iv) Invasive alien species generally share common characteristics which can make them difficult to control and contain, including:

(v) Higher reproduction rate- it has been estimated that one Purple Loose strife plant can produce 3 million seeds.

(vi) Fewer natural predators- newly introduced species are often free of predation and disease, two major factors that keep native plant and animal populations in balance.

(vii) Ability to thrive in different environments – most invasive alien species can survive in a different variety of habitat types and climate regions.

A Control action has been developed and used worldwide against invasive aliens, with adaptations to local realities and conditions. Not only can the many methods be used to control or eradicate alien invasive; they are also used with equal or more devastating effect to destroy natural ecosystems to make place for agriculture, and in crop management systems where the intent is increase agricultural production.

Mechanical methods: These methods include the use of machines, hand picking, soil tillage, deliberate fire, shooting, trapping,

(i) **Hand removal of Plants:** The removal of alien plants can take place in natural areas such as parks. Although they are labour intensive, organized volunteers can usually readily be found.

(ii) **Fire:** This method is helpful in reducing and eradicating the preponderance of alien species.

(iii) **Shooting, snaring, trapping, etc.:** Whether one is intending to manage problem alien species or those native species whose populations have exploded due to human activities.

(iv) **Tillage:** In the farmer agriculture areas this is a powerful approach (but thus far little-used) for the elimination of alien species as well as seed bank reduction which are designated for restoration to its natural condition. It involves the use of plows, cultivators, harrows over several years i.e. summer fallow

Biological Methods: Biological control includes a number of techniques centered on the purposeful use of a living organism - predator with the aim of controlling a particular undesirable alien invasive. Biological control agent which could be a parasite, parasitoid, pathogen, predator, herbivore insect, antagonist or a competitor

(i) Introduction (classical biological control) of a herbivore or parasite from the 'pest's' area of origin;

(ii) Inoculation -repeated releases (of sterile males, for example) so as to prevent pest build-up;

(iii) Inundation -where large numbers of natural enemies are cultured and released during critical periods in the life cycle of the crop or other alien species;

(iv) Conservation – the main goal is to conserve and enhance the diversity of natural enemies existing already in an area thus decreasing the mortality of the affected species; and

(v) Augmentation -where natural enemies of a pest are at too low a level and the numbers are augmented by artificial rearing and release.

Chemical methods:

(i) **Herbicides/Pesticides:** By far, this is the most widely used method for eradicating unwanted animals and plants in agricultural areas.

(ii) **Anti-coagulant Poisons:** Single-dose anticoagulant poisons such as brodifacoum in special bait formulations, and the development of bait stations and aerial application methods for eradicating rodents

(iii) **Immunization.** The deliberate immunization of racoons and skunks in Ontario to prevent the spread of an alien invasive - the rabies virus.

(iv) **Impeding Reproductive Ability:** This is the use of hormones chemically or surgically to lower reproductive potential of a species impeding the reproductive ability of individual animals.

(v) **Community Succession:** Depending on the ecosystem, different variations of community succession can be used as a technique to eliminate alien species and replace them with ones that are native to the area

Integrated Methods: Increasingly, the trend today is to employ "integrated pest control methods" and there is an extensive literature. This means that several of the above approaches can be knowledgeably combined to achieve the desired control or eradication of the alien organisms. The national integrated pest management (IPM) program is the mechanism to prevent and control the threat posed by IAS within the country.

Legal and institutional needs

(i) A legal and institutional approach to the country's biosecurity threat is a prerequisite to long-term success against invasive species.

(ii) The introduction of wild and domesticated animals and plants into new areas by unauthorized means, between states and within the country should be reviewed and monitored by concerned Government departments.

(iii) Techniques to be developed to make rapid evaluation of the status and movement of invaders and of their impacts on ecosystem.

(vi) The Government of India has approved the notification of a new (Plant Quarantine Order, 2003) in harmonizing India's regulatory framework with the International plant protection convention and internationally accepted standards and the tenets of the SPS agreement of the World Trade Organization.

