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THE USE AND EXCHANGE OF BIOLOGICAL CONTROL AGENTS FOR FOOD AND AGRICULTURE

Submission by the Food and Agriculture Organization of the United Nations (FAO)

Note by the Executive Secretary

1. Further to the request of the Commission on Genetic Resources for Food and Agriculture, the Executive Secretary is pleased to circulate herewith, for the information of participants in the ninth meeting of the Ad Hoc Open-ended Working Group on Access and Benefit-sharing, a study entitled "The use and exchange of biological control agents for food and agriculture" prepared at the request of the Secretariat of the Commission on Genetic Resources for Food and Agriculture and considered at its twelfth regular session.

2. The paper is being circulated in the form and language in which it was received by the Secretariat.

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COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

THE USE AND EXCHANGE OF BIOLOGICAL CONTROL AGENTS FOR FOOD AND AGRICULTURE

by

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This document has been prepared at the request of the Secretariat of the Commission on Genetic Resources for Food and Agriculture by the Global Commission on Biological Control and Access and Benefit-Sharing of the International Organisation for Biological Control of Noxious Animals and Plants (IOBC), as a contribution to the cross-sectoral theme, *Consideration of policies and arrangements for access and benefit-sharing for genetic resources for food and agriculture*, which the Commission will consider at its Twelfth Regular Session.

The content of this document is entirely the responsibility of the authors, and does not necessarily represent the views of the FAO, or its Members.

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ABOUT THIS PUBLICATION

The Commission on Genetic Resources for Food and Agriculture (the Commission), at its Tenth Regular Session, recommended that the Food and Agriculture Organization of the United Nations (FAO) and the Commission contribute to further work on access and benefit-sharing, in order to ensure that it moves in a direction supportive of the special needs of the agricultural sector, in regard to all components of biological diversity of interest to food and agriculture.

At its Eleventh Regular Session, the Commission agreed on the importance of considering access and benefit-sharing in relation to all components of biodiversity for food and agriculture, and decided that work in this field should be an early task within its Multi-Year Programme of Work (MYPOW). Accordingly, the Commission decided to consider arrangements and policies for access and benefit-sharing for genetic resources for food and agriculture at its Twelfth Regular Session (19-23 October 2009). To facilitate discussions and debate on access and benefit-sharing for genetic resources for food and agriculture at the Twelfth Regular Session, the Secretariat of the Commission has commissioned several background study papers on use and exchange patterns of genetic resources in the different sectors of food and agriculture. The studies provide an overview of past, current and possible future use and exchange patterns, as well as a description of terms and modalities for use and exchange of animal, aquatic, forest, micro-organism genetic resources; and of biological control agents. This study deals with use and exchange of biological control agents. Cross-sectoral studies have been commissioned to analyse use and exchange patterns in light of climate change and to review the extent to which policies and arrangements for access and benefit-sharing take into consideration the use and exchange of genetic resources for food and agriculture in particular.

The broad ranges of studies are intended to provide insight, necessary to maintain, establish and advance policies and arrangements for access and benefit-sharing for biodiversity for food and agriculture. The studies may also contribute to the negotiations of an International Regime on Access and Benefit-sharing in the Ad Hoc Open-ended Working Group on Access and Benefit-sharing under the Convention on Biological Diversity.

LIST OF ABBREVIATIONS

ABS	access and benefit sharing
AFFP	African Fruit Fly Programme (formerly African Fruit Fly Initiative)
AJOL	African Journals Online
AQIS	Australian Quarantine and Inspection Service
ARS	Agricultural Research Service (of USDA)
BC	biological control
BMZ	German Federal Ministry for Economic Cooperation and Development (Bundesministerium für Wirtschaftliche Zusammenarbeit)
AAFC	Agriculture & Agri-Food Canada (formerly Agriculture Canada)
AGOR	Access to Global Online Research in Agriculture
AGRICOLA	Agricultural OnLine Access
AGRIS	Agricultural Information Centre
ANBP	Association of Natural Biocontrol Producers
CABI	CAB International
CBD	Convention on Biological Diversity
CGEN	Genetic Resources Council (Brazil)
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture (Centro Internacional de Agricultura Tropical)
CIP	International Potato Center (Centro Internacional de la Papa)
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CNPq	Conselho Nacional de Desenvolvimento Científico e Tecnológico (Brazil)
COP	Conference of Parties (to the CBD)
CRI	Crown Research Institute (New Zealand)
CSIR	Council for Science and Industrial Research (South Africa)
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
DFID	Department for International Development (UK)
DNR	Department of Natural Resources (Queensland, Australia)
DPI	Department of Primary Industry (Queensland, Australia)
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agricultural Research Corporation)
ERMA	Environmental Risk Management Authority; ERMA New Zealand
ESALQ/USP	Escola Superior de Agricultura 'Luiz de Queiroz'/Universidade de São Paulo (Brazil)
ETH	Swiss Federal Institute of Technology (Eidgenössische Technische Hochschule), Zurich

EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GATT	General Agreement on Tariffs and Trade
GR	genetic resources
HINARI	Health InterNetwork Access to Research Initiative
IAPSC	Inter-African Phytosanitary Council
IBAMA	Instituto Brasileiro do Meio Ambiente E Dos Recursos Naturais Renováveis (Brazilian Institute of Environment and Renewable Natural Resources)
IBMA	International Biocontrol Manufacturers Association
icipe	International Centre of Insect Physiology and Ecology
IFAD	International Fund for Agricultural Development
IOBC	International Organisation for Biological Control
IPM	integrated pest management
IPPC	International Plant Protection Convention
ISPM	International Standards for Phytosanitary Measures (of the IPPC)
JSTOR	Journal Storage
MAT	mutually agreed terms
MCT	Science and Technology Ministry (Brazil)
OARE	Online Access to Research in the Environment
SBSTTA	Subsidiary Body for Scientific, Technical and Technological Advice (to the CBD)
SCOPES	Scientific Co-operation between Eastern Europe and Switzerland
SDC	Swiss Agency for Development and Cooperation
SECO	State Secretariat for Economic Affairs (Switzerland)
SMEs	small and medium-sized enterprises
TIM	material transfer term (Portuguese)
TRM	material responsibility term (Portuguese)
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WGABS	Working Group on Access and Benefit Sharing

EXECUTIVE SUMMARY

This report was prepared by the IOBC (International Organisation for Biological Control; www.iobc-global.org) Global Commission on Biological Control and Access and Benefit Sharing, with support from FAO (www.fao.org/) and CABI (www.cabi.org/). It sets out to summarise the past and current situation regarding the practice of biological control (BC) in relation to the use and exchange of genetic resources relevant for BC agents.

There are two main categories of BC. Classical BC is the introduction of a BC agent, usually from a pest's area of origin, to control the pest in an area where it has invaded. Once introduced, the BC agent will become established, reproduce and spread, and have a self-sustaining effect on the target pest. Augmentative BC involves the production and release of BC agents, indigenous or exotic, into specific crop situations, where they cause mortality of the target pest, but are not expected to persist from one cropping cycle to the next.

Allowing access to BC agents for use in another country imposes no risk of liability to the source country. Local scientific knowledge about habitats, fauna and flora, can be helpful for locating suitable sites for surveys and collections. BC is a research-based activity that requires access to Genetic Resources (GR) but that is not expected to generate large monetary returns. It is not the practice in the BC sector to patent BC organisms.

1. The research process and opportunities for benefit sharing

Preliminary surveys for the target pest and its natural enemies will often need to be carried out in several countries. These surveys offer limited opportunities for financial benefit sharing, but benefit the source country through provision of training in survey methods, joint surveys, capacity building and information generated to better understand biodiversity. Specimens of pests and natural enemies would normally need to be exported for identification and taxonomic studies.

Detailed studies on natural enemies to assess their potential as BC agents must in part be carried out in the source country, while host-specificity studies involving plants or animals not naturally occurring in the source country would best be carried out in quarantine in the target country or in a third country. It is this stage of a biological control programme that provides great scope for collaboration, shared research and capacity building. In comparison, there is relatively little scope for routinely sharing research with the source country during the BC agent release stage.

