Chapter 18
Biological Control as a Key Tool for the Management of Invasive Species in Latin America and the Caribbean

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Abstract The attack of pests and diseases represents one of the main limitations for agricultural production in the Neotropical region. The intensification of trade between Latin American countries, the Caribbean, and other regions, among other factors, has resulted in the introduction of a large number of invasive pests in the Neotropical region, affecting crop production and causing large significant losses. Despite efforts to prevent their entry to Latin America and the Caribbean, through the establishment of quarantine systems in the different countries and the implementation of tactics to reinforce phytosanitary surveillance, each year new pests are reported to be introduced in areas where they were not present. This when added to the effects of climate change, represents a challenge for plant protection since it favours the displacement of pests to new areas due to the increase of temperature and changes in the climatic conditions, facilitating the establishment of some introduced species. This chapter presents the use of biological control agents through the implementation of programmes adapted to local conditions as a key strategy for the sustainable management of pests currently present in and potential pests to the region. Initiatives are also presented to strengthen the quarantine system and phytosanitary surveillance in a joint effort with institutions and government agencies of the countries where CABI implements the Plantwise and Action on Invasives programmes, and sustainable production projects with the objective of reinforcing food security in Latin American and the Caribbean countries.

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Introduction

Importance of Preventing the Entry of Invasive Species

Natural environments are continuously submitted to severe transformations, including movement of species beyond the limits of their native geographic ranges into areas in which they do not naturally occur, where they can inflict substantial changes (Gaston 2009). Thus, considering changes inflicted by alien species on the properties of an ecosystem an increasing number of studies that consider the environmental impacts have been published (Blackburn et al. 2014). However, according to Ricciardi et al. (2013) predictive understanding of the ecological impacts of invasive species has developed slowly, owing largely to an apparent lack of clearly defined hypotheses and of a broad theoretical framework. In this regard, confusion about terminology used for the designation of non-indigenous species, which alternatively have been called 'exotic', 'introduced', 'invasive', and 'naturalised', is particularly acute, leading to confusion about ecological concepts (Colautti and MacIsaac 2004).

After an alien species invasion, strategies addressing preservation or restoration of healthy ecosystems should be developed which include an initial survey of native and alien species (and their impacts) to define a base for comparison as the programme progresses (Wittenberg and Cock 2001).

Klapwijk et al. (2016) divided strategies against invasive species into three categories: prevention and interception, early detection and surveillance, and reporting and management.

1. *Prevention and interception*: Both are considered the first and most cost-effective options. According to Wittenberg and Cock (2001), exclusion methods should be based on pathways rather than on individual species since the former will provide the most efficient way to concentrate efforts at sites where pests are most likely to enter and thus intercept several potential invaders linked to a single pathway. Prevention of invasions includes interception based on regulations enforced with inspections and fees, treatment of material suspected to be contaminated with non-indigenous species, and prohibition of particular commodities in accordance with international regulations (Wittenberg and Cock 2001; Klapwijk et al. 2016).
2. *Early detection and surveillance*: During the early stages of invasions the invasive species are generally rare, making it difficult to detect them. Checking at

potential entry points (ports, airports, etc.) and in sensitive areas is mandatory since monitoring would improve the capacity to respond quickly to pest invasions, although it requires extensive resourcing and enforcement from the central authorities (Klapwijk et al. 2016).

3. *Reporting and management:* Eradication and/or prevention of spread of the detected invasive species is a crucial step carried out by the National Plant Protection Organisations (NPPO) based on pest risk analyses. However, this is hampered due to variable inspection protocols across different countries, even being visual inspections, which are less effective, and on the other hand, once biosecurity is breached, responses by each country may also be different, including not reporting or delaying reporting of incursions even of high-risk organisms (Brasier 2008). In fact, official reports of invasive organisms' presence are often made several years after detection, allowing invasive species to spread before eradication measures can be taken (Landeras et al. 2005).

Although eradication is often costly, it could be efficient, mainly when referred to invasive species with low level populations, low reproductive rates, and no dormant life stages (such as vertebrates, especially mammals) (Clout and Veitch 2002). For success to be achieved, eradication programs must meet a set of conditions including proper planning, a commitment to complete, putting the entire population of the target species at risk, removing them faster than they reproduce, and preventing re-invasion, and support from local people is desirable. Table 18.1 shows a description of the invasive species reported in Latin America and the Caribbean region.

Importance of Biological Control for Invasive Species Management

Many of the most important insect and mite pests, nematodes, and plant pathogens as well as the majority of the most invasive weed species are exotic, and these invasive species cause severe damage to agricultural, forest, and urban ecosystems costing billions of dollars annually and threatening the integrity of natural environments and the viability of endangered species (Perrings et al. 2002; Foy and Forney 1985).

Classical biological control constitutes a cost-effective and sustainable management strategy that potentially can mitigate costs and impacts of biological invasions on biodiversity. Classical biological control can be used to manage populations of a wide variety of invasive species (invasive plants, invertebrates, plant pathogens, and some vertebrates) that negatively impact biodiversity and ecosystem services (IUCN 2018).

Literature reports show various examples of successful cases in which biological control has contributed in the control of invasive species. Thus, populations of the rubber vine (*Cryptostegia grandiflora*), an asclepiadaceous species native to South West Madagascar that became invasive in Queensland (Australia) was effectively controlled by the Madagascan rust fungus, *Maravalia cryptostegiae*, which reduced

Table 18.1 List of invasiveinsectspecies in Latin America and the Caribbean region

Species	Comments about the species	Distribution
Acromyrmex octospinosus (Hymenoptera: Formicidae)[a]	Leaf-cutting ants *Acromyrmex octospinosus* are regarded as serious pests of crops. In the wild, they are a threat to many species of native plants that are vulnerable to defoliation.	Guadeloupe
Aedes albopictus (Diptera: Culicidae)[a]	The Asian tiger mosquito is spread via the international tire trade (due to the rainwater retained in the tires when stored outside). The tiger mosquito is associated with the transmission of many human diseases, including the viruses dengue, West Nile, and Japanese encephalitis.	Argentina, Barbados, Bolivia, Brazil, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Guatemala, Honduras, Mexico, Nicaragua, Panamá, Paraguay, Trinidad and Tobago, Venezuela
Anoplolepis gracilipes (Hymenoptera: Formicidae)[a]	*Anoplolepis gracilipes* (so-called because of its frenetic movements) has invaded native ecosystems and caused environmental damage from Hawaii to the Seychelles and Zanzibar. On Christmas Island in the Indian Ocean, it has formed multi-queen supercolonies. It is also decimating the red land crab (*Gecarcoidea natalis*) populations. Crazy ants also prey on, or interfere in, the reproduction of a variety of arthropods, reptiles, birds, and mammals on the forest floor and canopy. Their ability to farm and protect sap-sucking scale insects, which damage the forest canopy on Christmas Island, is one of their more surprising attributes. Although less than 5% of the rainforest on Christmas Island has been invaded so far, scientists are concerned that endangered birds such as the Abbott's booby (Sula abbotti), which nests nowhere else in the world, could eventually be driven to extinction through habitat alteration and direct attack by the ants.	Bolivia, Chile, Mexico, Panama

