# The uptake of biological control in Latin America and the Caribbean.

Biological control in Latin America and the Caribbean: its rich history and bright future

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# 32 The Uptake of Biological Control in Latin America and the Caribbean

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**Abstract**

Biological control started to be used in the 1880s in Latin America and the Caribbean and has since developed into a widely applied pest management method. Currently almost 32 million hectares are under classical, more than 31 million hectares under augmentative and hundreds of thousands of hectares under conservation biocontrol. Achievements in this region have been impressive and are documented in this chapter. Several factors frustrate the implementation of biocontrol on an even larger area. The most important are the dominance of the pesticide industry, the negative effect of pesticides on biological and natural pest control, governmental 'subsidies' to keep chemical control cheap, the lack of funding for research and implementation of biocontrol, and an expensive, time-consuming regulatory framework. However, inherent positive characteristics of biocontrol contribute to sustainable pest management, a healthier and biodiverse environment, pesticide-free food and improved yields. These characteristics, together with the large-scale natural enemy prospecting programmes, the documentation of the many cases of natural control and the successful regional collaboration on area-wide control of new invasive pests, point at a bright future for biocontrol in Latin America and the Caribbean.

## 32.1 Introduction

Since its first use in 1884, biological control with arthropod natural enemies and microbial control agents has seen a strong increase in the number of species of biocontrol agents used and areas treated in Latin America and the Caribbean. Until 1970, mainly classical biocontrol was used, though in some countries augmentative biocontrol was employed as well; later, conservation biocontrol was applied and natural control was documented. Most first uses of biocontrol involved the release of invertebrate natural enemies, usually insect predators or parasitoids, but microbial agents and vertebrates were also used. Another characteristic of this early period in the Latin American region is that biocontrol was mainly aimed at insect control, with control of weeds and diseases of plants developing later.

Van Lenteren and Bueno (2003) concluded from data in the few published reviews concerning biocontrol in South and Central America and the Caribbean that in the period from 1880 to 1970, 16 countries used classical biocontrol. Well known examples of early classical biocontrol for South America are the introduction of *Rodolia cardinalis* (Mulsant) for control of cottony cushion scale *Icerya purchasi* Maskell, the release of a species of *Encarsia* for control of the

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white peach scale *Pseudaulacaspis pentagona* (Targ-Tozz) and the introduction of *Aphelinus mali* (Hald.) for control of woolly apple aphid *Eriosoma lanigerum* (Hausmann), which have usually led to substantial or complete control in a number of countries. Examples of successful classical biocontrol for Central America and the Caribbean during this period are the complete biocontrol of the citrus blackfly *Aleurocanthus woglumi* Ashby as a result of inoculative releases with the parasitoid *Eretmocerus serius* Silv. and/or *Amitus hesperidium* Silv. in Cuba, Costa Rica, Mexico and Panama; and the use of tachinid and hymenopteran parasitoids to control sugarcane borers on different Caribbean islands. Only four countries applied augmentative biocontrol before the 1970s and areas under biocontrol were seldom provided. Augmentative biocontrol concerned inundative releases with egg parasitoids of the genera *Trichogramma* and *Telenomus* to control pests in sugarcane.

Based on data in papers published since 1970, and after obtaining information by contacting researchers in the region, van Lenteren and Bueno (2003) stated that by the year 2000, 16 countries still used classical biocontrol. Due to lack of quantitative data, a reliable estimate of the total area under classical biocontrol could not be made. The number of countries using augmentative biocontrol in this period had increased to 17, with a total estimated area under augmentative biocontrol about 4,350,000 ha (see Table 1.1 in Chapter 1).

Information provided in the country-specific chapters of this book shows that nowadays all forms of biocontrol and all types of biocontrol agents are applied in Latin America and the Caribbean (Table 32.1). The estimates for the number of countries with classical, augmentative and conservation biocontrol will be reliable. However, the number of countries with natural control (19) is underestimated, as many countries have not yet tried to document which potential pests are kept below densities causing damage. The area under augmentative biocontrol has strongly increased since 2000 and now exceeds 31 million hectares. The first estimate for classical biocontrol for Latin America and the Caribbean shows an area of more than 30 million hectares being protected.

In this chapter the achievements in biocontrol in Latin America and the Caribbean will be summarized. Next, the use of classical biocontrol in this region will be illustrated with data obtained from the BIOCAT databank (Cock *et al.*, 2016). Then, factors limiting and stimulating biocontrol in the region will be presented and, finally, the future of biocontrol in the region is sketched based on remarks made in the country chapters.

## 32.2 Achievements

The major biocontrol activities during different periods for each of the Latin American and Caribbean countries are summarized in Table 32.2.

Table 32.2 provides information about similarities and differences in biocontrol approaches in various countries. The similarities concern the import and release of many of the same natural enemies in classical biocontrol projects during the early period of biocontrol in the region. Often, these natural enemies had been used successfully in Asia, Europe and North America and were introduced without additional research in Latin America and the Caribbean. Currently, area-wide biocontrol programmes aim at releasing the same natural enemies of several recently introduced invasive pests. These programmes are based on more

**Table 32.1.** Use of different forms of biological control and area under biocontrol in Latin America and the Caribbean.

| | No. of countries using biocontrol / area (ha) under biocontrol | | | |
|---|---|---|---|---|
| Period | Classical | Augmentative | Conservation | Natural |
| 1895–1969 | 16 / ? | 4 / ? | | |
| 1970–1999 | 16 / ? | 17 / 4,350,000 | | |
| 2000–2018 | 29 / 30,747,889 | 27 / 31,381,131 | 13 / 447,114 | 19 / 2,001,846 |

**Table 32.2.** Summary of achievements in biocontrol during three periods, with future plans and factors limiting and stimulating biocontrol for each Latin American and Caribbean country.

| Period 1800–1969 | Period 1970–1999 | 2000–now | Future | Factors limiting and *stimulating* biocontrol |
|---|---|---|---|---|
| ***Argentina***: Many CBC introductions; few ABC projects; provider of natural enemies, particularly for weed BC, with as major success of control of prickly pear in Australia | Many CBC introductions; few ABC projects, few successes; start of weed BC research; important provider of weed BC agents | Continuation of CBC of arthropods in agriculture, forestry, and of weeds; increase in ABC activities; initiation of work on ConsBC; important provider of weed BC agents | Anticipated increase of all forms of BC in all areas of agriculture, forestry and of weed BC<br>***Specific for Argentina: use of weed CBC and provider of weed BC agents*** | Dominance of CC<br>Limited collaboration BC research and application; limited development of practical BC; limited funding for BC<br>*Good BC expertise available* |
| ***Barbados***: Many CBC introductions, successes in sugarcane and citrus; few ABC projects, success in cotton; provider of many BC agents to other islands in the region | Several new CBC projects, e.g. of pests in vegetables; few ABC projects | CBC in sugarcane and vegetables; new CBC successes in palm plantations, citrus orchards, and of pink hibiscus mealybug on various plants; ABC cotton; many NC successes | Anticipated increase in BC activities due to new invasive pests<br>***Specific for Barbados: documentation of NC, large scale use of CBC*** | Many new invasive species<br>*Need for biocontrol of new invasive pests* |
| ***Belize***: Several CBC attempts without success; documentation NC in sugarcane | Several CBC attempts without success | Successes with CBC of Asian citrus psyllid and pink hibiscus mealybug | Continuation CBC pink hibiscus mealybug and Asian citrus psyllid; initiation of ABC with microbials of pests in sugarcane<br>***Specific for Belize: use of CBC*** | *Presence of international institute OIRSA* |
| ***Bolivia***: Several unsuccessful CBC attempts; important CBC success with *Rodolia cardinalis;* ABC of sugarcane borers | Several attempts with CBC and ABC; successes with ABC in sugarcane, citrus, potato storage, coffee; documentation of NC in several crops | Successes with several large ABC and CBC projects in citrus, coffee, potato, sugarcane, quinoa, and soybean; documentation of NC in several crops | Anticipated increase in production and use of local microbial agents; documentation and use of NC<br>***Specific for Bolivia: ABC with local microbials, documentation of NC*** | Dominance of CC<br>Lack of funding for BC, lack of collaboration among BC experts, lack of education in BC and lack in transfer of knowledge<br>*Recent positive results in BC projects* |

**Table 32.2.** Continued.

| Period 1800–1969 | Period 1970–1999 | 2000–now | Future | Factors limiting and *stimulating* biocontrol |
|---|---|---|---|---|
| ***Brazil***: Unsuccessful attempts of CBC of white peach scale, coffee berry borer, woolly apple aphid, Mediterranean fruit fly and oriental fruit moth; successful CBC of Rhodes grass scale; ABC of sugarcane borer with native natural enemies; early use of microbials for pest and disease control | Successful CBC of wheat aphids, cassava mealybug, citrus leaf miner, and Sirex woodwasp; ABC with natural enemies of citrus mealybugs, flies in poultry pens, fruit flies in vars fruit crops, lepidopterans in eucalyptus, and Sirex woodwasp in pine; ABC with microbials of spittle-bugs, soybean caterpillar, mate tree borer, and soil-borne diseases; large scale local production of arthropod and microbial ABCs | CBC and ABC with natural enemies of pests in eucalyptus and pine. ABC with natural enemies of lepidopteran pests in sugarcane, soybean, cotton, corn, beans, millet and tomatoes, of stink bugs in soybean, of spider mites, fungus gnats and thrips in cotton, soybean, fruit orchards, ornamentals and vegetables, cotton bollworm, Asian citrus psyllid, aphids, thrips, lepidopterans and spider mites in greenhouse crops, various scales in various crops. ABC with microbials of pests in coffee, eucalyptus, pine, of mate tree borer, Asian citrus psyllid, soil nematodes in soybean, corn and coffee, rubber lace bug, cotton bollworm, fall army worm in corn, soil-borne diseases in many crops; prospecting for weed BC agents | Anticipated development of new ABC projects with natural enemies and microbials; strong growth of ABC industry; development of more efficient BC agent production, quality control, shipment, release and monitoring methods; progress in technology transfer from research to application, improved collaboration and networking; development of ConsBC<br>***Specific for Brazil: early and current large scale use of ABC with natural enemies and microbials for pest and diseases; large scale local production of BC agents, many BC research projects*** | Dominance of CC industry<br>Poor transfer of BC technology to farmer<br>Poor quality of non-registered BC products and with insufficient farmer guidance<br>*Rich biodiversity as source for BC agents*<br>*Good expertise in BC, many researchers*<br>*Large production units for BC agents, strong private industry*<br>*International market demands for food with low pesticide residue levels*<br>*Improved BC agent registration procedures* |
| ***Chile***: Many successful early CBC projects, e.g. control of olive black scale, scales in citrus, avocado and other fruit, woolly apple aphid; use of ABC with microbials to control coleopterans and lepidopterans in various crops; weed BC; provider of BC agents | Successful CBC of wheat aphids, of the eucalyptus psyllid, and of weeds in various crops; CBC and ABC of pine shoot moth; ABC of diseases in fruit; prospecting for and commercialization of microbial agents and nematodes for ABC of coleopterans in various crops, and of pine shoot moth | CBC of walnut aphids, codling moth and woolly apple aphid in apple, wood wasps and eucalyptus weevil in forestry; attempts to use microbials for ABC of lepidopterans and coleopterans in various crops and forestry; ABC of *T. absoluta* with predator, of diseases in various crops and forestry; development of technology transfer models; prospecting for and evaluation of microbial agents | Continue prospecting for microbials for pest and disease control; improved formulations of BC agents of diseases; improved monitoring and release of natural enemies; improved BC training of agricultural technicians<br>***Specific for Chile: many early CBC projects, ABC with local microbials of pests and diseases, large scale prospecting for and production of microbials*** | Insufficient quality control of BC products<br>Access and Benefit Sharing regulations<br>*Improved formulations for microbials*<br>*Presence of BioControl Technological Center*<br>*National and international pesticide regulations*<br>*Expertise in research and application of BC*<br>*Organic production for international market* |