In source countries, local partners are essential to carry out BC surveys and research. When added to the moral obligation in the spirit of ABS, there is a compelling case for local partnerships. Some of these local partners will become the leaders in developing BC options for their country in the future.

2. The implementers

Two main groups of producers are involved in augmentative BC: commercial and centralised. The former are independent companies who produce and sell BC agents to users. Such companies have mostly operated in developed countries, but new ones are increasingly common globally, particularly supporting cash crop production in middle-income countries. The centralised production units are government- or industry-owned and produce natural enemies for a particular niche, normally large-scale agriculture or forestry, which are either provided free or sold to users. In the case of classical BC, those who implement it are normally national agencies or programmes. Classical BC in developing countries is often carried out with the financial support of international development agencies and technical support of implementation agencies.

3. The benefits to users and their customers

In the context of agriculture and forestry, the main beneficiaries of classical BC are the farmers who have their pest problems reduced without necessarily actively using BC agents, which by spreading and reproducing naturally contribute to the public good. The reduced crop losses from pests lead to improved food security and improved livelihoods. Farmers in all parts of the world have benefited from this. Consumers also benefit from reduced use of pesticides, and hence less pesticide residues in food. Thus, classical BC is in the domain of public good, as the benefits reach all who grow and benefit from the crop, without requiring them to make any intervention. The use of augmentative BC and classical BC enables producers to reduce pesticide use and residues to meet the high standards of profitable northern export markets, resulting in job creation amongst the growers and a very significant influx of foreign exchange in developing countries.

To make augmentative BC products available in developing countries it is necessary to establish mass-production facilities, which creates job opportunities. Also important is the creation or retention of jobs in agricultural production systems dependent upon augmentative BC or classical BC.

BC also addresses invasive alien species that are problems in agriculture, forestry and the environment. BC is an effective tool to tackle alien pest problems. Furthermore, BC is environmentally friendly and does generally not lead to a reduction of biodiversity which is often observed when chemical pesticides are used.

4. The extent of use of biological control

At least 7,000 introductions of BC agents involving almost 2,700 BC agent species have been made. The most widely used BC agents have been introduced into more than 50 countries. BC agents from 119 different countries have been introduced into 146 different countries. High-income countries have implemented classical BC the most and have also been the main source of BC agents. Low-income countries have contributed slightly more BC agents than they have received.

In augmentative BC, more than 170 species of natural enemies are produced and sold, but some 30 species make up more than 90% of the market worldwide. There is a trend in augmentative BC to first look for indigenous natural enemies when a new, even exotic, pest develops.

Once a BC agent has been used successfully in one country the opportunity has often been taken to repeat that success in other countries through redistribution of the BC agent. Developing countries have benefited from access to such tested BC agents because research and implementation was carried out by developed countries. For example, the work of developed countries with subtropical and tropical regions, e.g. Australia and the USA, has directly benefited developing countries in the tropics and subtropics. Usually BC agents for redistribution have been re-collected in the target country rather than the original source country.

5. Control of genetic resources and opportunities for profit

In the case of classical BC, a national or international research institute usually carries out the research, but once established, a BC agent ceases to be under its control. The agent breeds and ideally contributes effectively to management of the target pest. The BC agent will disperse to the geographic range limits to which it is suited, often including other countries. The classical BC ethos is to establish a free-of-charge public good. The sector has traditionally made no use of intellectual property rights to regulate access to, or use of classical BC agents. All knowledge generated is put into the public domain, and other countries are encouraged to take advantage of this new BC agent. Benefits to farmers, consumers, and the local economy, do not return to the research institute or development agency in monetary form.

In the case of augmentative BC, a company might survey for a useful new BC agent to control a particular pest. They research it and develop rearing, distribution and release methods at their own expense. The augmentative BC company then sells it to growers or other customers, generating profits for the company. Farmers who paid for the BC agent benefit from effective pest control and improved yields, growing food without pesticides with implications for their own health, and the price they can obtain for their produce. The customers who buy the food are able to get healthy food at an acceptable price. It is not the practice in the augmentative BC sector to use patents for the control BC agents, so any one can collect and use the agents from nature. Augmentative BC companies may establish patents on rearing processes, but more usually handle this by keeping the relevant know-how secret.

Worldwide, some 30 larger commercial producers of augmentative BC agents are active, of which 20 are located in Europe. In addition to the larger producers, some 100 small commercial producers are active, employing fewer than five people. The total market for augmentative BC natural enemies at end-user level in 2008 was estimated at about US$100–135 million. With an average net profit margin of around 3–5%, the total commercial augmentative BC industry profit is under US$15 million per year. Augmentative BC is a small activity undertaken by small and medium-sized enterprises and with modest profits.

6. Regulation of introduction of biological control agents

Over the last 20 years, the introduction of BC agents has increasingly followed international or national legislation. ISPM3 (International Standards for Phytosanitary Measures No. 3) of the IPPC (International Plant Protection Convention) sets out the responsibilities of the different players, but does not address the issue of ABS.

Since the earliest days of BC, there has been a community of practice based on free multilateral exchange of BC agents, rather than bilateral exchange or defined benefit sharing agreements. Countries are both providers and users of BC agents. It has usually made good practical sense to collaborate with a research organisation in a (potential) source country, and as the need for more detailed risk and environmental impact assessment studies has grown, the need for collaborative research in the source country has grown. Conversely, there is a general trend for access to GR, including BC agents, to become increasingly restrictive, for a variety of reasons, including ABS regulations and, in the case of BC, phytosanitary legislation. The existing multilateral free exchange ethos and effective global networking of BC practitioners is a foundation that deserves special consideration with regards to ABS.

New legislation has been and is being introduced in some countries regarding access to GR. If legislation is not designed to accommodate BC, it becomes a very difficult and challenging process, for both international researchers and their national collaborators. In the short term, this legislation will remain in place and have to be complied with. There is a risk that new international ABS legislation not tailored to the needs of the sector will add another layer of regulation to the research, which is likely to slow the process.

The arrival of a new invasive alien pest in a country can be devastating. In such cases, there is an argument that an emergency response may be needed before irreversible harm is done. That emergency response could be classical BC. In such cases fast-track procedures for access to GR should be anticipated and facilitated.

7. User perspectives

The attitudes and views of BC players reflect a mixture of positions regarding ABS. Much of the classical BC community has been unaware of the potential of ABS to affect its activities, although the pragmatic need for a good local collaborator is recognised. However, there is now growing awareness of ABS policies and the need for continued exchange of BC agents so that BC and the resultant public good will be guaranteed.

The implementers of classical BC have long been aware that classical BC does not bring them cash benefits. It is against the classical BC ethos, which is based on government and donor financing to create a free-of-charge public good. Furthermore, there is no pathway or mechanism to collect monetary benefits from the beneficiaries, such as smallholder farmers. For this reason, forms of non-monetary benefit sharing are appropriate, based around shared research activities and capacity building.

On the other hand, the augmentative BC community has been more aware of the issues, perhaps because augmentative BC does generate some modest commercial profits. Larger augmentative BC producers, such as members of the International Biocontrol Manufacturers Association (IBMA) and the Association of Natural Biocontrol Producers (ANBP), are willing to consider benefit sharing in the form of knowledge sharing, training, provision of natural enemies, and other ways. In the event that a natural enemy obtained from a source country becomes a commercially successful BC agent, some augmentative BC producers foresee that payment of 'royalties' to the country of origin might be possible, but if the industry had to pay for each natural enemy collected, they would anticipate not being able to continue with this type of work. On balance, these producers believe that shared activities and capacity building would be a more realistic approach, given the relatively small profits and profit margins in the augmentative BC industry.

8. Recommendations

ABS regulations should recognise the specific features of BC:

- Countries providing BC agents are also themselves users of this technology;
- Many BC agents are exchanged, but have little recoverable monetary value;
- Organisms are not patented, so can be used by anyone at any time;
- Classical BC information and to a degree augmentative BC information are publicly shared;
- There are societal benefits for all, such as environmental and public health benefits, and reduction in pesticide use;
- BC is widely used in both developing and developed countries, often using the same BC agents;
- Most use of BC relates to food and agriculture.