(continued)

Table 18.1 (continued)

Species	Comments about the species	Distribution
Anthonomus grandis (Coleoptera: Curculionidae)[a]	*Anthonomus grandis* is a brown to greyish-brown beetle native of Mexico to Central America and invasive in the United States. A. grandis feeds and develops only in cotton and closely related tropical (malvaceous) plants. In temperate zones *A. grandis* spends the winter in an adult reproductive dormancy where it subsists without food until it returns to cotton in the early spring. In sub-tropical and tropical areas adults are periodically active during warm periods of the non-cotton production seasons and will feed and reproduce whenever suitable hosts are available. *A. grandis* has caused serious losses to the cotton industry in the United States. Recent eradication programs and management strategies have reduced *A. grandis* populations dramatically and have prompted a rebound in the cotton market within the United States.	Argentina, Brazil, Colombia, Paraguay, Venezuela
Apis mellifera *scutellata* (Hymenoptera: Apidae)[a]	Warwick Kerr brought *Apis mellifera scutellata* from Africa to South America in 1957 to help revive the failing Brazilian beekeeping industry, which was using various European subspecies of *Apis mellifera* L., unsuitable for the South American environment. The queens and workers of several colonies were accidentally released, and these aggressive bees hybridized with local colonies. *A. m. scutellata* has been gradually spreading ever since, causing economic, social, and ecological problems due to the more aggressive behaviour shown by these hybrid bees.	Puerto Rico
Bemisia tabaci (Hemiptera: Aleyrodidae)[a]	This whitefly species has been reported from all continents except Antarctica. Over 900 host plants have been recorded for B. tabaci, and it reportedly transmits 111 virus species. It is believed that *B. tabaci* has spread throughout the world through the transport of plant products that were infested with whiteflies. Once established, *B. tabaci* quickly spreads and through its feeding habits and the transmission of diseases, it causes destruction of different crops around the world. *B. tabaci* is believed to be a species complex, with a number of recognized biotypes and two described extant cryptic species.	Brazil, Costa Rica, Curaçao, Dominican Republic, Jamaica, Mexico, Puerto Rico, Saint Kitts and Nevis, Saint Lucia

(continued)

Table 18.1 (continued)

Species	Comments about the species	Distribution
Ceratitis capitata (Diptera: Tephritidae)[a]	*C. capitate* is considered a major tephritid fruit fly pest of economic importance attacking more than 300 different hosts, primarily temperate and subtropical fruits. The medfly as it is commonly called has invaded many countries and caused major economic losses for fruit farmers. *C. capitate* shows the ability to tolerate cooler climates better than most other species of fruit flies. It lays its eggs under the skin of fruit, usually around already broken skin. Due to this reproduction habit, *C. capitate* thrives in agricultural areas where fruit is left out and becomes damaged. It spreads to new locations via exports and the local sale of fruit that contains eggs.	Argentina, Brazil, Colombia, Ecuador, Guatemala, Honduras, Panama, Nicaragua, Paraguay, Peru, Uruguay, Venezuela
Diaphorina citri (Hemiptera: Psyllidae)[b,c]	*Diaphorina citri* (Hemiptera: Psyllidae) is native to Southeast Asia and is considered one of the more important pests in Citrus and other rutaceous plants. Also, D. citri vectors cause a devastating disease called 'huanglongbing' or citrus greening disease transmitted by the bacterium *Candidatus Liberibacter asiaticus* that reduces fruit yield and quality. *D. citri* has been introduced into other regions, including Latin American and the Caribbean regions.	Antigua and Barbuda, Bahamas, Barbados, Belize, Brazil, Cayman Islands, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Guadeloupe, Haiti, Honduras, Jamaica, Paraguay, Puerto Rico, United States Virgin Islands, Uruguay, Venezuela
Harmonia axyridis (Coleoptera: Coccinellidae)[a]	The harlequin ladybird is native to Asia and has been used extensively around the world for biological control of various aphid species. While it is a popular control agent, it has also brought with it several negative effects. Its establishment appears to decrease the diversity of native Coccinellidae. *Harmonia axyridis* can also quickly become a human nuisance when it seeks shelter during the winter months and takes up residency in the walls and insulation of houses and other structures. Surprisingly, *Harmonia axyridis* has also attained status as a pest of fruit production, particularly in the vineyards of the midwestern United States.	Argentina, Brazil, Venezuela

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Table 18.1 (continued)

Species	Comments about the species	Distribution
Homalodisca vitripennis (Hemiptera: Cicadellidae)[a]	The glassy-winged sharpshooter (GWSS), *Homalodisca vitripennis* (Germar), is a xylem-feeding leafhopper native to southeastern United States and regions of northern Mexico. This insect is an important vector of the xylem-limited bacterium, *Xylella fastidiosa*. This pathogenic microorganism is responsible for many economically important diseases including phony peach disease, numerous leaf scold and scorch diseases, variegated citrus chlorosis, and Pierce's disease of grapes. This insect has been accidently introduced to California, Arizona, and several South Pacific islands where it threatens the grape and citrus industries. They lay their eggs inconspicuously below the epidermis of plant leaves which has allowed them to spread to new locations through the nursery trade at an alarming rate.	Chile, Honduras
Linepithema humile (Hymenoptera: Formicidae)[a]	The Argentine ant invades sub-tropical and temperate regions and is established on six continents. Introduced populations exhibit a different genetic and social makeup that confers a higher level of invasiveness (due to an increase in co-operation between workers in the colony). This allows the formation of fast-growing, high-density colonies, placing huge pressures on native ecosystems. For example, *Linepithema humile* is the greatest threat to the survival of various endemic Hawaiian arthropods and displaces native ant species around the world (some of which may be important seed dispersers or plant pollinators), resulting in a decrease in ant biodiversity and the disruption of native ecosystems.	Chile, Cuba, Peru, Mexico

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Table 18.1 (continued)

