

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Invasive Insects in India

*Swoyam Singh, Jai Hind Sharma, Avinash Udikeri
and Hashib Ansari*

Abstract

Invasive alien species (IAS) is an exotic species that becomes established in natural or seminatural ecosystems or habitats. It is an agent of change and threatens native biological diversity. Invasive insects in India have been a major threat to household commodities, human health, agricultural produce and environment. India is highly diversified in its weather and climate, which supports the establishment of various introduced insects from other parts of the world. Furthermore, globalisation has facilitated numerous introductions of invasive insect pests. There have been 23 invasive alien insects reported from India to date. This chapter exclusively deals with the characteristics of insects that make them invasive, the common pathways of entry of the invasive insects, the steps through which the introduced insect has established itself in the foreign land and finally the ways to manage them.

Keywords: India, invasive, insects, biological control

1. Introduction

India is the seventh largest country in the world with a total area expanse of 3.2 million square kilometres (appox.) [1]. It measures 3214 km from north to south and 2933 km from east to west. India is the largest peninsula, whose three parts are covered with water, *viz.* the Arabian Sea in the west, the Bay of Bengal in the east and the Indian Ocean at the south. India, being such a huge landscape, bears various climatic conditions, soils and vegetations all around the country. This makes India one of the richest diversities in the world. The country has 15 agro-climatic zones comprising of mountains, plateaus, deserts, river, lakes, oceans and grasslands [2]. Apart from that 21.54% of the total area is covered by dense forests [3]. Hence, the complex topography, diversified climate and vegetation make India one of the favourite venues for alien species invasion. Furthermore, India being one of the fastest-growing economies has contributed an export of \$330.07 billion in 2014 to as many as 190 countries in the world. On the other hand, the import statistics reveal an importation of \$462.9 billion from around 140 countries around the world. This excessive trade among nations has made India an opportunistic target for the entry of the alien species [4].

Biological invasion can be well regarded as a biological pollution which causes maximum losses to the biodiversity [5]. Invasive species are threats to agricultural biodiversity as well as human and animal health. These species are non-native

or exotic species which have great power of dispersal and adaptation. They are introduced unintentionally into a new area where they get a favourable climate increase in number and establish. Furthermore, the new area will be devoid of its natural enemy which unleashes the invasive species' growth without any limitation. According to the International Union for Conservation of Nature (IUCN), an invasive alien species (IAS) is an exotic species which becomes established in natural or seminatural ecosystems or habitats, is an agent of change and threatens native biological diversity. India has harboured a total of 173 invasive species including 47 invasive species of agricultural ecosystem, out of which 23 are insects [6].

2. Pathways of invasion

Pathways are the predicted routes helping the invasive species in transit to new environments. There is a long history regarding the classification of these pathways. The most common pathways include the sea, land or air. There have been several examples of entry of various species through these pathways into India. For example, cashew which is considered as one of the most important cash crops of India was introduced in the sixteenth century by the early Portuguese purposefully realising its importance, through their sea voyages [7]. Today, due to globalisation, the frequency of invasion and its consequences has increased exponentially. Some of the species were knowingly transported to a new ecosystem, while some are a matter of ignorance.

- i. **Introduced as contaminants.** The trade of logs is considered to be one of the most profitable businesses. It provides a huge foreign exchange, but it comes with the consequence of introduction of alien species also. Being stored in godowns for a long period without any treatment makes these logs store house of many insects and pathogens. The importation of these logs also transmits their residing alien species [8].

There has been an importation of various food products and seeds to India from foreign countries. In the past when there was a lenient legal restriction for importation of food products, an admixture of contaminants in the food lot have been proven to be detrimental to the importing country. For example, the importation of food grains from the USA under the US PL 480 scheme (a food assistance programme of the US government to India) also brought *Parthenium hysterophorus* along with it [9].

- ii. **Living industry pathway.** Living industry implies the trade of living organisms including landscaping or horticultural crops, agriculture, aquaculture/aquarium, pet trade and live seafood trade. There is every possibility that these living entities escort their respective pests while being exported. For example, Apple woolly aphids have been predicted to enter India through the importation of apple rootstock from England [10].
- iii. **Transportation related.** India being rich in its cultural heritage attracts numerous tourists every year. The foreign tourist arrival rate has increased from 2.54 million per annum in 2001 to 10.56 million per annum in 2018 [11]. The increase in number of tourists has increased the chances of invasion by the following ways:

- Accidental introduction of insects or other organisms [12]
- Unintentional transit of alien species from one place to another
- Cargo shipments by air, land and water [13, 14]
- Food trade [15, 16]
- Infested fruits or vegetables carried by tourists [17]

There has been enhanced domestic conveyance with enriched networks of railways, highways, airways and harbours which further facilitate the easy spread of the introduced insects all over the country mostly by unintentional transit along with passengers.