In view of these specific positive features, the following recommendations are made:

1. Governments should build on the existing multilateral practice of exchange of natural enemies for BC on a complementary and mutually reinforcing basis, which ensures fair and equitable sharing of the benefits of BC worldwide.
2. ABS regulations should encourage further development of the BC sector, by facilitating the multilateral exchange of BC agents.

3. Countries are encouraged to have a single point of contact to facilitate survey missions, provision of information, institutional linkages and taxonomic support, and provide advice on compliance with regulations for BC, including ABS.
4. ABS in relation to BC will normally be based on non-monetary benefit sharing, e.g. capacity building, shared research programmes and/or technology transfer, as already practised by many organisations and the augmentative BC industry.
5. A document describing best practices for ABS in relation to BC, including guidelines for joint research that are equitable but not restrictive, should be prepared and disseminated. BC organisations would be expected to follow these guidelines.
6. To improve transparency in the exchange of BC agents, mechanisms should be supported globally to establish and allow free access to database information on BC agents including source and target countries.
7. In the case of a humanitarian or an emergency situation for food security, governments should cooperate within FAO to fast track action in the exchange of BC agents.

I. SCOPE OF THE STUDY

1. Background

This report was prepared by the Global Commission on Biological Control and Access and Benefit Sharing of the International Organisation for Biological Control (IOBC), with support from FAO and CABI . It sets out to summarise the past and current situation regarding the use and exchange of genetic resources relevant for biological control.

BC provides a focus in relation to ABS and the use of invertebrates, as it is one of the highest profile, largest turnover, and greatest public good portions of the sector. However, in the broader picture it should be remembered that other invertebrate groups are treated similarly with regard to ABS and are important for agriculture, forestry and the environment. This includes invertebrates that provide ecosystem services, such as dung beetles and earthworms, as well as pollinators, including several species of bees as well as more specialised species, such as the oil palm pollinator, Elaeidobius kamerunicus Faust (Coleoptera: Curculionidae), introduced from West Africa to South-east Asia (Greathead 1983), and subsequently to most oil palm producing areas in the tropics outside Africa.

2. Scope

This report specifically addresses the use of invertebrate BC agents introduced from one country to another for control of pests. Up until now, these target pests have mostly comprised other invertebrates and weeds, and only these two groups will be considered here.

The use of indigenous invertebrates is not addressed, although it is recognised that indigenous natural enemies play a major role in agricultural pest control, including augmentative BC as will be discussed below. The use of pathogens as BC agents (Butt et al. 2001; Hajek et al. 2005) is not addressed in this report, as the scope is restricted to invertebrates, but it is important to point out that the use of pathogens in BC, both classical and augmentative, is not fundamentally different to the use of invertebrates. In developing ABS for the two sectors, there is merit in trying to harmonise the use of the two groups, invertebrates and pathogens, in BC.

3. Biological control

In this section we outline the practice of biological control (BC) and introduce the key terminology which may not be familiar to those working in the area of ABS. Biological control is based on the use of natural enemies of pests, often referred to as BC agents. These are predators and parasitoids of invertebrate pests, and herbivores attacking weed pests (Van Driesche et al. 2008)

Almost all BC comes under one of three categories: natural, classical and augmentative.

Natural BC is used to describe the effects of the indigenous natural enemies already present in natural or managed ecosystems. In a healthy ecosystem, these natural enemies act to keep the populations of many (or all) pests at acceptable levels, below the economic threshold at which a control intervention is justified. There are a variety of methods to increase the number, diversity and impact of these naturally occurring BC agents, and this interventionist approach is often referred to as conservation BC (for the purposes of this report, the term natural BC encompasses both aspects). Equally important, it is recognised that the application of broad-spectrum insecticides will kill many of these natural BC agents, so that minimising the use of pesticides and delaying their use as long as possible into the cropping season are key elements of integrated pest management (IPM). Natural BC is widely recognised as the foundation of IPM, and in the interests of the public and the environment, most governments now recommend an IPM approach to pest management in agriculture. The savings in crop yield due to natural BC are already recognised to be enormous, and much greater than those that accrue from classical BC or augmentative BC (Costanza et al. 1997). Although natural BC keeps most pests at acceptable levels, it does not prevent or solve all problems, and the most intractable pests in this regard are often invasive alien species, freed of their specialised natural enemies from their area of origin. In this case, classical BC or augmentative BC may be the best option.

Classical BC, also referred to as introduction BC (Waage 2007), is the introduction of one or more BC agents, usually from a pest's area of origin, to control the pest in an area where it is introduced. Once introduced, the BC agent will become established, reproduce and spread, so that no further intervention is needed for the BC agent to have its effect on the target pest. Thus, the introduced BC agent in a classical BC programme becomes part of the natural BC in the ecosystem, working in combination with it (Case Study 1).

Augmentative BC using invertebrates involves the production and release of BC agents into specific crop situations, where they cause mortality of the target pest, but are not expected to persist from one cropping cycle to the next. A great proportion of augmentative BC is applied to greenhouse crops, but field crops are also treated. The BC agents used in augmentative BC may be indigenous or exotic. Where they are exotic, they should under best practice be evaluated before use in a similar way to BC agents for classical BC, which is now common practice in several countries (van Lenteren et al. 2006). Indigenous natural enemies may be indigenous to the country where they are being introduced, or indigenous to the region, e.g. natural enemies produced in The Netherlands may have been originally collected in The Netherlands, but may occur naturally across northern Europe, and are also sold across the same region.

Biological control, particularly classical BC, is a cost-effective, environmentally friendly approach that can solve alien pest problems in diverse ecosystems, including agriculture and forestry, but also natural, semi-natural and urban habitats, freshwater, etc. Alien species are being introduced around the world at an increasing rate, driven by factors such as increasing trade, travel and tourism (Wittenberg & Cock 2001). A proportion of these become established and a proportion of those established become pests or invasive in natural habitats. It should also be noted that most of the world's crops are grown as alien species in much of the area where they are planted; there remains great potential for pests from the crops' areas of origin to be introduced into the areas where the crops are being grown as aliens. Furthermore, as new crops are adopted and spread around the world, e.g. new agri-fuel crops, there will be new opportunities for such introductions.

BC is an important tool that is and will be needed by all countries to tackle existing and future alien pest problems. Recent experience tells us that future introductions of pests and invasive species will occur when source countries fail to prevent the accidental export of these organisms, thus not meeting part of their obligation under the CBD.

It should also be noted at this point that allowing access to BC agents for use in another country imposes no risk of liability to the source country. Local scientific knowledge about habitats, fauna and flora, can help greatly in finding relevant places for surveys and collections.

In setting up a classical BC programme against a new pest from the beginning, e.g. for a newly introduced pest, there are various stages, with different implications with regard to ABS. More or less the same procedure would be followed for augmentative BC where a BC agent is to be used in an area where it is not indigenous:

Preparation and planning. This involves a literature survey to find out what is known about the pest and its natural enemies throughout the world. Sometimes the literature will be comprehensive, for example assessing the invertebrate herbivores associated with a weed which originated in Western Europe. Other times, almost nothing may be known, and in the extreme case, the area of origin of the pest may be completely unknown, and the pest itself may not be known except as an alien pest problem (Case Study 2). In order to plan the search for natural enemies of an introduced pest, it is necessary to know the area of origin of the pest, and the best place to look for natural enemies – these are not necessarily the same. It may be necessary to collect genetic material of the target pest from a variety of countries in order to understand what exactly has been introduced from where, and so define where detailed surveys for natural enemies should best be undertaken. It would be cost and time efficient to make a rapid survey of associated natural enemies at the same time, so that these can be identified and help with planning the next stage, i.e. with provisional identifications to hand, insight into groups difficult to identify, areas where taxonomic research will be needed, provisional selection of priority natural enemies for study, etc., will be facilitated. These initial surveys would be rather superficial, compared to the more detailed studies that would follow, focussed on prioritised natural enemies in one or more selected areas.

