Supplementary Material for:

Do new Access and Benefit Sharing procedures under the Convention on Biological Diversity threaten the future of Biological Control?

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Annex 1 Case studies

We have prepared this paper with two principle audiences in mind - those doing biological control and those concerned with ABS. The case studies were selected and prepared to illustrate a variety of points relevant to ABS, ranging from the difficulties that ABS already represents to practical examples of situations where application of ABS is not straightforward, to successes and the implications for ABS sharing. All were prepared with an ABS perspective that will not be found in standard sources and biological control text books, which simply do not consider ABS at all. So although for some, the basic information is available from other sources, the implications for ABS are not specified. We believe the Case Studies will add considerably to the value of this paper. They will give BC practitioners an immediate grasp of the points being made, but also give concrete examples to help those concerned with ABS to understand practical issues related to the implications of BC. The Case Studies are arranged in the sequence in which they are referred to in the text – from where they would normally be accessed, but the following table may help the reader identify particular case studies and what each is intended to convey.

Case Study	Title	Authors	Purpose
1	Negative impacts of Access and Benefit Sharing regulations on a programme to help African smallholder mango producers	Fabian Haas & Sunday Ekesi	ABS concerns indefinitely delay BC programme
2	Conducting research into classical biological control in India since the Indian Biodiversity Act (2002)	Rob Tanner	New ABS legislation delays BC programme
3	Access and benefit sharing legislation blocked biological control of leaf miner in Peru and Europe	Phyllis G. Weintraub	ABS legislation preventing BC research
4	*Eretmocerus mundus*, a global answer for the global invasive pest *Bemisia tabaci*	Johannette N. Klapwijk	Global search for augmentative BCA in many countries
5	Problems caused by water hyacinth as an invasive alien species	Matthew J.W. Cock	Diversity of impacts by an alien species would lead to a diversity of beneficiaries if BC implemented
6	Biological control of a pest of a globally grown plantation crop: coffee	Matthew J.W. Cock	Free exchange of BCAs for a commercial crop
7	*Rodolia cardinalis*, an international biological control icon originating from Australia	Jacques Brodeur	Example of multiple re-use of same BCA and an agro-industry saved
8	The classical biological control of a cassava mealybug in Brazil	Fernando L Cônsoli & José Roberto Postali Parra	Straightforward introduction of classical BCAs based on results of earlier surveys for another, similar pest (and public good impact)
9	The successful importation and use of *Ageniaspis citricola* from South-east Asia via the USA for controlling the citrus leaf miner *Phyllocnistis citrella* in Brazil	José Roberto Postali Parra & Fernando L Cônsoli	Re-use of BCA, and public good impact
10	Early example of a collect-and-ship project: citrus blackfly in Cuba, 1930	Peter G. Mason	Early casual access to BCAs
11	Biological control of water weeds	Matthew J.W. Cock	Developing countries reaping the benefits of research by developed countries
12	Biological control of *Chromolaena odorata* using cultures of *Pareuchaetes pseudoinsulata* from countries where it had been introduced and established	Matthew J.W. Cock	Possible genetic changes in BCA through establishment in new country being re-used in other countries
13	Over thirty years of successful release of a	José Roberto Postali Parra &	A classical BCA being re-used as an augmentative

	natural enemy: *Cotesia flavipes*	Fernando L Cônsoli.	BCA
14	The search for a natural enemy of the cassava mealybug	Fabian Haas & Matthew J.W. Cock	The need to conduct surveys in many countries, but eventually focus in one
15	Indigenous leaf miner parasitoids for augmentative biological control in Europe	Joop C. van Lenteren	How indigenous natural enemies can be developed for ABC of exotic pests and re-used around the world
16	Supply of natural enemies for biological control of pink hibiscus mealybug in the Caribbean: the rapid and simple supply of a known biological control agent	Matthew J.W. Cock	Simple example of supply and ship project with little in-country research needed; a bilateral exchange of BCAs; international cooperation in BC community
17	Saving millions of cassava smallholder farmers in Africa	Fabian Haas	Flagship public good impact
18	*Amblyseius swirskii*, an exotic solution for an endemic problem	Karel J.F. Bolckmans	Substitution of an exotic augmentative BCA with a more effective indigenous one
19	Biological control of orthezia scale in St Helena: a public good	Matthew J.W. Cock	Public good through control of an environmental pest threatening biodiversity loss
20	Biotypes of pest weevil parasitoids introduced into New Zealand	Barbara I.P. Barratt	The need to look at different biotypes of the same species
21	*Encarsia formosa* and *Phytoseilus persimilis*: two accidental but highly appreciated importations	Joop C. van Lenteren	Accidentally introduced BCAs subsequently used for ABC
22	Uninvited but welcomed guests: the case of two psyllid parasitoids in Brazil	Fernando L Cônsoli & José Roberto Postali Parra	Accidentally introduced BCAs provide effective CBC (accidental introduction facilitated by deliberate introduction elsewhere)
23	Successful biological control of a forest insect pest	Peter G. Mason	Introduced specialists BCAs effective in combination with generalist indigenous BCAs (public good impact in the forest sector and contribution to science of population ecology)
24	Spread of a biological control agent in North America	Peter G. Mason	BCAs will spread from one country to another
25	Collaboration between CABI and Uzbekistan based on weed biological control	Urs Schaffner	Example of shared research programme built on CBC exploration (in the absence of ABS legislation)
26	Fast-track biological control of orthezia scale in St Helena implemented with no research in intermediate source country	Matthew J.W. Cock	BCA obtained with no in-country research in order to meet emergency need.
27	Programme on biological control of gorse shared between countries	Richard Hill & Barbara I.P. Barratt	Countries will share BC research activities against pests in common (effective international collaboration)

Case Study 1. Negative impacts of Access and Benefit Sharing regulations on a programme to help African smallholder mango producers

Icipe's African Fruit Fly Programme (AFFP, formerly African Fruit Fly Initiative) was started in 1998 (initially funded by IFAD (International Fund for Agricultural Development) but currently by BMZ (German Federal Ministry for Economic Cooperation and Development)) and operates in more than ten African countries. The objectives are to improve income and nutrition of smallholder families and to increase export earnings of developing countries by improving yield and quality of fruits and vegetables through the management of damaging fruit flies.

The invasive fruit fly, Bactrocera invadens Drew, Tsuruta & White (Tephritidae) was first recorded in Kenya in 2003. Research indicated that Sri Lanka was the putative origin of this fruit fly. The invasion of B. invadens has not only devastated mango production and export in several African countries, but also made inaccessible lucrative export markets in South Africa, Europe and the USA because of the quarantine implications. Export of mango from Africa valued at US$ 42 million annually is being rapidly eroded due to the spread of B. invadens.

The AFFP initiated cooperation with the Sri Lankan Ministry of Agriculture, through the Horticultural Crop Research and Development Institute (HORDI), Peradeniya, to search for natural enemies of B. invadens in Sri Lanka for possible release in Africa in a classical biological control programme. Although exploration in Sri Lanka by icipe and HORDI has identified several parasitoids with potential as biological control agents of B. invadens, and the process of applying for permission to export these for use in biological control started in 2007, up until now (2009) it has been impossible to obtain an export permit from the Sri Lankan authorities. A formal reason for refusal has not been given. Although Sri Lanka seems to have no ABS (access and benefit sharing) regulation as such in place (i.e. no entry on the Convention on Biological Diversity (CBD) webpage on ABS measures, www.cbd.int/abs/measures.shtml), the uncertainty regarding ABS regulation is considered to have contributed to preventing the export of the parasitoids to Africa.

The research project has benefited the Sri Lankan partners through capacity building and scientific cooperation. icipe will not generate revenue for itself from the proposed activities, as the CBC management of this pest would be a public good benefiting smallholder farmers (80% of mango producers are smallholders) in Kenya and other countries in East Africa. For now, the implementation of this CBC programme to help smallholder farmers in Africa has been indefinitely delayed.

Prepared by Fabian Haas & Sunday Ekesi (icipe)

Source:

Drew, R.A.I.; Tsuruta, K.; White, I.M. (2005) A new species of pest fruit fly (Diptera: Tephritidae: Dacinae) from Sri Lanka and Africa. African Entomology 13, 149-154.

Mwatawala, M.W.; White, I.M.; Maerere, A.P.; Senkondo, F.J.; De Meyer, M. (2004) A new invasive Bactrocera species (Diptera: Tephritidae) in Tanzania. African Entomology 12, 154-156.

Prepared by Fabian Haas & Sunday Ekesi (*icipe*)

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Case Study 2. Conducting research into classical biological control in India since the Indian Biodiversity Act (2002)

Impatiens glandulifera Royle (Balsaminaceae), commonly known as Himalayan balsam, is a highly invasive plant introduced into the UK in 1839 as a garden plant. Following its escape into the wild it has spread throughout the country, invading wasteland, damp woodland and riparian systems. It is also now invasive in 24 countries in mainland Europe, North America and New Zealand. The plant often forms monocultures where it grows – affecting native biodiversity by outcompeting native plant species. As an annual species, Himalayan balsam dies down in winter leaving riverbanks bare of supporting vegetation and liable to erosion.

Since 2006, Himalayan balsam has been the focus of a CBC (classical biological control) programme in the UK supported by a consortium of national and local departments and organisations. One of the main components of the research has been to survey the plant in its native range (the foothills of the Himalayas from north-west Pakistan to Garhwal in India) and understand the associated natural enemy community. Scientists from CABI have surveyed Himalayan balsam throughout its native range and identified an array of plant pathogens and arthropods which merit evaluation as potential CBC agents in the plant's introduced range. The diversity of natural enemies recorded in the Indian region of the Himalayas is considerably higher than that of similar areas surveyed in Pakistan, and therefore the project and future surveys are now focussing on India.

Exporting biological material from India has become more difficult in recent years since the enactment of the National Biodiversity Act in 2002 (a direct result of India signing the Convention on Biological Diversity). Up until now (2009), it has not been possible to export any genetic material of any form from India under this project. This has mainly been due to lack of understanding of the practical implementation of the new legal instrument by both Indian and international scientists, and the inevitable time-lag involved with this process. This in itself has not greatly delayed the Himalayan balsam project, but has changed the plans to focus more on in-country work than was anticipated at the outset. Thus, in 2009, CABI will conduct host-range testing of potential biological control agents in India in collaboration with Indian partners, with a view to exporting the BCAs into UK quarantine for further specificity and impact testing in 2010.

The delays caused by applying for permission, and following the guidelines and protocols for exporting genetic material from the country have affected the implementation of the research programme. If, however, the complexity of the access issues had been fully understood, a setting-up phase to address this would have reduced the disruption. There are clear provisions and guidelines set out in the Indian Biodiversity Act (http://www.nbaindia.org/) designed to facilitate collaborative research and sharing of genetic resources for scientific purposes. Foreign biological control scientists wishing to survey, identify, study and export biological material from India require collaborators in-country, and prior informed consent from the National Biodiversity Authority of India to export material.

Prepared by Rob Tanner, CABI.

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Case Study 3. Access and benefit sharing legislation blocked biological control of leaf miner in Peru and Europe

The agromyzid pea leaf miner, *Liriomyza huidobrensis* (Blanchard), is native to the cool foothills of the Andes in South America. This fly was not a significant pest in South America until the 1970s, when in response to intensive insecticidal treatment of potatoes and other crops it developed resistance to many insecticides, and became a major pest. The leaf miner was accidentally introduced into Europe, probably on cut flowers, in about 1989–1990 and spread quickly, reaching Israel in 1990–1991. In Europe and Israel there are few parasitoids that attack *L. huidobrensis*, and none that are effective at cool winter temperatures.

Since *L. huidobrensis* is a 'cool weather' pest and was known as a pesticide-induced pest of potatoes in South America, colleagues were contacted at CIP (Centro Internacional de la Papa) in Lima, Peru. A mutually beneficial grant proposal 'Control of the leaf miner, *Liriomyza huidobrensis* in potatoes through IPM' was prepared: Israel would apply its knowledge and experience of control of this pest to the situation in Peru, and joint research would provide the means to look for a good 'cool weather' parasitoid for use in biological control. The project was funded by the United States Agency for International Development from 2001 to 2005 to:

1. Determine the native parasitoid and predator guilds. Written into this section were the methods of collection, and that all unknown species would be sent to an acknowledged world expert for identification.
2. Determine the efficacy of translaminar larvicides on pest and parasitoid populations.
3. Develop an integrated pest management approach, using indigenous predators/parasitoids and insecticides.

Thus, the project foresaw different non monetary benefit-sharing mechanisms including increasing the taxonomy and documentation of known and new species of natural enemies of Peru and improved use by local farmers and national companies of the parasitoids in augmentative biological control.

In the first annual report for this project, it was stated that 15 parasitoids had been sent for identification. However, subsequently new national legislation required scientists in Peru to obtain permission to collect both the pest and its parasitoids in each of Peru's different departments, and no biological material , including dead insects, could be sent out of the country for identification. Yet there was no one in Peru able to identify them. A scientist from CIP went to Argentina to try and learn how to identify the species known there, but becoming an expert taxonomist is something that requires years of experience. By the end of the project, specimens were still unidentified with little prospect of getting them identified. Much of the benefit-sharing in Peru planned under the project could not take place.

Europe and the Mediterranean Basin have been invaded by this polyphagous South American pest. Even though greenhouses in northern Europe are heated in the winter, the commercially available parasitoid species are not completely effective. Greenhouses and tunnels in southern Europe and the Mediterranean Basin are not heated in the winter and the existing parasitoids are even less effective. In classical biological control one searches for beneficial insects in the native country as these are usually the most efficacious, and this was planned and funded in this project. The situation at present is that no new efficacious 'cool weather' parasitoids have become available for use in Europe and chemical treatment must continue.