(v) Other supporting and managerial steps are also being taken to improve to international standards, the entire gamut of the country's quarantine activity and phyto-sanitary control at border level, like import and export inspections, on-field surveillance for pests and vectors, treatment standards and processes, and certification methodology. Efforts are also continuing to improve the export certification process and standards (Khoshoo, 1996).

(vi) The 2003 new order for plant quarantine in India makes pest risk analysis a precondition for imports and prohibit import of commodities contaminated with weeds and/or alien species. Restriction should be on import of packaging untreated material of plant origin..

(vii) At molecular level biotechnologists may adopt techniques for early characterization of native and non-native species like by using molecular markers. Information networks can also serve an invaluable function tools for data on IAS around the globe. National- and regional-level monitoring may assist with populating these accessible databases and, ultimately, identification, mapping, and modeling of IAS distributions, abundance, and impacts at local, national, and global scales. Individuals, too, have a responsibility. Abiding by local and international quarantine and customs regulations will prevent the spread of insect pests, weeds and diseases.

(viii) People crossing international borders every year act as vectors for IAS. Internationally, they can carry living plants that can be introduced back home, eventually becoming invasive.

(ix) Plant quarantine facilities enhancement

Plant quarantine structure and policy in India: Across the country 35 new plant quarantine stations to be opened at all major and minor ports for the development of an integrated information management system, national phytosanitary database, establishment of advanced molecular diagnostic facilities at major plant quarantine stations for rapid pathogen detection, computerization and networking of all the plant quarantine stations, standardization of the export certification process so that uniform and credible certificates with a common format and seal are issued by all phytosanitary certification authorities, both in central and state governments, across the country, human resource development and skill upgrading or training programmes for scientists researchers and others.

Obtaining ISO quality certification for major plant quarantine stations, production of guidelines for training of plant quarantine inspectors, production of guidelines for the improvement of new disinfestations techniques and vapour heat treatment of fruit fly host commodities, development of fumigants as an alternative to the ozone-depleting methyl bromide, development of international standards for phytosanitary measure sand planned production of guidelines for accreditation of post-entry quarantine facilities and inspection. Plant quarantine operations in India are carried out by the Directorate of Plant Protection, Quarantine and Storage, which functions under the aegis of the Ministry of Agriculture. The administrative structure of plant quarantine is shown in the organizational chart (Fig. 1).

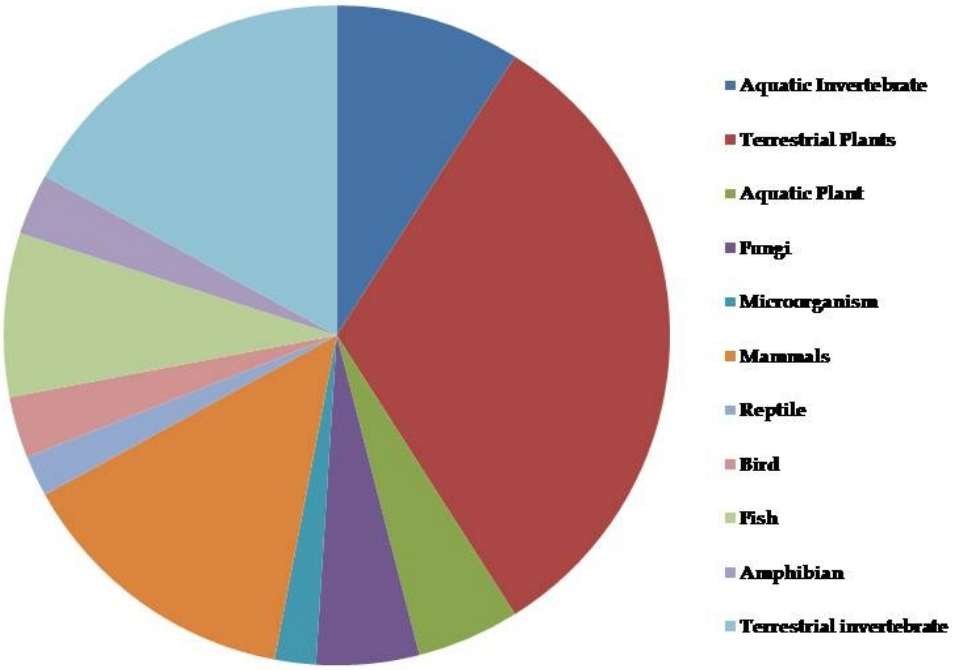

Fig. 1. Taxonomic representation of 100 of the world's worst alien invasive species.