Thus, preliminary surveys of the target and its natural enemies will often need to be carried out in several different countries, in order to establish where further studies should focus. At the preparation stage, the researcher would need to collect the pest and closely related species and their natural enemies for identification and molecular studies. Material of both pests and natural enemies would normally need to be exported for study. Much of this material would be dead and preserved, but often would include living immature stages to be reared through for identification and study. Where facilities, relevant taxonomists and a competent partner exist in-country, this could be done in the source country. However, when several countries are surveyed, identifications of each taxonomic group of natural enemies and molecular studies should be done by the same taxonomist, i.e. in the same location.

These surveys offer rather more limited opportunities for benefit-sharing than the detailed studies that follow, but training in survey methods, joint surveys and similar capacity building activities nevertheless yield information of value to the source country, sometimes of unexpectedly high value (Case Study 3).

Detailed studies on natural enemies to assess their potential would focus on identification, biology, rearing methods, host specificity, impact, etc. The options would be to do this in the source country, the target country, a third country or some combination of these. All options occur. Some studies must be carried out in the source country, e.g. surveying for field incidence, surveying related species to assess host specificity, open field testing to assess specificity and impact. It would be safest if host-specificity studies involving plants or animals not already occurring in the source country were carried out in quarantine in the target country or in a third country. Other studies, such as identification, may need to be carried out by a specialist taxonomist at one of the world's museums.

Thus, the needs for access to GR are similar to the preparation and planning stage, but more material would be involved, and living cultures of the invertebrate natural enemy would normally need to be established outside the source country for at least some of the detailed studies. On the other hand, it is this stage of a BC programme that provides much of the greatest scope for collaboration, shared research and capacity building.

Releases. The preliminary studies carry no specific expectation that anything collected and exported will be developed as a BC agent for classical BC or augmentative BC. The detailed studies should establish which, if any, natural enemies are suitable for use as BC agents – it is possible that none will be suitable. The detailed studies will then be used to compile a dossier for the target country authorities to evaluate the risks and potential benefits of making an introduction. On the basis of this dossier, permission for introduction may (or may not) be given with stipulated conditions, following established procedures under national regulations or the IPPC (2005). Although the objective of the whole programme has been towards this end throughout, it is only at this stage that it becomes clear whether a release of a BC agent from a particular country will go ahead.

In the past, the research up until this point has assumed that the source country will not object to the release of a BC agent exported from their country. Given the possible requirements of ABS legislation, this should no longer be taken for granted. Early on in the process there needs to be an understanding with the source country about what further permission may be required, if any, before a BC agent is released in the target country.

There is relatively little scope for routinely sharing research in the implementation stage with the source country, particularly if the research agency is not the same as the implementing agency. However, there may be scope to build some aspects into capacity building activities, which will assist the source country to implement its own BC releases in turn.

Identification of potential biological control agents (and targets). It should be emphasised that taxonomy provides critical underpinning to BC activities, and is relevant at all steps in a BC programme. All necessary steps should be taken to facilitate the access of taxonomists to the material necessary for their studies to characterise and identify biodiversity, as the first step to making it available for use. Because identification is so important, this needs to be done by the most competent taxonomists for each group, and usually complemented with molecular studies. Sometimes this can be done in the source country, but often material will need to be exported for identification as outlined in the steps above. There is no single country that has taxonomic competence for all groups of organisms, so international cooperation is essential. Key taxonomists involved are often in a country otherwise not involved in the BC project. If a BC agent is released, voucher material should be preserved and distributed to museums in the source country, target country and countries to which the BC agent is likely to spread.

In many cases the same approach is followed for augmentative BC. There is one main difference: the first search for BC agents is made in the region invaded to identify indigenous natural enemies that may be suitable to control the pest. This will often involve pest exposure methods that involve putting pest-infested plants in ‘natural areas’ and monitoring what attacks the pest. This approach was used very successfully to find parasitoids for exotic leaf miners in Europe (Case Study 4). The result of the approach of first checking for indigenous BC agents is that over the years the proportion of indigenous BC agents used in augmentative BC has increased (see section 2.1.1).

4. Variety of users and uses

There are two main groups of producers involved in augmentative BC: commercial and centralised. The former are independent companies who produce and sell BC agents to users. Independent companies have mostly operated in developed countries, particularly in Europe and North America, but new companies and franchised companies are increasingly common globally, particularly supporting cash crop production in middle-income countries.

The centralised production units are government- or industry-owned and produce natural enemies for a particular niche, normally large-scale agriculture or forestry, which are either provided free or sold to users. This approach was prevalent in China and many countries within the Russian sphere of influence for many years, mostly using indigenous BC agents, but this activity has declined in many areas, as imported or locally manufactured pesticides have become available. The tradition continues, e.g. in Latin America where BC agents are produced and distributed for plantation crops such as sugar (Case Study 5) and coffee, and forestry. Some of these activities are now becoming privatised, which is probably the future trend.

The main users of BC agents produced for augmentative BC are:

- Greenhouses, where IPM based on BC of key pests is widely practised in Europe and North America;
- Open field agriculture and forestry in various countries in Latin America, China and elsewhere, usually for cash crops;
- Domestic residences, public places (including offices, hospitals, shopping malls, botanical gardens, etc.), and research facilities. This is a relatively much smaller market, but uses many more different species of natural enemies. In these situations, pesticide use is deemed unacceptable because of human health risks or plants without pesticide residues are needed for studies, particularly those involving insects.

Thus in augmentative BC, it is the growers who purchase the BC agents who reap the benefits in terms of effective pest management, with little or no pesticide use.

In the case of classical BC, those who implement are normally national agencies or programmes. In the case of developing countries, this is often with the financial support of international development agencies and technical support of implementation agencies. It is quite common for international implementation agencies to take a lead in the exploration for, and evaluation of, natural enemies on behalf of a developing country. The national agencies implement classical BC in order to achieve long-term effective pest management for the benefit of one or more sectors of their country, including agriculture, forestry and fisheries, as well as human and animal health and the environment. In addition to government agencies, implementation agencies might include:

- National industry groups or producer boards;
- Local governments within a country, e.g., provincial or state governments;
- International agricultural research centres.

Apart from the various implementing agencies of classical BC, there are the beneficiaries, i.e. growers who have reduced pest problems, etc. (see Section 2.3), but they do not actively use the BC agents, which spread and reproduce naturally, and provide a free public good.

This report is concerned with BC principally in the context of agriculture and forestry, although BC is also used to address invasive alien species and pests as environmental problems (Wittenberg & Cock 2001). It should also be noted that BC has been used or considered in the context of other sectors including:

- Control of vectors of human and animal diseases;
- Control of pests of humans and animals (e.g. red poultry mite, Dermanyssus gallinae (De Geer));
- Management of nuisance and disease-transmitting flies breeding in animal dung;
- Management of alien species in other production systems, e.g. water weeds affecting fisheries, transport, power generation, etc. (Case Study 6);
- Ecosystem services such as recycling animal dung in pasture.

Most or all points made about BC in this report can also be made with regard to these sectors.

II. USE AND GLOBAL EXCHANGE OF BIOLOGICAL CONTROL AGENTS AND THEIR BENEFITS

1. Use of genetic resources

1.1. Extent of use

Classical BC and, to a lesser extent, augmentative BC have been widely practised over many years. In support of the preparation of this report, we compiled a list of as many BC introductions as possible by extracting data from databases and to a limited extent the published literature as set out in Annex 1. Much of this information is not in a form immediately suitable to answer ABS questions related to independent countries (due to use of dependencies, changing political units, treating separately different zoogeographical parts of the same country, etc.) so only limited analysis is possible at this time. For greater clarity regarding the use of GR and transparency of ABS, it would be desirable to invest in upgrading these data into a form that can report more effectively on the types of questions that could be asked in the context of ABS.

Based on the compilation described above, 7,094 introductions of BC agents involving about 2,677 BC agent species have been made. Of these 1,070 have been used more than once, and the remaining 1,607 only once, although this number is probably an overestimate owing to uncertainties of taxonomy. The most widely used BC agents have been introduced more than 50 times (Case Study 7; Table 1, Annex 1).