3. Characteristics of an invasive species

- Very resilient
- Short life cycle
- Broad host range
- High dispersal ability
- Ability to withstand many environmental conditions
- High fecundity
- Voracious feeders
- Benefits from mutualist interaction

4. Steps in invasion

The process of invasion of an alien species follows certain sequential steps, *viz.* introduction, establishment, spread and naturalisation [18].

i. **Introduction.** In order to become a habitant of a new locality, beyond the natural ranges, the insect must have to first move or get itself moved from its current habitat. This movement of the insect is called as passive transport which is brought about by vectors. The most common vectors nowadays are humans or human consignments. Passive transports of these invasive species are very common and are difficult to control. Even after strong quarantine inspections, it is difficult to detect the cryptic early stages of the insect which might be transported through the tourists. The transportation of a single gravid female insect also has the ability to create havoc in the introduced environment since it is a prolific breeder and lacks its natural enemy. One of the most common examples

of passive transportation of insect is the occurrence of timber beetles (Cerambycidae) in Antarctica which is predicted to be introduced through transported logs to one of the base camps [19].

Sometimes insects themselves have an inherent capacity of migration to long distances. Hence any deviations from the favourable condition make them migrate from that place. Fall armyworm, *Spodoptera frugiperda*, is one of the recent invasive insect pests in India. They are excellent fliers [20, 21] and can fly almost 100 kilometres in certain hours; hence they are believed to have fled from Africa to the Indian subcontinent, but still the mode of arrival of the invasive pest is uncertain. Another example is the Monarch butterfly, *Danaus plexippus* (Nymphalidae), native to North America which has been found migrating to Australia in the early nineteenth century [22].

ii. **Establishment.** Short colonisation is very common, but the insect cannot be regarded as an invasive one unless it has established itself in the new environment which is possible only when the invaded insect overcomes the environmental barriers. Unlike local colonisation, establishment of an invasive species is dependent on the amount of propagule introduced. It is believed that the establishment is promoted by disturbances conducted at the receiving environment. Disturbance promotes establishment either because native species are poorly adapted to the frequency, intensity or timing of human-mediated disturbances or because IAS are often adapted to disturbance and thus predisposed for colonisation in such environments [23]. Insects are more prone to invasiveness due to increased resource availability and decreased biotic resistance.

Global warming is another cause of rapid invasiveness of the insects. Global warming has modified the resource availability and habitat suitability, thereby deteriorating biological regime of the native insects, hence favouring the establishment of the alien insects [24]. However some of the regions might be least affected by climate change as far as the invasiveness is concerned, whereas climate change always affects negatively the native species [25].

iii. **Spread.** Spreading is the process where the initially established species spreads to other areas. Spreading is guided by environmental factors such as weather conditions, microclimate and habitat quality [26]. The community context of spreading includes interspecific competition and predators also. The decision for spreading in an individual insect is also brought about either by its behavioural responses (aggressiveness or sociality of the insect) or morphological responses (wing development as in the case of aphids). Apart from that the established insect can also spread through human-mediated transportation. The latter conserves energy for the invasive insect since the human-mediated transports are quick but the success rate of the spread is highly dependent on the habitat permeability of the habitat to which the alien insect spread [27].

5. Current status of invasive insects in India

There are 173 invasive species introduced to India including 54 terrestrial plants, 56 aquatic organisms, 47 organisms having agricultural importance and 14 organisms of island ecosystem. On the other hand, there are 23 insect pests introduced to India (Table 1) [6].