Prepared by Phyllis G. Weintraub, Agricultural Research Organization, Gilat Research Station, Israel.

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Case Study 4. *Eretmocerus mundus*, a global answer for the global invasive pest *Bemisia tabaci*

Bemisia tabaci Gennadius, the tobacco whitefly, was described in 1889 from specimens collected on tobacco in Greece. Later collections showed it to be present throughout tropical and subtropical regions. For many years it was an inconspicuous pest in many crops. It was only from 1986 onwards that Florida growers of greenhouse crops (especially poinsettia) experienced devastating outbreaks of *B. tabaci* that exhibited biological characteristics not previously recorded for the species. It appeared to be a previously unknown and very aggressive biotype of *Bemisia tabaci* which was spreading very rapidly throughout the southern part of the USA. It was subsequently described as a new species, *B. argentifolia* Bellows & Perring, but this is not universally accepted and, for practical reasons, the complex is simply treated as *B. tabaci* in many pest management situations. The pest spread to greenhouse crops all over the world on poinsettia cuttings, becoming a major threat to many crops.

Concerns about the invasive character of the pest and the huge economic damage in many crops led to a concerted research and action plan to development management methods for *B. tabaci*. Between 1992 and 1998, scientists from the USA and elsewhere searched in over 25 different countries in Africa, Central and South America, the Mediterranean Basin, South and South-east Asia for parasitoids, predators and pathogens of *B. tabaci*. In all, 235 populations were collected of which 56 were cultured for varying lengths of time in support of evaluations conducted in different research programmes. Eventually a few of them were selected for field research. One of the promising candidates was the aphelinid parasitoid *Eretmocerus mundus* Mercet. This is the main species naturally parasitising *B. tabaci* in Kenya, Malawi, southern Europe and the Middle East. In the US states of California, Texas and Arizona, programmes were established to mass rear and release *E. mundus* from Pakistan and Spain for classical biological control of *B. tabaci*. The parasitoid appeared to make a very good contribution to the control of *B. tabaci*. During surveys on weeds and cotton in San Joaquin Valley in California in 2002, the most abundant species found emerging from *B. tabaci* was *E. mundus* (Picket et al. 2008), showing that the introduction of this exotic parasitoid resulted in permanent establishment in the field.

With the increasing interest in biological control of greenhouse pests in Spain, *B. tabaci* control became an issue there too. Attempts to control the whitefly with the aphelinid parasitoids *Encarsia formosa* Gahan and *Eretmocerus eremicus* Rose & Zolnerowich failed, but control was achieved with natural occurring *E. mundus*. This was the start of the mass production of *E. mundus* for seasonal inoculative introduction in greenhouse crops. Nowadays *E. mundus* is sold to and released in many countries in Europe, Asia, North and Central America and northern Africa.

Faced with a global pest of uncertain origin, researchers had to search in many different countries, to understand the natural enemy complex and locate the most effective BCAs. Subsequently, not only was *E. mundus* established in the field following augmentative releases in the USA, but it was also used as a rapid augmentative biological control response to control *B. tabaci*, when other parasitoids were not succeeding in Spain.

Prepared by Johannette N. Klapwijk, Koppert Biological Systems

Sources:

Gerling, D.; Mayer, T. (1995) Bemisia*: Taxonomy, biology, damage, control and management.* Intercept, Andover, UK.

Hoelmer, K.A.; Kirk, A.A. (1999) An overview of natural enemy explorations and evaluations for *Bemisia* in the U.S. *Bulletin OILB/SROP* 22, 109-112.

Picket, C.H.; Simmons, G.S.; Goolsby, J.A. (2008) Releases of exotic parasitoids of *Bemisia tabaci* in San Joaquin Valley, California. Pp. 225-241 in Gould, J.; Hoelmer, K.; Goolsby, J. (eds) *Classical biological control of* Bemisia tabaci *in the United States – a review of interagency research and implementation.* Springer, Dordrecht, The Netherlands.

Stansly P.A.; Calvo, F.J.; Urbaneja, A. (2005) Augmentative biological control of *Bemisia tabaci* biotype "Q" in Spanish greenhouse pepper production using *Eretmocerus* spp. *Crop Protection* 24, 829-835.

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Case Study 5. Problems caused by water hyacinth as an invasive alien species

Water hyacinth, *Eichhornia crassipes* (Mart.) Solms (Pontederiaceae), native to South America, but now an environmental and social menace throughout the Old World tropics, affects the environment and humans in diverse ways. Most of these are detrimental, although some are beneficial or potentially useful. Many of these effects are due to the plant's potential to grow rapidly and produce enormous amounts of biomass, thereby covering extensive areas of naturally open water.

A most striking and little-understood effect of water hyacinth is on aquatic plant community structure and succession. Water hyacinth replaces existing aquatic plants, and develops floating mats of interlocked water hyacinth plants, which are colonised by several semi-aquatic plant species. As succession continues, floating mats dominated by large grasses may drift away or be grounded. This process can lead to rapid and profound changes in wetland ecology, e.g. shallow areas of water will be converted to swamps. In slow-moving water bodies, water hyacinth mats physically slow the flow of water, causing suspended particles to be precipitated, leading to silting. The reduced water flow can also cause flooding and adversely affect irrigation schemes. Water hyacinth acts as a weed in paddy rice by interfering with rice germination and establishment. Water hyacinth is reported to cause substantially increased loss of water by evapo-transpiration compared to open water, although this has recently been challenged. Displacement of water by water hyacinth can mean that the effective capacity of water reservoirs is reduced by up to 400 m^3 of water per hectare, causing water levels in reservoirs to fall more rapidly in dry periods. Water displacement, siltation of reservoirs and physical fouling of water intakes can have a major impact on hydroelectric schemes. Water hyacinth mats are difficult or impossible to penetrate with boats, and even small mats regularly foul boat propellers. This can have a severe effect on transport, especially where water transport is the norm. Infestations make access to fishing grounds increasingly time consuming or impossible, while physical interference with nets makes fishing more difficult or impractical. Some fishing communities in West Africa have been abandoned as a direct result of the arrival of water hyacinth.

Water hyacinth has direct effects upon water chemistry. It can absorb large amounts of nitrogen and phosphorus, other nutrients and elements. It is this ability to pick up heavy metals which has led to the suggestion that water hyacinth could be used to help clean industrial effluent in water. By absorbing and using nutrients, water hyacinth deprives phytoplankton of them. This leads to reduced phytoplankton, zooplankton and fish stocks. Conversely, as the large amounts of organic material produced from senescent water hyacinth decompose, this leads to oxygen deficiency and anaerobic conditions under the floating water hyacinth mats. These anaerobic conditions have been the direct cause of fish death, and changes in the fish community by eliminating most species at the expense of air-breathing species. Stationary mats of water hyacinth also shade out bottom-growing vegetation, thereby depriving some species of fish of food and spawning grounds. The potential impact on fish diversity is enormous. The conditions created by water hyacinth encourage the vectors of several human diseases, including the intermediate snail hosts of bilharzia (schistosomiasis) and most mosquito vectors, including those responsible for transmission of malaria, encephalitis and filariasis. In parts of Africa, water hyacinth mats are reported to provide cover for lurking crocodiles and snakes.

The diversity of impact means that the problems occur in the mandates of diverse ministries. It also means that if classical biological control is successfully implemented, many different sectors of government and society are likely to benefit.

Prepared by Matthew J.W. Cock

Source:

Witttenberg, R.; Cock, M.J.W. (2001) *Invasive alien species: a toolkit of best prevention and management practices.* CABI Publishing, on behalf of the Global Invasive Species Programme, Wallingford, UK.

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Case Study 6. Biological control of a pest of a globally grown plantation crop: coffee

Coffee originated in Africa, but is now grown in many developing tropical countries as a cash crop for export, both by smallholder farmers and by large multi-national plantation groups. Where it is grown with good technical support and infrastructure, even small to medium-sized farms are able to generate good profits, making coffee a major contributor to local economic growth and stability. Equally, as value is added from the farm to the consumer, many other enterprises make profits, and globally this is a multi-billion dollar business. When several major growers such as Brazil and Vietnam have a good harvest, there is over-production, and the price of coffee on the international market can fall substantially. This directly affects the price that the farmer is paid, and in countries which had a poor harvest that year, the short-term adverse financial impact can be dramatic.

Coffee is affected by a variety of insect pests and diseases, the most damaging of which originated in Africa and have since spread to other continents. Biological control is an obvious approach to the economic control of these pests where they have been accidentally introduced. One such case is the scoyltid beetle known as coffee berry borer, *Hypothenemus hampei* Ferrari. The female adult beetles bore into maturing coffee berries, lay their eggs and the resultant larvae develop in the coffee berry. The impact is a combination of quality loss, damaged berries that are still marketable but at a lower price, weight loss, premature fall of berries and the costs of attempted control using pesticides and manual control.

In Africa, coffee berry borer is widespread, but not generally an important constraint. Amongst the reasons for this is a suite of natural enemies, including parasitic wasps of the families Bethyliidae and Eulophidae, which are naturally found in Africa only. Since the first half of the 20th century, efforts have been made to introduce these wasps from Africa into other coffee growing countries, notably Latin America, but more recently Asia. Results have varied, and generally coffee berry borer remains more of a problem outside Africa than in Africa – partly because there are other major constraints to the coffee industry in Africa.

The African source countries could (and perhaps in post-colonial times did) ask themselves why they should help a competing industry by allowing their parasitoids to be exported to what were competing growers, especially since 1989, when coffee competition globalised. For example, around 1990, CABI was facilitating the export of some of these parasitoids from Kenya to Mexico and Colombia. There was no access and benefit sharing mechanism but the work of the CABI centre in Kenya was overseen by a national advisory committee, chaired by a responsible government scientist. The chairman raised exactly this question of why Kenya should help a competing industry. He answered it himself, saying it is because Kenya equally expects to benefit from BCAs (biological control agents) from other countries to protect its crops – and in the case of coffee, the Kenya coffee industry was itself saved in the 1920s by the introduction of a parasitoid of the coffee mealybug, *Planococcus kenyae* (Le Pelley), which was destroying coffee plants east of the Rift Valley.

Thus, although exporting BCAs useful against pests of plantation crops could be seen as helping competing countries, this need not be seen as a loss to the source country, but an opportunity to help others in the expectation of receiving the same support to protect this or other crops.

Prepared by Matthew J.W. Cock

Source:

Jaramillo, J.; Borgemeister, C.; Baker, P. (2006) Coffee berry borer *Hypothenemus hampei* (Coleoptera: Curculionidae): searching for sustainable control strategies. *Bulletin of Entomological Research* 96, 1-12.

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Case Study 7. *Rodolia cardinalis*, an international biological control icon originating from Australia

In 1868, the cottony-cushion scale, *Icerya purchasi* Maskell, was found on acacia in northern California. Ten years later the citrus industry was at the verge of collapse because of the scale. Natural enemies were sought in the native home of the pest, southern Australia, where *I. purchasi* was not causing damage in orchards. This search resulted in the introduction into California in 1888 and 1889 of a coccinellid predator, *Rodolia cardinalis* (Mulsant), since known as the vedalia beetle.

The voracious vedalia beetle rapidly became established and by late 1889 the cottony-cushion scale was no longer regarded as a threat to citrus. *Rodolia cardinalis* provides one of the earliest and most impressive examples of classical biological control. The entire project, from prospection in Australia to introduction in California, cost less than US$ 2,000 (between US$50,000 and US$250,000 today). Nevertheless, the exotic BCA (biological control agent) saved the American citrus industry. This case is considered by many to "mark the beginning of the practice of BC (biological control) as an effective pest control strategy" (Greathead 1995).

The Australian cottony-cushion scale has spread throughout most of the subtropical and tropical regions of the world, developing into a pest of many fruit (citrus, mango, guava) and shade trees. The pioneering and successful case of the control of the scale in California led to introductions of *R. cardinalis* into some 57 countries. Establishment of the vedalia beetle and good control, achieved by it alone or together with other native or introduced species of natural enemies, have been reported in most instances. Furthermore, following its release against the cottony-cushion scale, *R. cardinalis* has been shown to control other species of scales; for example, *I. palmeri* Riley & Howard and *I. montserratensis* Riley & Howard in Chile and Ecuador, respectively. In most of these cases, the beetle was re-collected in various countries and re-released in new areas. Although southern Australia provided the first shipment of beetles, it did not remain the unique supplier once *R. cardinalis* had been established throughout the world.

Rodalia cardinalis has become an icon in BC. Its introduction in California at the end of the19th century has become the most widely known BC triumph. This case study further illustrates that successful BCAs may become 'citizens of the world' and be re-collected in different countries to be re-released elsewhere.

Prepared by Jacques Brodeur

Sources:

De Bach, P. (1964). *Biological control of insect pests and weeds*. Chapman & Hall. London.

Greathead, D.J. (1995) Benefits and risks of classical biological control. Pp. 53–63 in Hokkanen, H.M.T.; Lynch, J.M. (eds) *Biological control: benefits and risks*. Cambridge University Press, Cambridge, UK.