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| ***Colombia***: Successful CBC of woolly apple aphid and cottony cushion scale; use of microbials to control locusts | ABC of pests in cassava, cotton, maize, sorghum, soybean, sugarcane and tomato, in forestry, and in greenhouse vegetables and ornamentals; CBC and ABC of coffee berry borer in coffee; use of microbials for ABC of pests and diseases; prospecting, evaluation and production of microbials | Documentation of NC in cassava; FBC and CBC of Columbian fluted scale; ConsBC in sugarcane, chilli pepper, oil palm, coffee and ornamentals; ABC of pests in cassava, citrus (e.g. Asian citrus psyllid), coffee (coffee berry borer), cotton, maize, oil palm, greenhouse vegetables and ornamentals, potato, sorghum, sugarcane, rice, and forestry, of flies in livestock production and vectors of human diseases; prospecting, evaluation and production of microbials | Anticipated production and use of entomopathogenic nematodes for root borer control, improved formulation technology for *Trichoderma,* development of quality control of BC agents.<br>***Specific for Colombia: ABC projects, many BC activities in greenhouse ornamentals; prospecting for and production of microbials; use of ConsBC*** | Dominance of CC industry<br>Complicated national legislation for import of exotic BCs<br>Access and Benefit Sharing regulations<br>Poor quality of unregistered BC products<br>*Expertise in research and application of BC*<br>*Good infrastructure and several centres for BC research*<br>*Local production of BC agents*<br>*Compulsory use of some forms of BC* |
| ***Costa Rica***: Successful CBC in citrus, coffee and sugarcane | ABC in avocado, pineapple and cotton; ABC and CBC in sugarcane; CBC, ABC and NC in citrus; ConsBC in palm plantations and in ornamental crops; NC of pests in banana, coffee, cashew, and timber; prospecting for and development of mass production of natural enemies and microbial agents | Start of CBC of Asian citrus psyllid, ConsBC and ABC in palm plantations; CBC with ABC, NC and ConsBC in citrus, coffee and sugarcane; NC and ABC in banana; prospecting for natural enemies and microbial agents | Anticipated improved and increased local production and use of microbials; improved quality control methods for BC agents<br>***Specific for Costa Rica: ABC with local microbials, large scale prospecting, documentation of NC, use of ConsBC*** | Aggressiveness of CC<br>Poor quality of local BC products<br>*Use of organic agriculture*<br>*Export demands for agricultural products*<br>*Establishment of national programme for BC* |

*Continued*

**Table 32.2.** Continued.

| Period 1800–1969 | Period 1970–1999 | 2000–now | Future | Factors limiting and *stimulating* biocontrol |
|---|---|---|---|---|
| ***Cuba***: Successful CBC of citrus blackfly with parasitoid; ABC of sugarcane borer with native parasitoid | ABC of many pests and several diseases in many crops with predators, parasitoids and microbial agents; ConsBC of sweet potato weevil with predatory ants; creation of hundreds of centres for mass production of entomophagous species; prospecting for microbial control agents | ABC with *Trichogramma* spp. of various lepidopterans in several crops; study and large scale use of ConsBC; local production of parasitoids, predators, entomo-pathogenic nematodes and fungi, nematopathogenic fungi and bacteria, and phytopathogenic fungi; strong governmental support for BC | Continued support for development of new control agents, for better formulations of microbial control agents, and for more efficient production to replace imported products. Increase use of ConsBC<br>***Specific for Cuba: ConsBC, many local centres for mass production of BC agents.*** | *Awareness among farmers and community of contribution of BC to economy, ecology, environment and society*<br>*Strong governmental support for BC*<br>*Many local centers for production of BC agents*<br>*Appreciation / broad use of BC by farmers* |
| ***Dominica***: Several unsuccessful CBC projects in citrus, banana, coffee, vegetables; successful CBC of sugarcane borers | Successful CBC of citrus blackfly; unsuccessful ABC of diamondback moths and armyworms in various crops | Continuation of successful CBC programmes in citrus and sugarcane | | |
| ***Dominican Republic***: CBC with coccinellids, e.g. *Cryptolaemus* and *Rodolia*, for control of cottony cushion scale; introduction of mongoose for rat control and toads for pests in sugarcane; documentation of fungal pathogens of weeds | ABC of sugarcane pests, of whitefly in vegetables, of coffee berry borer and of rice stalk stink bug; CBC, ABC and NC of citrus pests, CBC of vector transmitting snails; testing and use of microbials; testing of weed BC; prospecting for and mass rearing of natural enemies | CBC of papaya mealybug, pink hibiscus mealybug, *Anastrepha* fruit flies, and pigeon pea pod fly; NC of diamondback moth, red palm mite and other mites, many pests of oriental vegetables, and of exotic pests in *Ficus* and *Cycas;* NC and ConsBC of pests in organic fruit and coffee; ABC with microbials | Anticipated increased funding for BC by the Ministry of Agriculture; increased field testing of BC within IPM projects<br>***Specific for the Dominican Republic: prospecting, demonstration of NC*** | Lack of resources for BC research and application, lack of expertise in BC<br>Dominance of CC<br>*Export demands for products without pesticides*<br>*Organic production, GAP labels* |

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| ***Ecuador***: CBC of woolly apple aphid in apple, *Icerya* sp., purple scale, and citrus blackfly in citrus, and of sugarcane borer in sugarcane | CBC of cottony cushion scale and citrus leaf miner in citrus, of white rice borer in rice, of coffee berry borer in coffee, of white mango scale in mango; ABC of leafhoppers in sugarcane, of soil-borne pests in vegetables, of lepidopteran pests in maize, soybean, sugarcane, banana and cotton; prospecting for natural enemies of whiteflies, and of *Tuta absoluta* | CBC of citrus leaf miner, fruit flies in tropical fruit and scales in mango. CBC of cottony cushion scale on the Galapagos islands; ABC of pests in banana, of soil-borne pests and diseases in broccoli, pod rot disease in cacao, diseases and pests in oil palm, rice, pineapple, in ornamentals and vegetables in greenhouses, of diseases in papaya, and of pests in sugarcane; prospecting for BC agents, including entomopathogenic fungi and nematodes; improvement of formulations of microbial control agents | Continued governmental support for local training and production of BC agents<br>Regulation for and registration of BC agents<br>Increase of CBC of invasive weeds and insects, and of ABC of agricultural pests on the Galapagos islands<br>***Specific for Ecuador: many CBC and ABC projects, disease BC in many crops; BC of invasive species in natural ecosystems; prospecting for BC agents*** | *Governmental infrastructure BC research, training and extension, prospecting for BC agents, and collection of BC agents*<br>*Governmental, private national and international producers of BC agents*<br>*Demand for pesticide-residue free food by farmers, consumers and the international market* |
| ***El Salvador*** | NC in fruit trees and coconut palm; CBC and FBC in citrus; NC and CBC in cotton, corn and bean; ABC of lepidopterans and mosquitos; prospecting for nematophagous fungi | Microbial control of soil diseases, and of lepidopterans, coleopterans and nematodes in several crops; control of mosquitos with tilapia fish | ***Specific for El Salvador: demonstration of NC in several crops*** | |
| ***French Guiana, Guadeloupe and Martinique***: Successful CBC of sugarcane borers | Successful CBC of sugarcane borers, pink hibiscus mealybug, Asian citrus psyllid, and citrus blackfly; first attempts at CBC of fruit flies | Successful CBC of sugarcane borers, pink hibiscus mealybug, Asian citrus psyllid, and citrus blackfly; ABC in vegetable crops; prospecting for and use of natural enemies in ConsBC in various crops | Anticipated studies on new exotic species for CBC of mango mealybug, and for improved ABC of the Asian citrus psyllid<br>***Specific for French territories: prospecting and use of ConsBC*** | |

*Continued*

**Table 32.2.** Continued.

| Period 1800–1969 | Period 1970–1999 | 2000–now | Future | Factors limiting and *stimulating* biocontrol |
|---|---|---|---|---|
| ***Guatemala*** | ABC of lepidopterans in cotton, corn and vegetables, of coffee berry borer and nematodes in coffee; CBC of citrus blackfly | NC and ABC in coffee; CBC of fruit flies; ABC in cotton; ABC of vector of malaria with microbials; testing of microbials against spittle bugs in pastures | Anticipated start with CBC of Asian citrus psyllid<br>***Specific for Guatemala: IPM including NC and ABC of coffee pests*** | Few BC experts, limited funding, expensive registration of BC agents<br>*Export demands for agricultural products*<br>*Health risks of pesticides for workers and consumers*<br>*Positive experiences with BC* |
| ***Guyana***: Successful CBC of sugarcane borer, and ConsBC of lepidopteran in rice; prospecting for natural enemies of various pests | Successful ABC of lepidopteran in palm, and CBC of hibiscus mealybug | CBC in sugarcane; CBC attempts for control of fruit fly; ABC in palm; ABC attempts for control of red palm mite; ConsBC of rice pests | Continued studies for ABC of red palm mite<br>***Specific for Guyana: prospecting and ConsBC*** | |
| ***Haiti***: Partial successful CBC of sugarcane borer, successful CBC citrus blackfly | Attempts for CBC of coffee berry borer | Successful CBC of pink hibiscus mealybug; prospecting for natural enemies | Continued studies of CBC of fluted scale in peanuts and other crops | Lack of finances for CC |
| ***Honduras***: Prospecting for BC agents | CBC of weed; CBC attempts for control of lepidopterans in various crops; ABC of lepidopterans, whiteflies; microbial control of lepidopterans; ConsBC in various crops; creation of teaching and research Center for Biological Control in Central America; large scale prospecting | ABC with microbials in various crops; mass production of natural enemies (including nematodes) for ABC in vegetables, sweet potato, coffee berry borer, plantain; training of many BSc students; development and production of microbial control agents for disease and pest control | Continued positive attitude towards BC, and training and production facilities<br>***Specific for Honduras: prospecting, teaching and research in BC, development and production of microbial agents for disease and pest control*** | *Positive attitude towards BC*<br>*Good training facilities*<br>*Good local production facilities for BC agents* |

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|---|---|---|---|---|
| ***Jamaica***: CBC of rats, citrus black fly, banana weevil, cocoa thrips, various other pests and weeds; NC and CBC of sugarcane and coconut pests; provider of BC agents | CBC attempts for control of fruit flies; NC and CBC of sugarcane borer, of lepidopterans in cruciferous crops and of pine mites; ABC of sweet potato weevil; NC of whiteflies and coffee leaf miner, NC and ABC of citrus root weevils and of coffee berry borer; prospecting | NC and CBC of brown citrus aphid, NC of false Colorado beetle in gully bean, ensign scale in various crops, of lime swallow tail, of red palm mite; CBC of pink hibiscus mealybug; NC and ABC of citrus root weevil; NC and FBC of papaya mealybug; ABC and FBC of Asian citrus psyllid; ABC of coffee berry borer, sweet potato weevil, and beet armyworm | Anticipated reduction in use of high risk pesticides necessitates construction of new BC facility; development of ConsBC; new invasive pest are targets for BC<br>***Specific for Jamaica: early and recent CBC successes, documentation many NC cases, prospecting*** | Agriculture still highly dependent on pesticides<br>Increased registration of lower risk class pesticides, including biopesticides.<br>*Available expertise, infrastructure and funding for BC research and application*<br>*New invasive pest offer possibilities for BC* |
| ***Mexico***: Many successful early CBC projects in alfalfa, apple, banana, bean, citrus, cotton, mango, sugarcane; ABC in pastures and sugarcane; construction of mass production centres for natural enemies in the 1960s | CBC in citrus, coffee, corn, cotton, fruit, forest, potatoes, and of water hyacinth; ABC of pests in coffee, cotton, cruciferous crops, fruit, forest, sorghum, sugarcane, vegetables and ornamentals; construction of 20 regional centres for mass rearing of natural enemies and entomopathogenic fungi; 65 private insectaries | BC of many hemipteran pests. CBC in citrus, corn, cotton, eucalyptus, mango, strawberry and of weeds in water; ABC in citrus, corn, cotton, cruciferous crops, fruit, grape, ornamentals vegetables (field and greenhouses), sorghum, soybean, and sugarcane, weeds in wetlands, and grasshoppers; mass production of 40 species of BC agent in 65 laboratories | Development of risk scenarios for more than 1200, pests; development of BC for new pests and diseases, e.g. laurel ambrosia beetle, *Drosophila suzukii;* increase in use of BC; promotion of use of eco-friendly products<br>***Specific for Mexico: many ABC and CBC successes, good infrastructure for research and application of BC, risk scenarios for new pests, pro-active development of BC*** | *Good governmental infrastructure and support for research, production and application of BC*<br>*Risk scenarios for new pests and diseases, development of BC for new pests and diseases*<br>*Specific pesticide residue requirements for export markets* |
| ***Nicaragua*****:** ABC of pests in cotton; prospecting | IPM in cotton; BC studies of pests in cotton and citrus; studies of microbials for control of mosquitos; mass production of *Chrysoperla* and *Trichogramma*, and microbial agents; ABC attempts to control diamondback moth | ABC of whiteflies, aphids and pests in sugarcane; CBC of Asian citrus psyllid; construction of biofactories for mass production of *Trichogramma* and native *Orius* spp.; prospecting | Anticipated production of entomopathogens<br>***Specific for Nicaragua: prospecting, local mass production of BC agents*** | Dominance of CC<br>Poor selling and logistic mechanism for BC agents<br>*Local production of BC agents* |