Of the 7,094 introductions, 222 were from and to different parts of the source country, of which 171 were from mainland USA to Hawai'i (section 2.2.4). The remaining 6,872 introductions were from and to different countries, and involved BC agents from 119 countries introduced into 146 countries (Table 2). These are independent countries only, so that more than 1,000 introductions in overseas non-independent territories associated with the former colonial powers are treated as part of that country (France, UK, USA, etc.)

Of these 7,094 introductions, 449 involved material from more than one country. Treating each of these as a separate introduction, and eliminating all records where the source is ambiguous, leaves 6,331 introductions where a source country is clearly identified (Table 3). However, since most of the data are based on published sources, this total also includes some countries which were secondary sources of BC agents, i.e. the BC agents were themselves introduced in those countries.

The data are not yet in a form that would enable us to generate statistics on establishment and impact. However, there are clear indications available from earlier surveys. Greathead & Greathead (1992) analysed an earlier version of the BIOCAT database of insect BC using insects with 4,769 records; of these, 1,445 (30%) were known to have resulted in establishment and 517 (11%) achieved substantial control of the target pest. These rates are probably conservative for classical BC as a whole, since the rates in weed BC tend to be higher, and the establishment and impact rates have improved in recent decades, following on from the introduction of more careful study and evaluation of potential BC agents.

In Table 4 we have broken down source and target countries on the basis of the World Bank country groups by income (World Bank 2009). While it is clear that high-income countries have implemented classical BC more than middle- and low-income countries have, it is also clear that all groups have participated. Equally, high-income countries have been the main source of BC agents, and although low-income countries have contributed more BC agents than they have received, the numbers are not totally disproportionate.

The implementation of classical BC in low-income countries depends entirely or almost entirely on donor assistance, often linked to the availability of BC agents as spin-offs from high- and middle-income country research. BC research targeted at pests primarily of concern to low-income and lower middle-income countries is rare, and in the case of weed BC, the long-term nature of the research and the need to carry out much survey and evaluation research in other countries can make this superficially unattractive to donors (Cock et al. 2000). Nevertheless, targeted classical BC research has been shown to have enormous potential benefits to these countries (Case Study 3 and Section 2.3). Increased donor support to develop and implement classical BC in support of agriculture and food security is needed.

Table 1. The most used biological control agents (BCAs) for classical biological control.

BCA	**Classification** (insects except as indicated)	**Origin**	**Target(s)**	**Number of countries where BCA was released**
Cryptolaemus montrouzieri	Coccinellidae	Australia	Mealybugs	58
Rodolia cardinalis	Coccinellidae	Australia	*Icerya purchasi*	56
Diachasmimorpha longicaudata	Braconidae	SE Asia	Fruit flies	49
Teleonemia scrupulosa	Tingidae	Neotropical	Lantana weed, *Lantana camara*	39
Cotesia flavipes	Braconidae	South Asia	Sugarcane stem borers (Crambidae)	38
Aphelinus mali	Aphelinidae	North America	Woolly apple aphid, *Eriosoma lanigera*	37
Euglandina rosea	Mollusca, Gastropoda, Spiraxidae	USA	Other snails	35
Lixophaga diatraeae	Tachinidae	Caribbean	Sugarcane stem borers (Crambidae)	35
Neochetina eichhorniae	Curculionidae	Neotropical	Water hyacinth, *Eichhornia crassipes*	35
Uroplata girardi	Chrysomelidae	Neotropical	Lantana weed, *Lantana camara*	31
Cotesia plutellae	Braconidae	Europe	Diamondback moth, *Plutella xylostella*	29
Encarsia perniciosi	Aphelinidae	East Asia	San José scale, *Quadraspidiotus*	29

			perniciosus	
Neochetina bruchi	Curculionidae	Neotropical	Water hyacinth, *Eichhornia crassipes*	28
Lydella minense	Tachinidae	Brazil	Sugarcane stem borers,mainly *Diatraea* spp.	27
Paratheresia claripalpis	Tachinidae	Neotropical	Sugarcane stem borers, mainly *Diatraea* spp.	26
Rhinocyllus conicus	Curculionidae	Europe	Thistles, especially nodding thistle, *Carduus nutans* group	26
Cactoblastis cactorum	Pyralidae	Argentina	Prickly pear cacti, *Opuntia* spp.	24
Trissolcus basalis	Scelionidae	Widespread	Green stink bug, *Nezara viridula*	24
Ageniaspis citricola	Encyrtidae	SE Asia	Citrus leaf miner, *Phyllocnistis citrella*	23
Aphytis lingnanensis	Aphelinidae	SE Asia	Red scale, *Aonidiella aurantii*	23
Cryptognatha nodiceps	Coccinellidae	Neotropical	Armoured scales, Diaspidae	23
Apoanagyrus lopezi	Encyrtidae	Brazil, Paraguay, Bolivia	Cassava mealybug, *Phenacoccus manihoti*	22

Table 2. The numbers of classical biological control introductions made in different countries.

Number of releases per country	Number of countries	Total number of releases in these countries	% of total releases
>100	12[1]	4,231	61.6%
50-100	14[2]	997	14.5%
10-49	55	1,399	20.4%
1-9	65	245	3.6%
	146	6,872	

1 In order: USA, Australia, Canada, New Zealand, South Africa, UK (almost entirely overseas territories), Fiji, Mauritius, India, France (mostly overseas territories), Israel, Guam.

2 In order: Russia, Italy, Barbados, Chile, Trinidad and Tobago, Ghana, Kenya, Philippines, Mexico, St Kitts and Nevis, Papua New Guinea, Greece, Peru, Bahamas.

Table 3. The numbers of biological control agent (BCA) species obtained from different countries for classical biological control (only those records where the source is clear are included).

Number of BCAs obtained from country	Number of countries	Total number of BCA introductions from these countries	% of total releases
>100	16[1]	4,482	70.8%
50-100	9[2]	646	10.2%
10-49	40	1,032	16.3%
1-9	54	171	2.7%
	119	6,331	

1 In order: USA, India, Australia, Trinidad and Tobago, Mexico, France, Brazil, China, South Africa, Japan, UK, Argentina, Pakistan, Indonesia, Italy, Austria.

2 In order: Philippines, Colombia, Germany, Switzerland, Canada, Kenya, Malaysia, Papua New Guinea.

Table 4. The supply and use of biological control agents (BCAs) broken down by country income economy groups (World Bank 2009).

	BCAs obtained				BCAs released			
	Number of countries	Total number origins in these countries	% of total origins	Average number /country	Number of countries	Total number releases in these countries	% of total releases	Average number /country
High-income economies	28	3,100	49.0%	111	33	4,078	63.7%	124
Upper middle-income economies	30	1,310	20.7%	44	31	1,355	21.2%	44
Lower middle-income economies	31	1,375	21.7%	44	37	666	10.4%	18
Low-income economies	26	491	7.8%	19	37	148	2.3%	4
Unclassified	2	55	0.9%	28	7	152	2.4%	22

Total	117	6,331			145	6,399		

In augmentative BC worldwide, more than 170 species of natural enemies are produced and sold, but only some 30 of these species are reared in great numbers and these make up more than 90% of the market value (Table 5, and see Section 2.5).

Table 5. The most important biological control agents (BCAs) used in augmentative biological control.