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Case Study 8. The classical biological control of a cassava mealybug in Brazil

The cassava mealybug, *Phenacoccus herreni* Cox & Williams, was described in 1981 from Guyana and northern South America during South American surveys for *P. manihoti* Matile-Ferrero and its natural enemies (Case Study 14). It had been misidentified from Brazil as *P. manihoti* following its discovery in the 1970s infesting a cassava (*Manihot esculenta* Crantz; Euphorbiaceae) germplasm bank in Belém, Pará State, and this was corrected following the description of *P. herreni*. Its presence in Belém probably resulted from transportation of cassava stems from Amapá State, bordering French Guiana. The infestation spread to commercial areas of cassava production in the Paraiba and Pernambuco states of north-east Brazil in the early 1980s, soon causing losses of up to 80%. It spread to neighbouring states, such as Ceará and Bahia, from 1985 to 1987, and by 1990 it was recorded from seven out of the nine states of north-east Brazil. In the 1990s, infestations were so high that cassava production ceased to be viable in some areas of Pernambuco and Bahia, affecting one of the major agroecosystems of north-east Brazil.

An initiative involving several Brazilian research institutions and governmental agencies, supported by UNDP (United Nations Development Programme) led to a search for exotic natural enemies that could be introduced for the control of *P. herreni*. Three encyrtids were imported from 1994 to 1995: *Acerophagus coccois* Smith and *Aenasius vexans* (Kerrich) from Venezuela, and *Apoanagyrus diversicornis* (Howard) from Colombia. They were sent to the EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária) 'Costa Lima' Quarantine Laboratory and, once importation was cleared, shipped to the EMBRAPA research centre at Cruz das Almas (Bahia) were they were mass produced and later released in infested areas.

Over 35,000 of the three parasitoid species were released from 1994 to 1996, leading to the establishment and dispersal of natural enemies, with some of them being found as far as 550 km away from the initial release site 33 months later. The establishment of these natural enemies reduced the infestation level of the cassava mealybug from nearly 12 to less than two mealybugs per shoot, allowing the re-establishment of the cassava agroecosystem in the region.

Thus, in contrast to the classical biological control programme against *P. manihoti* (Case Study 14), the natural distributions of *P. herreni* and some of its parasitoids were already known, as a direct result of the search for biological control agents to send to Africa for CBC of *P. manihoti* – an unanticipated benefit to Brazil, one of the source countries for BCAs of *P. manihoti*.

Prepared by Fernando L Cônsoli & José Roberto Postali Parra

Sources:

Bento, J.M.S.; Moraes, G.J.; Matos, A.P.; Warumby, J.F.; Bellotti, A.C. (2002) Controle biológico da cochonilha da mandioca no Nordeste do Brasil. Pp. 395-408 in Parra, J.R.P.; Botelho, P.S.M.; Corrêa-Ferreira, B.S.; Bento, J.M.S. (eds) *Controle biológico no Brasil: parasitóides e predadores*. Ed. Manole, São Paulo, Brazil.

Cox, J.M.; Williams, D.J. (1981) An account of cassava mealybugs (Hemiptera: Pseudococcidae) with a description of a new species. *Bulletin of Entomological Research* 71, 247-258.

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Case Study 9. The successful importation and use of *Ageniaspis citricola* from South-east Asia via the USA for controlling the citrus leaf miner *Phyllocnistis citrella* in Brazil

The citrus leaf miner moth, *Phyllocnistis citrella* Stainton (Gracillariidae), was first recorded in Brazil in March 1996, causing direct damage by feeding and indirect damage by facilitating the spread of the canker bacterium in citrus orchards. In 1998, an initiative of governmental agencies (EMBRAPA; Empresa Brasileira de Pesquisa Agropecuária), researchers at public and private institutions and commercial producers, with the collaboration of Dr Marjorie Hoy (Florida University), imported the encyrtid parasitoid *Ageniaspis citricola* Logvinovskaya from the USA (Florida), where it had been introduced as a CBC BCA from Australia, where it had been introduced from Thailand. The process of importation was handled through the 'Costa Lima' Quarantine Laboratory (EMBRAPA), and once the imported insects were released from the quarantine laboratory, research efforts were concentrated in developing a rearing system to allow for the production of a large number of insects to be released in infested areas.

The first adults of *A. citricola* were released in October 1998 in citrus orchards of Nova Granada and Descalvado, both in the State of São Paulo. Augmentative releases were consistently done until 2004, by then close to one million parasitoids had been released in the main citrus growing areas of São Paulo and nine other states. The parasitoid became well adapted even in areas of lower temperature, yielding very high levels of parasitism. In 2004, the natural parasitism of the citrus leaf miner by *A. citricola* ranged from 17.8% in the south to 81.1% in the north of São Paulo State. Natural parasitism even reached 100% in Santa Catarina State.

A rapid decline in the population of *P. citricola* was observed after the successful introduction of *A. citricola* from Australia via the USA to São Paulo State, with reduction in leaf damage and incidence of citrus canker.

Prepared by José Roberto Postali Parra & Fernando L Cônsoli

Sources:

Chagas, M.C.M.; Parra, J.R.P.; Namekata, T.; Hartung, J.S.; Yamamoto, P.T. (2001) *Phyllocnisits citrella* Stainton (Lepidoptera: Gracillariidae) and its relationship with the citrus canker bacterium *Xanthomonas axonopodis* pv *citri* in Brazil. *Neotropical Entomology* 30, 55-59.

Chagas, M.C.M.; Parra, J.R.P.; Milano, P.; Nascimento, A.M.; Parra, A.L.G.C.; Yamamoto, P.T. (2002) *Ageniaspis citricola*: criação e estabelecimento no Brasil. Pp. 377-394 in Parra, J.R.P.; Botelho, P.S.M.; Corrêa-Ferreira, B.S.; Bento, J.M.S. (eds) *Controle biológico no Brasil: parasitóides e predadores*. Ed. Manole, São Paulo, Brazil.

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Case Study 10. Early example of a collect-and-ship project: citrus blackfly in Cuba, 1930

The aphelinid parasitoid wasp *Eretmocerus serius* Silvestri was introduced into Cuba in early summer 1930 to control the citrus blackfly, *Aleurocanthus woglumi* Ashby. The parasitoid was obtained from Singapore and the introduction of *E. serius* was made into citrus groves around Havana in early summer. Establishment and spread were so rapid that within one year complete control occurred at locations where releases had been made. Results were dramatic: pest populations declined from over 100 million citrus blackflies per 2 ha in infested groves to only a few individuals per tree. By 1932–1933 complete control of the pest in Cuba was achieved. Populations of *E. serius* were then relocated to several other Caribbean islands and Central American countries where similarly dramatic results were achieved.

The citrus blackfly was identified as a pest in the Caribbean and Central America in 1913–1919. Eradication failed and spraying programmes were not effective, and classical biological control was considered to be the only real option. The focus of the biological control programme was to find effective parasitoids and predators, determine which were most effective and ship these to the target area as soon as possible. Major concerns included survival of natural enemies during lengthy sea voyages and the risk of introducing citrus diseases into the target country. Surveys were made in South-east Asia, the area of origin of *A. woglumi*, in 1929-1931. Of the four parasitoid and one predator species collected in the first surveys in Malaya (now West Malaysia), Java and Sumatra, three parasitoid species were considered to be effective and these were shipped first. Later shipments also included two predatory species. *Eretmocerus serius* was the only species to survive shipping conditions, establish in the field, and build up populations to control the target pest over time. The founder population of the first shipment in 1930 consisted of 42 females and 19 males, some of which were released. The second shipment was more successful, and from then on the parasitoid rapidly built up numbers in the insectary and in the field.

In those days, regulation was less restrictive than today, and introductions of BCAs (biological control agents) were easy to make – so much so that it was simpler to try a BCA and see if it worked (the so-called shot-gun approach), rather than do the studies necessary to assess its ecology and safety so that a more confident prediction could be made. Thus, although there were some spectacular successes like this one, there were also many poorly documented failures.

Prepared by Peter G. Mason

Source:

DeBach, P.; Rosen, D. (1991) *Biological control by natural enemies*. Cambridge University Press, Cambridge, UK.

Clausen, C.P. (1978) *Introduced parasites and predators of arthropod pests and weeds: a world review.* Agricultural Handbook No. 480. United States Department of Agriculture, Washington DC, USA.

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Case Study 11. Biological control of water weeds

In the last 60 years, three water weeds of South American origin have stood out as problems in the Old World tropics: water hyacinth, *Eichhornia crassipes* (Mart.) Solms (Pontederiaceae), salvinia fern, *Salvinia molesta* Mitchell (Salviniaceae) and water lettuce, *Pistia stratiotes* L. (Araceae). All have been the targets for programmes of BC (biological control) in developed countries, each of which has had significant or substantial impact, and each of which has been repeated successfully in developing countries.

These three weeds frequently occur together, and when they do so, water hyacinth normally is the most dominant, and water lettuce is the least dominant. Any of the three species will dominate the indigenous flora and take over calm and slow-moving open water. Accordingly, it is often recommended that BC of all three weeds should be considered together. *Salvinia molesta* was first described from Africa, when it was thought to be a hybrid between the South American *S. auriculata* Aubl. and an indigenous African species. In 1969–79, initial attempts at BC by introducing natural enemies from the closely related *S. auriculata* in South America were not very successful. It was only when *S. molesta* was discovered as an indigenous species in south-east Brazil, and the associated weevil, *Cyrtobagous salviniae* Calder & Sands, was introduced into Australia in 1980, that successful control was achieved. This weevil has now been introduced into Australia, India, Kenya, Malaysia, Namibia, Papua New Guinea, South Africa, Sri Lanka and Zambia. Everywhere it has been released it has provided effective and often spectacular control of salvinia fern in a matter of months.

BC of water hyacinth, native to South America but now an environmental and social menace throughout the Old World tropics, is still the subject of active research. Since 1971, two South American weevils, *Neochetina eichhorniae* Warner and *N. bruchi* Hustache, have been widely introduced into Australia, Asia and Africa. In some areas they have provided substantial control, but this is not consistent in all areas. Water nutrient status, average temperature, winter temperatures and other factors probably affect their impact. The search for new insects and pathogens to use as biological control agents continues, and recent discoveries in the Upper Amazon suggest better control may yet be achieved.

The BC of water lettuce has by comparison proved relatively straightforward. Although there are doubts about the true origin of the plant, its richest associated diversity of natural enemies occurs in South America, and one of these, the weevil *Neohydronomus affinis* (Hustache), was selected and introduced into Australia in 1982, giving good control within two years. This success has been repeated in Botswana, Papua New Guinea, South Africa, the USA and Zimbabwe.

Biological control of water weeds provides a clear demonstration of how developing countries can easily benefit from the substantial investments made in BC by developed countries.

Prepared by Matthew J.W. Cock

Source:

Witttenberg, R.; Cock, M.J.W. (2001) *Invasive alien species: a toolkit of best prevention and management practices.* CABI Publishing, on behalf of the Global Invasive Species Programme, Wallingford, UK.

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Case Study 12. Biological control of *Chromolaena odorata* using cultures of *Pareuchaetes pseudoinsulata* from countries where it had been introduced and established

Chromolaena odorata (L.) King & Robinson (= *Eupatorium odoratum*) is a perennial, sprawling Asteraceae shrub native to the Caribbean and Central and South America. It is a serious problem as an introduced weed in western Africa, South Africa, South and South-east Asia and Micronesia, particularly in plantation crops such as coconut, rubber, oil palm, tea and teak, as well as pasture and fallow land. It impedes access to the crop and, during die-back after flowering, can constitute a fire risk, particularly in areas with a pronounced dry season.

In 1968, studies on its natural enemies started in Trinidad, West Indies. One of the natural enemies recommended for use as a biological control agent was an arctiid moth, *Pareuchaetes pseudoinsulata* Rego Barros. In the early 1970s, this moth was released in several countries but became established only in Sri Lanka and Malaysia.

Cultures of moths from Trinidad were set up but could not be maintained successfully in Trinidad because of affliction by a nuclear polyhedrosis virus. Therefore, eggs were sent to India in 1970 and a culture was successfully established there. Extensive releases were made in 1973–74 at several sites in Karnataka but no establishment occurred.

Material was taken from the Indian culture to culture and release in Sri Lanka. It became established from the first releases and caused widespread but sporadic defoliation.

In 1984, releases started again in India, this time from a culture that was established from material collected in Sri Lanka. This led to establishment at one location in Kerala and another in Karnataka, but not elsewhere. In Karnataka the moth dispersed over more than 1,000 square kilometres within ten years resulting in pockets of defoliation.

A culture was set up in Guam using mixed material from Trinidad and the new culture in India. Releases starting in 1985 led to the moth becoming established and widespread, providing successful control and causing 100% defoliation in some areas. By 1989 this weed was no longer the predominant weed species in Guam.

Pareuchaetes pseudoinsulata from Guam was then released in the Pacific (Federated States of Micronesia, Northern Mariana Islands, Palau), South-east Asia (Indonesia, Thailand, Vietnam) and Africa (Côte d'Ivoire, Ghana, South Africa) with varying success.

Thus, the early releases of material brought into culture in Trinidad were only successful in Sri Lanka, and it was only once the moth was taken back into culture from the Sri Lanka field population that it started to become established and provide control in other areas. However, the most widely distributed population is the one that was established in Guam, based on a mixture of moths from Trinidad and Sri Lanka. The original genetic resources were from Trinidad and Tobago; the bottleneck of establishment in Sri Lanka probably made it more effective, and there was a second bottleneck in Guam before the moth was more widely distributed. The final genetic stock being released owed something to all three countries, but the relative importance of each would be very difficult to establish objectively.