*Continued*

**Table 32.2.** Continued.

| Period 1800–1969 | Period 1970–1999 | 2000–now | Future | Factors limiting and *stimulating* biocontrol |
|---|---|---|---|---|
| ***Panama***: CBC of citrus blackfly | ABC of sugarcane borer and diamond back moth; prospecting | CBC of coffee berry borer, ConsBC of thrips in cucurbits and lepidopterans in rice; prospecting, production and application of microbial control agents and natural enemies | Anticipated development of artificial media to economize mass rearing of natural enemies<br>***Specific for Panama: prospecting*** | |
| ***Paraguay*** | ABC of soybean caterpillar with baculovirus, and sugarcane borer with parasitoids | ConsBC in several crops; ABC with locally produced microbials in various crops for pest and disease control; large scale prospecting for predators, parasitoids and microbial control agents | ***Specific for Paraguay: large scale prospecting, local mass production of microbial control agents*** | Dominance of cheap CC<br>Limited governmental support for BC<br>*Production of organic food*<br>*Pesticide resistance against important pests*<br>*Appreciation of pesticide free food* |
| ***Peru***: CBC woolly apple aphid in apple, cottony white scale in cotton, hemispheric scale and olive blackfly in olive, cottony cushion scale, purple scale, Florida red scale and aphids in citrus; ABC of cotton aphid and tobacco budworm in cotton, and sugarcane borer in sugarcane; NC of pests in several crops; creation of centre for introduction and rearing of useful insects | CBC of West Indian red scale, citrus woolly whitefly, and citrus leaf miner in citrus, alfalfa green aphid in alfalfa, blue psyllid in eucalyptus; ABC of sugarcane borers in sugarcane, fruit flies in fruit, pink bollworm in cotton, and house flies; development of BC of diseases; increased role of governmental centre for research and application of BC; creation of private BC agent production laboratories; governmental financial support to reduce negative impacts of CC | Many ABC projects for control of pests in cotton, sugarcane, asparagus, avocado, olive, pomegranate, forest, coffee, cacao, vine, vegetables, and quinoa; continued strong role of governmental centre for research, mass production and application of BC; production of many predators, parasitoids, entomopathogenic and antagonistic agents in network of regional laboratories; large collection of microbial agents; agro-exporting companies with high demand for BC; demonstration that BC is considerably cheaper than CC and prevents secondary pests | Increase in certification of pesticide free food; governmental agreements with association of citrus farmers to use BC, with association of asparagus farmers and large private exporting companies to use IPM, including BC; development of ConsBC<br>***Specific for Peru: strong governmental support and infrastructure for BC; many CBC and ABC projects; certification of food produced under BC*** | *Early and continuous governmental infrastructure for research and mass rearing of BC agents*<br>*Private production labs supported by governmental center for BC*<br>*Governmental financial support to reduce impacts of CC*<br>*Large agro-exporting companies with high demand for BC*<br>*Demonstration that BC is cheaper than CC and prevents secondary pests*<br>*Certification of pesticide free products* |

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| ***Puerto Rico***: NC and CBC of several pests in sugarcane; CBC in citrus and coffee | CBC of water weeds; NC, FBC and CBC of several pests in citrus, sugarcane, of melon worms in cucurbits, of pink hibiscus mealybug and papaya mealybug; ConsBC of pests in coffee | FBC of Asian citrus psyllid; development of CBC of Harrisia cactus mealybug; NC, ABC and ConsBC of coffee berry borer | Anticipated increase in BC use due to growth of organic and environmentally-friendly agriculture; development of more ConsBC<br>***Specific for Puerto Rico: CBC successes, documentation of NC, ConsBC*** | *Good infrastructure for BC research*<br>*Organic and environmentally-friendly agriculture stimulate research in BC* |
| ***Remaining Caribbean Islands*:** Many unsuccessful CBC releases; CBC successes of pests in arrowroot, citrus, coconut, cotton, sugarcane, and prickly pear and puncture vine weeds; ConsBC of cotton leafworm in cotton, of white grub larvae in sugarcane, and arrowroot leaf roller in arrowroot; ABC of sugarcane borers in sugarcane; demonstration of NC of West Indian cane fly in sugarcane | CBC of cottony cushion scale and citrus blackfly in citrus, and of coconut mealybug and coconut scale in coconuts; reduction in CBC attempts since 1980 | Successful region wide CBC programmes for control of the pink hibiscus mealybug and the papaya mealybug; demonstration of NC of the coconut whitefly and the passion vine mealybug; use of FAO Code of Conduct for the Import and Release of Exotic Biological Control Agents; implementation of Farmers Field Schools to enable farmers to use IPM and become less dependent on CC | Continuation of Farmer Field Schools; increased role of implementation of region-wide BC programmes<br>***Specific for the Remaining Caribbean islands: many early CBC projects, recent region-wide collaboration resulting in CBC successes*** | Many small islands with small and diverse crop areas<br>Many new invasive pests<br>Limited extension service<br>Domination of CC industry<br>*Presence of several region-wide organizations assisting in development of BC*<br>*Implementation of Farmer Field Schools* |
| ***Suriname***: Prospecting and identification of natural enemies responsible for NC of several pests | Attempts of ABC with nematodes; demonstration of NC of coconut pests, green cassava mite and *Pomacea* snails; prospecting | CBC of pink hibiscus mealybug; research on BC of Carambola fruit fly; prospecting | Continued prospecting and efforts to control Carambola fruit fly. ***Specific for Suriname: prospecting, documentation of NC*** | |

*Continued*

**Table 32.2.** Continued.

| Period 1800–1969 | Period 1970–1999 | 2000–now | Future | Factors limiting and *stimulating* biocontrol |
|---|---|---|---|---|
| ***Trinidad and Tobago***: CBC of various pests, ConsBC with birds and insects for control of sugarcane pests, ABC with predator and microbial to control sugarcane froghopper; important provider of BC agents in the region | Successful ABC and CBC of sugarcane pests; unsuccessful CBC of cabbage pests; important provider of BC agents for the region | Successful CBC of citrus blackfly and pink hibiscus mealybug | Increase of accidental import of exotic pests creates need for BC<br>***Specific for Trinidad and Tobago: good BC research infrastructure, important provider of BC agents in the region*** | *Consumer appreciation for food with low pesticide residues*<br>*Good BC research infrastructure*<br>*BC appreciated by farmers* |
| ***Uruguay***: Successful CBC of white peach scale, cottony cushion scale, woolly apple aphid, San Jose scale, eucalyptus weevil; unsuccessful ABC with entomopatho-gens; prospecting for native natural enemies; provider of natural enemies for the region | ABC of lepidopterans in sugarcane, vine and cotton with *Trichogramma*, of pine wood wasp with nematodes, of the sunflower caterpillar and the soybean caterpillar with viruses; prospecting for native BC agents including microbials | CBC in eucalyptus and pine; CBC attempts in citrus; ABC in vegetables and soybean. Start of centre for forest research, including BC; research of ABC with parasitoids and microbials of stinkbugs; development of ConsBC in soybean and sorghum | Start of mandatory registration for BC agents; creation of centre for collection and storage of microbials; increase in ABC of diseases<br>***Specific for Uruguay: many early and current CBC successes in fruit orchards and forestry, prospecting*** | Farmers adhere to low price CC<br>Insufficient BC agents available<br>*Well established research and application network for BC*<br>*Consumer concern about CC*<br>*Demands for residue-free food for export* |

| | | | | |
|---|---|---|---|---|
| ***Venezuela***: Several CBC attempts in various crops; successful ABC of sugarcane borer; mass production of *Lydella* | Successful CBC of citrus blackfly; ABC of sugarcane borers with parasitoids and nematodes; improved mass production of *Lydella*, *Trichogramma* mass rearing for ABC of lepidopteran pests, and *Metarhizium* for froghopper control; development of IPM for many crops, including mass rearing of natural enemies for ABC by private company | CBC in citrus; continuation of ABC research of sugarcane pests; establishment of network of 19 regional laboratories producing BC agents and promoting agro-ecological production methods resulting in application of ABC in many crops; prospecting and study of BC potential of BC agents including antagonists for disease control | New laws promoting sustainable agriculture<br>***Specific for Venezuela: many ABC projects; research on* Trichogramma*; prospecting; testing and use of disease antagonists; network of BC laboratories*** | Lack of transfer of knowledge from research to application<br>Shortage of chemical pesticides<br>*Laws promoting sustainable agriculture*<br>*Network of BC laboratories* |

Abbreviations: ABC = augmentative biocontrol, BC = biocontrol, CBC = classical biocontrol, CC= chemical control, ConsBC = conservation biocontrol, FBC = fortuitous biocontrol, NC = natural control extensive local research and involve pre-release risk evaluations, as well post-release assessment of the effect of introductions.

### 32.2.1 Examples of early use of the same natural enemies in many countries in the region

From 1900, a number of natural enemies were introduced into Latin America and the Caribbean and resulted in permanent, classical biocontrol of important pests. Notable examples are as follows.

- Importation from various sources of the parasitoids *Aphytis diaspidis* (How), *Aphytis fuscipennis* (How), *Encarsia* (= *Prospaltella*) *berlesei* How, *Aspidiotiphagus citrinus* (Crwf), *Arrhenophagus chionaspidis* Auriv. and the predator *Scymnus* sp. into Peru in 1904 for control of the cotton white scale *Pinnaspis strachani* Ferris and Rao. Later, these natural enemies were used in several other countries for control of similar pests in various crops.
- The predator *Cryptolaemus montrouzieri* Mulsant was imported into Puerto Rico from the USA in 1912 to control mealybugs in sugarcane. This predator was later introduced from the USA or from a regional country into many other Caribbean and Latin American countries for control of various pests in various crops.
- Introduction of *E. berlesei* from Italy into Uruguay in 1913 for control of white peach scale *P. pentagona*. The parasitoid was then sent from Uruguay to other Latin American countries.
- The predator *R. cardinalis*, native from Australia, imported into Uruguay in 1919 from France for control of cottony cushion scale *I. purchasi*. The predator was then introduced into other Latin American countries and the Caribbean, but later obtained from other sources as well.
- Importation of the parasitoid *A. mali* from the USA into Uruguay in 1921 for control of woolly apple aphid *E. lanigerum* and later introduced from Uruguay into other countries in Latin America.
- Introduction of the predator *Chilocorus bivulnerus* (Mulsant) from the USA into Uruguay in 1924 for control of San José scale *Comstockaspis perniciosus* (Comstock). The predator was later introduced from Uruguay into other countries in Latin America, but was on other occasions introduced from the USA as well.
- The parasitoids *E. serius*, *Encarsia opulenta* (Silv.), *A. hesperidum* and *Encarsia perplexa* Huang and Polaszek were imported from India into Cuba in 1930 for control of citrus blackfly *A. woglumi*. One or more of these species were then exported in 1930 to Costa Rica, Haiti and Jamaica and in 1931 to the Bahamas and Panama. Later, one or more of these species of parasitoids were introduced into other countries in the region.
- The predator *Cryptolaemus montrouzieri* and the parasitoid *Leptomastidea abnormis* (Girault) were introduced in 1931 into Chile from the USA for control of *Planococcus citri* (Risso).
- Importation of the parasitoid *Metaphycus helvolus* (Compere) in 1931 into Chile from the USA to control olive black scale *Saissetia oleae* (Olivier). The parasitoid was introduced into several other Latin American countries for control of olive black scale or other scale species.
- Introduction of the pyralid herbivore *Cactoblastis cactorum* (Berg) originating from Argentina into Nevis in 1957 for control of *Opuntia* spp. cacti, then released in Antigua, the Cayman Islands and Montserrat. It later spread naturally to other islands in the Caribbean, including the Bahamas.
- A special case is that of the biocontrol of sugarcane borers, *Diatraea* spp. Initially several tachinid parasitoids native to Latin America and the Caribbean were found (*Lixophaga diatraeae* (Tns.) and *Lydella minense* Tns.). Natural control of sugarcane borers by *L. diatraeae* parasitoids was documented as early as 1930 in Jamaica and later in Cuba. Also in Puerto Rico the important role of natural control of borers by native natural enemies was demonstrated, in this case by three native parasitoids *Trichogramma minutum* Riley, *Tetrastichus haitiensis* Gahan and *L. diatraeae*. *L. minense* was originally found in the Amazon area of Brazil and introduced into Guyana in 1932, where it reduced sugarcane borer

populations. The tachinid parasitoid species were redistributed over the region, often resulting in establishment and reduction in borer numbers. Later, in the 1950s, mass rearing and augmentative releases of native tachinids were initiated in Cuba, a practice followed by other countries in the region. In this period, extensive trials were made with inundative releases of native *Trichogramma* spp., e.g. in Barbados and Guyana. Since 1950, a number of exotic stem borer parasitoids have been imported from Africa and Asia by CABI into Trinidad and Tobago, and one of these, *Cotesia flavipes* (Cam.) originating from Asia, has been particularly successful in borer control. This parasitoid has been distributed to most countries in the region that face sugarcane borer problems and is currently released augmentatively on millions of hectares of sugarcane (see e.g. Chapter 6: Brazil).

### 32.2.2 Recent examples of use of the same natural enemies in the region

In the Caribbean and Central America, several area-wide biocontrol projects have recently been realized or are in the implementation phase. The natural enemies used in these projects are also used in a number of Central and South American countries. Examples of these projects are as follows.