SI. No	Common name	Scientific name/ family	Introduced from/year	Hosts	Symptoms	Natural enemies
Order: Hemiptera						
1.	Woolly aphid [28]	<i>Eriosoma lanigerum</i> (Aphididae)	China (1889)	Apple, pear	Nymphs and adults are sap suckers, roots are damaged by the formation of swellings, and plants look unhealthy even leading to death	Parasitoids <i>Aphelinus mali</i> Predators <i>Coccinella septempunctata</i> , <i>Coccinella transversoguttata</i> , <i>Balli anacharis</i> , <i>Chrysopa</i> <i>nigricornis</i> , <i>Exochomus</i> <i>uropygialis</i> , <i>Coleophora</i> <i>sunzetti</i>
2.	San Jose scale [29]	<i>Quadraspidiotus perniciosus</i> (Diaspididae)	China (1911)	<i>Populus</i> spp.; <i>Salix</i> spp.; <i>Aesculus</i> spp.; <i>Alnus</i> spp.; <i>Betula</i> spp.; <i>Celtis</i> spp.; <i>Fagus</i> spp.; <i>Morus</i> spp.	Nymphs and adults suck the sap usually from the twigs and branches even fruits and leaves depending on severity. Heavy infestation on bark causes gumming which will be fatal to plant. Pink discolouration around the parts infested by scales	Parasitoids <i>Aphytis</i> sp., <i>Novaproclia</i> sp., <i>Encarsia perniciosi</i> <i>Teleterbratus perversus</i> Predator <i>Chilocorus infernalis</i>
3.	Lantana bug [30]	<i>Orthezia insignis</i> (Orthezidae)	Sri Lanka/ West indies (1915)	<i>Lantana</i> , coffee, <i>Jacaranda</i> , <i>Citrus</i> , sweet potato, gumwood, brinjal, rose	Reproduction is parthenogenetic. Bug feeds by sucking the sap from the phloem. As a by-product, honeydew is excreted which leads to attraction of ants and development of sooty moulds (Green, 1922) resulting in foul odour and decrease of market value of fruits	Predator <i>Hyperaspis pantherina</i>
4.	Cottony cushion scale [29]	<i>Icerya purchasi</i> (Margarodidae)	1921	<i>Acacia decurrens</i> , <i>Acacia dealbata</i> , and also a wide range of forest trees and agriculture are affected by this insect	Insect is a sap sucker. Abundant amount of honeydew is excreted leading to the sooty mould development eventually affecting photosynthesis and yield	Predator <i>Rodolia cardinalis</i>
5.	Pine woolly aphid [29]	<i>Pineus pini</i> (Adelgidae)	1970	<i>Pinus</i> spp. <i>Pinus patula</i>	Aphid feeds on shoots of plants causing dieback from the tip	Predator <i>Cheilomenes aurora</i>

SI. No	Common name	Scientific name/ family	Introduced from/year	Hosts	Symptoms	Natural enemies
6.	Subabul psyllid [31]	<i>Heteropsylla cubana</i> (Psyllidae)	Central America (1988)	<i>Leucaena</i> sp.	These insects are sap suckers from the young shoots, leaves and inflorescences leading to complete deformation of young shoots	Predator <i>Curinus coeruleus</i>
7.	Spiralling whitefly [32]	<i>Aleurodicus dispersus</i> (Aleyrodidae)	Caribbean region, Central America (1993)	Wide range of plants (481 hosts)	Nymphs and adults suck sap from host plants. Premature leaf drop. Nymphs secrete white, waxy and flocculent material. Honeydew is produced which develops sooty mould affecting photosynthesis	Parasitoids <i>Encarsia haitiensis</i> <i>Encarsia guadeloupe</i> Predators <i>Axinoscymnus puttarudiah</i> <i>Oecophylla smaragdina</i> <i>Solenopsis geminate</i>
8.	Silver leaf whitefly [29]	<i>Bemisia argentifolii</i> (Aleyrodidae)	1999	Tomato, Squash, Poinsettia, Cucumber, Eggplants, Okra, Beans, and Cotton	Four types of damages can be seen Disorder symptoms (irregular ripening), sooty mould development due to honeydew secretion, viral disease (tomato leaf curl virus transmitted by adults) and cosmetic damage due to the presence of adults and nymphs on leaves	Parasitoids <i>Encarsia formosa</i> , <i>Eretmocerus eremicus</i> Fungal pathogens <i>Lecanicillium lecanii</i> , <i>Beauveria bassiana</i> , <i>Paecilomyces fumosoroseus</i>
9.	Papaya mealy bug [33]	<i>Paracoccus marginatus</i> (Pseudococcidae)	Central America (2007)	Mulberry, tapioca, <i>Jatropha</i> , cotton and several fruits, flowers and plantation crops	Stylets are inserted into leaves and skin of the fruits and suck the sap. Injection of toxic substance leads to chlorosis, stunting, distortion, early leaf and fruit fall. Sooty mould is developed disturbing photosynthesis	Parasitoid <i>Acerophagus papayae</i> Predator <i>Cryptolaemus montrouzieri</i>
10.	Cotton mealy bug [34]	<i>Phenacoccus solenopsis</i> (Pseudococcidae)	USA (2005)	Cotton, brinjal, okra, tomato, sesame, sunflower, rose	Sap suckers Infestation of this mealybug on cotton causes: stunting, yellowing, distortion and premature drop of leaves and fruits	Parasitoid <i>Aenasius bambawalei</i>