Prepared by Matthew J.W. Cock

Source:

Zachariades, C.; Day, M.; Muniappan, R.; Reddy, G.V.P. (2009) *Chromolaena odorata* (Asteraceae) and its biological control. Pp. 130-162 in Muniappan, R.; Reddy, G.V.P.; Raman, A. (eds) *Biological control of tropical weeds using arthropods*. Cambridge University Press, Cambridge, UK.

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Case Study 13. Over thirty years of successful release of a natural enemy: *Cotesia flavipes*

Brazil, one of the largest producers of sugarcane, has a long-term tradition of fighting a major pest, the sugarcane borer *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae). Biological control of the sugarcane borer dates from the early 1950s, with the use of native tachinid flies, *Lydella minense* (Townsend) and *Paratheresia claripalpis* (Wulp). Later, another tachinid, *Lixophaga diatraeae* (Townsend), was imported from Cuba and introduced in an attempt to improve on parasitism achieved by the native species. However, *L. diatraeae* became established only in very humid areas such as in the northern states of Brazil, e.g. Amapá.

Cotesia flavipes (Cameron) (Hymenoptera: Braconidae) was first introduced into Brazil by Copersucar and the Department of Entomology, ESALQ/USP (Escola Superior de Agricultura 'Luiz de Queiroz'/Universidade de São Paulo) in 1971. However, the release programme was not successful because of a lack of reliable mass-rearing techniques for both the host and its natural enemy. A second attempt to introduce this parasitoid was made in April 1974, when specimens were imported from Trinidad and Tobago and released in the state of Alagoas by Planalsucar (a former government institution now part of the Federal University of São Carlos). After successful establishment, from 1974 to 1976 the parasitoid was taken to six states of north-eastern Brazil to control the borers *D. saccharalis* and *D. flavipenella* Box*,* and to São Paulo and Amapá for *D. saccharalis*. In 1978, with the collaboration of Dr F.D. Bennett (CABI), a third introduction of *C. flavipes* from cooler humid areas in India and Pakistan was also made.

The impact of *C. flavipes* was improved in the 1980s with the development of rearing techniques that allowed mass production of the parasitoid. Repeated release of this natural enemy reduced the infestation levels of the sugarcane borer in São Paulo State from 10%, which corresponds to losses of US$ 100 million/year, to 2% (= US$ 10 million/year).

Today, *C. flavipes* is produced by several private companies and sugar mill laboratories, and released over two million hectares. *Diatraea saccharalis* is also controlled by the release of the egg parasitoid *Trichogramma galloi* Zucchi (Hymenoptera: Trichogrammatidae) in areas with a low incidence of egg predators or in dry areas where *C. flavipes* has shown a reduced efficacy.

Thus, *C. flavipes* was originally introduced as a BCA (biological control agent) for classical biological control from several different sources, but subsequently the established population was mass produced, distributed and sold as a BCA for augmentative biological control.

Prepared by José Roberto Postali Parra & Fernando L Cônsoli.

Sources:

Botelho, P.S.M.; Macedo, N. (2002) *Cotesia flavipes* para o controle de *Diatraea saccharalis.* Pp. 409-426 in Parra, J.R.P.; Botelho, P.S.M.; Corrêa-Ferreira, B.S.; Bento, J.M.S. (eds) *Controle biológico no Brasil: parasitóides e predadores*. Ed. Manole, São Paulo, Brazil.

Parra, J.R.P.; Zucchi, R.A. (2004) Trichogramma in Brazil: feasibility of use after twenty years of research. Neotropical Entomology 33, 271-281.

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Case Study 14. The search for a natural enemy of the cassava mealybug

Cassava (*Manihot esculenta* Crantz; Euphorbiaceae) is a crop of South American origin now grown as an important staple in many parts of the tropics. In Africa it is an essential staple crop for several hundred million people. This came under threat, when a new pest appeared in the 1970s in Zaire (now Democratic Republic of the Congo) and the Republic of Congo. The new pest, unchecked by natural enemies, found ideal conditions to multiply explosively and cassava crops were devastated. It quickly spread throughout all cassava producing regions in Africa, and threatened the food security of over 200 million people.

The pest was a new species of mealybug, which was described in 1977 as *Phenacoccus manihoti* Matile-Ferrero from African material, and subsequently became known as the cassava mealybug. Up until its discovery in Africa, this species had never been recorded causing damage anywhere in the world. Because it seemed specialised on cassava, it was assumed that the pest's origin, like cassava, was Neotropical. Since it had not been recorded in that region, it was presumed it was probably under good natural biological control, and there was a priori a good opportunity for a classical biological control programme.

Narrowing down the location was not possible at this early stage of the research, so it was therefore necessary to survey the whole indigenous range of cassava, from Central America and the Caribbean to Paraguay. An international research survey programme started with IITA (International Institute for Tropical Agriculture) searching in Central America and CABI working out of its base in Trinidad searching the Caribbean and northern South America. Later, CIAT (Centro Internacional de Agricultura Tropical) and EMPRAPA (Empresa Brasileira de Pesquisa Agropecuária) were involved, and surveys extended to Paraguay, Bolivia and Brazil.

The search for *P. manihoti* did not meet immediate success. Polyphagous species of *Phenacoccus* were quickly found, and then a mealybug was found on cassava in northern South America, from Colombia to north-eastern Brazil, causing similar symptoms to *P. manihoti*, but this proved to be another species new to science, and was described as *P. herreni* Cox & Williams in 1981.

The search continued until finally *P. manihoti* was located in Paraguay. Further surveys showed that it was restricted to a small area of Paraguay, Bolivia and south-west Brazil. Associated parasitoids were present, and subsequently used in the flagship success against cassava mealybug in Africa (Case Study 17).

Thus, surveys were made in several different countries yielding only negative data with regard to the target pest over a period of years, before the pest was finally located in its natural habitat. Only then was there an opportunity for significant shared research, which was undertaken in Brazil.

In this particular example, one of the biggest beneficiaries of the wide-ranging survey programme was Brazil itself (Case Study 8).

Prepared by Fabian Haas & Matthew J.W. Cock

Sources:

Cox, J.M.; Williams, D.J. (1981) An account of cassava mealybugs (Hemiptera: Pseudococcidae) with a description of a new species. *Bulletin of Entomological Research* 71, 247-258.

Löhr, B.; Varela, A.M.; Santos, B. (1990) Exploration for natural enemies of the cassava mealybug, *Phenacoccus manihoti* (Homoptera: Pseudococcidae), in South America for the biological control of this introduced pest in Africa. *Bulletin of Entomological Research* 80, 417-425.

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Case Study 15. Indigenous leaf miner parasitoids for augmentative biological control in Europe

The usual approach for developing BC (biological control) of an exotic pest is to travel to the area of origin of the pest, collect natural enemies and evaluate their capacity to reduce pest populations to below the damage threshold. However, sometimes the solution for control of an exotic pest can be found in an area where the pest was accidentally imported and has established. In The Netherlands, several leaf miner species are potential pests of various vegetables and ornamental crops, but they usually do not create serious problems, probably because they are under natural BC. When, at the end of the 1970s, a new agromyzid leaf miner species from the USA, *Liriomyza trifolii* Burgess, had entered The Netherlands, the Ministry of Agriculture first tried to eradicate the pest by requiring growers to spray pesticides up to three times per week. These sprays interfered with the existing IPM (integrated pest management) programme against greenhouse pests. After a few months it became clear that eradication of *L. trifolii* was not possible, but frequent sprays remained necessary to reduce pest numbers. At the same time, BC researchers tried to develop a quick solution for this pest by putting plants infested with leaf miner in woody, semi-natural areas. After exposure in the field, the plants were brought into the laboratory and all leaf miner larvae and pupae were kept until emergence. Several species of parasitoids emerged from the leaf miner pupae, and three species (a eulophid, *Diglyphus isaea* (Walker), and two braconids, *Dacnusa sibirica* Telenga and *Opius pallipes* Wesmael) showed promise for effective control of the leaf miner.

Within a few years, a mass-rearing and release method was developed, and the successful IPM programmes developed for greenhouse crops could be used again. About a decade later, another leaf miner species (*L. huidobrensis* (Blanchard)) accidentally entered The Netherlands from the USA and became established. Luckily, two of the parasitoids being used against *L. trifolii*, *D. sibirica* and *Diglyphus isaea*, attacked this new leaf miner species and were able to control it. Since then, these natural enemies have been used all over Europe, as well as in Africa and Latin America.

It can be concluded that (1) it is not always necessary to seek biological control agents in the area of origin of the pest in order to find an effective natural enemy, and (2) some natural enemies collected in temperate areas of Europe can be used in many other areas in the world.

Prepared by Joop C. van Lenteren

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Lenteren, J.C. van; Woets, J. (1988) Biological and integrated pest control in greenhouses. *Annual Review of Entomology* 33, 239-269.

Lenteren, J.C. van (2003) Commercial availability of biological control agents. Pp. 167-179 in Lenteren, J.C. van (ed) *Quality control and production of biological control agents: theory and testing procedures*. CABI Publishing, Wallingford, UK.

Minkenberg, O.P.J.M.; Lenteren, J.C. van (1986) The leafminers *Liriomyza bryoniae* and *L. trifolii* (Diptera: Agromyzidae), their parasites and host plants: a review. *Wageningen Agricultural University Papers* 86(2), 1-50.

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Case Study 16. Supply of natural enemies for biological control of pink hibiscus mealybug in the Caribbean: the rapid and simple supply of a known biological control agent

Pink hibiscus mealybug, *Maconellicoccus hirsutus* Green, is native to parts of Asia, but has been introduced to other parts of the tropics. It was first reported in the Caribbean in Grenada in 1994, and subsequently spread to at least 25 territories in the region. Pink hibiscus mealybug attacks the new flush growth, young shoots, flowers and fruits of a wide range of plants, particularly those in the family Malvaceae. Important hosts include ornamental hibiscus (*Hibiscus rosa-sinensis* L.), blue mahoe (*Hibiscus elatus* Sw., an important indigenous watershed tree in Grenada), samaan (*Samanea saman* (Jacq.) Merril), teak (*Tectona grandis* L. f.), soursop, ochro, sorrel (*Hibiscus sabdariffa* L.), cotton, cocoa and citrus. Damage on these hosts was often substantial, including loss of fruit, defoliation, and death of plants.

Pink hibiscus mealybug had been the subject of a successful BC (biological control) programme in Egypt, is the target of ongoing augmentative efforts in India, and was fortuitously controlled in Hawaii when it was introduced with its natural enemies. Based on this background, two natural enemies were introduced into Grenada: a narrowly host-specific encyrtid wasp (*Anagyrus kamali* Moursi) and a polyphagous coccinellid mealybug predator (*Cryptolaemus montrouzieri* Mulsant), although other BCAs (biological control agents) were introduced later. Both became established and good control in most situations was rapidly achieved. The programme was considered an outstanding success.

The wasp was obtained by CABI as part of an FAO regional support programme, and supplied to affected countries. Having considered various possibilities for obtaining the parasitoid, CABI approached colleagues in China, a member country of CABI, with good experience in BC. The original culture was provided by the Guangdong Entomological Institute, China, under a small contract with CABI to collect, arrange export clearance and air-freight parasitised mealybugs to CABI's UK quarantine facility. A culture of mealybugs was set up in quarantine, and contaminants and hyperparasitoids removed, before material was taken to the Caribbean for culture and release.

No other research was necessary to implement the programme, although improved rearing, release and assessment methods were subsequently developed. Thus, in this case of using a known BCA, there was no real opportunity for benefit sharing with China. On the other hand, there was an unintentional public relations success: *Anagyrus kamali* soon became known in the Caribbean as the 'Chinese wasp' creating a very positive association with the successful control of the mealybug.

A few years later, the Caribbean was able to directly reciprocate, by agreeing to the use of a rust fungus from Trinidad for weed BC in China. This was a fortuitous bilateral exchange, and demonstrates that sometimes a direct equivalence can be found.

These examples also demonstrate the long-standing tradition of collaboration and cooperation of BC scientists around the world to use biodiversity to create public good.

Prepared by Matthew J.W. Cock

Source:

Kairo, M.T.K.; Pollard, G.V.; Peterkin, D.D.; Lopez, V.F. (2000) Biological control of the hibiscus mealybug, *Maconellicoccus hirsutus* Green (Hemiptera: Pseudococcidae) in the Caribbean. *Integrated Pest Management Reviews* 5, 241-254.

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Case Study 17. Saving millions of cassava smallholder farmers in Africa

Cassava, yucca or manioc (*Manihot esculenta* Crantz; Euphorbiaceae) was introduced from South America into Africa by the Portuguese in the 16th century and today is a staple root crop for more than 200 million people in Africa alone. This major source of carbohydrates came under threat from a devastating pest, the cassava mealybug (*Phenacoccus manihoti* Matile-Ferrero).

The cassava mealybug was first recorded in Congo and Zaire (now Democratic Republic of the Congo) in the early 1970s. It remains unclear how cassava mealybug crossed the Atlantic from its home range in South America to Africa, but increasing trade provided enough opportunity for transport even across large distances. Once in Africa, since there were no natural enemies to control it in its new habitat, cassava mealybug quickly spread through the whole cassava growing area, causing cassava production to collapse.

In a combined effort involving IITA (International Institute of Tropical Agriculture), CABI, IAPSC (Inter-African Phytosanitary Council) and other agencies, biological control agents were found in three South American countries (Paraguay, Brazil and Bolivia) following extensive surveys (Case Study 14). A parasitoid wasp *Anagyrus lopezi* (DeSantis) (Encyrtidae) was quarantined in the UK, shipped to Africa, mass reared, and finally, after the local authorities granted permission, released in field trials. The operation was so successful that throughout sub-Saharan Africa cassava mealybug is now under complete control and no longer poses a threat to cassava production.