Species	Comments about the species	Distribution
Maconellicoccus hirsutus (Hemiptera: Pseudococcidae)[a]	The pink hibiscus mealybug is a polyphagous pest of a wide range of ornamental and agricultural plant species. Native to tropical and subtropical Asia and Africa, M. hirsutus forms colonies covered by a white waxy, elastic ovisac material. Feeding causes plant deformation and lowered aesthetics which can result in heavy economic losses. The overall potential annual cost of control and damages to the U.S. economy from *M. hirsutus* has been estimated to be around US$ 700 million, with the global estimate being around US$ 5 billion. While chemical and physical control methods are generally ineffective, effective biological control of *M. hirsutus* has been achieved in several countries.	Barbados, British Virgin Islands, Cayman Islands, Dominica, Guadeloupe, Grenada, Mexico, Montserrat, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Martin, Trinidad and Tobago, Turks and Caicos Islands, Venezuela
Monomorium floricola (Hymenoptera: Formicidae)[a]	The primarily arboreal flower ant (*Monomorium floricola*) is one of the world's most broadly distributed tramp ants. Most occurrence records of M. floricola are in tropical and sub-tropical regions from latitudes above 30°; populations in latitudes above 35° are found in heated buildings or inside greenhouses. *M. floricola* has been identified as a significant arboreal predator of insect eggs; in Guam it is recognized as one of three most important ant species attacking eggs of native butterflies resulting in their reduced populations.	Antigua and Barbuda, Aruba, Bahamas, Barbados, Bolivia, Brazil, British Virgin Islands, Cayman Islands, Colombia, Costa Rica, Cuba, Curaçao, Dominica, Dominican Republic, Ecuador, Grenada, Guadeloupe, Guatemala, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Nicaragua, Panama, Paraguay, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Martin, Saint Vincent and the Grenadines, Trinidad and Tobago, Venezuela

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Table 18.1 (continued)

Species	Comments about the species	Distribution
Paracoccus marginatus (Hemiptera: Pseudococcidae)[d,e]	This mealybug species is native to Mexico and Central America, and currently it widely distributed in the Caribbean Island, United States, and other regions worldwide. P. marginatus is polyphagous that can damage a large number of tropical and subtropical fruits, vegetables, and ornamental plants and is a potential threat to commercial papaya plantations.	Antigua and Barbuda, Bahamas, Barbados, Belize, British Virgin Island, Cayman Island, Costa Rica, Cuba, Dominican Republic, Grenada, Guadeloupe, Guatemala, Haiti, Martinique, Mexico, Monserrat, Netherlands Antilles, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Martin, U.S. Virgin Island, United States (Florida and Hawaii)
Paratrechina longicornis (Hymenoptera: Formicidae)[a]	The crazy ant is a tramp ant, which, by definition, is an ant that is widely dispersed through commerce and other human-assisted avenues. It is extremely easy to identify by observing its rapid and erratic movements. *Paratrechina longicornis* is highly adaptable to various environments and can be a major pest. It occurs in large numbers in homes or outdoors and is capable of displacing other ants and possibly other invertebrates. *Paratrechina longicornis* forages over long distances away from its nest, making the nest hard to find and the ants difficult to control.	Anguilla, Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Brazil, British Virgin Islands, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, Grenada, Guadeloupe, Guatemala, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Martin, Saint Vincent and the Grenadines, Trinidad and Tobago, Turks and Caicos, Venezuela

(continued)

Table 18.1 (continued)

Species	Comments about the species	Distribution
Pheidole megacephala (Hymenoptera: Formicidae)[a]	*Pheidole megacephala* is one of the world's worst invasive ant species. Believed to be native to southern Africa, it is now found throughout the temperate and tropical zones of the world. It is a serious threat to biodiversity through the displacement of native invertebrate fauna and is a pest of agriculture as it harvests seeds and harbours phytophagous insects that reduce crop productivity. *Pheidole megacephala* is also known to chew on irrigation and telephone cabling as well as electrical wires.	Brazil, Chile, Cuba, Ecuador, Mexico, Puerto Rico
Philornis downsi (Diptera: Muscidae)[a]	Adult flies feed on fruit, but larvae are semi-hematophagous (blood and tissue-feeding) parasites of birds. *P. downsi* larvae were first discovered in finch nests on Santa Cruz Island in 1997, although retrospective examination of insect collections show that the fly was present in the Galapagos Islands as early as 1964. Since then the parasite has spread to 12 of the 13 main Galapagos Islands and its larvae have been found in 64–100% of Darwin's finch nests. The blood sucking larvae cause mortality in up to 76% of nestlings. For this high impact, it is given the highest risk ranking amongst introduced insects and amongst diseases/parasites.	Ecuador
Raoiella indica (Acari: Tenuipalpidae)[f]	R. indica feeds on abaxial surface of arecaceous and musaseous plants showing yellowish on both surfaces of the leaflets. Both eggs and active stages of this mite are dark red in colour with black markings. *R. indica* is considered as an important pest of coconut in the Caribbean region and South America and potentially can cause damage in banana and plantain.	Barbados, Brazil, Colombia, Cuba, Dominica, Dominican Republic, Grenada, Guadeloupe, Guatemala, Haiti, Jamaica, Martinique, Puerto Rico, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, United States Virgin Islands, Venezuela

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Table 18.1 (continued)

Species	Comments about the species	Distribution
Rhynchophorus ferrugineus (Coleoptera: Curculionidae)[a]	The red palm weevil, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Dryophthoridae), is widely distributed in southern Asia and attacks various palm species such as Phoenix sylvestris, Cocos nucifera, and *Metroxylon sago*. Recently it was accidentally introduced into the Caribbean where a monitoring program was established to determine the population level and distribution of infestations on Aruba and Curacao using commercially available pheromone traps.	Aruba, Curaçao, Netherlands Antilles
Schizotetranychus hindustanicus (Acari: Tetranychidae)[g]	The Hindu mite or citrus nest-webbing mite was originally described from citrus from southern India. In the early 2000, it was reported in northwestern Venezuela, Colombia, and Brazil. Feeding symptoms appear on the upper leaf surface along the main rib, later extending to the entire leaf blade; fruits become uniformly silvered and hard under severe infestation levels.	Brazil, Colombia, Venezuela
Scyphophorus acupunctatus (Coleoptera: Dryophthoridae)[a]	This species is becoming a major pest of native Agavaceae and Dracaenaceae species worldwide. Native to Mexico, it has decimated populations of agave crops, particularly those species used in the tequila and henequen industries. The importation of ornamental agave plants worldwide has facilitated *S. acupunctatus*' establishment in many parts of the world, particularly in Central America and the Caribbean, in Africa, Asia, and South America. On its host species, it causes rot and sometimes mortality due to its larvae boring holes which then facilitates the micro-organism entering the host. Due to the species being found generally inside the host species, typical insecticides have proven ineffective. However, research on the species' pheromones has shown that these could be a potential management tool, attracting individual adults away from hosts to collection sites.	British Virgin Islands, Cayman Islands, Costa Rica, Cuba, Dominican Republic, Haiti, Guatemala, Honduras, Jamaica, Nicaragua

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Table 18.1 (continued)