SI. No	Common name	Scientific name/ family	Introduced from/year	Hosts	Symptoms	Natural enemies
11.	Solenopsis mealy bug [35]	<i>Phenacoccus solenopsis</i> (Pseudococcidae)		Malvaceae (okra), Solanaceae (tomato, brinjal, potato, chilly), Leguminosae (field bean), Cucurbitaceae (pointed gourd, cucumber, melons and gourds)	Apart from sap sucking, they develop black sooty moulds which disturb photosynthetic activity	Parasitoid <i>Aenasius bambawalei</i>
12.	Rugose spiralling whitefly [36]	<i>Aleurodicus rugioperculatus</i> (Aleyrodidae)	2016	Coconut, guava, banana, mango, drumstick, jackfruit	Young ones and adults suck the sap from leaves by remaining ventral surface of the leaves	Parasitoid <i>Encarsia</i> sp.
13.	Woolly whitefly [37]	<i>Aleurothrixus floccosus</i> (Aleyrodidae)	Neotropical (2019)	Guava, <i>Citrus</i> species		Parasitoid <i>Cales noacki</i>
14.	Neotropical whitefly [38]	<i>Aleurotrachelus atratus</i> (Aleyrodidae)	Neotropical (2019)	<i>Cocos nucifera</i> and <i>Dyopsis lutescens</i>		Parasitoid <i>Encarsia</i> spp. Predators <i>Dichochrysa astour</i> <i>Cybocephalus</i> spp. <i>Chilocorus nigrita</i> and <i>Jauravia pallidula</i>
Order: Lepidoptera						
15.	Potato tuber moth [29]	<i>Phthorimaea operculella</i> (Gelechiidae)	Italy (1937)	Tobacco, tomato, brinjal, beet and stored potato	Caterpillars mine the leaves and bore holes on tender shoots and tubers. They can move through veins into the petiole	Parasitoids <i>Chelonus blackburni</i> , <i>Copidosoma kochleti</i> Predators <i>Chrysoperla zastrowi</i> , <i>Orius albidipennis</i> , <i>Labdura riparia</i>

SI. No	Common name	Scientific name/ family	Introduced from/year	Hosts	Symptoms	Natural enemies
16.	Diamondback moth [39]	<i>Plutella xylostella</i> (Plutellidae)	1914	Cabbage, cauliflower, radish, Knol-khol (rabi), turnip, beetroot, mustard	Mining and skeletonisation of leaves and caterpillar also bores into heads of cabbage	Parasitoids <i>Brachymeria excarinata</i> , <i>Tetrastichus sokolowskii</i> Predators <i>Motacilla flava</i> , <i>Tapinoma melanocephalum</i> , <i>Pheidole</i> spp., <i>Camponotus sericeus</i>
17.	South American tomato leaf miner [40]	<i>Tuta absoluta</i> (Gelechiidae)	South America (2014)	Tomato, potato, pepper, brinjal	Larvae attack leaves, buds, stalks and fruits. Feeding results in blotches visible from both sides, galleries on leaves and pinholes on fruits from stalk end stuffed with frass	Parasitoid <i>Trichogramma achaea</i> Predator <i>Nesidiocoris tenuis</i>
18.	Fall armyworm [41]	<i>Spodoptera frugiperda</i> (Noctuidae)	America to Africa, Africa to India (2018)	Maize, millet, sorghum, sugarcane, rice, wheat, cowpea, groundnut, potato, soybean, cotton	Eggs are laid in the whorl (inner side) and also under leaves in mass. Hatched larvae feed on leaves by scraping and skeletonising leaving a silvery transparent membrane. Feeds unopened leaves in whorls and stuffs with frass. Older larvae feed on primordial shoot and tassel leading to dead heart symptom	Parasitoids <i>Telenomus</i> sp., <i>Trichogramma</i> sp.
Order: Hymenoptera						
19.	Blue gum chalcid [29]	<i>Leptocybe invasa</i> (Eulophidae)	Australia	<i>Eucalyptus</i> sp.	<i>L. invasa</i> lay eggs in the bark of shoots or the midribs of leaves. Small, white maggots produce galls on the midrib of leaves, petioles and twigs leading to gnarled appearance, stunted growth, lodging, dieback and eventually death of the tree	