The development of the new Plant Quarantine (Regulation of Import into India) Order, 2003 (referred to hereafter as "the new Order) compiles the primary plant quarantine concerns of the Government of India. These are:

(i) To prevent the introduction and spread of exotic pests that are destructive to the country by regulating the import of plants and plant products through adequate policy and statutory measures

(ii) To support India's agricultural exports through credible export certification

(iii) To facilitate safe global trade in agriculture by assisting producers, exporters and importers and by providing technically comprehensive and credible phytosanitary certification.

C. Alien species in India

India occupies only 2.4% of the world's land area and contributes about 8% to the world's species diversity. The described number of species on earth is estimated to be 1.75 million, of which more species have been described in India. Nearly 60% of India's bio-wealth is contributed by the fungi and insects (Ananymous 2008). India harbors 45,000 wild plant species and about 90,000 animal species in less than 50% geographical region surveyed so far as mega diversity country (Raghubanshi *et al.*, 2005). In India, 18,000 plant species, 30 mammal species, 4 bird species, and over 300 fish species are alien and about 40% of the Indian flora is alien, of which 25% are IAS (Weber, 1968). A global survey was conducted '100 of the World's Worst Invasive Alien Species' in which some of the I.A.S. are listed in Table 3 & Fig. 1.

D. Risk Assessment for Invasive Alien Species

Pest risk analysis is a key element of all three major international agreements relating to plant protection, namely the International Plant Protection Convention, the World Trade

Organization's Agreement on the Application of Sanitary and Phytosanitary Measures and the Convention on Biological Diversity. The IPPC framework, including the national plant protection organizations of all its contracting parties, could well provide an institutional framework that serves the objectives of the CBD and WTO as well.

In a transparent and acceptable way individual countries can manage these risks by determining:

(i) Those pests that could cause unacceptable damage to plants or plant products

(ii) The means and likelihood of their introduction

(iii The measures available to prevent such introduction.

Risk assessments for IAS will be helpful to select species that warrant immediate control as most aggressive species could be identified during the screening process. Results of risk evaluation are implemented into risk management, a process that weighs policy alternatives and selects appropriate incorporating options to accept, minimize or reduce the risks of IAS identified and characterized by the risk assessment (Clemen and Winkler, 1999). Risk analysis for IAS could be conducted through different approaches. Risk analysis for effects of IAS on biodiversity is being conducted by various authorities/agencies having different responsibilities (Harrison *et al*., 2002). In contrast, risk assessments for impacts of IAS on natural ecosystems have been difficult for environmental agencies to conduct as there is no well defined 'currency' to evaluate the impacts. It is well known that increased trade and tourism, human travel and migrations facilitated international and unintentional introductions of species all over the world (Weber and Gut, 2004)**.** According to the International Standards for Phytosanitary Measures (ISPM) of the International Plant Protection Convention (IPPC risk assessments are conducted among nations to restrict the movement of 'pests' The ISPM standards are adopted by contracting parties of the International Plant protection Convention (IPPC), members under the 'Agreement on application of sanitary and phytosanitary measures of World Trade Organization (WTO) and FAO member countries. Risk assessment protocols development has been focused more on invasive alien flora than invasive alien fauna. Most of the currently available risk assessment protocols for IAS are linked with (or included under) 'weed risk assessments. Weed risk assessment protocols have been developed and adopted recently in much country.