Species	Comments about the species	Distribution
Solenopsis geminate (Hymenoptera: Formicidae)[a]	This ant has spread almost worldwide by human commerce. It usually invades open areas but can easily colonise human infrastructure and agricultural systems, such as coffee and sugarcane plantations in hot climates. Its greatest known threats are its painful sting and the economic losses due to crop damage caused by its tending of honeydew-producing insects. *Solenopsis geminate* is known to reduce populations of native butterfly eggs and larvae. It has the potential to displace native ant populations but is susceptible to competitive pressures from other ant species.	Antigua and Barbuda, Argentina, Bahamas, Barbados, British Virgin Islands, Ecuador, Trinidad and Tobago, Turks and Caicos Islands
Solenopsis invicta (Hymenoptera: Formicidae)[a]	*Solenopsis invicta* is an aggressive generalist forager ant that occurs in high densities and can thus dominate most potential food sources. They breed and spread rapidly and, if disturbed, can relocate quickly so as to ensure survival of the colony. Their stinging ability allows them to subdue prey and repel even larger vertebrate competitors from resources.	Bahamas, British Virgin Islands, Cayman Islands, Paraguay, Puerto Rico, Trinidad and Tobago, Turks and Caicos Islands
Solenopsis richteri (Hymenoptera: Formicidae)[a]	It is commonly known as the black imported fire ant and is native to South America. It builds large mounds that can reach 46 cm in height. *Solenopsis richteri* damages crops, impedes recreational activities, and can undermine roads and asphalt. It is also very dangerous to those who experience anaphylaxis from the venom of its bite. Eradication of *Solenopsis richteri* is not an option. It can be controlled but this is an ongoing process.	Paraguay
Steneotarsonemus spinki (Acari: Tarsonemidae)[h]	*Steneotarsonemus spinki* Smiley is distributed geographically in Asia, the Caribbean region, North, Central, and part of South America, and it is considered the most important rice pest worldwide. Other than rice, more than 70 species of plants have been reported as host including wild rice, Argentine grass, etc.	Costa Rica, Cuba, Haiti, Nicaragua, Panama, Puerto Rico, Colombia, Venezuela

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Table 18.1 (continued)

Species	Comments about the species	Distribution
Tapinoma melanocephalum (Hymenoptera: Formicidae)[a]	It is known as a tramp ant as its spread around the globe has been assisted by human activities. It is highly flexible in the habitats it occupies, providing there is some form of disturbance allowing it to establish ahead of more dominant ant species, and it nests readily outdoors or indoors. *Tapinoma melanocephalum* is a household pest, disturbs greenhouse environments, and can transport pathogenic microbes in hospitals.	Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Brazil, Cayman Islands, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, Guadeloupe, Haiti, Honduras, Jamaica, Martinique, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, Venezuela
Tecia solanivora[i] (Lepidoptera: Gelechiidae)	*Tecia solanivora* is part of the complex of gelechid moths attacking potato (Solanum tuberosum L.). It is native to Central America and is considered in several countries of this area and in the Andean countries (Venezuela, Colombia and Ecuador) as one of the main pests of potato crops.	Costa Rica, Colombia, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Venezuela
Trogoderma granarium (Coleoptera: Dermestidae)[a]	*Trogoderma granarium* is considered a pest of considerable impact to stored foodstuffs. It maintains its presence in food storage in very low numbers and can survive long periods of time in an inactive state.	Mexico, Venezuela
Vespula germanica (Hymenoptera: Vespidae)[a]	It is commonly known as the German or European wasp and is a social wasp species. In introduced regions, where it is often more successful than in its native range, it efficiently exploits important food resources, such as nectar and insects, that native fauna may depend on. *V. germanica* displays many characteristics that make the species a successful invader, and a new colony can be established from a single inseminated female.	Argentina, Chile

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Table 18.1 (continued)

Species	Comments about the species	Distribution
Xylosandrus compactus (Coleoptera: Scolytidae)[a]	Originally from Asia, *Xylosandrus compactus* has spread to various coffee-growing areas throughout the world where it causes damage not only to agricultural crops but also to native forest trees. Beetles (Coleoptera) in the family Scolytidae, to which *Xylosandrus compactus* belongs, are among the most damaging insects worldwide. Because most scolytids breed under bark or inside wood, it has long been recognized that scolytids can easily be moved through international trade.	Brazil, Cuba

[a]ISSG (2009)
[b]Invasive Species Compendium (2020a)
[c]Quereshi et al. (2009)
[d]Mani et al. (2012)
[e]Invasive Species Compendium (2020d)
[f]Invasive Species Compendium (2020b)
[g]Invasive Species Compendium (2020c)
[h]Plantwise Knowledge Bank (2020)
[i]EPPO Global Database (2020)

the weed by up to 90% in some areas, allowing for more cattle production and reducing the costs of weed control, and also, experience gained in Queensland has benefitted other places where the rubber vine had colonized (https://www.cabi.org/projects/our-impact/biocontrol-of-invasive-species/).

Cassava mealybug (*Phenacoccus manihoti* Matile-Ferrero) was accidentally introduced in Africa causing damage to a staple crop that is particularly important in times of drought, leading to famine (Herren and Neuenschwander 1991). In the 1970s the cassava mealybug population erupted and spread rapidly, mainly due to it not having any natural enemies. Surveys carried out in Bolivia and Brazil found a native parasitic wasp which was introduced to Africa and within a decade had reduced the mealybug population by 95%.

Although the Asian citrus psyllid, *Diaphorina citri*, is native to Asia where is considered an important pest in citrus plantations, it is currently known to occur throughout the southern part of the United States, Caribbean islands, Central and South America, but invasion routes remain undetermined (Guidolin et al. 2014). The Asian citrus psyllid is currently the major threat to the citrus industry as it is the vector of *Candidatus Liberibacter*, the causal agent of huanglongbing disease (HLB) or 'greening' that seriously affects large numbers of citrus cultivars in several countries (Tsai et al. 2002). Efforts to control the Asian citrus psyllid have been made. Thus, *Tamarixia radiata* Waterston (Hymenoptera: Eulophidae), a *D. citri* ectoparasitoid native to India, has been released in Réunion Island and Florida (United States) causing a significant reduction in 'greening' severity (Quereshi et al. 2009). Moreover, this parasitoid has been found in Brazil and Puerto Rico where releases have not been documented (Pluke et al. 2008).

The red palm mite, *Raoiella indica* Hirst is a notorious example of invasion. It was introduced in the Caribbean in 2004, in Martinique (Flechtmann and Etienne 2004), and rapidly moved to other islands (Rodrigues et al. 2007). Approximately, 5 years later it reached almost all Caribbean islands, Florida (United States), Mexico, Venezuela, Colombia, and the north of Brazil (Roraima State) (Carrillo et al. 2011; Kane et al. 2012; Návia et al. 2011; Vásquez et al. 2008). This tenuipalpid mite is of Oriental origin and it can cause severe damage to Arecaceae, especially coconut (*Cocos nucifera* L.), but also to Musaceae and other plant families (Flechtmann and Etienne 2004; Flechtmann and Etienne 2005; Etienne and Flechtmann 2006).