SI. No	Common name	Scientific name/ family	Introduced from/year	Hosts	Symptoms	Natural enemies
20.	Erythrina gall wasp [42]	<i>Quadrastrichus erythrinae</i> (Eulophidae)	2005	<i>Erythrina</i> sp., black pepper vanilla	Wasp forms galls on the leaves, stems, petioles, and youngs. Due to galls there reduction in size and number eventually decreases the growth. One wasp per gall is present, whereas galls on shoots and petiole have five individuals. Trees affected become scrawny with crinkle leaves later leading to defoliation and death	
Order: Coleoptera						
21.	Coffee berry borer [43]	<i>Hypothenemus hampei</i> (Scolytidae)	Northeast Africa (1990)	Arabica and robusta types of coffee	The fertilised female bores an entrance hole at the terminal pore or in the calyx ridge of the differential tissue that surrounds the pore and lays bean shaped eggs	Parasitoids <i>Prorops nasuta</i> , <i>Cephalonomia stephanoderis</i> , <i>Phymastichus coffea</i> , <i>Cephalonomia stephanoderis</i>
Order: Diptera						
22.	Serpentine leaf miner [44]	<i>Liriomyza trifolii</i> (Agromyzidae)	USA (1990)	Pea, cucurbits, tomato, castor, ornamental plants (feeds on more than 78 annual plant species)	The adult female makes punctures in the leaf tissue with its ovipositor for both feeding and oviposition. The larvae that hatch out from the eggs mine the leaf feeding on the mesophyll region leaving a serpentine structure	Parasitoid <i>Hemiptarsenus varicornis</i>
Class: Arachnida						
23.	The coconut eriphyid mite [29]	<i>Aceria guerreronis</i> (Eriophyidae)	1997	Coconut	Nuts are discoloured resulting in the reduction of market value	Predator <i>Neoseiulus baraki</i> Fungal pathogen <i>Hirsutella thompsonii</i>

Table 1.
Current status of invasive insects in India.

6. Management of invasive insects

The process of management of invasive insects (**Figure 1**) includes management at three different levels of invasion of pest:

- a. When the pest has not been introduced: Preventive measures are taken to avoid the entry of the invasive insect, *viz.* pest risk analysis (PRA), quarantine and monitoring. This is the best way in managing the invasive species.
- b. When the species is introduced but is not spread to nearby areas: Postquarantine measures are taken in such cases such as rejection of the consignment from which the pest has introduced and eradication by means of fumigation of the consignment lot.
- c. When the introduced insect has established itself: Various curative measures such as cultural, biological and chemical means of management are adopted.

The Indian government has framed certain laws to cope with the invasive species. The formulation of laws to prevent the entry of invasive species ages back to 1914 when the Destructive Insects and Pests Act 1914 was framed [45]. With the elapse of time, these laws were modified from time to time. Presently, the primary plant quarantine concerns of India are dealt by the Plant Quarantine Order 2003. The Plant Quarantine Order 2003 includes new import policies with required statutory measures which aim to restrict the import of infested plants or plant products. The order advocates a prior PRA to estimate the phytosanitary measures required to protect plant resources against the invasive pest [46].

Plant quarantine facilities include:

- An integrated information management system
- An integrated pest risk analysis system and a national pest risk analysis unit for conducting an integrated pest surveillance
- An integrated phytosanitary border control system
- A national phytosanitary database
- A national management centre for phytosanitary certification to continuously review the national standards for export phytosanitary certification

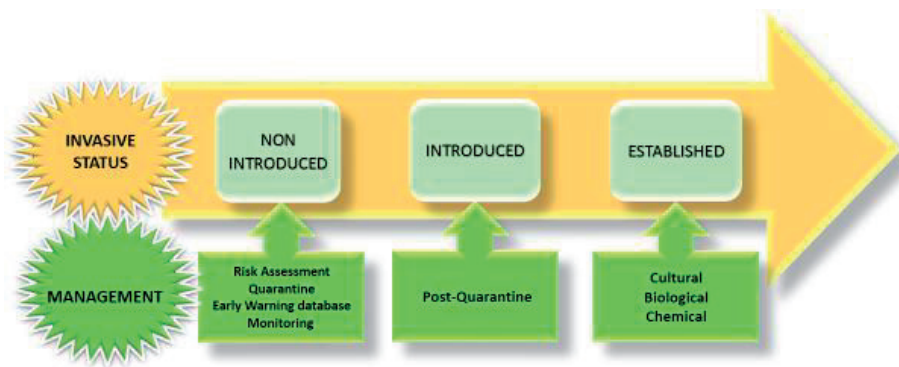


Figure 1.
Management of invasive insects.

i. **Monitoring.** There is a total of 71 plant quarantine stations across major and minor ports (34 seaports, 12 airports, 14 land frontiers and 11 foreign post offices) in India [47] which deals exclusively on restricting the import of any foreign contaminants. One of the major approaches for managing the invasive insects is its early detection. But the problem lies with the exact identification of the insect (to species level). Identification of the species requires expertise in insect taxonomy which is a limiting constraint in India [48]. Hence the government of India has established molecular diagnostic facilities across the quarantine station for easy and rapid detection of invasive insects [49]. Apart from molecular techniques, monitoring is also done by the use of chemical pheromones (sex pheromones and attractants) or by physical with the help of yellow sticky traps, light traps, etc.