Similar schemes have also been adopted in Europe (by European Plant Protection Organization – EPPO) **(**FAO, 2006). Weed risk assessments are not only being conducted at country borders to forecast the consequences of a particular species introduction but also at post border level for those already present in the country or region (Harrison and Congdon, 2002)**.** Use of such risk assessment protocols have been extended to develop 'invasive plant inventories which are being updated time to time. These inventories developed for the use in California, Arizona and Nevada, Minnesota states of USA had categorized invasive alien flora that threatens the state's wild lands into high, moderate and limited categories based on the ecological impact, ability to invade natural vegetation communities and current extent of invasion of the species. Wet tropics Vertebrate Pest Risk Assessment Scheme developed by at the Cooperative Research Centre for Tropical Rainforest Ecology and Management, Cairns, Australia is one such scheme (Bomford, 2008)**.** More recently, risk assessment models have been proposed for the introduction of exotic mammals, birds, reptiles and amphibians in Australia and New Zealand. The UK non-native risk assessment scheme is also based on internationally recognized procedures developed by the European and Mediterranean Plant Protection Organization for freshwater fish, marine fish, amphibians and marine invertebrates (Uknnra, 2005).

E. Addressing environmental risks associated with plant pests

For development of PRA strategy different approaches to the management of invasive alien species are given as following:

(i) To explore monitoring and regulation to cover taxa and pathways that have not been covered previously

(ii) An NPPO could set up a quick screening process or a partial pest risk analysis on all plant species imported for planting. It would reduce the risk of introducing species of plants that "escape" their intended use and become countryside weeds or that become more invasive than in their native environment.

(iii) Identification of most important natural systems and/or native plants and review all potential threats to these

(iv) NPPOs work with a wide range of stakeholders, such as environmental NGOs, to decide which species or ecosystems that are not already the focus for plant protection effort are the most important to start protecting.
(v) To focus efforts on particular geographic areas or areas with specific levels of protected status.

F. Pest risk assessments resources

(i) National data sources
(ii) From the PRA areas National data will be needed and, to assess entry potential, from the country of origin.
(iii) International data sources
(iv) Data sources for assessing entry potential
(v) Data reports are most impotent on trade pathways and interceptions (detections in consignments) but usually require specific enquiries for unpublished data.
(vi) Data sources for evaluating the potentiality of establishment
(vii) If the origin area and the host plants are known, climates in the origin area can be compared with climates in the area under threat and the distribution of host plants determined.
(viii) Data sources for assessing economic, environmental and social impacts
(ix) Assembling comprehensive data on a pest's impacts in its current range, sufficient biological data to predict its spread and population dynamics in the PRA area coupled with financial, economic, environmental and social data for the enterprises, ecosystems and people likely to be affected may prove difficult. However, assessments can still be made even if data are lacking.

Weed risk assessment: To the review of sanitary and phytosanitary risks principles of pest risk analysis associated with the intentional importation of exotic plant species not yet established in the country. The system of weed risk assessment was developed to help assess the weed potential of such species. The WRA score for 30 percent of these was considered too high and the species were prohibited from entry into the country.

Assessing economic and social impacts: After establishment of a pest, evaluating the magnitude of the consequences for plants in the PRA area ideally requires knowledge of the pest's impacts in its current range, sufficient biological data to predict its spread and population dynamics in the PRA area coupled with financial, economic, environmental and social data for the enterprises, ecosystems and people likely to be affected. As for establishment potential, assessments can still be made even if data are lacking, for example by using expert opinion.

Assessing entry potential: To assess the extent to which a pest will be able to pass through all the stages of the pathway from the origin to the PRA area requires variety of information. Data on trade pathways and interceptions (detections in consignments) are most important. Unfortunately, no readily available compilations of these data sets exist and, for most purposes, specific enquiries for unpublished data have to be made

Assessing establishment potential: Data required and the techniques that can be used both for assessing establishment potential and for predicting the limits to the distribution of quarantine pests once established in a country. Essentially, ecological factors (such as the suitability of the ecological environment, presence of hosts and natural enemies) and factors intrinsic to the pest itself (such as its reproductive strategy and genetic adaptability) should be considered.

International Agreements in relation to IAS: (i) Article 8(h) of the Convention on Biological Diversity (CBD) states that "Each contracting Party shall, as far as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species."
(ii) Ironically, India is a signatory to CBD but hasn't made any significant laws in this regard.
(iii) United Nations Convention on the Law of the Sea (UNCLOS): It was adopted in 1982 & came in force in 1994. It requires the member state to protect & preserve the sea or marine environment from alien species.
(iv) Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES): It tries to make sure that the trade in endangered species of plants or animals do not create any threat for their survival.
(v) The Global Invasive Species Programme was set up to create awareness and provide advice and support in combating IAS.