BCA	**Family** (insects except as indicated)	**Source area**	**Target(s)**	**No. of countries where used**	**Year of first use**
Amblyseius swirskii	Phytoseiidae	Israel	whiteflies, thrips, mites	20	2005
Aphidius colemani	Braconidae	Middle East	aphids	20	1991
Aphidoletes aphidimyza	Cecidomyiidae	Europe	aphids	20	1989
Dacnusa sibirica	Braconidae	Europe	leafminers	20	1981
Diglyphus isaea	Eulophidae	Europe	leafminers	20	1984
Encarsia formosa	Aphelinidae	Central America	whiteflies	20	1926
Macrolophus pygmaeus (= *nubilis*)	Miridae	Europe	whiteflies	20	1994
Neoseiulus cucumeris (= *Amblyseius cucumeris*)	Phytoseiidae	Europe	thrips	20	1985
Phytoseiulus persimilis	Phytoseiidae	Chile	mites	20	1968
Steinernema feltiae	Steinernematidae[1]	Europe	Sciaridae	18	1984
Aphidius ervi	Braconidae	Europe	aphids	17	1996
Orius laevigatus	Anthocoridae	Europe	thrips	17	1993
Cryptolaemus montrouzieri	Coccinellidae	Australia	mealybugs, scales	16	1989
Galeolaelaps aculeifer (= *Hypoaspis aculifer*)	Laelapidae	Europe	Sciaridae	16	1996

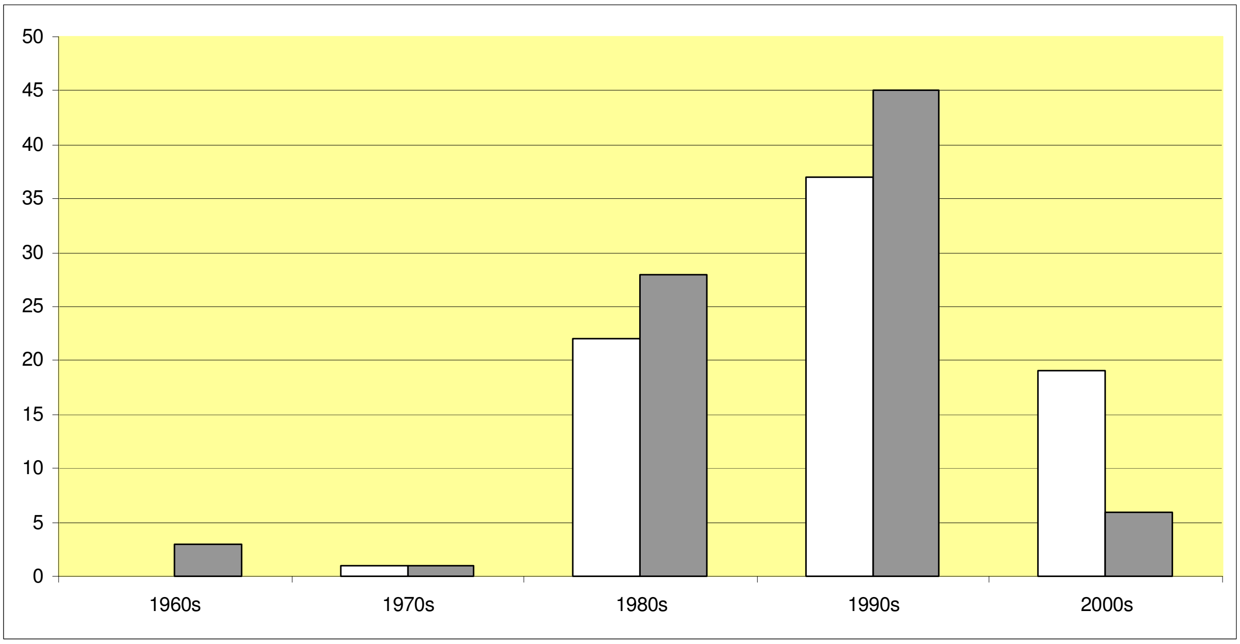
Feltiella acarisuga (=Therodiplosis persicae)	Cecidomyiidae	Europe	mites	15	1990
Leptomastix dactylopii	Encyrtidae	South America	mealybugs	15	1984
Stratiolaelaps miles (= *Hypoaspis miles*)	Laelapidae	Europe	Sciaridae	15	1995
Aphelinus abdominalis	Aphelinidae	Europe	aphids	14	1992
Heterorhabditis bacteriophora	Heterorhabditidae[1]	Europe	Coleoptera	14	1984
Heterorhabditis megidis	Heterorhabditidae[1]	Europe	Coleoptera	14	1990
Neoseiulus californicus (= *Amblyseius californicus*)	Phytoseiidae	Central America	mites, thrips	14	1985
Eretmocerus eremicus	Aphelinidae	North America	whiteflies	13	1995
Eretmocerus mundus	Aphelinidae	Europe	whiteflies	13	2001
Episyrphus balteatus	Syrphidae	Europe	aphids	11	1990
Trichogramma evanescens	Trichogrammatidae	Europe	Lepidoptera	11	1975
Chrysoperla carnea (= *Chrysopa carnea*)	Chrysopidae	Europe	aphids, whiteflies etc.	10	1987
Steinernema carpocapsae	Steinernematidae[1]	Europe	Lepidoptera	9	1984
Iphiseius degenerans (= *Amblyseius degenerans*)	Phytoseiidae	Europe, Mediterranean	thrips	4	1993
Aphidius matricariae	Braconidae	Europe	aphids	3	1990
Delphastus catalinae (= *pusillus*)	Coccinellidae	America	whiteflies	3	1993

Neoseiulus barkeri (= *Amblyseius barkeri*)	Phytoseiidae	Europe	thrips	3	1981
Nesidiocoris tenuis	Miridae	Europe	whiteflies	3	2003
Orius majusculus	Anthocoridae	Europe	thrips	3	1993
Neoseiulus fallacis (= *Amblyseius fallacis*)	Phytoseiidae	North America	mites	1	1997

1Entomopathogenic nematode.

Currently, there is a trend to first look for indigenous natural enemies when a new, even exotic, pest develops (Case Study 4). This is clearly illustrated by the number of natural enemies that were used for the first time in previous decades (Fig. 1). Until 1970, the only two species commercially used in Europe were exotics. During the following three decades, more new exotic species (77) were used than indigenous species (58). In the last decade, this trend changed and for the first time more indigenous species (18) were commercialised than exotic species (six). During the past ten years, seven exotic natural enemies that were used in Europe have been replaced by indigenous natural enemies. Three of these seven species had large market values.

Fig. 1. First use of natural enemies in augmentative biological control in Europe by decade, since 1960 (white = indigenous; grey = exotic).



The rate at which new species have been added to the augmentative BC market in Europe was greatest in the 1980s and 1990s, but has slowed substantially in the 2000s (Fig. 2). Exotic and indigenous species are now used in about equal numbers, as indigenous species comprise the largest proportion of new species on the market (Fig. 3).

Of the 26 natural enemy species commercially allowed for use in Africa, 25 result from material collected in and initially mass reared on other continents. A similar situation exists in Mexico. In Australia and New Zealand almost equal numbers of indigenous and exotic natural enemies are used. The situation is quite different in several South American countries (e.g. Argentina, Brazil) where many of the natural enemies used in augmentative BC are indigenous species.

Fig. 2. Cumulative number of natural enemies in use in augmentative biological control in Europe since 1960 (white = indigenous; grey = exotic).