Besides the successful control of cassava mealybug, this joint effort led to close South-South and international cooperation and to a significant increase in the capacities in biological control and agricultural entomology in sub-Saharan Africa. In fact, it is no exaggeration to say that practically all African agricultural entomologists of that generation were educated through this programme. The programme cost, according to Swindale (1997) about US$ 27 million, while the benefits are estimated at US$ 4.5 billion (10^8)!

The beneficiaries are the millions of cassava growing smallholders who – often unaware of the programme or the parasitoid wasp – enjoy the fruits of this work. Food security has been increased through improved harvests and health through reduced pesticide use, both of which come at no cost to the smallholders, who nevertheless receive the full benefits.

Prepared by Fabian Haas

Sources:

Neuenschwander, P. (2003) Biological control of cassava and mango mealybugs in Africa. Pp. 45-59 in Neuenschwander, P.; Borgemeister, C.; Langewald, J. (eds) *Biological control in IPM systems in Africa*. CABI Publishing, Wallingford, UK.

Swindale, L.D. (1997) The globalization of agricultural research: a case study of the control of the cassava mealybug in Africa. Pp. 189-194 in Bonte-Friedheim, C.; Sheridan, K. (eds) *The globalization of science: the place of agricultural research.* ISNAR, Den Haag, The Netherlands.

Wikipedia (2009) http://en.wikipedia.org/wiki/Cassava

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Case Study 18. *Amblyseius swirskii*, an exotic solution for an endemic problem

The two most important pests of greenhouse sweet peppers, cucumbers and eggplants (aubergines) are western flower thrips, *Frankliniella occidentalis* (Pergande), and whiteflies, *Trialeurodes vaporariorum* (Westwood) and/or *Bemisia tabaci* (Gennadius), depending on the area of the world. They can be especially damaging because they can transmit different plant viruses and because they quickly develop resistance to pesticides. The predatory mite *Amblyseius cucumeris* (Oudemans) has been used against western flower thrips in these crops for many years. In addition, flower bugs (*Orius* spp.) are released in sweet peppers and eggplants. Different species of aphelinid parasitoids are used against whiteflies (*Encarsia formosa* Gahan, *Eretmocerus eremicus* Rose & Zolnerowich and *Eretmocerus mundus* Mercet). In areas with high pest pressure, large numbers of natural enemies have to be released frequently in order to attain sufficient control. This often leads to prohibitively expensive IPM (integrated pest management) programmes.

Research in The Netherlands by two research institutes and a private company showed that the predatory phytoseiid mite *Amblyseius swirskii* Athias-Henriot was a highly effective against whiteflies and much more effective against western flower thrips than *A. cucumeris*. This predatory mite occurs naturally in the coastal areas of the eastern Mediterranean. The development of a highly economic mass-rearing technology means that large numbers of the predator can be produced. *Amblyseius swirskii* was introduced commercially in January 2005. Because of its efficacy against whiteflies and thrips, it quickly replaced the use of *A. cucumeris* and parasitoids in sweet peppers, cucumbers and eggplants.

In Almería, Spain, about 7,000 hectares of sweet peppers are grown in plastic greenhouses, among thousands of hectares of other greenhouse vegetables such as tomatoes, cucumbers and eggplants. The pest pressure in this area can be extremely high. Biological control was virtually unused in Almería because the growers deemed it too expensive and too difficult to implement. Owing to the development of pesticide resistance, growers were spraying more and more frequently, using increasingly high doses of pesticides to control mainly whiteflies and thrips. In 2006 a study by Greenpeace Germany revealed that there was a significant food safety issue with sweet peppers from Almeria owing to pesticides substantially exceeding the maximum residue levels and the use of illegal insecticides. Action taken by European supermarkets immediately compelled the Spanish greenhouse peppers growers to find an alternative solution. IPM and biological control were the only option for the farmers to stay in business. In 2007, more than 75% of the pepper growers of Almería changed to biological control. This was only possible because of the availability of a simple and economic but highly effective IPM programme based on the use of *A. swirskii* and *O. laevigatus*. Today more than 95% of the pepper growers in Almería use biological control and achieve much better control of their pests than they achieved in the past with chemical control.

Amblyseius swirskii is now used in many countries around the world as the cornerstone of simple and economic but highly effective biological control programmes.

Prepared by Karel J.F. Bolckmans

Sources:

Bolckmans, K.; Houten, Y. van; Hoogerbrugge, H. (2005) Biological control of whiteflies and western flower thrips in greenhouse sweet peppers with the phytoseiid predatory mite *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae). Pp. 555-565 in Hoddle, M.S. (compiler) *Second International Symposium on Biological Control of Arthropods*, Davos, Switzerland, 12-16 September 2005. USDA Forest Service Publication FHTET-2005-08. Forest Health Technology Team, Morgantown, West Virginia, USA. (http://www.fs.fed.us/foresthealth/technology/pdfs/2ndSymposiumArthropods05_08V1.pdf)

Nomikou, M.; Janssen, A.; Schraag, R.; Sabelis, M.W. (2001) Phytoseiid predators as potential biological control agents for *Bemisia tabaci*. *Experimental & Applied Acarology* 25, 271-291.

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Case Study 19. Biological control of orthezia scale in St Helena: a public good

St Helena is a small isolated oceanic island in the Atlantic. It is a globally important centre of endemism, in spite of being heavily degraded due to destruction of habitat and invasion of alien species. One of the main habitat types on higher ground was gumwood forests, dominated by the endemic gumwood *Commidendrum robustum* DC (Asteraceae), but only two significant stands remained in recent decades.

Orthezia (*Orthezia insignis* Browne), a South American fluted scale insect, appeared in St Helena in the 1970s or 1980s probably as a contaminant of food produce from South Africa. It is a highly polyphagous species, attacking indigenous and exotic plants from many families, including both important endemics such as the gumwood, and agricultural and garden plants. The infestation of gumwoods started in 1991 and was particularly severe, so much so that 400 of the remaining 2000 trees had been killed by 1993 and the remaining stands of gumwood forest were under threat of rapid extinction due to this exotic species.

Fortunately, between 1908 and 1959 successful biological control programmes had been carried out against this pest in several countries using the predatory ladybird beetle *Hyperaspis pantherina* Fürsch, so a solution was known. A culture of the ladybird was imported from Kenya and released. It established and rapidly brought the orthezia populations down to a low level. The rapid response almost certainly saved the gumwood forest from extinction.

This successful project brought orthezia under control in the target ecosystem (endemic gumwood forest), providing a more or less pure public good with no financial benefits.

Prepared by Matthew J.W. Cock

Source:

Fowler, S.V. (2005) The successful control of *Orthezia insignis* on St. Helena island saves natural populations of endemic gumwood trees, *Commidendrum robustum*. Pp. 52-63 in Hoddle, M.S. (compiler) *Second International Symposium on Biological Control of Arthropods,* Davos, Switzerland, 12-16 September 2005. USDA Forest Service Publication FHTET-2005-08. Forest Health Technology Team, Morgantown, West Virginia, USA. (http://www.fs.fed.us/foresthealth/technology/pdfs/2ndSymposiumArthropods05_08V1.pdf).

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Case Study 20. Biotypes of pest weevil parasitoids introduced into New Zealand

The weevil *Sitona discoideus* Gyllenhal is an introduced pest of lucerne and other *Medicago* species in New Zealand. The adults feed on the foliage, but the larva is the most damaging stage, feeding on and destroying root nodules and placing the plants under nitrogen stress. A braconid parasitoid, *Microctonus aethiopoides* Loan, was introduced into New Zealand in 1982 for classical biological control of *S. discoideus*. The parasitoid was initially accessed from Morocco by CSIRO (Commonwealth Scientific and Industrial Research Organisation) for use in Australia and was later passed on to New Zealand. It established successfully in all parts of New Zealand where lucerne was grown. When another species of *Sitona*, the clover root weevil, *S. lepidus* Gyllenhal, was discovered in New Zealand in 1995, laboratory tests were carried out to determine whether *M. aethiopoides* would be a suitable BCA (biological control agent) for this pest. Unfortunately this proved not to be the case, with only very low levels of parasitism of *S. lepidus* occurring with the already established Moroccan parasitoid biotype.

Exploratory research in Europe found that biotypes of *M. aethiopoides* from several European countries were likely to be effective BCAs for *S. lepidus*, and so several of these were brought to New Zealand for quarantine evaluation and biosafety testing, including a biotype from Ireland which was parthenogenetic. This Irish biotype was found to be effective against *S. lepidus*, but its big advantage over others from Europe was that its parthenogenicity meant there was unlikely to be an opportunity for hybridisation between the two *M. aethiopoides* biotypes. This was a particularly significant consideration since research in quarantine showed that if hybridisation did occur, the offspring were compromised in their ability to be effective BCAs for their respective hosts.

Following quarantine host-range testing, an application was made to the regulatory agency, ERMA (Environmental Risk Management Authority) New Zealand for a 'conditional' release of the Irish biotype of *M. aethiopoides*. The condition to be met was that only *M. aethiopoides* from Ireland populations shown to be parthenogenetic could be released. Releases took place in 2006 and early indications are that the parasitoid has established successfully and that field parasitism levels are quite high in some areas.

Thus, as in this case, there can be important biological variation between different populations of the same morphological species, and this needs to be taken into consideration when selecting potential BCAs for introduction. This may involve laboratory comparison of populations from several different countries.

Prepared by Barbara I.P. Barratt

Source:

Goldson, S.L.; McNeill, M.R.; Proffitt, J.R.; Barratt, B.I.P. (2005) Host specificity testing and suitability of a European biotype of the braconid parasitoid *Microctonus aethiopoides* Loan as a biological control agent against *Sitona lepidus* (Coleoptera: Curculionidae) in New Zealand. *Biocontrol Science and Technology* 15, 791-813.

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Case Study 21. *Encarsia formosa* and *Phytoseilus persimilis*: two accidental but highly appreciated importations

In 1926 in the UK, a tomato grower drew the attention of an entomologist to black pupae among the normally white scales of the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood). The whitefly itself had been accidentally imported into Europe on ornamental plants around 1850 from the New World (possibly Mexico). From the black pupae, parasitoids emerged that were identified as *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae), which is also of New World origin. Within a few years, a research station in the UK was supplying 1.5 million of these parasitoids annually to about 800 nurseries. During the 1930s, the parasitoid was shipped to several other European countries, Canada, Australia and New Zealand. When synthetic chemicals came onto the market around 1945, interest in the use of this parasitoid diminished. But in the 1970s enormous outbreaks of greenhouse whitefly took place which were difficult to control with chemical pesticides and large-scale mass production of *E. formosa* was resumed. Nowadays, this parasitoid is one of the most used biological control agents, and accounts for about 50% of the income of the largest commercial natural enemy producer. The total annual production of *E. formosa* is in the order of billions of individuals per year and it is used in many countries for control of whiteflies.

The two-spotted spider mite, *Tetranychus urticae* Koch, is a well-known pest in many crops, both indoors and outdoors. Its pest status is thought to have risen after the adoption of synthetic pesticides in the 1940s, because the spider mite developed resistance to various types of pesticides and, at the same time, its natural enemies were greatly reduced by the same pesticides. A search for native natural enemies was undertaken, but although some appeared efficient in reducing the spider mite populations, they were difficult to mass produce. In Germany, the predatory phytoseiid mite *Phytoseiulus persimilis* Athias-Henriot was found on a shipment of orchids from Chile. Research in The Netherlands showed the efficiency of this predatory mite and, subsequently, mass-rearing methods were developed. The predator is currently mass produced by the billions per year and used in many countries for control of spider mites.

In conclusion, two of the most acclaimed successes in augmentative biological control resulted from accidental introductions of these natural enemies.

Prepared by Joop C. van Lenteren

Sources:

Hussey, N.W.; Scopes, N.E.A. (eds) (1985) *Biological pest control: the glasshouse experience*. Blanford, Poole, Dorset, UK.

Lenteren, J.C. van; Woets, J. (1988) Biological and integrated pest control in greenhouses. *Annual Review of Entomology* 33, 239-269.

Lenteren, J.C. van (2003) Commercial availability of biological control agents. Pp. 167-179 in: Lenteren, J.C. van (ed) *Quality control and production of biological control agents: theory and testing procedures*. CABI Publishing, Wallingford, UK.

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Case Study 22. Uninvited but welcomed guests: the case of two psyllid parasitoids in Brazil

Psyllids (Hemiptera) are a common group of widely distributed insects that cause direct and indirect damage to several crops and forest trees. In recent years, three psyllid pest species have become established in Brazil, threatening forestry and citrus industries, and causing losses of several millions of dollars.