- Introduction of the parasitoid *Anagyrus kamali* Moursi from China and the predators *C. montrouzieri* and *Scymnus coccivora* Aiyyar from India for control of the pink hibiscus mealybug *Maconellicoccus hirsutus* (Green). This mealybug, native to Asia, was accidentally introduced into Grenada in 1994, then into Trinidad and Tobago in 1995, and next into other locations in the Caribbean and South, Central and North America. Parasitoids and predators were shipped from Trinidad and Tobago to many countries in the region. Classical biocontrol of the pink hibiscus mealybug is considered one of the highlights of recent biocontrol.
- Importation and release of the parasitoids *Anagyrus loecki* Noyes and Menezes, *Acerophagous papaya* Noyes and Schauff and *Pseudleptomastrix mexicana* Noyes and Schauff for control of papaya mealybug *Paracoccus marginatus* Williams and Granara de Willink. This pest originates from Mexico and was first detected in the Caribbean in 1993. Natural enemies are reared at the USDA APHIS parasitoid-rearing facility in Puerto Rico (see Chapter 26: Puerto Rico), among other locations, and have been introduced with success into many countries in the region.
- Introduction of *Tamarixia radiata* Waterston, native to Asia, for control of the Asian citrus psyllid, *Diaphorina citri* Kuwayama. This pest is native to southern Asia and is a vector of the currently most serious citrus disease worldwide, referred to as citrus greening or huanglongbing. The parasitoid has been imported into and is mass reared in many countries in the region and has successfully reduced citrus psyllid populations.
- Natural control of the red palm mite *Raoiella indica* Hirst. This pest is native to Asia; it was accidentally introduced into the Caribbean in 2004 and now also occurs in South America. Barbados, the Dominican Republic and Jamaica, among others, have documented the role of native organisms (a predatory mite, coccinellid and neuropteran predators and acaropathogenic fungi) in reduction of this pest (see country-specific chapters).

### 32.2.3 Differences in use of biocontrol in the region

Although there are many similarities in biocontrol programmes applied throughout the region, there are also a number of interesting differences, which are summarized below and become obvious when looking at Table 32.2.

#### *Classical biological control*

In the early period of biocontrol up to 1970, many countries in the region imported natural enemies that had been shown to be successful in other areas of the world. Some countries have been relatively inactive in classical biocontrol, e.g. Cuba, Dominica, French territories and Suriname. From 1970 to 1999, import of natural enemies for classical biocontrol strongly decreased in many countries, with the exception of Argentina, Mexico, Peru, the Caribbean and Venezuela (see Section 32.3 for details). Currently, classical biocontrol is documented as being used in all countries in the region, with the exception of Paraguay.

### *Augmentative biological control*

Only a few countries were involved in augmentative biocontrol in the early period. Brazil, Chile, Colombia, Cuba, Mexico and Peru played a major role during this time and were using arthropod natural enemies as well as microbial control agents. Many countries started with a few augmentative biocontrol projects during the period 1970–1999. The countries that applied a lot of augmentative biocontrol in the early period continued to do so, with Ecuador as a new country with many new projects. The spectrum of biocontrol agents used showed an impressive growth in diversity. Also, the area on which augmentative biocontrol of pests, and in particular control of diseases, was applied strongly increased. Many countries started to mass produce biocontrol agents. Currently, augmentative biocontrol is used in most countries in the region, but is limited in others (e.g. El Salvador, Paraguay and Suriname) and not used in Belize and a number of Caribbean islands. Local mass production of biocontrol agents for pest and disease control occurs in many countries.

### *Conservation biological control*

Large differences exist among countries in the use of conservation biocontrol. Early application of conservation biocontrol by promoting the presence of beneficial birds, lizards and arthropods took place in Guyana and on a number of Caribbean islands (see country-specific chapters). During the period 1970–1999, particularly Cuba developed important conservation biocontrol projects, and also Costa Rica, Honduras and Puerto Rico started to use this form of biocontrol in several crops. Currently, Colombia, the Dominican Republic, French islands, Panama, Paraguay and Uruguay also use conservation biocontrol, in addition to the countries that started with this type of biocontrol in previous periods. Still, quite a large number of countries in the region do not study or apply conservation biocontrol.

### *Natural control*

Early documentation of natural control of pests in sugarcane was reported by Belize, Jamaica, Puerto Rico and the Remaining Caribbean islands, and for several other pests in various crops in Peru and Suriname (see country-specific chapters). In the period 1970–1999, the following additional countries documented cases of natural control for a number of pests in different crops: Bolivia, Costa Rica, El Salvador. Recently, several other Caribbean islands and Colombia documented natural control.

### *Biological control of weeds*

Many aquatic and terrestrial weeds that are at present found throughout the world originated in the Neotropical region. Also, a number of the most successful examples of biological weed control involve species that originated in this region, but only a few countries have been playing a role in weed biocontrol research. In Latin America, Argentina has been an important provider of weed biocontrol agents since 1899, when a phytophagous coleopteran was sent to the USA for control of snake weed, followed by many other agents for control of weeds all over the world (see Chapter 2: Argentina). In the Caribbean, Trinidad and Tobago have been an important source of weed biocontrol agents (see Chapter 29: Trinidad and Tobago; and Cock, 1985). Today, biocontrol of weeds in the region is applied in only Argentina, Chile, Honduras, Mexico and Puerto Rico, but it is studied in Brazil, Ecuador (Galapagos) and Suriname, among others.

### *Biological control of pests in forests*

Relatively few countries use biocontrol in forestry. Uruguay is a pioneer country in forest pest biocontrol and currently also Argentina, Brazil, Chile, Colombia, Mexico and Peru apply biocontrol agents to control pests in forests.

### *Biological control in natural areas*

Only the chapters for Chile and Ecuador mention projects about biocontrol in natural areas.

In Chile (Chapter 7), two weed species have been brought under classical biocontrol in nature: phytophagous *Chrysolina hyperici* (Foster) beetles have been released for control of St John's wort *Hypericum perforatum* L.; and the phytopathogen *Phragmidium violaceum* (Schulz) Winter was applied for control of the weedy shrub *Rubus ulmifolius* (Schott.). On the Galapagos islands in Ecuador (Chapter 13), the invasive cottony cushion scale *I. purchasi*, which was seriously affecting threatened endemic plant species, was successfully controlled by the predator *R. cardinalis*. The success of this programme resulted in ideas for biocontrol of other invasive plant and insect species in the Galapagos islands.

### 32.2.4 Developments of particular interest in Latin America and the Caribbean

#### *Early and continued large-scale prospecting for natural enemies, pathogens and antagonists for pest, disease and weed control*

Prospecting for biocontrol agents started before 1900 and the first biocontrol agent was exported from the region in 1899 (see Chapter 2: Argentina). After identification of many arthropod natural enemies, a large number of microbial agents were isolated. The many prospecting projects resulted in: (i) documentation of natural control; (ii) development of conservation biocontrol; (iii) identification of biocontrol agents that could be used in augmentative and classical biocontrol within and outside the region; and (iv) local large-scale mass production of arthropod natural enemies, pathogens and antagonists.

#### *Early and continued documentation of natural control and use of conservation biocontrol*

In Section 32.2.3, the use of natural and conservation biocontrol was summarized. Compared with other world regions, the documentation and use of these two activities started early and is used in a growing number of countries in this region. Some interesting early examples, with more information in the country-specific chapters, are as follows.

- Use of the native parasitoid *Scelio famelicus* Riley for control of the migratory locust *Schistocerca paranensis* (Burmeister) in Venezuela in 1884.
- Demonstration of natural control of the sugarcane borer *Diatraea saccharalis* Fabricius by *Apanteles* sp. and *Euplectrus* sp. in Puerto Rico in 1895; realization of the importance of birds, lizards and other reptiles to reduce pests.
- Demonstration of the role of predacious birds for control of the giant moth borer *Telchin licus* (Drury) (= *Castnia licoides* (Boisduval)) in sugarcane in Trinidad in the early 1900s. Construction of bird roosts and planting of bamboo clumps to encourage birds close to sugarcane fields. Use of plants as nectar sources for attracting arthropod natural enemies and the construction of predatory wasp shelters close to crops.
- Use of the native Jack Spaniard wasp *Polistes cinctus cinctus* Lepeletier, predator of the cotton leaf worm *Alabama argillacea* (Hb.) and other pests in St Vincent since 1910, and later on other Caribbean islands. Populations of the wasp have been encouraged in the Caribbean by the construction of shelters near the cotton fields under which they can nest.
- Demonstration of effectiveness of insectivorous birds in reduction of *Spodoptera frugiperda* Smith populations in rice nurseries in Guyana in the 1910s, in particular when erecting perches in the fields for birds to sit on.
- Demonstration of epizootics in populations of the grasshopper *Schistocerca americana* (Drury) caused by the native entomopathogenic bacterium *Coccobacillus acridiorum* D'Herelle in Mexico in 1911. Shortly after this observation, the bacterium was used in Argentina and Colombia to cause epizootics in grasshopper and locust populations.

#### *Provider of biological control agents*

Like some other countries worldwide, many countries in this region have provided biocontrol agents to other countries in the region, or to other world regions. Trinidad and Tobago imported many species for arthropod control and distributed these imported species and native species across the Caribbean, as well as providing them to several South and Central American countries (see Chapter 29: Trinidad and Tobago). For a long time Argentina has been playing a very important role as provider of weed biocontrol agents to other world regions (see Chapter 2: Argentina), while Trinidad and Tobago have also provided several weed biocontrol agents to other countries.

### *Governmental support and guidance for development of IPM and biocontrol*

In most countries in the region, governmental support for the development of IPM and biocontrol is limited. There are some countries in the region that are showing an active approach in sustainable pest management by strategies to reduce chemical control and replace it with IPM and biocontrol programmes. Examples are Bolivia, Cuba, Jamaica and Peru.

### *Proactive approach with regard to control of potential invading organisms*

Often, pest control activities are planned only after a new pest has entered a country. This then usually results in attempts to eradicate the pest, which generally involves frequent chemical pesticide applications that rarely have the intended effect of eradication. Mexico has taken the initiative to compile risk scenarios for more than 1,200 potential pests, of which more than 1,000 are not yet present in the country. For some of these species, biocontrol programmes are being designed. Jamaica is following a similar approach.

### *Impressive areas under classical biological control*

Worldwide, information about areas of pests, diseases and weeds under classical biocontrol is scattered and incomplete. The same holds for several countries treated in this book, though this information could be obtained for a number of countries and the most impressive cases, i.e. those with areas of more than 100,000 ha under biocontrol, are:

- millions of hectares of weeds in pastures, crops and nature (Argentina, Chile);
- millions of hectares with papaya mealybug and pink hibiscus mealy bug in ornamentals and various other crops and plantings (Jamaica, Mexico);
- millions of hectares of pests in cassava (Brazil);
- hundreds of thousands to millions of hectares of insect pests in pine and eucalyptus forests (Argentina, Brazil, Chile, Uruguay);
- hundreds of thousands of hectares of insect pests of citrus (Argentina, Brazil, Mexico, Peru);
- hundreds of thousands of hectares of spittlebugs in pastures (Mexico);
- hundreds of thousands to a million of hectares of wheat aphids in wheat (Brazil, Chile);
- hundreds of thousands of hectares of Rhodes grass scale in pastures (Brazil);
- hundreds of thousands of hectares of white rice borer in rice (Ecuador);
- hundreds of thousands of hectares of sugarcane borers in sugarcane (Ecuador); and
- hundreds of thousands of hectares of mealybugs in various crops (Chile).

### *Impressive areas under augmentative biological control*

Areas under augmentative biocontrol are usually better documented than those for classical biocontrol, both for the world and for the Latin American and Caribbean region. When data for this region are compared with information presented about worldwide use of augmentative control (van Lenteren *et al.*, 2019), the conclusion is that application is by far the largest in Latin America. The major augmentative projects, i.e. those with more than 100,000 ha under biocontrol, in the region are:

- millions of hectares of Asian citrus psyllid in citrus (Brazil);
- millions of hectares of coffee berry borer in coffee (Brazil);
- millions of hectares of lepidopterans in maize (Brazil);
- millions of hectares of soil-borne nematodes in corn (Brazil);
- millions of hectares of cotton boll worm in cotton (Brazil);
- millions of hectares of hemipterans and lepidopterans in soybean (Bolivia, Brazil, Cuba);

- millions of hectares of soil-borne diseases in soybean (Brazil);
- millions of hectares of sugarcane borers and spittlebugs in sugarcane (Brazil, Colombia);
- hundreds of thousands of hectares of mate tree borer in mate (Brazil);
- hundreds of thousands of hectares of whitefly in soybean (Brazil);
- hundreds of thousands of hectares of soil-borne nematodes in soybean (Brazil);
- hundreds of thousands of hectares of lepidopterans and coleopterans in various crops (Brazil);
- hundreds of thousands of hectares of spittlebugs in sugarcane (Bolivia, Dominican Republic);
- hundreds of thousands of hectares of potato weevils in potato (Bolivia);
- hundreds of thousands of hectares of lepidopterans in quinoa (Bolivia);
- hundreds of thousands of hectares of hemipterans and lepidopterans in various crops (Cuba);
- hundreds of thousands of hectares of rice stem stink bug in rice (Dominican Republic);
- hundreds of thousands of hectares of sugarcane aphid in sorghum (Mexico);
- hundreds of thousands of hectares of sugarcane borer in sugarcane (Mexico);
- hundreds of thousands of hectares of aphids and budworms in cotton (Peru); and
- hundreds of thousands of hectares of pests and diseases in sugarcane (Peru).