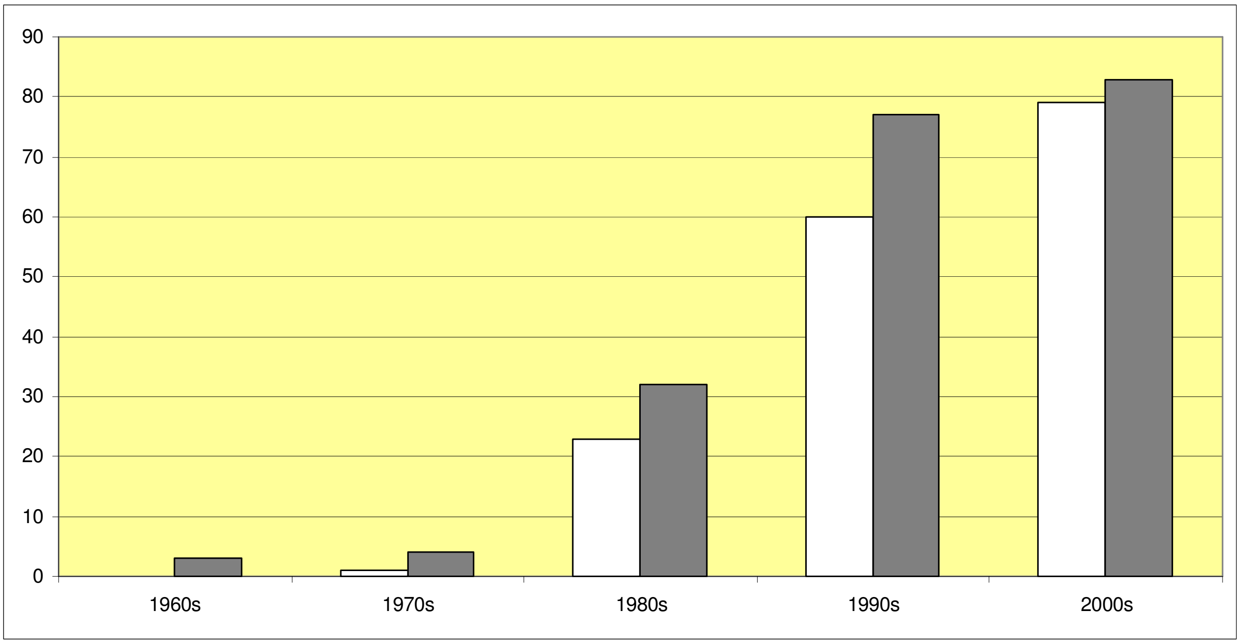
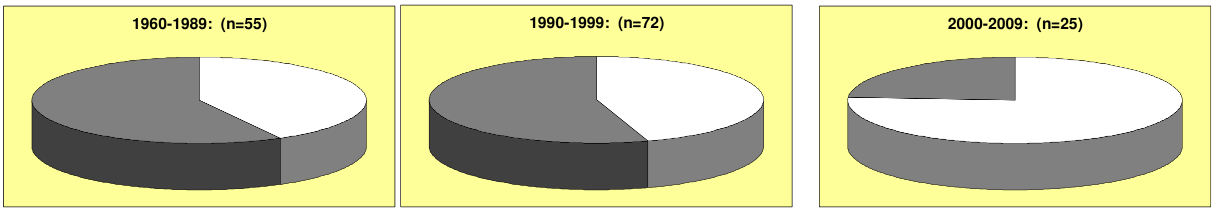


Fig. 3. The changing proportions of first use of exotic (grey) and indigenous (white) natural enemies in augmentative biological control in Europe over time.



1.2. Addition of value

BC does not involve simply taking a BC agent from one country and releasing it in another. It is a lengthy research process, except where one is using a BC agent that has already been released in different countries and zoogeographic regions and has a proven track record for safety and effectiveness. Issues such as the risk to humans, economic plants and the environment need to be addressed (Bigler et al. 2006; van Lenteren et al. 2006; Van Driesche et al. 2008). There are regulations regarding the introduction process (IPPC 2005 and national legislation). In section 1.3, some of the key stages in the process are outlined. These add value to the natural enemy in a variety of ways, including:

- Authoritative identification, and thereby access to any published information, and much unpublished information, e.g. on the internet or in databases;

- Treatment to remove possible contaminants, including parasitoids and pathogens;
- Development of rearing methods for use in the laboratory or insectary;
- Studies on the host range in the field and in the laboratory;
- Impact studies in the field or laboratory (sometimes);
- Preparation of documentation and publications to present all relevant information to the regulatory authorities and the scientific community;
- Development of release strategies and protocols;
- Development of monitoring and evaluation procedures.

Researchers wishing to evaluate a natural enemy as a potential BC agent need to carry out some or all of these steps, and in making this investment make the natural enemy increasingly useful as a BC agent. On the other hand, some of these steps could also demonstrate that the natural enemy is not suitable for use as a BC agent. It should be noted that several, but not all, of these steps are best addressed in the area of origin and provide opportunities for scientific collaboration between research groups in the source country and the implementing agency or research groups in the receiving country.

Value may be further added by discriminating between different populations of the natural enemy with different biological characteristics, making one or some of them better adapted to the target country or target pest (Case Study 8). This will involve detailed laboratory studies, supported by molecular methods.

In establishing an insect culture for the first time, a population bottleneck is created by having only a comparatively small number of individuals available, i.e. only some of the genetic variation in the source population is included. There is a second bottleneck since not all individuals will necessarily breed in captivity, and the culture will be based on the descendants of those individuals who were able to thrive under the laboratory conditions. This will result in a population better suited to laboratory culture, but potentially less effective as a BC agent for field release. This may generate the need for further research, which will add value.

A special case is where a BC agent is released successfully in one country and thereafter made available to other countries, from field material re-collected in the country of introduction (Case Studies 7, 9, 10). Just as a BC agent would go through a bottleneck when established in culture, so it would go through another bottleneck when introduced and established into a new country (Case Study 11) – the GR will be slightly different. The fact that BC agents have been re-used in other countries so often in BC has contributed significantly to the number of introductions, and by using BC agents already known to be effective in one country, the success rate per introduction is also increased.

In addition to the value added to the natural enemy as a potential BC agent, it should also be noted that these studies which add value, may also provide direct benefits to the source country in terms of information about biodiversity and ecosystem services, but also new knowledge about the natural BC already operating in the source country, which needs to be understood to develop the best IPM methods in that country.

1.3. Typology of main users

There are important distinctions that need to be made between who implements BC, who pays for it and who benefits from it, and, linked to this, who is responsible for the benefits which might be shared with the source country.

An augmentative BC company might survey for and find a useful new BC agent to control a particular greenhouse pest for which farmers will otherwise use pesticides. They research it and develop rearing, distribution and release methods at their own expense. The augmentative BC company then sells it to growers or other customers with a profit margin, generating profits for the company. Farmers who paid for the BC agent benefit from effective pest control and improved yields, growing food without pesticides with implications for their own health, the price they can obtain for their produce, and obviating the risk of disrupting the other BC agents in their greenhouses. The customers who buy the food are able to buy healthy food at an acceptable price. However, the company does not patent the BC agent, so in principle there is nothing to stop another company collecting the BC agent from the crops where it has been used and developing their own product, benefiting from the pioneering work of the first company. For this reason the augmentative BC company tries to keep secret its production know-how, in order not to facilitate competition. It is also clear that while the total profits for a pharmaceutical company could be very large, in the millions of US$, those of an augmentative BC company would be relatively small, probably never more than hundreds of thousands of US$ (see Section 2.5).

In the case of classical BC, a national or international research institute may carry out the research, with funding from a government or a development agency. The research institute may find, study and release a BC agent, but once released, it ceases to be under their control, breeds, disperses and all being well brings the target pest under control. The research institute will not be paid any more than the costs of the research and cannot generate a profit from its action. The BC agent is not patented, and the research institute will put all that it has learnt into the public domain, and often encourage other countries to take advantage of this new BC agent. Farmers and consumers benefit, as may the local economy, but these benefits do not return to the research institute or development agency in a monetary form, nor does a funding government receive a direct return, although it may need to spend less on health treatment, and receive more in taxes from an improved economy.

Thus while those producing BC agents for augmentative BC can make a small profit, those implementing classical BC are not in a position to do so. Clearly there can be substantial benefits to individuals and society from applying classical BC, but these are not in a form that can be easily measured and collected and hence are very difficult to share.

1.4. Trends in genetic diversity

Trends in genetic diversity which are important in relation to crop breeding are not really an issue for invertebrates used in BC.

Weed BC and some insect BC programmes require surveying for BC agents in natural habitats, in which case lack of suitable habitat (perhaps due to habitat loss) and access to the remaining suitable habitat could be a problem. This is particularly the case in the search for indigenous natural enemies for use in augmentative BC. As yet, there is very limited evidence to suggest that lack of suitable habitat is a problem (Case Study 12), but in time more and more of the best habitat for some types of surveys will be in protected areas such as national parks and nature reserves so that special permission may be needed for access.

When searching for natural enemies of a crop pest in the area of origin of the pest, this will often require that the crop(s) on which the target pest is found are available. If this crop were no longer being grown in the source area, at worst it would be necessary to establish a new planting of the crop, in order to re-establish the agroecosystem for the pest and its natural enemies. It seems unlikely that a crop pest and its natural enemies would cease to be available in its area of origin.

Similarly, natural enemies may be scarce in the source area if crops are being grown in which the pests and their natural enemies are suppressed by pest management options, e.g. with heavy pesticide use. However, this is generally not a problem, especially if IPM or organic production systems are available, and again, if necessary a new planting of the crop could be organised.