Two of these psyllids, the redgum lerp psyllid, *Glycaspis brimblecombei* Moore, and *Ctenarytaina eucalypti* (Maskell) are serious pests of *Eucalyptus* spp. (Myrtaceae). *Ctenarytaina eucalypti* was first detected in 1998 attacking several species of *Eucalyptus* in south Brazil, particularly *E. dunnii* Maiden. *Glycaspis brimblecombei* was first detected in June 2003 infesting hybrids of *Eucalyptus grandis × E. urophylla* in the state of São Paulo; this followed its introduction into the USA in 1998, and preceded its subsequent spread to Mexico in 2000 and Chile in 2002. In a short period, *G. brimblecombei* spread to other eucalyptus growing areas of Brazil, including Minas Gerais, Goiás and Paraná. However, population dynamics studies in 2000–2001 indicated a drastic reduction in the population levels of this pest due to the high rate of parasitism of nymphs by a *Psyllaephagus* sp. (Hymenoptera: Encyrtidae), presumably indigenous. Another species of *Psyllaephagus*, *P. bliteus* Riek, was found parasitising nymphs of *G. brimblecombei* in Mogi Guaçu, São Paulo, showing promising natural parasitism rates. *Psyllaephagus* species have been used in the control of eucalyptus psyllids in several countries in Europe and the Americas, and the fact that *P. bliteus* was deliberately introduced into the USA early in 2000 led to the suggestion that this parasitoid was accidentally introduced into Brazil together with its host.

The third psyllid species, the Asian citrus psyllid, *Diaphorina citri* Kuwayama, has been known in Brazil since the early 1940s as a secondary pest of citrus orchards. However, with the detection of the greening disease-causing bacterium in the state of São Paulo, *D. citri* became a major citrus pest as it is known to be the vector for this disease. An earlier survey (1993/1994) of its natural enemies had not found any parasitoids, but natural parasitism by *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae) was subsequently revealed in citrus orchards in the state of São Paulo, ranging from 27.5% to 80.0% between August 2004 and September 2005. A psyllid-rearing technique was developed and parasitoids collected in the field were multiplied in the laboratory and used in augmentative releases in several orchards, leading to parasitism rates of 52–73%. The introduction of *T. radiata* was also accidental, but this natural enemy has been shown to be effective in controlling the Asian citrus psyllid in Guadaloupe and La Réunion, and it was also introduced into the USA. The successful cases already reported where this natural enemy has been used and the availability of a rearing procedure are likely to make the biological control of the Asian citrus psyllid successful in Brazil as well.

In conclusion, two parasitoids have spread accidentally to Brazil, either directly or following their deliberate introduction into the USA, providing fortuitous effective control of two important introduced psyllid pests.

Prepared by Fernando L Cônsoli & José Roberto Postali Parra

Sources:

Etienne, J.; Quilici, S,; Marival, D.; Antoine, F. (2001) Biological control of *Diaphorina citri* (Hemiptera: Psyllidae) in Guadaloupe by imported *Tamarixia radiate* (Hymenoptera: Eulophidae). *Fruits* 56, 307-315.

Nava, D.E.; Torres, M.L.G.; Rodrigues, M.D.L.; Bento, J.M.S.; Parra, J.R.P. (2007) Biology of *Diaphorina citri* (Hem., Psyllidae) on different hosts and at different temperatures. *Journal of Applied Entomology* 131, 709-715.

Santana, D.L.Q.; Menezes, A, Jr.; Silva, H.D.; Bellote, A.F.J.; Favaro, R.M. (2003) O psilídeo-de-concha (*Glycaspis brimblecombei*) em Eucalipto. *Comunicado Técnico EMBRAPA* 105, 3 pp.

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Case Study 23. Successful biological control of a forest insect pest

A defoliating geometrid, the winter moth (*Operophtera brumata* (L.)) was accidentally introduced from Europe into North America before 1930 and became an important defoliator of deciduous forest and fruit trees on the eastern and western seaboards.

The parasitoids *Cyzenis albicans* (Fallen) (Diptera: Tachindae) and *Agrypon flaveolatum* (Gravenhorst) (Hymenoptera: Ichneumonidae) were introduced into Nova Scotia and later British Columbia, Canada, to control the winter moth infesting oaks. The parasitoids were obtained from Central Europe by the Canadian Forest Service and introductions of both species were made in Nova Scotia between 1959 and 1965. Both parasitoids established successfully. The declines in winter moth populations that occurred just a few years after introduction of *C. albicans* and *A. flaveolatum* were significant and plans to introduce additional parasitoid species to Nova Scotia were cancelled in 1965.

When winter moth was discovered in British Columbia in 1977, populations of *C. albicans* and *A. flaveolatum* were relocated from Nova Scotia, became established, and caused similar declines in winter moth populations. Although winter moth remains a problem in orchard environments in Nova Scotia, populations in oak woods remain very low.

Life-table studies in the area of introduction showed that the introduced parasitoids contributed significantly to the mortality of winter moth during the decline phase and have a weak, delayed density-dependent effect when winter moth populations are low, appearing to have little or no impact. Life-table studies in the area of origin showed that pupal mortality in the soil was the single most important regulatory factor. Further study in the area of introduction showed that predation by generalist species of unparasitised winter moth pupae in the soil is a major and directly density-dependent mortality factor when densities are low. Population studies such as these, comparing population regulation in the source and introduced range have made a significant contribution to our understanding of population ecology.

This case study illustrates that specialist natural enemies from the area of origin can combine with generalist natural enemies from the area of introduction to provide effective control.

Prepared by Peter G. Mason

Sources:

Embree, D.G.; Otvos, I.S. (1984) *Operophtera brumata* (L.) winter moth (Lepidoptera: Geometridae). Pp. 353-357 in Kelleher, J.S.; Hulme, M.A. (eds) *Biological control programmes against insects and weeds in Canada, 1969–1980.* Commonwealth Agricultural Bureaux, Slough, UK.

Roland, J. (1994) After the decline: what maintains low winter moth density after successful biological control? *Journal of Animal Ecology* 63, 392-398.

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Case Study 24. Spread of a biological control agent in North America

The braconid parasitoid *Peristenus digoneutis* Loan was introduced in the early 1980s into the north-eastern USA for biological control of the tarnished plant bug, *Lygus lineolaris* (Palisot), and the alfalfa plant bug, *Adelphocoris lineolatus* (Goeze) (Miridae). The parasitoid populations, introduced by the United States Department of Agriculture, originated from Central Europe and *P. digoneutis* was determined to be established in 1984. By 1994, tarnished plant bug populations had decreased by 75% and parasitism increased by 40–50% in the area where it was initially released.

Peristenus digoneutis was first introduced into New Jersey in the north-eastern USA. Ongoing post-release monitoring indicated that the introduced biotype of *P. digoneutis* preferred cool humid climates, thus its dispersal into hotter and drier parts of the southern and western USA did not occur. However, in 1997 *P. digoneutis* was found in southern Quebec in Canada, a region adjacent to the north-eastern US states where it was first released and with a similar cool climate. By 2006 this parasitoid had dispersed into Ontario and Nova Scotia and it is now well established in south-eastern regions of Canada where its impact is increasing.

This case study illustrates how introduction of a biological control agent by one country can have impacts in a neighbouring country where ecozones are similar.

Prepared by Peter G. Mason

Day, W.H.; Romig, R.F.; Faubert, H.H.; Tatman, K.M. (2008) The continuing dispersion of *Peristenus digoneutis* Loan (Hymenoptera: Braconidae), an introduced parasite of the tarnished plant bug, *Lygus lineolaris* (Palisot) (Hemiptera: Miridae) in northeastern USA and southeastern Canada. *Entomological News* 119, 77-80.

Goulet, H.; Mason, P.G. (2006) Review of the Nearctic species of *Leiophron* and *Peristenus* (Hymenoptera: Braconidae: Euphorinae) parasitizing *Lygus* (Hemiptera: Miridae: Mirini). *Zootaxa* 1323, 1-118.

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Case Study 25. Collaboration between CABI and Uzbekistan based on weed biological control

First contact was made between CABI (Dr Urs Schaffner) and the Institute of Zoology, Uzbek Academy of Sciences (Prof. Aloviddin Khamraev) in 2000 during a visit to Tashkent by Dr Schaffner to establish collaboration in a CBC (classical biological control) project for Russian knapweed, *Acroptilon repens* (L.) DC. (Asteraceae). Central Asia is home to numerous plant species that have become serious invaders in North America and elsewhere.

Central Asia has long-standing expertise in BC (biological control), but in contrast to the CBC approach against invasive exotic species, the expertise in this region is primarily rooted in the ABC (augmentative biological control) approach using parasitoids or pathogens against insect pests (e.g. in cotton). During Prof. Khamraev's previous position as the Chair of Biological Control Protection at the Tashkent Agricultural Institute and his current position at the Institute of Zoology, the agricultural area in Uzbekistan on which crop pests were managed with mass-reared biological control agents (BCAs) was increased from 200 ha in 1972 to 7.6 million hectares in 2000. Since then, BC programmes have decreased substantially in Central Asia, and research groups such as Prof. Khamraev's largely depend on international collaboration.

One weakness in today's research and educational system in Uzbekistan – and in several other developing countries – is that young researchers are not rigorously trained in the design and analysis of experiments. This is a significant handicap for those wishing to establish themselves in the international scientific community, since manuscripts that are based on poorly designed observations or experiments, or are inappropriately analysed, are usually rejected by high-ranked scientific journals.

The goals of the collaboration have been:

- To assess the scope for CBC against plant species native to Central Asia and invasive in North America.
- To support Prof. Khamraev's working group in facilitating transfer to the next generation, of the knowledge and experience of Prof. Khamraev, who is close to retirement.
- To train young scientists in English, experimental ecology and sustainable weed management, thereby strengthening their position, and their University's position, in the international scientific community.

Between 2000 and 2009 this has involved:

- Collaboration on CBC of two weeds native in Uzbekistan and invasive in North America (2000–present), including co-supervision of a PhD student, two joint papers for international journals, and the release of two BCAs in North America.
- An Institutional Partnership project, funded by the Swiss National Science Foundation (SNSF) within the SCOPES (Scientific Co-operation between Eastern Europe and Switzerland) programme (2001–04), which included: provision of scientific equipment, developing teaching materials on BC, translation into English of a manual by Prof. Khamraev on 'Crop pest species in Central Asia', training a young researcher at CABI Europe–Switzerland (CABI E-CH), a scientific visit by Prof. Khamraev and a young scientist to Switzerland, and a joint appearance on the first Uzbek TV channel at prime time.
- A joint research project, also funded by SNSF within the SCOPES programme (2005–09), involving: joint research in Uzbekistan to assess the mechanisms underlying the weedy character of *A. repens* in its native range in Uzbekistan compared with its introduced range in North America, in collaboration with the University of Montana, USA; training young Uzbek scientists in experimental biology and statistics in two workshops; developing teaching materials on experimental biology and statistical analysis; training an Uzbek scientist at CABI E–CH for two months; and preparation of two joint papers for peer-reviewed journals.

In the absence of any formal ABS (access and benefit sharing) mechanism when this collaboration started, the spirit of the ABS process has been followed by developing a shared research and training programme of mutual interest. This has been facilitated by the long-term nature of the BC studies needed in Uzbekistan, including open field experiments in the area of origin to assess field host specificity.

Prepared by Urs Schaffner, CABI.

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Case Study 26. Fast-track biological control of orthezia scale in St Helena implemented with no research in intermediate source country

An earlier case study (Case Study 19) outlined the example of the public good achieved by the introduction of the ladybird beetle *Hyperaspis pantherina* Fürsch to St Helena to control orthezia fluted scale (*Orthezia insignis* Browne), which was killing the endemic gumwood, *Commidendrum robustum* DC (Asteraceae), a key plant in the main upland forest ecosystem of this globally important hotspot of endemism. Populations of gumwood had already been reduced to only two significant stands by habitat destruction. The orthezia attack on gumwoods started in 1991 and was particularly severe, so much so that 400 of the remaining 2000 trees had been killed by 1993 and the remaining stands of gumwood forest were under threat of rapid extinction due to this exotic species. The death of trees was proceeding at an exponential rate, and most would have been dead by 1995.

Fortunately, between 1908 and 1959 successful biological control programmes had been carried out against this pest in several countries using the predatory ladybird beetle *H. pantherina* Fürsch, so when the problem became apparent in 1991, a solution was known. The predator was originally taken from Mexico to Hawaii and from there to Kenya and from Kenya to other African countries, achieving rapid success in most or all cases. It was against this background that the UK Department for International Development funded CABI to support the Government of St Helena to carry out a small project to solve its orthezia problem.

The ladybird was obtained from Kenya because this was logistically simple, involving just a few hours work for staff at CABI's centre in Kenya, and because collections from the introduced range were less likely to be contaminated by diseases and parasitoids from the ladybird's area of origin. The ladybirds were first sent to CABI's UK quarantine facility, where a breeding culture was established, and was checked for contaminants and tested for host specificity. It was then hand carried to St Helena and released. The ladybird established and rapidly brought the orthezia populations down to a low level. Thus, the BCA (biological control agent) was sourced from a country which itself had introduced and established it from another country that had done the same, rather than the original country/region.

It should be noted that the collection of the predator in Kenya involved almost no local collaboration, and nor was any research carried out at this stage – nor was it necessary. The only benefit to Kenya was confirmation of the continuing existence of *H. pantherina*, apparently keeping orthezia under control.

It took two years from the point when the gumwoods were first realised to be under attack, to mobilise concern and resources, find a source for the ladybird, culture it in quarantine, make sure that it was not contaminated with diseases or parasites, carry out some basic host-specificity tests, and summarise the available information for the Government of St Helena to make the decision to proceed.

Up until now (2009), ABS (access and benefit sharing) negotiations have not been notable for their simplicity or speed of resolution. Had the supply of this BCA been further delayed while ABS issues were addressed, it seems likely that the remaining stands of gumwood would have been eradicated by orthezia, and St Helena and the world would have lost the last ecosystem remnants of this type, together with much of the associated flora and fauna.