### 32.2.5 Achievements in areas under biocontrol in Latin America and the Caribbean

An important indicator for achievements is the area under biocontrol in a certain country. Unfortunately, even when exhaustive attempts were made to obtain those figures for each of the countries, for some countries data were simply not available and for several others data were incomplete. It was particularly difficult to obtain data for conservation and natural biocontrol. Although papers quite often mentioned that classical biocontrol programmes successfully developed in the period 1880–1969 were still functioning well, specification of the areas on which these programmes still worked was lacking. In such cases attempts were made to estimate the areas under biocontrol by using information about areas harvested in 2016 or 2017 published by FAO (http://www.fao.org/faostat/en/#data/qc). Data for augmentative programmes were easier to obtain, but for conservation and natural biocontrol authors often only mentioned that these types of control occurred (eight countries for conservation biocontrol and 12 for natural control) and did not specify on how many hectares. Areas under biocontrol are summarized in Table 32.3. The data indicate that classical biocontrol is applied on 30,747,889 ha, augmentative biocontrol on 31,381,131 ha, conservation biocontrol on 447,114 ha and natural control on 2,001,846 ha. As already said above, the figure for natural control will be vastly underestimated, as this form of control was not considered or studied by many countries. However, it is interesting to see that prospecting for natural enemies and determining their role in natural control is now on the research agenda of several countries (see Table 32.2).

When calculating total areas under biocontrol, attempts were made to minimize overestimates by checking whether pests in a certain crop were under more than one type of biocontrol. In these cases, the largest area under biocontrol for a certain type of biocontrol was taken as the estimate. For example, under the heading 'classical biocontrol' in Table 32.3, data are included for fortuitous biocontrol but these are not included in the estimate of 30,747,889 ha for classical biocontrol. In cases where more species of natural enemies are used for classical biocontrol of different pest species, only the estimate for the biocontrol agent applied on the largest area is used in the estimate for that crop. However, for augmentative biocontrol, the estimate of the total area treated given above (31,381,131 ha) is corrected for cases where more than one type of augmentative biocontrol is used to control more than one pest, but not for overlap with classical biocontrol. When correcting this figure for overlap with classical biocontrol. i.e. cases where classical biocontrol is active in controlling a certain pest in the total area of a certain crop and where augmentative biocontrol is applied for control of other pests in that crop, the area only under

**Table 32.3.** Types of biocontrol and surface areas (ha) currently treated in Latin America and the Caribbean.

| Country | Classical biocontrol (CBC) + (Fortuitous biocontrol (FBC)) | Augmentative biocontrol (ABC) | Conservation biocontrol (ConsBC) | Natural control (NC) | Country surface (ha)[a] | Inhabitants[b] | Biocontrol (ha): per ha land / per inhabitant |
|---|---|---|---|---|---|---|---|
| Argentina | 4,298,000 | 26,778 | | | 278,040,000 | 44,000,000 | 0.015 / 0.098 |
| Barbados | 3,069 | 300 | | | 43,000 | 290,000 | 0.078 / 0.012 |
| Belize | 16,000 | | | | 2,297,000 | 360,000 | 0.007 / 0.044 |
| Bolivia | 54,000 | 412,000 (+ 1,112,800 overlap with NC) | | 1,558,000 | 109,858,000 | 11,000,000 | 0.018 / 0.184 |
| Brazil | 3,012,000 | 21,762,000 (+ 3,711,000 overlap within ABC) | | | 851,577,000 | 207,360,000 | 0.029 / 0.119 |
| Chile | 7,726,465 | 62,197 | | | 75,670,000 | 17,800,000 | 0.103 / 0.438 |
| Colombia | 4,000 (+ 4,000 overlap with FBC) | 378,896 | + (?) | + (?) | 114,174,900 | 47,700,000 | 0.003 / 0.008 |
| Costa Rica | + (?) | 15,650 | + (?) | + (?) | 5,110,000 | 4,930,000 | 0.003 / 0.003 |
| Cuba | 723,000 | 2,221,306 | 140,000 | 140,000 | 10,988,000 | 11,150,000 | 0.293 / 0.224 |
| Dominica | 2,750 | | | + (?) | 75,000 | 73,900 | 0.037 / 0.037 |
| Dominican Rep. | 169,691 (+ 67,704 overlap with FBC) | 290,451 (+ 66,000 overlap with CBC) | | + (?) | 4,867,000 | 10,735,000 | 0.095 / 0.043 |
| Ecuador | 558,853 | 66,293 | 150,000 | +(?) | 25,637,000 | 16,300,000 | 0.030 / 0.048 |
| El Salvador | 1,500 (+ 1,500 overlap with FBC) | + (?) | | 755 | 2,104,000 | 6,000,000 | 0.001 / 0.000 |
| French Guiana | 20,903 | + (?) | + (?) | | 9,280,700 | 1,125,160 | 0.002 / 0.019 |
| Guatemala | 1,500 | 19,976 | | 275,000 | 10,889,000 | 15,500,000 | 0.027 / 0.019 |
| Guyana | 44,000 | 12,000 | 150,000 | | 21,497,000 | 740,000 | 0.010 / 0.278 |
| Haiti | 56,967 | | | +(?) | 2,775,000 | 10,900,000 | 0.021 / 0.005 |
| Honduras | 1 | 25,400 | + (?) | +(?) | 11,249,000 | 9,000,000 | 0.002 / 0.003 |
| Jamaica | 1,059,676 (+ 1,023,923 overlap with FBC) | 7,846 | | 23,923 | 1,099,000 | 2,700,000 | 0.971 / 0.404 |
| Mexico | 11,810,404 | 763,000 | | +(?) | 196,437,500 | 124,100,000 | 0.064 / 0.101 |
| Nicaragua | + (?) | 10,484 | | | 13,037,000 | 6,000,000 | 0.001 / 0.002 |
| Panama | 19 | 38,630 | 177 | 3,416 | 7,542,000 | 3,750,000 | 0.006 / 0.011 |
| Paraguay | | + (?) | + (?) | | 40,675,200 | 7,000,000 | ? / ? |
| Peru | 108,507 | 330,327 | + (?) | + (?) | 128,522,000 | 31,000,000 | 0.003 / 0.014 |

*Continued*

**Table 32.3.** Continued.

| Country | Classical biocontrol (CBC) + (Fortuitous biocontrol (FBC)) | Augmentative biocontrol (ABC) | Conservation biocontrol (ConsBC) | Natural control (NC) | Country surface (ha)[a] | Inhabitants[b] | Biocontrol (ha): per ha land / per inhabitant |
|---|---|---|---|---|---|---|---|
| Puerto Rico | 10,529 (+ 1,896 overlap with FBC) | + (?) | 6,937 | + (?) | 887,000 | 3,350,000 | 0.020 / 0.005 |
| Remaining Caribs. | + (?) | + (?) | + (?) | + (?) | 1,744,200 | 1,200,000 | ? / ? |
| Suriname | + (?) | 0.5 | | 752 | 16,382,000 | 600,000 | 0.000 / 0.001 |
| Trinidad and Tobago | 32,390 | 350 | + (?) | + (?) | 513,000 | 1,200,000 | 0.064 / 0.010 |
| Uruguay | 1,016,165 | 1,356 | | | 17,622,000 | 3,360,000 | 0.058 / 0.303 |
| Venezuela | 17,500 | 46,000 | | | 91,205,000 | 31,300,000 | 0.001 / 0.002 |
| **Total** | **30,747,889** (31,846,912 with FBC) | **31,381,131** (26,491,331 without overlap with CBC) | **447,114** | **2,001,846** | | | |

[a]Country surface areas for 2017 or 2018 based on World Bank data (https://data.worldbank.org/indicator/ag.srf.totl.k2)
[b]Inhabitants mainly based on data from Central Intelligence Agency (CIA) (https://www.cia.gov/library/publications/the-world-factbook/geos/)

augmentative biocontrol is 26,491,331 ha. Areas treated with products based on *B. thuringiensis* are not included in the estimates, because these products do not contain a living organism and thus are not considered to be biocontrol agents.

More data for each country (crop, pest, type of biocontrol used and areas under biocontrol for each type of biocontrol) are provided as supplementary material. Also, a list of all organisms (biocontrol agents, pests, crops, weeds, etc.) with author name, order, family and common name of the organism, and the country chapters in which these organisms are mentioned is provided as supplementary material. A preliminary check of the list with all organisms mentioned in the book indicates that 715 species of parasitoids, 436 species of predatory arthropods and 204 pathogens are mentioned in relation to biocontrol projects in Latin America and the Caribbean. This list with names of all organisms can be used, for example, to check where certain natural enemies and microbial agents have been found and whether they have been successfully applied in biocontrol programmes. Providing current locations of biocontrol agents as done in this list may help in simplifying issues related to Access and Benefit Sharing regulations (see Section 32.4.1 on factors limiting development and implementation of biocontrol, below).

Six countries (Argentina, Brazil, Chile, Jamaica, Mexico and Uruguay) apply classical biocontrol on more than 1 million hectares, while four countries (Cuba, Dominican Republic, Ecuador, Peru) use classical biocontrol on more than 100,000 ha (Table 32.3). Two countries (Brazil and Cuba) apply augmentative biocontrol on more than 1 million hectares, while five countries (Bolivia, Colombia, Dominican Republic, Mexico, Peru) use augmentative biocontrol on more than 100,000 ha. Three countries (Cuba, Ecuador and Guyana) use conservation biocontrol on more than 100,000 ha, while natural control is documented for more than 1 million hectares in Bolivia and more than 100,000 ha in two countries: Cuba and Guatemala.

Although it was said earlier that a country's area under biocontrol is an important indicator for the country's achievements, this statement needs some qualification. Surface areas differ considerably among the countries in Latin America and the Caribbean. For example, Barbados consists of only 43,000 ha, while Brazil covers 851,577,000 ha (Table 32.3). When using total surface areas for each country, use of biocontrol per hectare of the total surface ranks highest and above 0.1 ha per hectare for Chile, Cuba, Jamaica and Barbados, whereas the Dominican Republic, Mexico, Trinidad and Tobago and Uruguay have more than 0.05 ha per hectare under biocontrol. However, total country surfaces do not provide the best figures for a comparison of achievements, as some countries have vast areas where agriculture is not practised or even possible. Thus, many corrections should be made to these total country surface values for better comparisons. Another way to rank country achievements in biocontrol is to calculate the area under biocontrol per inhabitant. This results in nine countries (Argentina, Bolivia, Brazil, Chile, Cuba, Guyana, Jamaica, Mexico, Trinidad and Tobago) with at least 0.1 ha of biocontrol per inhabitant (Table 32.3). Each way of ranking has its advantages and disadvantages, but the most important conclusion that can be drawn from the data in Table 32.3 is that Latin America and the Caribbean are currently world leaders in biocontrol.

## 32.3 BIOCAT Data on Classical Biological Control in Latin America and the Caribbean

Summary tables and lists for classical biocontrol introductions for the region were compiled for the use of insects as classical biocontrol agents against insect pests. The numbers were generated from the BIOCAT database (Cock *et al.*, 2016), based on the corrected version used by Cock (2019), which can be referred to as BIOCAT 2010.3. Each combination of biocontrol agent, primary target, release country and date or period of release was treated as one introduction. Introductions that were reported to have achieved at least partial control were classed as 'successful'. It should be noted that BIOCAT 2010.3 is not up to date and the numbers should not be relied upon for the past decade or two. Nevertheless, the numbers capture the great majority of insect classical biocontrol introductions and provide valid comparisons between countries, regions, numbers of targets and biocontrol agents, establishments and successes.

Table 32.4 summarizes the records for control of insect pests by insect natural enemies in the region in classical biocontrol. The country chapters in this book mention classical biocontrol projects, but in a qualitative way. The table illustrates that many introductions have been made and that 30% of the introductions resulted in establishment, which is an impressively high rate. Also the high percentage of target species controlled (34%) and the percentage of successful agent species (15%) support the conclusion that classical biocontrol has been a profitable pest management method in this region and that many countries made use of it.