After its introduction into the region, some efforts have been made to search for natural enemies controlling the RPM. Thus, some studies searching for effective natural enemies have been carried out, resulting in the phytoseiid *Amblyseius largoensis* (Muma) as the most frequent predator associated with the pest on coconut in Americas (de Moraes et al. 2012; Gondim Jr. et al. 2012; Vásquez and de Moraes 2013).

As part of the efforts searching for native and exotic natural enemies of RPM, Brazilian researchers conducted surveys in Réunion Island and Thailand to identify potential biological control agents for this pest. In a study which compared the biology of a population of *A. largoensis* found in Réunion Island (Indian Ocean) with a population from Roraima State (northern Brazil), it was observed that the oviposition period, prey consumption, and net reproductive rate were significantly higher for the Réunion Island population, suggesting that further investigation could determine whether that population should be released in South America to control the pest (de Moraes et al. 2012; Domingos et al. 2013; Morais et al. 2016). Another population of *A. largoensis* and *Amblyseius cinctus* Corpuz-Raros & Rimando associated with the RPM on coconut palms in Thailand was also introduced in Brazil, and *A. largoensis* was efficient in controlling RPM. (Domingos et al. 2013). On the other hand, Colmenárez et al. (2014) carried out a survey to determine population trends and entomopathogenic fungi associated with the RPM in Trinidad, Antigua, St. Kitts and Nevis, and Dominica reporting 27 fungal isolates of which 15 isolates belonged to the genera *Cladosporium*, three to *Simplicillium* spp., and one to *Penicillium*, showing that *Simplicillium* and *Penicillium* isolates found in association with the RPM populations are of high potential for further use in pest management programs.

The papaya mealybug, *Paracoccus marginatus* Williams & Granara de Willink, is a poly-phagous pest, considered an important invasive species, was introduced in the Caribbean Islands and Florida (United States) in 1994–2002 and since then, it was rapidly reported as being present in different countries in Latin America and the Caribbean (CABI 2019). As part of the biological control, generalist predators such as *Cryptolaemus montrouzieri* Mulsant, lady beetles, lacewings, and hover flies have been reported as attacking the papaya mealybug (Walker et al. 2003). Encyrtid endoparasitoid wasps such as *Acerophagus papayae* (Noyes and Schauff), *Anagyrus loecki* (Noyes and Menezes), *Anagyrus californicus* Compere, and *Pseudaphycus* sp. were also reported as specific parasitoids of *P. marginatus* (Meyerdirk and

Kauffman 2001). From this group, *Acerophagus papayae* Noyes and Schauff has been highlighted as one of the most effective biocontrol agents of *P. marginatus* (Nisha and Kennedy 2016; Colmenárez et al. 2017). In the Caribbean, the introduction of some parasitoid species, such as *A. papayae*, reduced the pest population of *P. marginatus* from 82% to 97% (Meyerdirck and DeChi 2003).

Prediction Models and Climate Change Influence for the Establishment of New Invasive Species

Climate change is altering temperature, precipitation, the frequency of extreme weather events, atmospheric composition (mainly CO_2 concentration) and land cover, which are the key factors affecting species survival and, consequently, inducing stress of ecosystems (Simberloff 2000; Dukes and Mooney 1999). On the other hand, biological invasions are an important factor affecting biodiversity, being associated with nearly 60% of species extinctions (Bellard et al. 2018).

Predictions of the impact of climate change on biodiversity have frequently been based on an 'envelope' modelling approach which combines environmental variables and current distributions of species in order to predict distributions of species under future climate scenarios (Araújo et al. 2006; Thuiller et al. 2005). As invasion processes are a biological process, climate change is also expected to alter it (Bellard et al. 2018). Because climate change has a potential effect on fundamental biological processes, it will interact with other existing stressors influencing the distribution, spread, abundance, and impact of invasive species (Gritti et al. 2006). Although it is difficult to predict the effects of climate change on ecological systems, invasive species are likely to respond in ways that should be qualitatively predictable, and some of these responses will be distinct from those of native counterparts (Hellmann et al. 2008).

Several previous studies have stated that invasive species could be favoured by climate change (Thuiller et al. 2011; Vilà et al. 2007; Dukes and Mooney 1999); however, these studies have provided contradictory evidence, and no consensus has been reached (Bellard et al. 2018). Thus, more discussions about the distinctive consequences of climate change for invasive species are needed that evaluate key hypotheses to develop general theories and adaptive management about invasive species and climate change (Hellmann et al. 2008). In this regard, Harrington et al. (1999) have postulated two approaches for studying the impacts of climate warming on trophic interactions: to examine relationships between long-term or spatially extensive biological datasets and abiotic data, usually meteorological, available over a similar scale and to model interactions on the basis of experimentation that includes novel conditions expected in the future. Based upon the 'invasion pathway', these later authors identified five possible consequences of climate change, some of them being unique to invasive species because of traits and qualities associated with invasion, and in other cases sharing qualitative responses with native species, but the mechanisms or the outcomes are distinct (Hellmann et al. 2008).

During recent decades, the number of new invasive alien species discovered or reported per annum (rates of invasive alien species) for a recipient region has been increasing all over the world (Huang et al. 2011). This fact has been attributed to increasing international trade (Westphal et al. 2008) but rarely linked to climate changes that can directly or indirectly influence the successful establishment of an introduced alien species in new regions (Walther et al. 2002).

Although human activities could promote species movement, their subsequent establishment and dispersion at the new environment is strongly associated with altered site conditions due to climate change (Walther et al. 2002). Using basic research on ecological and physiological processes that are sensitive to climatic variables such as temperature and precipitation, Walther et al. (2002) stated that warmer temperatures at the end of the twentieth century have affected the phenology of organisms, the range and distribution of species, and the composition and dynamics of communities. Bellard et al. (2018) demonstrated the role of climate change as a main factor for the future distribution of invasive alien species, and they found that climate change will more frequently contribute to a decrease in species range size than an increase in the overall area occupied for the plants and vertebrates studied while the ranges of invertebrates and pathogens are more likely to increase following climate change.

Barbet-Massin et al. (2018) assessed the predictive accuracy of species distribution models (SDM) in predicting the expansion of the Asian hornet (*Vespa velutina nigrithorax*), a species native to China that is invading Europe at a very fast rate. These authors compared occurrence data from the last stage of invasion (independent validation points) to the climate suitability distribution predicted from models calibrated with data from the early stage of invasion, and they observed that SDM could adequately predict the spread of *V. v. nigrithorax*, which appears to be partially climatically driven. Based on climate projections from general circulation models and statistical models, Capinha et al. (2013) evaluated future distributions for the threatened European crayfish fauna in response to climate change, watershed boundaries, and the spread of invasive crayfish, which transmit the crayfish plague, a lethal disease for native European crayfish. They observed that the number of suitable areas decreased for native crayfish; meanwhile the overlap with invasive crayfish plague-transmitting species was predicted to increase.