Prepared by Matthew J.W. Cock

Source:

Fowler, S.V. (2005) The successful control of *Orthezia insignis* on St. Helena island saves natural populations of endemic gumwood trees, *Commidendrum robustum*. Pp. 52-63 in Hoddle, M.S. (compiler) *Second International Symposium on Biological Control of Arthropods,* Davos, Switzerland, 12-16 September 2005. USDA Forest Service Publication FHTET-2005-08. Forest Health Technology Team, Morgantown, West Virginia, USA.
(http://www.fs.fed.us/foresthealth/technology/pdfs/2ndSymposiumArthropods05_08V1.pdf)

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Case Study 27. Programme on biological control of gorse shared between countries

Gorse (*Ulex europaeus* L.; Fabaceae) is a thorny shrub of western European origin that has become established in more than 50 countries. It is now considered as a major weed in Australia, Canada, Chile, Costa Rica, New Zealand, Sri Lanka, and the western USA and montane regions of Hawaii. As an invasive species, gorse is often aggressive, forming impenetrable monocultures that can preclude grazing, reduce productivity of plantation forests, and modify native ecosystems.

Biological control of gorse has a long history, with the first BCA (biological control agent) release being made in Hawaii in 1926. More recently, New Zealand has led research, and seven invertebrate BCAs have been released there to date. Globally, ten agents have been released in six countries. The current status of this programme is reviewed by Hill et al. (2008) and references illustrating the scope of international collaboration are cited there. Collaboration between researchers in the most severely affected countries has included exchange of expertise, joint funding of research (often undertaken by CABI), host-range assessments undertaken on behalf of others, joint surveys for agents, and free interchange of insect cultures. A considerable amount of research has been carried out on the ecology of the plant under different climatic and environmental conditions, and on modelling to improve understanding of potential impacts of BCAs. None of the control agents released have achieved control of gorse, but the long-term population effects resulting from chronic attack by them are yet to be determined.

Five agents have been developed collaboratively and distributed internationally since 1989. For example, joint research between scientists from Landcare Research (New Zealand), the USDA (United States Department of Agriculture) Forest Service in Hawaii, State of Hawaii Department of Agriculture and CABI investigated the potential for biological control of gorse with a thrips, *Sericothrips staphylinus* Haliday, accessed from the UK, Portugal and France. During this programme, 83 plant species were screened in host-specificity tests carried out across several institutions. These tests indicated that *S. staphylinus* is a narrowly oligophagous species, but unlikely to develop significant populations on any species other than gorse in the field. The thrips was released and established successfully in a wide range of climates in both New Zealand and Hawaii. Initially *S. staphylinus* was slow to disperse but it is now becoming more common. Impacts on the gorse are yet to be determined.

The international community of biological weed control researchers and practitioners is a well-functioning network, and a high degree of collaboration is well established. This case study is an example of a biological control programme that has been assisted significantly by free sharing of information between researchers, and collaborative research on a weed that has become a significant pest in a number of countries to their mutual benefit. This collaboration is continuing.

Prepared by Richard Hill & Barbara I.P. Barratt

Hill, R.L.; Ireson, J.; Sheppard, A.W.; Gourlay, A.H.; Norambuena, H.; Markin, G.P.; Kwong, R.; Coombs, E.M. (2008) A global view of the future for biological control of gorse, *Ulex europaeus* L. Pp. 680-686 in Julien, M.H.; Sforza, R.; Bon, M.C.; Evans, H.C.; Hatcher, P.E.; Hinz, H.L.; Rector, B.G. (eds) *Proceedings of the XII International Symposium on Biological Control of Weeds*, La Grande Motte, France, 22-27 April 2007. CABI, Wallingford, UK.

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Annex 2. Processes by which access to BCAs are regulated and how benefit sharing is handled by various countries

***Africa*.** According to the Convention on Biological Diversity (CBD)'s website on ABS measures (http://www.cbd.int/abs/measures.shtml), i.e. regulations in a wider sense, only ten of the 53 countries in Africa have ABS regulations in place: the Central African Republic, Cameroon, Ethiopia, Kenya, Malawi, Namibia, South Africa, Tanzania, Uganda and Zimbabwe. Liberia and Seychelles are planning to pass such regulations in the near future. Even with regulations in place, it does not seem to be clear in all countries who is actually the responsible authority to lead the negotiations and issue the permits. Several agencies might be involved such as wildlife conservation agencies, national councils for science and technology, national environmental management agencies (or equivalent bodies), as well as the agriculture and environment ministries. Competences are not finally settled and indeed sometimes several permits seem to be necessary, e.g. when collecting is done in parks under supervision of the wildlife conservation agencies. A few countries have found that their ABS regulations prevented rather than stimulated the use of their biodiversity and have thus revised or are considering revising the regulations to allow easier access. None of the existing regulations addresses specifically the question of biological control (BC) or the transfer of biological control agents (BCA)s.

The ABS Capacity Development Initiative for Africa is actively supporting the capacity building efforts in the region, bringing stakeholders and administrators together. It supports the creation of an African ABS Compendium to collect and analyse the African legislation on this topic. However, none of these activities is sector specific and none targeted at BC.

Australia. The Department of Environment, Water, Heritage and the Arts is the agency developing ABS provisions in Australia (Australia 2009). Its focus is on protection of native Australian genetic resources. The new regulatory scheme tries to minimise transaction costs involved in reaching agreement between those seeking access and those granting it. Administrative fees for access permits are set at Aus$ 50 for commercial and at Aus$ 0 for non-commercial purposes. Australia's interests are safeguarded through benefit sharing agreements and encouraging the maximum amount of research and development. Application for permits can be completed online. The Department of the Environment, Water, Heritage and the Arts website also provides links to other permit applications under the Environment Protection and Biodiversity Conservation Act 1999 and accredited schemes. To avoid delay in decision-making and granting permit applications, specific timeframes are included in regulations. There is also an intention to reduce the number of permits that an applicant may require through arrangements that allow for flexible access arrangements for lengthy or even unlimited periods. These regulations will be reviewed after the first year of operation and the Department will liaise with key stakeholders as the regulations are implemented. The Australian Government recognises that benefits for providing access to genetic resources can be in both monetary and non-monetary form. The nature and value of benefits depend on factors such as the nature of the access agreement, the circumstances of the parties and the prevailing market conditions. Before the permit can be granted, the applicant is required to negotiate an equitable benefit sharing agreement/contract.Thus, access to biological materials in Australia is already at the stage of requiring a permit. When discussed in the context of BCAs it appears that if commercial gain is a likely outcome, they would almost certainly expect royalties, although for the agricultural sector these are likely to be quite low. They are using the FAO guidelines on royalty rate, but the Australian system will be flexible and negotiable.

BCAs have not been considered specifically in the context of ABS in Australia, but would be subject to a transfer agreement and conditions of use. Australia already has model contract documents in place for bioprospectors of any kind (including those undertaking exploration for BCAs). These applications are considered on a case-by-case basis. AQIS (Australian Quarantine Inspection Service) are involved in the regulation of BCAs imported into Australia. It was considered that the main checkpoint for compliance would be when the scientist applies for research funding, and then when publishing results. It could be that eventually AQIS will check for and ensure compliance as part of the application process.

South America. Countries belonging to the South American Southern Cone, such as Argentina, Brazil, Chile and Uruguay, have similar regulations for access to their natural resources. Here we describe the situation in Brazil. Use of genetic resources (and hence BCAs) is regulated in Brazil. Federal Law 5.197 (3-I-67) regulates the exploitation of the native fauna, while Amendment 74 (7-III-94) approved the 'Rules and quarantine procedures for the exchange of live organisms for research on biological control of pests, diseases, weeds and for other scientific applications' and the Normative Instruction 140 (by IBAMA; Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis/Brazilian Institute of Environment and Renewable Natural Resources), regulates the issuing of licenses for exporting the native fauna and flora (under the CITES protocol).

There is no specific regulation in Brazil for the collection of BC organisms, but access to such resources by foreigners is regulated by Presidential Decree 98.830 (15-I-90). This decree states that these activities will be possible only if they involve a Brazilian counterpart, who should have proven experience in the field of interest, as evaluated by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). However, Amendment 55 (14-III-90) of the Science and Technology Ministry (MCT) adjusted Decree 98.830, and waived the requirement for authorisation by MCT for collections of natural resources as part of scientific exchange programmes financed or supported by governmental agencies, programmes of international organisations approved by the Brazilian government, and research programmes financed by government research foundations.

In order to obtain a license to export genetic resources, it is necessary to first apply for a Material Transfer Term (TIM) or to register the Material Responsibility Term (TRM) in the SiiBio. The signature of the TIM is not a prerequisite for the approval of shipment authorisation, unless the genetic resources is to be used to access the genetic content. If that is the case, a specific authorisation is required. Authorisation to export a BCA also requires a copy of the authorisation for importation of the required BCAs issued by the importing country. The commercial utilisation of any biological resources collected by foreigners or a third party requires the approval by MCT as laid down under existing Brazilian legislation. Information about the authorisation request and the CITES license can be found on the SisCites system at http://servicos.ibama.gov.br/cogeq/. Access to genetic resources for commercial applications, including augmentative BC, requires a specific permit for material collection, which must be approved by the Genetic Resources Council (CGEN), where the benefit sharing associated with the exploitation of such a resource should be discussed for each particular case. As yet, there are no cases for natural enemies where benefit sharing has been discussed or agreed.

North America. Canada, Mexico and USA do not have common ABS policies. Each region in North America has unique biodiversity and biodiversity issues. Thus, the approach appears to be for independent development of ABS policy. National ABS working groups are developing proposals that will be the basis for guidelines and any new legislation. For example, Canada has established a website where interested parties can provide input on the ABS Policy Development Initiative.

Europe. Currently no European country has any regulations or specific guidance regarding the application of ABS to BCAs, as existing ABS legislation generally does not differentiate between genetic resources used for biological control and other type of uses. However, several countries differentiate between access for non-commercial research and commercial uses. Norway is reported to have excluded genetic resources for utilization in agriculture and forestry from the Prior Informed Consent procedure.

If it is recognised that classical BC falls in the non-commercial research sector, then some countries already have an approach that can be used for accessing BC agents - for example, Switzerland. BCAs receive no special consideration within the implementation programme of the CBD and ABS in Switzerland. However, Switzerland has taken a lead in developing good practice guidelines for Swiss researchers who wish to carry out research using genetic resources from other sources, and in the absence of other guidelines would expect these to apply to access to Swiss genetic resources. Thus, the Swiss Academy of Sciences has published a guidance document on ABS for good practice in academic research on genetic resources (Biber-Klemm and Martinez 2006), and in 2007, the State Secretariat for Economic Affairs (SECO) released a best practice standard for implementing ABS (SECO 2007). The purpose of the standard is to provide guidance and tools on ABS practice to help companies and government bodies ensure compliance with ABS requirements under the CBD, right through to commercialisation of products. Neither guidance document is legally binding.

References not in main text

Australia (2009) http://www.environment.gov.au/biodiversity/science/access/

SECO (State Secretariat for Economic Affairs) (2007) *ABS-management tool. Best practice standard and handbook for implementing genetic resource access and benefit-sharing activities.* SECO, Bern, Switzerland, 56 pp.

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Annex 3. Region-specific responses to the effect of legislation on exploration and collection of species for biological control

Australia. In Australia biological control (BC) researchers are experiencing difficulties with overseas exploration and collection of species to initiate cultures for further research both inside the source country and in transferring material to Australia for further study. In some cases BC programmes have been 'put on hold' because of difficulties in obtaining permission to undertake research.

Weed BC work in Australia is all in the public good domain and there is never financial gain by the research organisation. While benefits to stakeholders are sometime accrued, these could not easily be identified or recovered. In many instances the benefits are environmental rather than accruing to commercial agricultural and pastoral industries.

The transfer of control agents (BCAs) and expertise represents an outstandingly successful example of international aid. The example of water hyacinth (*E. crassipes*) is one of many that could be quoted. Here, the agents were sourced from South America by the USA and Australia. After proving successful in those countries the agents have been redistributed in many tropical areas (New Guinea, Asia, Africa) with great success and benefit. Hindering developed countries from pursuing BC will ultimately affect underdeveloped countries also.

North America. Current practices for obtaining BCAs in Canada and the USA have been in place for a long period of time. Normally BCAs are obtained from established overseas laboratories. In the case of Canada, CABI is contracted to find, evaluate and ship agents from source countries. In the case of the USA, overseas laboratories supported by the United States Department of Agriculture (USDA) find, evaluate and ship agents from source countries. The overseas laboratories have been tasked with obtaining whatever permissions are required by countries where BCAs originated.

Most BC workers in Canada, Mexico and the USA are not well-informed about the ABS issue. This is not surprising considering that the overseas laboratories were and continue to be the points of contact with source countries. However, awareness of the ABS issue is moving to the forefront through the increasing requirements for permits for collecting and exporting living material from source countries, especially those countries with mega-diverse flora and fauna. The permits must sometimes be obtained from different government agencies, who often have different requirements. Obtaining permits can sometimes take weeks and recipients in North America are taking note.