In Table 32.5, the introduced species of natural enemies that contributed to classical biocontrol in the region are listed. Most of these species are, not surprisingly, also mentioned in the country-specific chapters. Exceptions are three species that, according to the BIOCAT database (based on Zúñiga, 1985), were introduced

**Table 32.4.** Summary of records included in BIOCAT2010.3 concerning classical biological control of insects by insect biocontrol agents in Latin America and the Caribbean.

| Category | Number |
|---|---|
| No. of introductions (total records)[a] | 964 |
| No. of establishments (excluding temporary) | 287 |
| No. of primary pest targets | 118 |
| No. of agent species | 387 |
| No. of countries | 36 |
| No. of successful biological control agent introductions | 128 |
| No. of successful biological control agent species | 57 |
| No. of successful programmes | 103 |
| No. of different pest species controlled | 40 |
| No. of countries reporting at least one success | 29 |

[a]Each agent/target country/year is a separate introduction/establishment, e.g. an introduction of the same biocontrol agent from six countries at the same time counts as one introduction, but two introductions of the same biocontrol agent 10 years apart count as two introductions.

into Chile more than 50 years ago and contributed to success in forestry pest biocontrol, but are not mentioned in the Chilean chapter: *Habrolepis dalmanni* (Westwood) for complete control of *Asterodiaspis quercicola* (Bouché) in 1928; *Leucopis obscura* Haliday for partial control of *Pineus boerneri* Annand in 1945; and *Rhaphitelus maculatus* Walker for partial control of *Scolytus rugulosus* Müller in 1915–1916. The number of insect natural enemy species used in classical biocontrol (57) is much lower than the total number of arthropod natural enemy species mentioned in the country chapters (1150). This large difference is to be expected and can be explained as follows. The list for the country chapters: (i) includes all arthropod natural enemies mentioned, both the effective and ineffective agents, while Table 32.5 only includes successful species; (ii) includes many predatory mites, whereas Table 32.5 does not; and (iii) includes species used in all types of biocontrol, where Table 32.5 is limited to classical biocontrol. Particularly this last reason explains a large part of the difference, because in augmentative biocontrol many different species of natural enemies have been tried and are used in different countries (see, for example, Chapter 6: Brazil and Chapter 25: Peru). In classical biocontrol it is common to use the same natural enemies in different countries against the same pest (see the supplementary table with numbers of introductions of insect biocontrol agents per 10-year period for each country in Latin America and the Caribbean). Many more parasitoids have been successfully used than predators.

In Table 32.6 the names of the pest species are presented that were controlled as a result of the introduction of natural enemy species mentioned in Table 32.5.

A list of countries that have reported at least one insect pest successfully control by classical biocontrol and a table with numbers of introductions of insect biocontrol agents each decade for each country in Latin America and the Caribbean are presented as supplementary material.

Ten species of entomopathogens have been released in Latin America and the Caribbean for use in classical biocontrol (Table 32.7 and Hajek *et al*., 2016). Seven of the entomopathogens became established in at least one country and ten

**Table 32.5.** List of species of insect natural enemies that have contributed to a classical biological control success somewhere in Latin America and the Caribbean (retrieved from BIOCAT 2010.3).

| Biological control agent | Guild | Family | Primary target | No. of countries with success |
|---|---|---|---|---|
| *Aceratoneuromyia indica* | Parasitoid | Eulophidae | *Anastrepha ludens* | 1 |
| *Adalia bipunctata* | Predator | Coccinellidae | Aphids | 1 |
| *Aganaspis pelleranoi* | Parasitoid | Figitidae | *Anastrepha striata* | 1 |
| *Amitus hesperidum* | Parasitoid | Platygastridae | *Aleurocanthus woglumi* | 2 |
| *Amitus spiniferus* | Parasitoid | Platygastridae | *Aleurothrixus floccosus* | 1 |
| *Anagyrus kamali* | Parasitoid | Encyrtidae | *Maconellicoccus hirsutus* | 11 |
| *Anagyrus saccharicola* | Parasitoid | Encyrtidae | *Saccharicoccus sacchari* | 1 |
| *Aphelinus mali* | Parasitoid | Aphelinidae | *Eriosoma lanigerum* | 8 |
| *Aphidius matricariae* | Parasitoid | Braconidae | Aphids | 1 |
| *Aphidius smithi* | Parasitoid | Braconidae | *Acyrthosiphon pisum* | 2 |
| *Aphytis holoxanthus* | Parasitoid | Aphelinidae | *Chrysomphalus aonidum* | 4 |
| *Aphytis lepidosaphes* | Parasitoid | Aphelinidae | *Lepidosaphes beckii* | 6 |
| *Aphytis melinus* | Parasitoid | Aphelinidae | *Aonidiella aurantii* | 1 |
| *Aphytis roseni* | Parasitoid | Aphelinidae | *Selenaspidus articulatus* | 1 |
| *Aphytis* sp. | Parasitoid | Aphelinidae | *Lepidosaphes gloverii* and *Aonidiella aurantii* | 2 |
| *Billaea claripalpis* | Parasitoid | Tachinidae | *Diatraea saccharalis* | 2 |
| *Cales noacki* | Parasitoid | Aphelinidae | *Aleurothrixus floccosus* | 1 |
| *Chilocorus cacti* | Predator | Coccinellidae | *Bambusaspis bambusae* | 1 |
| *Cladis nitidula* | Predator | Coccinellidae | *Bambusaspis bambusae* | 1 |
| *Coccophagus gurneyi* | Parasitoid | Aphelinidae | *Pseudococcus calceolariae* | 1 |
| *Comperiella bifasciata* | Parasitoid | Encyrtidae | *Aonidiella aurantii* | 1 |
| *Copidosoma floridanum* | Parasitoid | Encyrtidae | *Trichoplusia ni* | 1 |
| *Cotesia flavipes* | Parasitoid | Braconidae | *Diatraea saccharalis* | 3 |
| *Cotesia glomerata* | Parasitoid | Braconidae | *Pieris brassicae* | 1 |
| *Cotesia sesamiae* | Parasitoid | Braconidae | *Diatraea saccharalis* | 1 |
| *Cotesia vestalis* | Parasitoid | Braconidae | *Plutella xylostella* | 1 |
| *Cryptognatha nodiceps* | Predator | Coccinellidae | *Aspidiotus destructor* | 1 |
| *Cryptolaemus montrouzieri* | Predator | Coccinellidae | *Maconellicoccus hirsutus* | 11 |
| *Encarsia berlesei* | Parasitoid | Aphelinidae | *Pseudaulacaspis pentagona* | 4 |
| *Encarsia clypealis* | Parasitoid | Aphelinidae | *Aleurocanthus woglumi* | 1 |
| *Encarsia noyesi* | Parasitoid | Aphelinidae | *Aleurodicus cocois* | 1 |
| *Encarsia opulenta* | Parasitoid | Aphelinidae | *Aleurocanthus woglumi* | 5 |
| *Encarsia smithi* | Parasitoid | Aphelinidae | *Aleurocanthus woglumi* | 1 |
| *Encarsia* sp. | Parasitoid | Aphelinidae | *Lepidosaphes beckii* | 1 |

*Continued*

**Table 32.5.** Continued.

| Biological control agent | Guild | Family | Primary target | No. of countries with success |
|---|---|---|---|---|
| *Eretmocerus serius* | Parasitoid | Aphelinidae | *Aleurocanthus woglumi* | 6 |
| *Gyranusoidea indica* | Parasitoid | Encyrtidae | *Maconellicoccus hirsutus* | 1 |
| *Habrolepis dalmanni*[a] | Parasitoid | Encyrtidae | *Asterodiaspis quercicola* | 1 |
| *Hippodamia convergens* | Predator | Coccinellidae | *Schizaphis graminum* | 1 |
| *Leucopis obscura*[a] | Predator | Chamaemyiidae | *Pineus boerneri* | 1 |
| *Lixophaga diatraeae* | Parasitoid | Tachinidae | *Diatraea saccharalis* | 4 |
| *Lysiphlebus testaceipes* | Parasitoid | Braconidae | *Schizaphis graminum* | 1 |
| *Lydella minense* | Parasitoid | Tachinidae | *Diatraea saccharalis* | 4 |
| *Metaphycus anneckei* | Parasitoid | Encyrtidae | *Saissetia oleae* | 1 |
| *Metaphycus helvolus* | Parasitoid | Encyrtidae | *Saissetia* spp. | 2 |
| *Neodusmetia sangwani* | Parasitoid | Encyrtidae | *Antonina graminis* | 1 |
| *Psyllaephagus pilosus* | Parasitoid | Encyrtidae | *Ctenarytaina eucalypti* | 1 |
| *Pteroptrix smithi* | Parasitoid | Aphelinidae | *Chrysomphalus aonidum* | 1 |
| *Rhaphitelus maculatus*[a] | Parasitoid | Pteromalidae | *Scolytus rugulosus* | 1 |
| *Rodolia cardinalis* | Predator | Coccinellidae | *Icerya purchasi* | 11 |
| *Telenomus alsophilae* | Parasitoid | Platygastridae | *Oxydia trychiata* | 1 |
| *Telenomus remus* | Parasitoid | Platygastridae | *Spodoptera frugiperda* | 2 |
| *Telenomus rowani* | Parasitoid | Platygastridae | *Rupella albinella* | 1 |
| *Trichogramma minutum* | Parasitoid | Trichogrammatidae | *Diatraea saccharalis* | 1 |
| *Trichogramma pretiosum* | Parasitoid | Trichogrammatidae | *Diatraea saccharalis* | 1 |
| *Trichogramma semifumatum* | Parasitoid | Trichogrammatidae | *Diatraea saccharalis* | 1 |
| *Trichogramma* sp. | Parasitoid | Trichogrammatidae | *Diatraea saccharalis* | 1 |
| *Tytthus mundulus* | Predator | Miridae | *Perkinsiella saccharicida* | 1 |

[a]Species not mentioned in Chilean chapter.

target pest species were brought under classical biocontrol. Correspondence between species of entomopathogens mentioned in the country-specific chapters and Table 32.7 is poor and six of the ten entomopathogens are not mentioned in the country-specific chapters: *Hirsutella thompsonii* (Argentina), *Neozygites parvispora* (Barbados), *Metarhizium anisopliae* (Guyana), *Aschersonia aleyrodis* (Virgin Islands), *Romanomermis culicivorax* (Colombia and Puerto Rico), *Romanomermis iyengari* (Cuba) and *Trichoplusia ni* nucleopolyhedrovirus (TnNPV) (Colombia). The difference for the first four species may be explained by the fact that they did not control the pest and are therefore not mentioned in the respective country-specific chapters. The two species of the genus *Romanomermis* might not have been mentioned in the country-specific chapters for Cuba and Puerto Rico because they concern agents controlling mosquitoes vectoring human diseases, a topic that may have escaped the attention of the authors.

The number of releases of insect natural enemies per decade is given in Fig. 32.1 and shows an increase during the initial four decades, which is interrupted as a result of the Second World War, but the increase continues in the 1950s, peaks during the 1970s and then dramatically drops. The peak in the 1960s and 1970s reflects a period when classical biocontrol agents were easily transported by air and introduced rather indiscriminately without careful pre-release studies, combined with the import and release of known biocontrol agents

**Table 32.6.** Pest target species reported to have been successfully controlled by classical biological control somewhere in Latin America and the Caribbean (retrieved from BIOCAT 2010.3)

| Target pest | Family | Crop | No. of biocontrol agents involved in success | No. of territories reporting success |
|---|---|---|---|---|
| *Acyrthosiphon pisum* | Aphididae | Peas, lucerne | 1 | 2 |
| *Aleurocanthus woglumi* | Aleyrodidae | Citrus | 4 | 9 |
| *Aleurodicus cocois* | Aleyrodidae | Coconut, palms | 1 | 1 |
| *Aleurothrixus floccosus* | Aleyrodidae | Citrus | 2 | 2 |
| *Anastrepha ludens* | Tephritidae | Fruit | 1 | 1 |
| *Anastrepha striata* | Tephritidae | Citrus | 1 | 1 |
| *Antonina graminis* | Pseudococcidae | Pasture grasses | 1 | 1 |
| *Aonidiella aurantii* | Diaspididae | Citrus | 3 | 2 |
| *Aspidiotus destructor* | Diaspididae | Coconut | 1 | 1 |
| *Asterodiaspis quercicola* | Asterolecaniidae | Oak | 1 | 1 |
| *Bambusaspis bambusae* | Asterolecaniidae | Bamboo | 2 | 1 |
| *Chrysomphalus aonidum* | Diaspididae | Citrus | 2 | 4 |
| *Ctenarytaina eucalypti* | Psyllidae | Eucalyptus | 1 | 1 |
| *Diatraea rosa* | Crambidae | Sugarcane | 1 | 1 |
| *Diatraea saccharalis* | Crambidae | Sugarcane, maize | 8 | 10 |
| *Eriosoma lanigerum* | Aphididae | Apple | 1 | 8 |
| *Icerya montserratensis* | Monophlebidae | Citrus | 1 | 1 |
| *Icerya purchasi* | Monophlebidae | Citrus, etc. | 1 | 11 |
| *Lepidosaphes beckii* | Diaspididae | Citrus | 2 | 7 |
| *Lepidosaphes gloverii* | Diaspididae | Citrus | 1 | 1 |
| *Maconellicoccus hirsutus* | Pseudococcidae | Various trees and ornamentals | 3 | 11 |
| *Nipaecoccus nipae* | Pseudococcidae | Various trees | 1 | 1 |
| *Oxydia trychiata* | Geometridae | Cypress | 1 | 1 |
| *Perkinsiella saccharicida* | Cicadellidae | Sugarcane | 1 | 1 |
| *Pieris brassicae* | Pieridae | Brassicas | 1 | 1 |
| *Pineus boerneri* | Cicadellidae | *Pinus radiata* | 1 | 1 |
| *Planococcus citri* | Pseudococcidae | Fruit trees, ornamentals | 1 | 1 |
| *Plutella xylostella* | Plutellidae | Brassicas | 1 | 1 |
| *Pseudaulacaspis pentagona* | Diaspididae | Mulberry, peach | 1 | 4 |
| *Pseudococcus calceolariae* | Pseudococcidae | ? | 1 | 1 |
| *Rupella albinella* | Crambidae | Rice | 1 | 1 |