ii. **Biological.** The boom reproduction of invasive insects in a new environment is because of non-availability of their natural enemy and unlimited food supply [50]. Biological control is an ancient practice to control introduced pests, which deals with a timely introduction (classical biological control), augmentation (mass release of native or exotic natural enemies) and conservation (habitat management) of natural enemy (predators and parasitoids) from their (invasive insect's) native places in hope that they may reduce the invasive pest population to non-harming levels [51]. There are many examples of biological control which are listed above (**Table 1**). Biological control is sufficient to control the alarming invasiveness if once the natural enemy is established, has long-term effects and is cost-effective too [52]. Sometimes the biological control comes with a consequence which should be pre-analysed before the introduction of the bioagent [53]. For example, *Zygogramma bicolorata* was introduced in India to manage *Parthenium hysterophorus* which ended up as a pest of sunflower [54]. There must be prior research to prevent such introduction of natural agents which may have a negative impact.

iii. **Chemical control.** Prevention is always better than cure. Hence, strict quarantine is the best solution for the management of invasive insects, that is, a thorough investigation of all kinds of imported goods and products in order to hamper the introduction of dangerous species. However, after the breaching for this barrier, the next prompt control measure is pesticides (chemicals). Pesticides are quick acting and are very efficient in reducing or eradicating the invasive insects. But prior knowledge about the insecticide regarding its mode of action, selectivity and residual effect is very much essential while applying an insecticide to manage the invasive insect.

7. Conclusion

Globalisation has enriched us beyond belief, but it too comes with a consequence. Increased connectivity due to globalisation has resulted in the introduction of numerous invasive insect pests to India which not only have devastated several agricultural crops but also have caused huge monetary loss. This situation further got worse with the advent of global warming and climate change which favoured the establishment and spread of the invasive species. Hence, management of the invasive insects is a challenge. Minimising the loss caused by invasive insects requires an “international management approach” with strict legislation laws and better cooperation among countries with respect to exchange of information regarding the invasive species and their natural enemies. Moreover, there should be a hierarchical setup

recruiting expertise personnel having sound knowledge on insect identification, preliminary risk assessment and monitoring of insects and their eradication. Besides, several public awareness campaigns can be conducted to educate the common people which will definitely reduce the chances of an accidental invasion.

IntechOpen

IntechOpen

Author details

Swoyam Singh*, Jai Hind Sharma, Avinash Udikeri and Hashib Ansari
GB Pant University of Agriculture and Technology, Uttarakhand, India

*Address all correspondence to: swoyamsingh@gmail.com

IntechOpen

© 2020 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. 

References

- [1] Stanley AW, Sanjay S, et al. India [Internet]. 2020. Available from: <https://www.britannica.com/place/India>
- [2] Ahmad L, Kanth RH, Parvaze S, Mahdi SS. Agro-climatic and agro-ecological zones of India. In: *Experimental Agrometeorology: A Practical Manual*. Cham: Springer; 2017. pp. 99-118
- [3] Wikipedia [Internet]. Available from: https://en.wikipedia.org/wiki/Geography_of_India
- [4] Gupta N, Verma SC, Sharma PL, Thakur M, Sharma P, Devi D. Status of invasive insect pests of India and their natural enemies. *Journal of Entomology and Zoology Studies*. 2019;7(1):482-489
- [5] Reshi ZA, Khuroo AA. Alien plant invasions in India: Current status and management challenges. In: *Proceedings of the National Academy of Sciences, India - Section B: Biological Sciences*. 2012;(82):305-312
- [6] Sandilyan S. Invasive Species of India Report. National Biodiversity Authority, Ministry of Environment Forests and Climate Change Government of India [Internet]. Available from: <http://nbaindia.org/uploaded/pdf/laslist.pdf>
- [7] Singh S, Mukherjee SK. Studies on flowering thrips of cashew and its correlation on nut shedding. *Journal of Entomology and Zoology Studies*. 2018;6(4):873-875
- [8] Piel F, Gilbert M, De Cannière C, Grégoire JC. Coniferous round wood imports from Russia and Baltic countries to Belgium. A pathway analysis for assessing risks of exotic pest insect introductions. *Diversity and Distributions*. 2008;14(2):318-328
- [9] Kaur M, Aggarwal NK, Kumar V, Dhiman R. Effects and management of *Parthenium hysterophorus*: A weed of global significance. *International Scholarly Research Notices*. 2014;2014:1-12
- [10] Gupta R. Management and comparative efficacy of various treatments against *Eriosoma lanigerum* HAUSMANN on apple trees (*Malus domestica* BORKH.) in Jammu province of Jammu & Kashmir state. *International Journal of Advanced Biological Research*. 2015;5(4):319-321
- [11] India tourism statistics at a glance. Government of India [Internet]. 2018. Available from: <http://tourism.gov.in/sites/default/files/Other/India%20Tourism%20Statistics%20at%20a%20Glance%202019.pdf>
- [12] Kiritani K, Yamamura K. Exotic insects and their pathways for invasion. In: *Invasive Species: Vectors and Management Strategies*. Washington: Island Press; 2003. pp. 44-67
- [13] Work TT, McCullough DG, Cavey JF, Komsa R. Arrival rate of nonindigenous insect species into the United States through foreign trade. *Biological Invasions*. 2005;7(2):323
- [14] Dobbs TT, Brodel CF. Cargo aircraft as a pathway for the entry of nonindigenous pests into south Florida. *Florida Entomologist*. 2004;87(1):65-78
- [15] Hulme PE. Trade, transport and trouble: managing invasive species pathways in an era of globalization. *Journal of Applied Ecology*. 2009;46(1):10-18
- [16] Yan X, Zhenyu L, Gregg WP, Dianmo L. Invasive species in China—An overview. *Biodiversity and Conservation*. 2001;10(8):1317-1341
- [17] Anderson LG, Rocliffe S, Haddaway NR, Dunn AM. The role of