Indian law in this regard:

(i) No specific law exists in India to deal with IAS.
(ii) But yes there exist some IAS specific laws that target some particular IAS species like the following laws: 1) The Livestock Importation Act

2) The Destructive Insects and Pests Act 3) Plant Quarantine (Regulation of Import into India) Order 4) The East Punjab Agricultural Pests, Diseases and Noxious Weeds Act

Protected Area and Indian Law: The so called protected areas in India under the forest are having a serious threat from the IAS. But the absence of any specific laws to deal with them is making the situation worse. Moreover, the government officials in these areas have actually the right to do something for these IAS. But hardly any of them is seen doing something for solving the problem of IAS.

Any positive effects of IAS: 1. Some people say that these IAS act as a food for another local species.
2. In some cases it has been seen that they help the local species to grow in number. It can be particularly helpful in the case where the local species being helped is an endangered one.
In some cases it has been seen that IAS helps to balance the ecosystem as their presence actually doesn't create any diversity problem.

Recent entry of IAS in India: In recent years, five new species of Invasive Alien Weeds namely *Ambrosia trifida* (Giant Ragweed) *Cenchrus tribuloides* (Spiny Burr Grass), *Cynoglossum officinale* (Hound'sTongue), *Solanum carolinense* (Horsenettle), *Viola arvensis* (European field Pansy) have entered in India, especially in Chhattisgarh, Orissa, West Bengal, Maharashtra, Kerala, Karnataka, Andhra Pradesh, Tamil Nadu and Madhya Pradesh. The surveillance of these weeds in the states is going on at large scale to check the expected loss as had been experienced earlier due to invasion of weeds like *Parthenium hysterophorus*, *Lantana camara*, *Eicchornia crassipes* etc.

CONCLUSIONS

Our studies have highlighted some of the difficulties that face researchers when they attempt to estimate the costs of invasive species and the benefits of control Plant invasions in the new areas alter indigenous community composition, deplete species diversity, affect ecosystem process and thus cause huge economic and ecological imbalance and poses a major threat to indigenous biological diversity in the world. The addition of new species (invasive or diseases) to an ecosystem can affect the well-being of people, whether through economics or health. The magnitude and net effects of biological invasion escalated rapidly over the twentieth century. During each decade, more species become invasive, more ecosystems were irreversibly altered, and an ever-increasing array of functions and processes was impacted by invasive alien species. For get rid of this problem we need to search specific biotic information such as species characteristics related to propagule, populations, monitoring provided to facilitate identification, monitoring and management. We need to rapid monitoring techniques for locations for the arrival of new species. We need to understand species interactions and the consequences to local ecosystems. We need to examine the problem at much greater geographical scales. We need to require proper control and management. The standard conditions for success are proper planning, a commitment to completing the task, dealing with the entire population of the target IAS, removing them faster than they reproduce and preventing reinvasion. This requires knowledge at regional and global scales, so we can assess how a particular new species becomes available for invasion, what controls invasion rates, and how preventative measures can be developed. This will improve our ability to predict which locations will be susceptible to invasion by a particular species, the potential effect on the local ecosystem and people, and what the most effective local countermeasures will be. Awareness strategies should be developed which could include involving local schools, volunteers or local groups in a targeted control of IAS within local communities or high profile sites. There are many useful data sets and tools that can be employed in pest risk analysis. it is important to stress that pest risk analyses do not need to be long and detailed. Good pest risk analysis practice needs to be captured and distilled in some form of manual enabling those new to pest risk analysis to learn the discipline as quickly and easily as possible. Increased publication of pest risk analyses would also help to demonstrate how pest risk analyses should be constructed. There are many challenging components of pest risk analysis that would benefit from additional scientific input, such as modeling pest spread, increasing the temporal and spatial resolution of risk maps, scaling up from one outbreak to many, modeling how impacts change over time, quantifying environmental impacts and managing uncertainty.

The increasing cooperation between plant health pest risk analysts and those analyzing the risks posed by invasive alien species to biodiversity is already proving to be highly beneficial.

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