*Continued*

**Table 32.6.** Continued.

| Target pest | Family | Crop | No. of biocontrol agents involved in success | No. of territories reporting success |
|---|---|---|---|---|
| *Saccharicoccus sacchari* | Pseudococcidae | Sugarcane | 1 | 1 |
| *Saissetia coffeae* | Coccidae | Citrus | 1 | 1 |
| *Saissetia oleae* | Coccidae | Citrus | 2 | 2 |
| *Schizaphis graminum* | Aphididae | Wheat, cereals | 2 | 2 |
| *Scolytus rugulosus* | Curculionidae | Peach | 1 | 1 |
| *Selenaspidus articulatus* | Diaspidae | Citrus | 1 | 1 |
| *Spodoptera frugiperda* | Noctuidae | Various arable | 1 | 1 |
| *Spodoptera* spp. | Noctuidae | Various arable | 1 | 1 |
| *Trichoplusia ni* | Noctuidae | Various arable | 1 | 1 |
| 'Aphids' | Aphididae | ? | 2 | 1 |

**Table 32.7.** Summary of records concerning use of entomopathogens in classical biological control in Latin America and the Caribbean (retrieved from Hajek *et al*., 2016).

| Country | Releases | Biocontrol agent | Established | Target species | Targets controlled |
|---|---|---|---|---|---|
| **Bacteria** | 0 | 0 | 0 | 0 | 0 |
| **Fungi** | | | | | |
| Argentina | 3 | *Fusarium coccophilum* *Hirsutella thompsonii* | 1 | *Aonidiella aurantia* *Eriophyes sheldoni* and *Phyllocoptruta oleivora* | 1 |
| Barbados | 1 | *Neozygites parvispora* | 0 | *Thrips tabaci* | 0 |
| Guyana | 1 | *Metarhizium anisopliae* | 1 | *Aeneolamia flavilatera* | 0 |
| US Virgin Islands | 1 | *Aschersonia aleyrodis* | 0 | *Aleurodicus cocois* & *Aleurothrixus floccosus* | 0 |
| **Microsporidia** | | | | | |
| Argentina | 1 | *Paranosema locustae* | 1 | *Dichroplus maculipennis*, *D. elongatus*, *D. pratensis* and *Scotussa lemniscata* | 1 |
| **Nematodes** | | | | | |
| Argentina | 2 | *Deladenus siricidicola* | 1 | *Sirex noctilio* | 1 |
| Brazil | 2 | *Deladenus siricidicola* | 1 | *Sirex noctilio* | 1 |
| Chile | 1 | *Deladenus siricidicola* | 1 | *Sirex noctilio* | 1 |
| Colombia | 1 | *Romanomermis culicivorax* | 1 | *Anopheles nyssorhynchus albimanus* | 1 |
| Cuba | 1 | *Romanomermis iyengari* | 1 | *Anopheline spp.* and *Culicine spp.* | 4 |
| El Salvador | 1 | *Romanomermis culicivorax* | 0 | *Anopheles nyssorhynchus albimanus* and *A. punctipennis* | 0 |
| Puerto Rico | 1 | *Romanomermis culicivorax* | 1 | *Scapteriscus didactylus* and *S. abbreviatus* | 1 |
| Uruguay | 1 | *Deladenus siricidicola* | 1 | *Sirex noctilio* | 1 |
| **Viruses** | | | | | |
| Colombia | 1 | *Trichoplusia ni* nucleopolyhedrovirus (TnNPV) | 1 | *Trichoplusia ni* | 1 |

used successfully in other parts of the world. Interest dropped off in the 1980s when all the obvious biocontrol agents had been introduced and few major new targets for classical biocontrol were spreading in the region. Figure 32.2 presents the number of classical biocontrol successes with insect natural enemies per decade and shows a similar trend as Fig. 32.1, but with the difference of an extra peak during the 1990s, reflecting the 11 successful programmes against *Maconellicoccus hibiscus* around the Caribbean.

## 32.4 Factors Limiting and Stimulating Biological Control in Latin America and the Caribbean

### 32.4.1 Factors limiting development and implementation of biological control

Authors of the country chapters mention many causes that may frustrate development and implementation of biocontrol. Factors limiting biocontrol are partly summarized in Table 32.2.

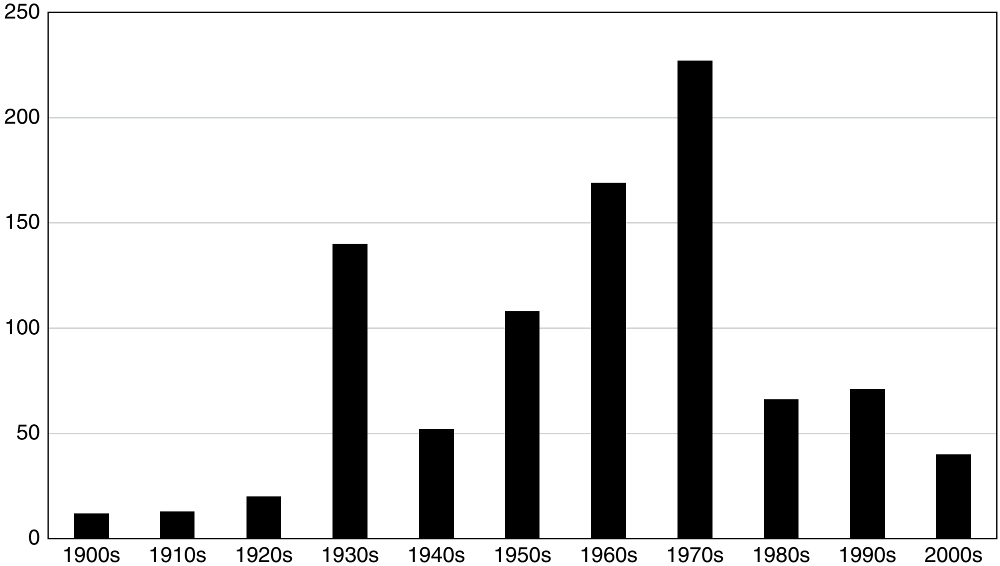


**Fig. 32.1.** Number of releases per decade of insect biocontrol agents for classical biological control of insect pests in Latin America and the Caribbean (retrieved from BIOCAT 2010.3).

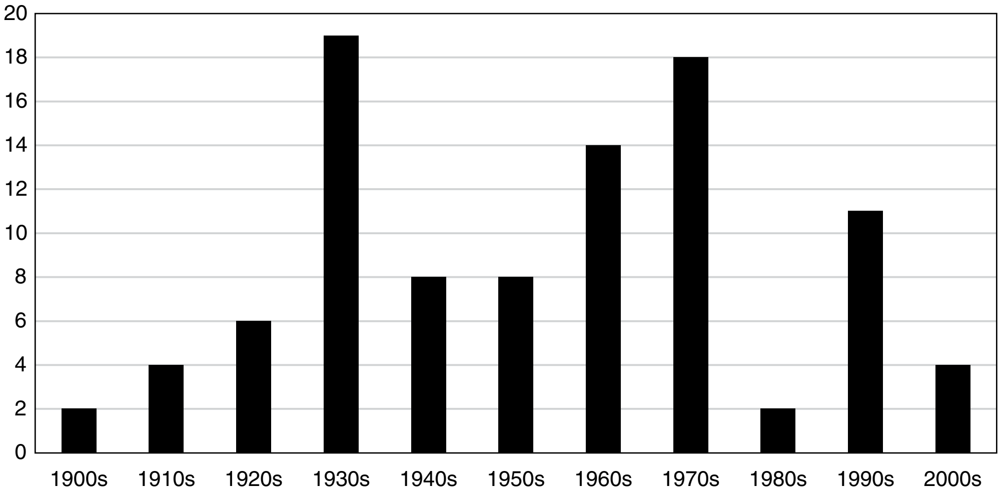


**Fig. 32.2.** Number of classical biological control successes of insect pests by insect biocontrol agents per decade in Latin America and the Caribbean (retrieved from BIOCAT 2010.3) Each target successfully controlled counts once for each country and is allocated to the decade when the first biocontrol agent contributing to that success was released.

The factor most often mentioned is the dominating role that the pesticide industry and their sales persons play. Pesticide companies strongly lobby at governmental levels for faster pesticide registration procedures and continuously stress the need to apply pesticides in order to be able to feed a growing human population. Crop protection advisors prefer to advise (over-) use of pesticides, as they are sold per unit of volume and their income is based on volumes sold. Another reason why they prefer to advise the use of pesticides is that the profit margins of synthetic pesticides are in the order of 25% or more, while they are only about 5% for biocontrol agents. Further, sales people and extension service personnel providing information about pest management often discourage the application of biocontrol by referring to it as being too complicated to use. Next, most people now involved in crop protection matters – from the highest level in ministries of agriculture down to farmers and their workers – have been raised under the mantra that 'the only good insect is a dead insect, and chemical control is able to kill insects fast and cheaply'. The result is that many crop protection advisors and farmers are pesticide addicted after having heard this mantra for 70 years, and this addiction appears to be hard to heal by the relatively small numbers of experts in the field of biocontrol.

Another factor often mentioned in the chapters in this book is also related to chemical pesticide use and concerns obstructing the ecosystem function of natural pest control as a result of pesticide applications. The effect of this is that other primary pests need to be sprayed as well, and that secondary pests, which are kept at low densities by naturally occurring beneficial organisms, start to create serious problems. The dramatic negative effect of pesticides in the reduction of biodiversity, including beneficial species like biocontrol agents, has been documented during the past decades and culminated in the 2019 assessment by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019). Many policy makers and pesticide-industry representatives repeat over and again that agriculture has to feed some 10 billion people by the year 2050 and that, for this reason, a substantial increase in food production is needed, which can only be achieved using synthetic pesticides. Van Lenteren *et al*. (2018) discussed, documented and explained why this reasoning is simplistic, erroneous and misleading. Related to the topic of this book – biocontrol – the above reasoning is simplistic, because by stating that synthetic pesticides are needed for increased food production, the presence of a multitude of other approaches to pest, disease and weed control illustrated in this book and in many other publications is ignored.

A third factor related to pesticides hampering the implementation of biocontrol and other non-chemical pest management methods is the unrealistically low cost of chemical products. Application of the 'true cost' principle for pesticides would strongly increase the market for biocontrol. Pesticides are currently 'subsidized' by governments because the industry is not held responsible for human illnesses and deaths as a result of chronic exposure to pesticides. Also, the pesticide industry does not have to provide funding for repairing damage done to the environment, such as reduction of biodiversity and inhibition of the functioning of the ecosystem services of pest control, pollination and cleaning of water. The pesticide costs related to all these harmful effects are externalized and paid for by society, while the pesticide industry only picks up the economic benefits without being responsible for the true costs. Realistic pricing involving these true costs would result in chemical pesticides being two to four times more expensive (van Lenteren *et al*., 2018), with the positive effect of fairer competition with non-chemical alternative control methods such as biocontrol.

Looking ahead, pest management in Latin America and the Caribbean (as elsewhere) will have to become more sophisticated, adaptable, flexible and sustainable than simply applying synthetic pesticides. This capacity will need to be developed in a changing world, where consumers will want and expect healthier produce, while climate change has the potential to substantially disrupt pest management (and society). Climate-smart pest management (Heeb *et al*., 2019) incorporating all the potential of biocontrol will be required. Researchers will have to develop new effective IPM strategies, extension staff will need to understand the IPM strategies in order to promote them and farmers will want access to advice and information on IPM, including biocontrol, delivered by the most suitable methods using appropriate information communication technology. Inevitably, it will take time to make this transition. Universities and technical training facilities should have the wherewithal (resources, suitable staff, information and material) to produce the next generation of researchers and extension staff who understand the role of biocontrol and IPM. They will then be able to generate and apply appropriate strategies to optimize agricultural and forestry production and protect the environment and biodiversity. Demonstrating how well beneficial agents can control pests, diseases and weeds, as is done in this book (published both in Spanish and in

English), will be a valuable resource for this and should help to promote a wider appreciation for and application of biocontrol as part of IPM.