In regard to impacts of climate change on natural enemies of pest species, Thomson et al. (2010) summarized the following effects:

(a) Alteration of the fitness of natural enemies in response to changes in host/prey quality and size induced by temperature and CO_2 effects on plants
(b) Decrease of the susceptibility of herbivores to predation or parasitism by altering life cycles of herbivores in response to plant phenological changes

(c) Decrease of the effectiveness of natural enemies to exert biocontrol if pest is introduced into regions outside the range of distribution of their natural enemies although a new community of enemies might then provide some level of control
(d) Alteration of the abundance and activity of natural enemies through adaptive management strategies adopted by farmers to cope with climate change, since these strategies may lead to a mismatch between pests and enemies in space and time, decreasing their effectiveness for biocontrol

As the global climate change will provoke the potential breakdown of current biological control agents and consequently promote pest outbreaks, suitable approaches are needed to improve biological control (Thurman et al. 2017). According to van Lenteren (2012), increases of future pest damage could be counteracted by augmentative releases to maintain high densities of biological control agents even in sub-optimal conditions. However, biological control agents performing well under specific environmental conditions will probably perform less efficiently when these conditions vary and thus we would expect that biological control agents suited for future climate scenarios will differ from those relied upon today (Thurman et al. 2017; Collier and van Steenwyk 2004). Consequently, efforts should be increased to identify biological control agents better adapted to the novel environmental conditions and be able to optimize control for pests under future climate scenarios (Thurman et al. 2017).

Because of the diverse and often indirect effects of climate change on natural enemies, predictions will be difficult unless there is a good understanding of the way environmental effects impact on tri-trophic interactions (Thomson et al. 2010). Probably parasitoids are significantly more affected by climate-induced perturbations, which will be modulated by direct effects on the organisms involved (effects on physiology and metabolism). The responses of those organisms and subsequent tri-trophic interactions and understanding what these effects might be is of critical importance (Furlong and Zalucki 2017).

Biological Control as a Key Tool for the Management of Invasive Species in Latin America and the Caribbean

Latin America and the Caribbean are the regions with the greatest biological diversity on the planet, and they host several of the world's megadiverse countries such as Brazil, Colombia, Ecuador, Mexico, Peru, and Venezuela (UNEP 2010; UNEP-WCMC 2016). South America harbours about 40% of the Earth's biodiversity, mainly in the Amazon rainforest which is the world's most biodiverse habitat (UNEP 2010, 2012), and high levels of endemism are observed in the region as 50% of the plant life of the Caribbean is unique, and this biodiversity also represents a source of abundant genetic resources for Latin America and the Caribbean region (UNEP 2010).

On the other hand, since LAC exhibits good climatic conditions it always has maintained a strong comparative advantage in agricultural production; thus LAC exported about 16% of global food and agriculture between 2012 and 2014. However intensive international trade increases the likelihood of pest species being introduced to this region, and thus challenges to crop production is higher insomuch as population is increasing rapidly (Fig. 18.1). The need to contribute to end hunger, achieve food security, and improve nutrition are key steps to sustainable development (UN 2019).

Impact of the Action on Invasive and Plantwise Programmes

Problems with invasive weeds, insects, plant diseases, and animals are increasing rapidly worldwide, consequently resulting in economic, social, and environmental impacts threatening the economic growth mainly of the world's most vulnerable people. In consequence, several international organizations, including CABI, are developing and implementing solutions for invasive species around the world based upon primary research to support global actions on the Action on Invasive Programme, helping to protect livelihoods and the environment.

In this regard, CABI's global Action on Invasive Programme is focused on an environmentally sustainable, regional, and cross-sectoral approach to managing

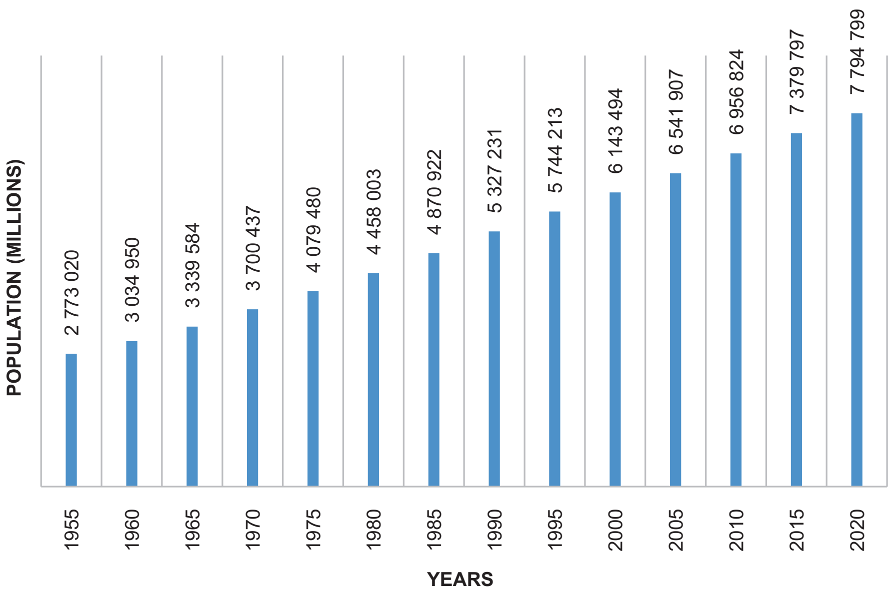

Fig. 18.1 World population increase. Figure developed by authors using World Population Prospects 2019 (UN 2019)

invasive species, which is based on a systems-based approach to managing biological invasions across sectors in three stages:

(a) Prevention: developing and implementing biosecurity policies to prevent the arrival and spread of invasive species and raising awareness of potential threats at a local level
(b) Early detection and rapid response: building capacity to develop and implement surveillance and emergency action plans for detecting and eradicating new invasions
(c) Control: scaling up existing invasive species management solutions, embedding control options in policy, and making sure that those living in rural communities have access to best practice and locally adapted solutions and are actively engaged in their implementation

CABI's global Action on Invasive Programme operates concomitantly with the Plantwise programme, which aims to help farmers to reduce their crop losses, working closely with national agricultural advisory services and establishing a global plant clinic network, where trained plant doctors are able to advise farmers to find practical solutions to crop management. Plant clinics work just like clinics for human health: farmers visit with samples of their crops, and plant doctors diagnose the problem and make science-based recommendations on ways to manage it. The Plantwise programme has been endorsed by member countries in 2011 as they recognized that CABI is well placed due to its network of centres in Africa (Kenya, Ghana), Asia (China, India, Malaysia, Pakistan), Europe (Switzerland, UK), and the Americas (Barbados, Bolivia, Brazil, Costa Rica, Grenada, Jamaica, Trinidad & Tobago, and Peru). Currently Plantwise has established a sustainable network of over 3700 plant clinics in 34 countries around the world (www.plantwise.org).