tourism and recreation in the spread of non-native species: A systematic review and meta-analysis. PLoS One. 2015;**10**(10):1-15

[18] Kolar CS, Lodge DM. Ecological predictions and risk assessment for alien fishes in North America. Science. 2002;**298**(5596):1233-1236

[19] Osyczka P, Mleczko P, Karasiński D, Chlebicki A. Timber transported to Antarctica: A potential and undesirable carrier for alien fungi and insects. Biological Invasions. 2012;**14**(1):15-20

[20] Johnson SJ. Migration and the life history strategy of the fall armyworm, *Spodoptera frugiperda* in the Western Hemisphere. International Journal of Tropical Insect Science. 1987;**8**(4-6):543-549

[21] Bajracharya AS, Bhat B, Sharma P, Shashank PR, Meshram NM, Hashmi TR. First record of fall army worm *Spodoptera frugiperda* (JE Smith) from Nepal. Indian Journal of Entomology. 2019;**81**(4):635-639

[22] Nail KR, Drizd L, Voorhies KJ. Butterflies across the globe: A synthesis of the current status and characteristics of monarch (*Danaus plexippus*) populations worldwide. Frontiers in Ecology and Evolution. 2019;**7**:362

[23] Diez JM, D'Antonio CM, Dukes JS, Grosholz ED, Olden JD, Sorte CJ, et al. Will extreme climatic events facilitate biological invasions? Frontiers in Ecology and the Environment. 2012;**10**(5):249-257

[24] Kelley AL. The role thermal physiology plays in species invasion. Conservation Physiology. 2014;**2**(1):1-14

[25] Pachauri RK, Allen MR, Barros VR, Broome J, Cramer W, Christ R, et al. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report

of the Intergovernmental Panel on Climate Change. Ipcc; 2014

[26] Bonte D, Baert L, Lens L, Maelfait J-P. Effects of aerial dispersal, habitat specialisation, and landscape structure on spider distribution across fragmented grey dunes. Ecography. 2004;**27**(3):343-349

[27] Renault D, Laparie M, McCauley SJ, Bonte D. Environmental adaptations, ecological filtering and dispersal central to insect invasions. Annual Review of Entomology. 2018;**63**:345-368

[28] Mishra SC. The American blight or wooly apple aphid *E. Lanigerum* (Hausmann). Agricultural Research Journal. 1920;**15**:627

[29] Singh SP. Some Success Stories in Classical Biological Control of Agricultural Pests in India. Asia-Pacific Association of Agricultural Research Institutions (APAARI). Bangkok, Thailand: FAO; 2004

[30] Muniappan R, Viraktamath CA. Status of biological control of the weed, Lantana camara in India. International Journal of Pest Management. 1986;**32**(1):40-42

[31] Jalali SK, Singh SP. Release and recovery of an exotic coccinellid predator, *Curinus coeruleus* (Muls.) on subabul psyllid, *Heteropsylla cubana* Crawf. in India. Journal of Insect Science. 1989;**2**(2):158-159

[32] Palaniswami MS, Pillai KS, Nair RR, Mohandas C. A new cassava pest in India. Cassava News. 1995;**19**(1):6-7

[33] Jhala RC, Bharpoda TM, Patel MG. *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), the mealy bug species recorded first time on cotton and its alternate host plants in Gujarat, India. Uttar Pradesh Journal of Zoology. 2008;**28**(3):403-406