Many countries in the region mention lack of funding for research in biocontrol as a main reason for the few projects realized and this particularly plays a role in Central America and the Caribbean. Sometimes limited funding is temporarily provided when a new invasive pest is observed, resulting in ad hoc trials to apply biocontrol, but if quick success is not obtained these projects are prematurely terminated and, often incorrectly, the conclusion is drawn that biocontrol does not work. Other countries mention that research funding is available, but that collaboration among universities, institutes, extension services and farmers needs to be improved (e.g. Argentina, Bolivia, Brazil and Venezuela).

Time-consuming and expensive registration procedures for natural enemies and microbial control agents are also often mentioned as a limiting or even prohibiting factor, because many of the relatively small biocontrol agent producers are not able to bear those high registration costs. Chapter 1 of this book mentions that procedures for registration vary widely in Latin America and the Caribbean, and this is also the case for regulations for import and release, and for demands for environmental risk assessments of biocontrol agents. Colmenarez *et al.* (in preparation) propose the formation of a regional platform for harmonization of procedures related to biocontrol.

A recent regulation concerning prospecting for exotic natural enemies resulted in an almost complete stop in searching for exotic control agents. Under the Convention on Biological Diversity (CBD, 1993), countries have sovereign rights over their genetic resources and agreements governing the access to these resources and the sharing of benefits arising from their use need to be established between involved parties, i.e. Access and Benefit Sharing (ABS) (Cock *et al.*, 2010). The Nagoya Protocol, which came into force in October 2014, is a supplementary agreement to the CBD and provides a framework for the implementation of ABS procedures. The consequence of this protocol is that currently a permission to survey and sample potential biocontrol agents can only be granted by the country that has the rights over the genetic resources, and that collection of new natural enemies has become increasingly difficult or impossible in countries that have first accidentally exported the pest, a situation which seems quite unreasonable.

Linked to the issues raised by the Nagoya Protocol is the need for taxonomic expertise to support agriculture and pest management (Lyal *et al.*, 2008). Apart from issues relating to the identity of pests and their infraspecific variation, there is the challenge of the taxonomy of the biocontrol agents, both those used for classical introductions and inundative releases, and the indigenous natural control agents found in farmers' fields. Names are needed to understand what is happening, recognize the different species and provide clarity regarding their roles and functions. Taxonomists able to support this work are few in number and often scattered across museums and universities, both within Latin America and the Caribbean and across the world. It is important that these taxonomists are supported, their numbers increased and key linkages with pest management built and sustained. Molecular tools to extract genetic information are a valuable tool for taxonomists today, enabling them to achieve far more in less time, but this depends on the ability to move specimens and genetic information freely between taxonomists and researchers and across national borders. Regulations put in place to implement the Nagoya Protocol are intended to ensure equitable sharing of the benefits arising from access to genetic resources, but already they are impeding important taxonomic and applied pest management research based on biological specimens (i.e. genetic resources). It is important that these regulations facilitate rather than impede these public-good activities, as was specified in the Nagoya Protocol itself.

Another reason for initial reservations in using biocontrol relates to the opinion that biocontrol often fails. This opinion seems to be supported by the various unsuccessful cases mentioned in many of this book's chapters. It is a fact that a lot of early attempts to introduce and establish natural enemies did not result in establishment of the natural enemy, and establishment often did not lead to control of the target pest. Early failures to obtain establishment might have been caused by a multitude of reasons, such as: (i) poor and long transport conditions resulting in high mortality and low quality of the imported and released natural enemies; (ii) bureaucratic and time-consuming import procedures at custom offices leading to death of the biocontrol agents; (iii) too low numbers of released individuals; (iv) inadequate synchronization between release of the natural enemy and presence of the pest; (v) lack of preceding research on agroecosystem characteristics where biocontrol agents should be functioning, including knowledge about already present natural enemies that might prevent establishment; and (vi) insufficient climate matching. Early failures to establish or have impact were also the result of the 'hit-and-miss' or 'shotgun' approach often followed until the 1990s: 'release every biocontrol agent that you can get hold of, and something should work'. However, the FAO Guidelines for the export, shipment, import and release of biocontrol agents and other beneficial organisms (IPPC, 2017), which were first issued in 1996 (IPPC, 1996) now help to guide many Latin American and Caribbean countries (Kairo *et al.*, 2003). Risk assessment procedures, as well as new approaches for agent selection that are explained in Chapter 1 of this book, allow for early exclusion of ineffective or problematic candidate species.

The increased investment in evaluating the risks and potential of new biocontrol agents, particularly for insect biocontrol agents to control insects, has reduced the number of biocontrol agent species introduced, but increased the establishment and success rate (Cock *et al.*, 2016). In contrast, from very early on, weed biocontrol involved the careful selection and detailed evaluation of potential biocontrol agents, leading to higher establishment and success rates than for insect biocontrol (Schwarzländer *et al.*, 2018). Although establishment and success rates in biocontrol have increased over time, it is, surprisingly, not uncommon to read in papers written by biocontrol experts that this success rate is still low. Actually, the success rate is surprisingly high: a comparison of the success rate and costs involved in the identification of a marketable synthetic pesticide (1:140,000 and US$256 million) and the success rate and costs involved in finding an effective natural enemy for augmentative biocontrol (1:10 and US$2 million) demonstrates the good success rate and low costs at which a success is obtained with biocontrol (data for 2010). Details and references illustrating this issue are given in van Lenteren (2012).

### *Factors stimulating development and implementation of biological control*

Compared with chemical pesticides, biocontrol agents show a number of inherent characteristics that make them preferred pest management tools now and in the future.

- They are less detrimental to the health of farm workers and those living in farming communities.
- Use of biocontrol does not imply a 'crop re-entry period' as is the case with most pesticides, and lack of this re-entry period makes continuous harvesting possible, which is particularly important with fresh products such as vegetables, fruit and ornamentals where market prices may vary strongly even during a day.
- They are more sustainable, as there has been no development of resistance against arthropod biocontrol agents.
- They do not cause phytotoxic damage to plants and, as a result, farmers report better yields and healthier crops after switching to biocontrol.
- Use of biocontrol results in residue-free or residue-poor products and, increasingly, produce will only be bought by exporters and local retailers when residue levels are well below the legal maximum residue levels (MRLs).
- Finally, reduction in or absence of chemical pesticide applications as a result of using biocontrol leads to increased biodiversity in and around crops.

Many of these inherent characteristics are not well known or explained to farmers and consumers, and several chapters in this book refer to this lack of knowledge. Documentation of the many successes obtained with biocontrol, as done in this book, as well as providing data showing that biocontrol can be cheaper than chemical control (see Chapter 6: Brazil and Chapter 25: Peru), may encourage farmers, consumers and policy makers to accept this sustainable pest management method.

Interesting specific factors for the Latin American and Caribbean region that stimulate implementation of biocontrol are the many prospecting projects and the large number of documented cases of natural pest control. Prospecting gives an insight into the many potential biocontrol candidates (e.g. Chapter 19: Honduras, Chapter 20: Jamaica and Chapter 24: Paraguay) and regional prospecting has resulted in many natural enemies and microbial agents that are now mass produced and released for augmentative biocontrol. Documentation of natural control not only illustrates the positive role of the ecosystem service of pest control, but also helps in understanding why excessive pesticide sprays interfere with this free pest control service and may result in causation of secondary pests.

Many countries mention that new invasive pests initiate new biocontrol research. As mentioned earlier, an interesting approach to try to solve problems caused by new invaders is used in Mexico, by first determining pest risk scenarios and then reviewing possibilities for biocontrol before these pests cause problems. Recent pest invasions in the region, e.g. pink hibiscus mealybug and papaya mealybug, have shown that regional cooperation can result in area-wide solutions using biocontrol. Regional cooperation seems a very positive option to stimulate biocontrol.

At the governmental level, adoption and funding of IPM and biocontrol approaches have a strong positive influence on application of biocontrol, as is explained for example in Chapter 5: Bolivia, Chapter 10: Cuba and Chapter 25: Peru. When such approaches are combined with concurrent measures to reduce chemical pesticide use as employed in Peru, the positive effect on application of biocontrol is even larger. Another important promoter of increased use of biocontrol is the availability of fast-track and priority registration of low-risk pest control agents such as biocontrol agents and a special registration procedure for microbial agents.

The chapters clearly show that organic food production and production of food under some form of certification for the export market is strongly growing in the Caribbean and in Central and South America. These forms of production stimulate the use of biocontrol. Also, local concerns about food safety and environmental impact issues in relation to synthetic pesticide use are mentioned in many chapters, resulting in a preference for low- or no-residue produce and a demand for biocontrol.

More efficient biocontrol agent selection methods (Chapter 1) and regional development of improved and more stable formulations for microbial biocontrol agents, cheaper and better quality production of natural enemies, and better application methods for biocontrol agents (e.g. equipment to release biocontrol agents in crops by use of drones or unmanned airplanes) also contribute to growth in uptake of biocontrol.

In conclusion: it is clear that the dominance of the chemical industry will not diminish soon, but governments, researchers, farmers and consumers are becoming increasingly aware of the negative effects of excessive pesticide use on the biosphere and its inhabitants, and this, together with the many positive effects of biocontrol, will result in a growth of this pest management method.

## 32.5 Future of Biological Control in Latin America and the Caribbean

In the chapters of this book, many largely varying issues are mentioned about the future of biocontrol in the region.

- Many countries anticipate a growth in application of all forms of biocontrol, because of the result of prospecting projects, increase in documentation and use of natural control, realization of more conservation biocontrol programmes as a result of better understanding of the role of insects in agroecosystem functioning, a large expansion of augmentative biocontrol after demonstration of large successes obtained in, for example, Brazil, and the long-term successes realized with classical biocontrol. Export demands for pesticide-poor or pesticide-free products are expected to boost all types of biocontrol.
- A lot of countries mention the future need of biocontrol to manage the many new invasive pests.
- A number of countries expect to increase governmental or industrial mass production of native natural enemies and, particularly, microbial agents to be able to meet

growing demands. Production of pathogens and antagonists for biocontrol of diseases is explicitly mentioned in several chapters (e.g. Brazil, Chile, Colombia and Uruguay). Also, future implementation of quality-control methods for biocontrol agents is thought by many countries to lead to better products, resulting in increasing sales.

- Anticipated continuation of current and future governmental support and guidance in development of biocontrol is mentioned by many countries.
- Several countries recognize an urgent need for harmonization of regulations for import and release of exotic biocontrol agents, as well as registration procedures. Current procedures are very diverse, resulting in the need to provide different documents for each country, leading to high costs that are difficult to cover for most of the small biocontrol companies. Harmonization is not expected to occur soon, but would certainly stimulate future application of biocontrol. A related problem that needs urgent action is to find a solution for the impasse in foreign exploration due to the Access and Benefit Sharing (ABS) issue that developed after acceptance of the Nagoya protocol (see Chapter 1 and above). The IOBC Global Commission on ABS (IOBC, 2019a) made an appeal to develop ABS regulations that support the biocontrol sector by facilitating the exchange of biocontrol agents, including development of clear guidelines. The Commission prepared best-practice guidelines for exchange of biocontrol genetic resources to assist the biocontrol community to demonstrate due diligence in complying with ABS requirements (Mason *et al.*, 2018), which will hopefully facilitate the resumption of foreign prospecting for biocontrol agents.
- The Caribbean region and Central American countries refer to the importance of future cooperation in development and application of biocontrol, especially for classical control of new area-wide invasive pests. Strengthening of the role of international institutions mentioned in Chapter 1 in coordination of biocontrol projects involving similar pests, diseases and weeds occurring in a number of countries in the region, and improved cooperation between countries, for example within the Neotropical Regional Section of IOBC (IOBC, 2019b), might help in realizing more biocontrol projects with the limited amount of national funding. A priority activity for regional cooperation in collaboration with FAO might be to compile a list of future invading organisms into the region and to identify potential biocontrol agents for management of these organisms.
- Several countries mention the need for training of technicians and farmers in the use of biocontrol. One option might be to do this via the farmer-participatory Farmers Field Schools system, which is currently implemented on several Caribbean islands with the aim of increasing the capability of farmers to use IPM and biocontrol and become less dependent on chemical control. See Chapter 27 (Remaining Caribbean Islands) for examples.
- Currently, few countries in Latin America and the Caribbean study or implement biocontrol of weeds and vectors of human and animal diseases, while much knowledge is available about biocontrol of these organisms elsewhere in the world. These are clearly areas for future attention in the region. The same holds, though for fewer countries, for biocontrol of plant diseases.
- Although a number of countries face serious economic problems that have repercussions on research, agriculture and forestry remain priority activities in these countries and in the region as a whole. Modernization of agriculture and forestry is proceeding rapidly in Latin America and the Caribbean, and the many examples of cutting-edge biocontrol projects provided in this book assist in this modernization process. Biocontrol further contributes to sustainable food production and protection of biodiversity of the region's many now-threatened natural areas.

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