According to Colmenárez et al. (2019), the Plantwise approach is based on three inter-linked components:

1. An ever-growing network of locally run plant clinics, where farmers can find advice to manage and prevent crop problems. Trained agricultural advisory staff learn methods to identify any problem on any crop brought to the clinics, with the support of a national and international network of diagnostic laboratories, and provide appropriate recommendations guided by national and international best practice standards.
2. Improved information flows between everyone whose work supports farmers (e.g. extension, research, input suppliers, and regulators). Collaboration within national plant health systems enables these actors to be more effective in their work to improve plant health with concrete benefits for farmers.
3. The Plantwise knowledge bank, a database with online and offline resources for pest diagnostic and advisory services, provides both locally relevant, comprehensive plant health information for everyone and a platform for collaboration and information sharing between plant health stakeholders.

The plant clinic network is reinforced by the Plantwise Knowledge Bank, a gateway to practical online and offline plant health information, including diagnostic resources, best-practice pest management advice, and plant clinic data analysis for targeted crop protection. Together, these two unique resources are part of the Plantwise approach to strengthen national plant health systems. The stronger the national plant health system, the better equipped the country will be to help farmers provide a safe and sustainable food supply and improve their livelihoods.

The problem of invasive species is not a recent issue, but climate change, trade, and tourism are all exacerbating the situation and increasing the need for effective responses at local, national, and regional levels. Thus, it is imperative that the sustainable development goals (SDGs) include a goal to 'introduce measures to prevent the introduction and significantly reduce the impact of invasive species on land and water ecosystems and control or eradicate the priority species'.

Action on Invasives is designed to enable countries and regions to adopt this approach through four interrelated work packages:

(a) Stakeholder engagement: fostering the right partnerships
(b) Providing best practice solutions for invasive species
(c) Community action: bringing information and action to scale
(d) Knowledge and data: creating and using knowledge

While the aim of Action on Invasives is to strengthen overall capacity to tackle invasive species, many of the activities focus on priority species as case studies. The first focus species are fall armyworm (*Spodoptera frugiperda*) (FAW), *Tuta absoluta*, and parthenium weed (*Parthenium hysterophorus*). Similarly, part of the national capacity involves regional and international collaboration; so Action on Invasives is working through selected countries as foci from which activities can be regionalized. The first countries for implementation are Ghana, Kenya, Pakistan, and Zambia.

As described by Colmenárez et al. (2016), the Plantwise theory of change refers to the following linkages that need to be strengthened (Fig. 18.2).

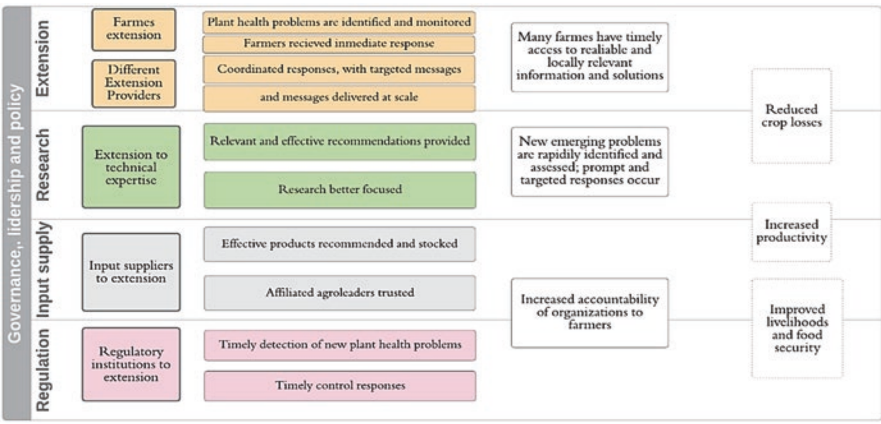

Fig. 18.2 Plantwise theory of change. (From Colmenárez et al. 2016)

Linkage between farmers and extension services in plant clinics: extension staff trained to diagnose plant disease or pest problems (plant doctor) place plant clinics so that farmers can bring any crop problem to the clinic.

Link different extension providers through clinics and the Knowledge Bank: regular meetings are made between plant doctors and plant clinic implementing organizations in order to share information on plant health problems and then this information is used in extension activities at different levels (local, district, or national).

Linkage between extension staff and technical expertise: there are networks of diagnostic laboratories associated with plant clinics for support in case of unknown problems. In these networks, researchers diagnose any new and emerging diseases and share their knowledge and expertise with plant doctors and then farmers. The Knowledge Bank supports extension staff with information about pests and plant health problems and records those encountered by farmers in their region.

Link extension and input suppliers: Plant clinics aim to work with trusted agro-input dealers to ensure that the products recommended by plant doctors are locally available and to promote codes of practice to help ensure ethical trading.

Extension staff should interact with government institutions: in cases where new pests are difficult to be identified at plant clinics or at outbreaks of the pest, government institutions (Ministry of Agriculture, NPPOs, etc.) are immediately informed in order to improve national pest lists as well as enabling early alerts to be issued and rapid response measures. The Plantwise Knowledge Bank provides a mechanism to capture data and enables those working in the national plant health and regulatory bodies to analyse the data as part of any pest risk analysis. The Knowledge Bank will allow countries to manage data in ways that will help them spot local problems before they flare up and become acute problems at the national level.

Some Case Studies of the Participation of CABI on the Management of Invasive Species Globally

Fall armyworm (*Spodoptera frugiperda*), a major maize pest in the Americas, has been found in Africa and Asia, and it has spread rapidly and is considered a serious invasive insect pest (FAO 2017). In the absence of any control method, the fall armyworm (FAW) has the potential to cause maize yield losses ranging from 8.3 to 20.6 million tons/year in just 12 maize-producing African countries, which can represent economic losses estimated at US$2.48–6.19 billion (Day et al. 2017). As part of integrated pest management practices, biological control plays an important role (FAO 2017; Day et al. 2017). FAO highlighted the importance of disseminating the management practices of FAW in order to ensure a proper management of the pest at field level. In this process, the CABI Plant Health Clinics, established as part of the Plantwise programme, have been considered as an important mechanism for facilitating dissemination of the FAW management options to a wider number of smallholder farmers (FAO 2017).