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Annex 4. An example of the information in the BIOCAT database: introductions of *Rodolia cardinalis* to control *Icerya purchasi*

Country	Date	Result	Reference[1]
Antigua	1966	Not known	Cock 1985
Bahamas	1934	Substantial control	Cock 1985
Barbados	1943	Substantial control	Cock 1985
Cayman Islands	1961	Substantial - complete control	Cock 1985
Chile	1939	Complete control with other BCA(s)	Marco 1959
China (Hong Kong)	1961	Substantial control with other BCA(s)	Rao et al. 1971
Commonwealth of the Northern Mariana Islands	1928	Established	Beardsley 1955
Cyprus	1938	Substantial control	Greathead 1976
Ecuador	1978	Complete control with other BCA(s)	Koch 1989
Egypt	1890	Substantial control with other BCA(s)	Kamal 1951
Ethiopia	1947	Substantial control	Haimonot and Crowe 1979
France	1912	Complete control	Greathead 1976
France (Guadeloupe)	?	Established	OPIE 1986
Greece	1927	Substantial control	Greathead 1976
Guam	1926	Temporarily established	Nafus and Schreiner 1989
Israel	1912	Complete control with other BCA(s)	Mendel et al. 1992
Italy	1901	Substantial control	Greathead 1976
Kenya	1917	Established	Greathead 1978
Madagascar	1951	Not known	Greathead 1971
Malta	1911	Complete control	Greathead 1976
New Zealand	1894	Complete control	Cameron et al. 1989
Palau	1928	Established	Beardsley 1955
Peru	1932	Complete control	Beingolea 1967
Philippines	1956	Failed to establish	Rao et al. 1971
Portugal	1897	Complete control	Greathead 1976
Sao Tome and Principe (Sao Tome)	before	Failed to establish	Greathead 1971
Senegal	1954	Not known	Greathead 1971
South Africa	1892	Complete control	Greathead 1971
Spain	1922	Substantial control	Greathead 1976
Sri Lanka	1918	Substantial control	Rao et al. 1971
St Kitts and Nevis (St Kitts)	1966	Substantial - complete control	Cock 1985
Switzerland	1924	Failed to establish	Greathead 1976
Taiwan	1909	Some impact	Chiu et al. 1985
UK (Bermuda)	1902	Substantial control with other BCA(s)	Cock 1985
UK (Montserrat)	1964	Substantial control	Cock 1985
UK (St Helena (Ascension Island))	1977	Complete control	CAB 1980
UK (St Helena)	1896	Established	Greathead 1971
Uruguay	1916	Complete control	Altieri et al. 1989
USA (Florida)	1893	Complete control	Rosen et al. 1994
USA (California)	1888	Complete control with other BCA(s)	Clausen 1978
USA (Hawaii)	1890	Complete control	Pemberton 1964
USA (Puerto Rico)	1932	Complete control	Altieri et al. 1989
USSR	?	Complete control	Izhevskii 1988
Venezuela	1941	Complete control	Altieri et al. 1989
Yugoslavia	1910	Not known	Greathead 1976

[1]These are not included in the references to this paper.

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Annex 5. Listing of all commercial augmentative biological control agents available in Europe - updated from van Lenteren (2003a, b)

Scientific name of natural enemy	Area where natural enemy was collected	Year of first introduction	Result of release	Market value
Adalia bipunctata	Europe	1998	C	S
Aleochara bilineata	Europe	1995	S	S
Aeolothrips intermedius	Europe	2000	P	S
Aleurodothrips fasciapennis	Exotic	1990	P	S
Amblyseius andersoni (= *potentillae*)	Europe	1995	P	S
Amblyseius largoensis	Exotic	1995	S	S
Amblyseius limonicus	Exotic	1995	S	S
Amblyseius swirskii	Exotic	2005	S	L
Ampulex compressa	Exotic	1990	P	S
Anthocoris nemoralis	Europe	1990	P	S
Anthocoris nemorum	Europe	1992	S	S
Anagrus atomus	Europe	1990	P	S
Anagyrus dactylopii	Exotic	1995	S	S
Anagyrus fusciventris	Exotic	1995	P	S
Anagyrus pseudococci	Europe	1995	P	S
Anaphes iole	Exotic	1990	S	S
Aphelinus abdominalis	Europe	1992	P	L
Aphelinus mali	Exotic	1980	C	S
Aphelinus varipes	Europe	2000	S	S
Aphidius colemani	Exotic	1991	S	L
Aphidius ervi	Europe	1996	S	L
Aphidius matricariae	Europe	1990	S	L
Aphidius urticae	Europe	1990	S	S
Aphidoletes aphidimyza	Europe	1989	S	L
Aphytis diaspidis	Europe	1990	C	S
Aphytis holoxanthus	Exotic	1996	C	S
Aphytis lepidosaphes	Exotic	1985	C	S
Aphytis lingnanensis	Exotic	1985	C	S
Aphytis melinus	Exotic	1985	C	S
Aprostocetus hagenowii	Exotic	1990	P	S
Arrhenophagus albitibiae	Exotic	1990	S	S
Dalotia coriaria	Europe	2000	P	S
Blastothrix brittanica	Europe	2005	S	S
Bracon hebetor	Exotic	1980	S	S
Cales noacki	Exotic	1970	C	S
Chilocorus baileyi	Exotic	1992	S	S
Chilocorus bipustulatus	Europe	1992 - 2005	P	S
Chilocorus circumdatus	Exotic	1992	S	S
Chilocorus nigritus	Exotic	1985	S	S
Chrysoperla (= *Chrysopa*) *carnea*	Exotic, Europe	1987	S	S
Chrysoperla rufilabris	Exotic	1987	S	S
Clitostethus arcuatus	Europe	1997	S	S
Coccidencyrtus ochraceipes	Exotic	1995	S	S
Coccidoxenoides perminutus	Exotic	1995	S	S
Coccinella septempunctata	Europe	1980	S	S
Coccophagus cowperi	Exotic	1985	S	S
Coccophagus gurneyi	Exotic	1985	S	S
Coccophagus lycimnia	Europe	1988	S	S
Coccophagus pulvinariae	Exotic	1990	S	S
Coccophagus rusti	Exotic	1988	S	S
Coccophagus scutellaris	Europe	1986	S	S
Coenosia attenuata	Europe	1996	S	S

Comperiella bifasciata	Exotic	1985	C	S
Coniopteryx tineiformis	Europe	1990-2005	P	S
Conwentzia psociformis	Europe	1990-2005	P	S
Cotesia glomerata	Europe	1995	S	S
Cotesia rubecola	Europe	2000	S	S
Cryptolaemus montrouzieri	Exotic	1989	S	S
Dacnusa sibirica	Europe	1981	C	L
Delphastus catalinae	Exotic	1985	S	S
Delphastus pusillus	Exotic	1993	P	L
Dicyphus errans	Europe	2000	S	S
Dicyphus tamaninii	Europe	1996	S	L
Dicyphus hesperus	Exotic	2000	S	L
Diglyphus isaea	Europe	1984	C	L
Diomus spec.	Exotic	1990	S	S
Encarsia citrina	Exotic	1984	S	S
Encarsia guadeloupae	Exotic	1990-2000	P	S
Encarsia hispida	Exotic	1990-2000	P	S
Encarsia formosa	Exotic	1926	C	L
Encarsia protransvena	Exotic	1990-2005	S	S
Encarsia tricolor	Europe	1985	S	S
Encyrtus infelix	Exotic	1990	S	S
Encyrtus lecaniorum	Europe	1985	S	S
Episyrphus balteatus	Europe	1990	S	S
Eretmocerus eremicus	Exotic	1995 - 2002	C	L
Eretmocerus mundus	Europe	2001	C	L
Euseius finlandicus	Europe	2000	S	S
Euseius scutalis	Exotic	1990	S	S
Exochomus laeviusculus	Exotic	1988	S	S
Exochomus quadripustulatus	Europe	2000	S	S
Feltiella acarisuga (= *Therodiplosis persicae*)	Europe	1990	S	S
Franklinothrips megalops (= *myrmicaeformis*)	Exotic	1992	S	S
Franklinothrips vespiformis	Exotic	1990	P	S
Galeolaelaps (*Hypoaspis*) *aculeifer*	Europe	1996	S	L
Gyranusoidea litura	Exotic	1990	S	S
Harmonia axyridis	Exotic	1995-2005	S	L
Heterorhabditis bacteriophora	Exotic, Europe	1984	S	L
Heterorhabditis megidis	Europe	1990	C	L
Hippodamia convergens	Exotic	1993	S	S
Holobus flavicornis	Europe, exotic	2000	S	S
Iphiseius degenerans (= *Amblyseius degenerans*)	Europe	1993	S	L
Kampimodromus aberrans	Europe	1960-1990	S	S
Karnyothrips melaleucus	Exotic	1985	S	S
Lamyctinus coeculus	Exotic	1995	S	S
Leptomastidea abnormis	Europe	1984	S	S
Leptomastix dactylopii	Exotic	1984	C	S
Leptomastix epona	Europe	1992	P	S
Leptomastix histrio	Exotic	1995	S	S
Lysiphlebus fabarum	Europe	1990	P	S
Lysiphlebus testaceipes	Exotic	1990	S	S
Macrolophus melanotoma (= *M. caliginosus*)	Europe	1994	S	L
Macrolophus pygmaeus (*nubilis*)	Europe	1994	P	L
Methaphycus flavus	Exotic	1995	S	S
Metaphycus helvolus	Exotic	1984	S	S
Metaphycus lounsburyi (*bartletti*)	Exotic	1997	S	S

Metaphycus stanleyi	Exotic	1990	S	S
Metaphycus swirskii	Exotic	1995	S	S
Metaseiulus occidentalis	Exotic	1985	S	S
Meteorus gyrator	Europe	2005	S	S
Microterys flavus	Exotic	1987	S	S
Microterys nietneri	Europe	1987	S	S
Muscidifurax zaraptor	Exotic	1982	P	S
Nabis pseudoferus ibericus	Europe	2009	P	S
Nasonia vitripennis	Europe	1982	P	S
Neoseiulus (*Amblyseius*) *barkeri*	Europe	1981	S	L
Neoseiulus (*Amblyseius*) *californicus*	Exotic	1985	P	L
Neoseiulus (*Amblyseius*) *cucumeris*	Exotic, Europe	1985	S	L
Neoseiulus (*Amblyseius*) *fallacis*	Exotic	1997	S	L
Nephus includens	Europe	2000	S	S
Nephus reunioni	Exotic	1990	S	S
Nesidiocoris tenuis	Europe	2003	S	L
Ooencyrtus kuvanae	Exotic	1923	S	S
Ooencyrtus pityocampae	Exotic	1997	S	S
Ophelosia crawfordi	Exotic	1980	S	S
Ophyra aenescens	Exotic	1995	P	S
Opius pallipes	Europe	1980	C	L
Orius albidipennis	Europe	1993	S	S
Orius insidiosus	Exotic	1991 - 2000	S	L
Orius laevigatus	Europe	1993	S	L
Orius majusculus	Europe	1993	S	L
Orius minutus	Europe	1993	S	S
Orius tristicolor	Exotic	1995 - 2000	S	S
Pergamasus quisquiliarum	Europe	2000	S	S
Phasmarhabditis hermaphrodita	Europe	1994	S	S
Phytoseius finitimus	Europe	2000	S	S
Phytoseiulus longipes	Exotic	1990	S	S
Phytoseiulus persimilis	Exotic	1968	C	L
Picromerus bidens	Europe	1990	S	S
Podisus maculiventris	Exotic	1996	S	S
Praon volucre	Europe	1990	S	S
Pseudaphycus angelicus	Exotic	1990	S	S
Pseudaphycus flavidulus	Europe	1990	S	S
Pseudaphycus maculipennis	Europe	1980	S	S
Psyttalia concolor	Exotic	1968 - 2000	P	S
Rhyzobius chrysomeloides	Europe	1980	S	S
Rhyzobius forestieri	Exotic	1980	S	S
Rhyzobius (*Lindorus*) *lophanthae*	Exotic	1980	S	S
Rodolia cardinalis	Exotic	1990	C	S
Rumina decollate	Europe	1990	S	S
Saniosulus nudus	Exotic	1990	S	S
Scolothrips sexmaculatus	Europe	1990	S	S
Scutellista caerulea (*cyanea*)	Exotic	1990	S	S
Scymnus rubromaculatus	Europe	1990	P	S
Steinernema carpocapsae	Europe	1984	S	S
Steinernema glaseri	Exotic	2002	S	S
Steinernema feltiae	Europe	1984	S	L
Steinernema kraussei	Europe	2000	S	S
Stethorus punctillum	Europe	1984	S	S
Stratiolaelaps (*Hypoaspis*) *miles*	Europe	1995	P	L
Sympherobius fallax	Europe	1994	S	S
Synacra paupera	Europe	2000	P	S
Tetracnemoidea brevicornis (= *Hungariella pretiosa*)	Exotic	1990	S	S

Tetracnemoidea peregrina (= *Hungariella peregrina*)	Exotic	1990	S	S
Tetrastichus coeruleus (asparagi)	Europe	2000	S	S
Thripobius semiluteus	Exotic	1995	P	S
Trichogramma brassicae (= *maidis*)	Europe	1980	P	S
Trichogramma cacoeciae	Europe	1980	P	S
Trichogramma dendrolimi	Europe	1985	P	S
Trichogramma evanescens	Europe	1975	S	L
Typhlodromus athiasae	Exotic	1995	P	S
Typhlodromus doreenae	Exotic	2003	S	S
Typhlodromips montdorensis	Exotic	2003	P	S
Typhlodromus pyri	Europe	1990	S	S

Key:
Exotic: originates from outside target area
Result of release: C= complete control (no other control needed), S= substantial control (other control methods not usually needed), P= partial (some observed impact on pest numbers)
Market value: L = large (thousands to millions of individuals sold per week), S = small (hundreds of individuals sold per week)
Grey shaded lines: natural enemy no longer in use

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