- [34] Nagrare VS, Kranthi S, Biradar VK, Zade NN, Sangode V, Kakde G, et al. Widespread infestation of the exotic mealybug species, *Phenacoccus solenopsis* (Tinsley) (Hemiptera: Pseudococcidae), on cotton in India. *Bulletin of Entomological Research*. 2009;**99**(5):537-541
- [35] Abbas G, Arif MJ, Ashfaq M, Aslam M, Saeed S. Host plants, distribution and overwintering of cotton mealybug (*Phenacoccus solenopsis*; Hemiptera: Pseudococcidae). *International Journal of Agriculture and Biology*. 2010;**12**(3):421-425
- [36] Srinivasan T, Saravanan PA, Josephraj Kumar A, Rajamanickam K, Sridharan S, David PM, et al. Invasion of the Rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae) in Pollachi tract of Tamil Nadu, India. *Madras Agriculture Journal*. 2016;**103**(10-12):349-353
- [37] NBAIR [Internet]. Available from: <https://www.nbair.res.in/sites/default/files/2019-07/pest%20alert%2023%20july%202019.pdf>
- [38] NBAIR [Internet]. Available from: <https://nbair.res.in/sites/default/files/2019-10/Pest%20Alert%20Aleurothrixus%20floccosus.pdf>
- [39] Fletcher TB. Some south Indian Insects and Other Animals of Importance Considered Especially from an Economic Point of View. Printed by the Superintendent, Government Press, Madras; 1914
- [40] Sridhar V, Chakravarthy AK, Asokan R, Vinesh LS, Rebijith KB, Vennila S. New record of the invasive South American tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in India. *Pest Management in Horticultural Ecosystem*. 2014;**20**(2):148-154
- [41] Shylesha AN, Jalali SK, Gupta AN, Varshney RI, Venkatesan T, Shetty PR, et al. Studies on new invasive pest *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) and its natural enemies. *Journal of Biological Control*. 2018;**32**(3):145-151
- [42] Faizal MH, Prathapan KD, Anith KN, Mary CA, Lekha M, Rini CR. Erythrina gall wasp *Quadrastichus erythrinae*, yet another invasive pest new to India. *Current Science*. 2006;**90**(8):1061-1062
- [43] Varaprasad KS, Balasubramanian S, Diwakar BJ, Rao CR. First report of an entomogenous nematode, *Panagrolaimus* sp. from coffee-berry borer, *Hypothenemus hampei* (Ferrari) from Karnataka, India. *Plant Protection Bulletin*. 1994;**46**(2/3):34
- [44] Shashank PR, Suroshe SS, Singh PK, Chandrashekar K, Nebapure SM, Meshram NM. Report of invasive tomato leaf miner, *Tuta absoluta* (Lepidoptera: Gelechiidae) from northern India. *Indian Journal of Agricultural Sciences*. 2016;**86**(12):1635-1636
- [45] Plant Quarantine India [Internet]. Available from: http://plantquarantineindia.nic.in/PQISPub/docfiles/dip_act.htm
- [46] MHFW. The Gazette of India. Notification.1037, 1-3. 2017. Available from: [http://www.cdscsco.nic.in/writereaddata/GSR327\(E\) Dated 03_04_2017.pdf](http://www.cdscsco.nic.in/writereaddata/GSR327(E) Dated 03_04_2017.pdf)
- [47] DPPQS [Internet]. Available from: <http://ppqs.gov.in/divisions/plant-quarantine/strengthening-modernisation-plant-quarantine-facilities-india>
- [48] Sreedevi K, Meshram N, Shashank PR. Insect Taxonomy- Basics to barcoding. In: Chakravarthy AK, editor. *New Horizons in Insect Science: Towards Sustainable Pest Management*.

India: Springer; 2015:3-12. DOI:
10.1007/978-81-322-2089-3

[49] Station AB-R, Cargo A. Plant Quarantine Including Internal Quarantine Strategies in View of Onslaught of Diseases and Insect Pests. New Delhi, India: NAAS; 2003. p. 1067

[50] David P, Thebault E, Anneville O, Duyck PF, Chapuis E, Loeuille N. Impacts of invasive species on food webs: A review of empirical data. *Advances in Ecological Research*. 2017;**56**:1-60

[51] Kenis M, Hurley BP, Colombari F, Lawson S, Sun J, Wilcken C, et al. Guide to the classical biological control of insect pests in planted and natural forests. *FAO Forestry Papers*. 2019;**182**:1-3

[52] Barratt BI, Moran VC, Bigler F, Van Lenteren JC. The status of biological control and recommendations for improving uptake for the future. *BioControl*. 2018;**63**(1):155-167

[53] Babendreier D. Pros and cons of biological control. In: *Biological Invasions*. Berlin, Heidelberg: Springer; 2008. pp. 403-418

[54] Siddhapara MR, Patel MB, Patel HV. Biology of *Zygogramma bicolorata* Pallister (Coleoptera:Chrysomelidae) and their feeding potential on Parthenium and sunflower. *The Madras Agricultural Journal*. 2012;**99**(10/12):841-844