Since its creation in 2009, Plantwise has expanded in several countries to the stage where it has directly reached about 1,900,000 farmers as well as indirectly through farmer-to-farmer exchange and other spill-over effects. The plant clinics are the entry point, where farmers bring to the plant doctors the queries about the problems they have with their crops. More and more plant clinic data are being stored in the knowledge bank and used as the basis for decision-making by plant health stakeholders and to provide critical information such as pest distribution maps, an example of online diagnostic tool and crop management support (CABI 2017). Plant clinic data is also being used in different ways, including the selection of research topics, determination of real problems at the field level, pest

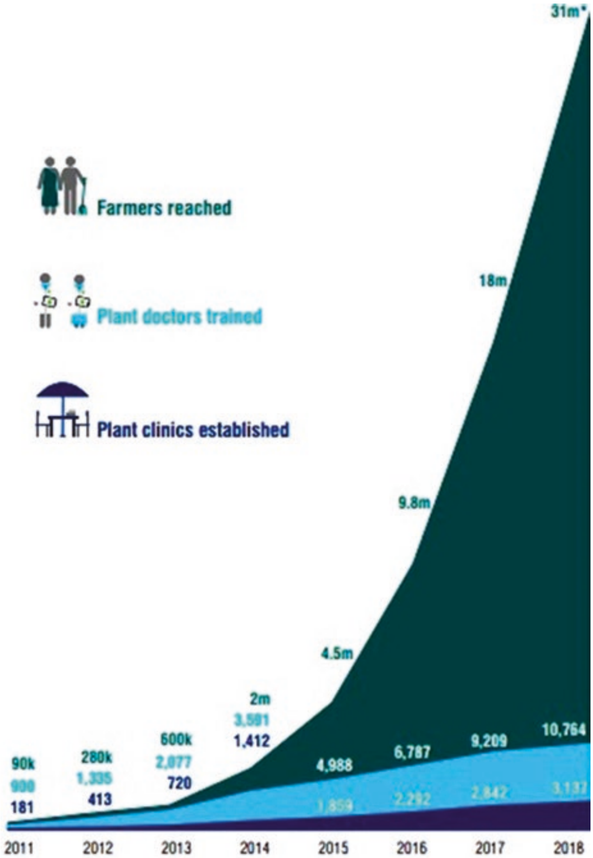

Fig. 18.3 Plantwise impact and progress (Plantwise 2018). Determined through estimations of primary reach (farmers reached directly through Plantwise activities) and secondary reach (farmers reached indirectly, e.g. as a result of plant doctors operating outside of Plantwise and farmers receiving advice from peers who visited plant clinics). Diagram not to scale

surveillance, reviewing the invasive species management practices, and distribution in the country. Thus, Plantwise will continue scaling up and reached 31 million female and male farmers in 2018 through the implementation of the Plantwise approach in a total of 34 countries (Fig. 18.3).

The FAW management strategies in Africa are focussed on identifying sustainable management practices to control the pest. Some advice and recommendations are directly available from the Americas, where both maize and FAW are native (FAO 2017). The FAO's broad framework for collaboration called South-South cooperation has also been highlighted as an important mechanism to transfer sustainable technology from the Americas to Africa for the control of FAW. As part of the dissemination process, the fall armyworm problem is frequently raised at Plantwise plant clinics, and brochures have been developed to provide information on the current extent of the fall armyworm invasion in Africa, known prevention, detection and control measures, short-term and long-term impacts of fall armyworm in Africa, and the invasion's potential impact on trade. The approaches include carrying out farmer perception surveys of fall armyworm impacts on maize, modelling the environmental suitability of Africa for fall armyworm, and carrying out national and continental economic analyses. Plant clinics provide the opportunity for developing smallholder capacity for managing the FAW in a sustainable manner (FAO 2017). Success of the Plantwise Program has primary relied on the support from farmers, governments, advisory services, NGOs, other plant health stakeholders and program donors (CABI 2018). The increasing number of partnerships has led to significant success for the program and consequently for low income farmers in countries where the program is being executed. CABI will maintain its close engagement with national and local partners in order to ensure a shared vision and commitment towards reaching sustainability of the Plantwise approach.

The establishment of a national plant clinics network conducted by trained extension officers as plant doctors allows the access of sustainable methods of control such as biological control by farmers. During the plant clinic sessions, famers can understand the technology of application of the biocontrol agents recommended, ensuring the adoption and the correct use of the bioproducts (Colmenárez et al. 2019).

In addition, other moth species, including *Tuta absoluta* have invaded several African countries causing economic impact on crops. However, pest resistance has developed due to heavy pesticide use to manage moth populations, thus supporting the need to find alternative biological based approaches that are economical and safer for farmers and consumers as well as for the environment (Mansour et al. 2018). Plant clinics have been an important tool in management of *T. absoluta* since PMDGs have been developed for Ethiopia, Kenya, Malawi, Tanzania, Uganda, and Zambia by providing recommendations that should contribute to strategies and/or criteria for controlling this pest, including use of pesticides Class II, III, and U (Rwomushana et al. 2019).

Sustainable management of invasive organisms must be based on an ecological approach and making biological solutions available to farmers, requiring regulators and input providers work together. The FAW action plan in Ghana was focused on four key elements: collaboration, awareness, surveillance, and research, and a management process that identified challenges such as the engagement of input dealers on recommended insecticides, the engagement of the media through training and press briefings/releases, improving two-way communication between national and local stakeholders, and identifying and harmonizing the activities of new collaborators. In Kenya, the programme has facilitated introduction of products based on a naturally occurring virus to control FAW and to produce a pheromone to disrupt FAW mating. Also, discussions have also been held with Koppert Biological Systems on facilitating access to biological control agents for *T. absoluta* (CABI 2017, 2018).

Parthenium hysterophorus: *Parthenium*weed is invasive in many countries around the world, including South Asia, where an eco-climatic model suggests that many uninvaded areas are a good climatic match for this noxious weed (McConnachie et al. 2010). The weed causes several problems including disruption of the ecology of grasslands and invades woodlands through aggressive competition and allelopathy. By inhibiting the growth of other plants, it poses serious health hazards to livestock and can cause severe allergenic reactions in people, and it has been reported to reduce crop yields from 40% to 97%. In terms of pasture production, this noxious weed has been found to reduce livestock carrying capacities by as much as 90% (McConnachie et al. 2010). On the other hand, in 2018, Action on Invasives supported the development of national action plans for *Parthenium* in Pakistan by focussing on two biological control lines: improving the efficacy of the beetle *Zygogramma bicolorata* (already present in Pakistan) and releasing more than 1000 individuals at two sites to increase its overall range in Pakistan, as well as importing *Listronotus setosipennis* from South Africa, although testing and training are also in progress. In fact, a course on invasion biology and classical biological control of weeds was held in Pakistan in order to reinforce weed biocontrol knowledge, particularly on *Parthenium* (CABI 2018).

Final Considerations

Biological control has been proven to be an efficient and sustainable method of control. Within integrated pest management programmes, biocontrol can suppress populations of currently present and introduced pests.

The commercialization and distribution of natural enemies is a determining factor for the use of biological control agents at the field level. However, it is important that farmers have access to a proper advisory service; in this way, the establishment of a network of plant clinics, organizing practical sessions to clarify questions and visualizing the recommended sustainable practices, is critical. It is important to involve farmers in the discussions about the recommended practices, including the technology of application for biocontrol agents to ensure a high adoption level and the correct use at the field level; in addition, they can help in the process of early detection of new introduced species, reinforcing the surveillance system in the country.

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