2. Global exchange of genetic resources

As described in Section 1.3, not all species found in surveys are studied in detail. For example, weed species originating in Europe will often have 100–200 or more phytophagous arthropods associated with them based on surveys and literature, but seldom will more than 10–15 of these be studied in any detail, others being rapidly discarded as polyphagous or having no useful impact (CABI Europe-Switzerland, unpublished). Only some of those species studied are recommended for use, many being discarded when detailed studies show them to be unsuitable. Of those that are recommended for release not all are authorised for release. However, species recommended for release have normally have been studied in sufficient detail, and in light of national requirements and expectations, so that permission to release is seldom refused. Finally species that are released may not establish or be effective (Section 2.1.1).

For example, an analysis of weed BC in New Zealand (Cameron et al. 1989) up to 1987 showed that for 70 target weeds, 321 agents were introduced into quarantine, 225 were released, 70 established and in 24 cases the target weed was reported to be impacted. Subsequent research and implementation has improved these figures as more releases have been made and more BC agents established.

The situation is different for augmentative BC, inasmuch as BC agents will have been tested and demonstrated to be effective or partially effective before they are mass produced and offered for sale.

The list of BC introductions described in Annex 1 shows that at least 7,000 classical BC releases of over 2,500 species have been made in 146 countries over the last 120 years. This represents a very large amount of research for implementation. Over time the amount of study needed before recommending release has steadily increased, particularly for BC agents being used for the first time. Extrapolating from these numbers, the original surveys and preliminary studies must have involved many more species, maybe of the order of 25,000, so that the total contribution to an increased understanding of the natural BC in source countries is very large.

2.1. Types of genetic materials

Genetic materials used in BC are primarily living organisms to be used as BC agents. These are almost always from in situ situations. As described in section 2.2.5, once a BC agent has been used successfully in one country there is a tendency to repeat that success using material from the field or laboratory where the introduction has been a success. This may also occur in the case of augmentative BC. Also as described in section 1.3, in the preliminary stages of a programme, researchers will need access to GR of the target and its natural enemies for taxonomic and molecular ecology studies.

The types of invertebrate organisms used as BC agents have not changed dramatically, although in recent decades the emphasis has shifted quite strongly towards BC agents that are more host specific and so present less potential threat to non-target organisms. The associated studies and procedures have also become more sophisticated, including host-specificity testing, removal of contaminants, climate matching and genetic characterisation. There is also a trend towards permits being issued based on a specific population or biotype of BC agent, rather than a blanket permit at the species level (Case Study 6).

2.2. Main providers of biological control agents

At least 119 countries have at some stage provided a BC agent to another. Providers are normally the source countries of the target invertebrate or weed pest. Often, more than one country is the source of a particular BC agent, but sometimes the area of origin and natural distribution is confined to just one country with a high degree of endemicity, e.g. Australia, Brazil, Madagascar and South Africa. Thus, in the former situation there may be some flexibility as to which country to collaborate with, which may reflect ease of collaboration under an ABS regime, but in the latter case there is only the one country that can assist with a particular pest (e.g. Case Study 7).

As described in section 1.3, it should be noted that quite often researchers do not know the true origin of their target pest, and need sometimes to survey and collect in several countries in order to establish this. This procedure is becoming more straightforward as molecular methods are increasingly applied routinely.

Oceanic islands, including most Small Island Developing States, suffer disproportionately from invasive alien species, and are seldom the source of invasive alien species themselves (Wittenberg & Cock 2001). Correspondingly, they are very rarely the source of BC agents (except those introduced for BC), but they are major beneficiaries (e.g. Case Study 13), as partially shown in Tables 2 and 3.

2.3. Transfer procedure

Over the last 20 years, the introduction of BC agents has increasingly followed ISPM3, the International Standards for Phytosanitary Measures No. 3 (IPPC 1996; Greathead 1997; Kairo et al. 2003; IPPC 2005), or equivalent national legislation. This standard sets out the responsibilities of the different players, and asserts the importance of a pest risk assessment procedure, but lacks practical guidance, and does not address the issue of ABS. As society's concerns have grown about the possibility of non-target effects of BC agents, the trend has been towards fewer, safer, better BC agents which will have been studied in more detail so that these concerns can be addressed authoritatively (Bigler et al. 2006; van Lenteren et al. 2006). The net impact is that the amount of BC has not necessarily decreased, but the process has taken significantly longer, and the success rate may also have increased since introductions are based on more extensive research (e.g. Barratt et al. 2000).

2.4. National vs. international transfers

Apart from transfers between continental USA and Hawai'i (171 in the list compiled as described in Annex 1), internal transfers have not been common (222 in total), and probably would only occur in countries with disjunct territory separated by the sea, or in a large heterogeneous country with major physical barriers, e.g. Russia, USA. In fact the great majority of classical BC transfers are intercontinental, which is to be expected since the targets are themselves often introduced species, usually of intercontinental origin. In contrast, for augmentative BC, indigenous natural enemies are used as frequently as exotic ones. In augmentative BC the approach is currently to first study and try out indigenous natural enemies, or at least natural enemies indigenous to a region, e.g. within Europe. If these are not found or are not effective, then a search for exotic natural enemies will take place, involving international transfers (Case Study 14).

2.5. Trends in global exchanges

Since the earliest days of BC, there has been a tradition of free multilateral exchange of BC agents (most Case Studies, but especially 15). Nevertheless, it has usually made good practical sense to collaborate with a research organisation in a (potential) source country, and as the need for more detailed safety studies has grown, the need for collaborative research in the source country has grown. Conversely, there is a general trend for access to GR, including BC agents, to become increasingly restrictive. This includes phytosanitary legislation not designed for BC.

New legislation has been and is being introduced in some countries regarding access to GR. If this is not designed to accommodate BC, it can make it very difficult, creating a challenging process, for both international researchers and their national collaborators (Case Studies 16–18). In the short term, irrespective of the ABS scheme currently developed under the CBD, this legislation will remain in place and have to be complied with. There is a risk that ABS will add another layer of regulations to the research process, which is likely to slow it.

Throughout the history of BC, BC agents that are effective in one country have been forwarded to other countries affected by the same pest problem (e.g. Case Studies 7, 9). In the past this was sometimes done rather casually (Case Study 19), without due consideration of the possible risks, but following the introduction of ISPM3 (IPPC 1996, 2005), this practice has been reduced (Kairo et al. 2003). However, it should be noted that access to such tested BC agents is one way that developing countries have benefited from research and implementation carried out by developed countries. This is particularly true of the work of developed countries in subtropical and tropical regions, e.g. Australia, South Africa, USA, which has been of direct benefit to developing countries in the tropics and subtropics (Case Studies 7, 10). Since BC agents such as these would normally have been re-collected in the target country rather than the original source country, the GR ownership is not totally clear (e.g. Case Study 11).

The relatively high up-front costs of BC control research means that countries with a common problem are increasingly collaborating by sharing research and research costs. For example, much of the work that CABI does on weed BC for North America is jointly funded by Canada and the USA; Australia and New Zealand cooperate on some targets; CABI, South Africa and the USA have collaborated with Brazil to study BC agents of water hyacinth (Eichhornia crassipes (Mart.) Solms; Pontederiaceae) in the Upper Amazon, etc. (see also Case Study 20).

The arrival of a new invasive alien species and pest in a country can be traumatic, and many stakeholders including farmers and members of the public are affected. There is strong public pressure for action to be taken, which is translated into political will. An emergency can be quickly recognised, for which immediate action is demanded, often to alleviate actual hardship amongst the poorest segments of the population. In these cases, there is an argument that an emergency response may be needed before irreversible harm is done. That emergency response will be classical BC in some cases. FAO has been responsive to such demands several times in the last 20 years. The need for occasional fast-track procedures for access to GR should be anticipated and facilitated (Case Study 21).

3. Benefits of use and exchange of genetic resources

3.1. Food security and poverty alleviation

One of the simplest and most obvious benefits of implementing BC is in terms of reduced crop losses caused by pests, leading to improved food security and improved or restored livelihoods. This is especially the case with classical BC of food crop pests. Some of the most dramatic success stories in BC can be cited, and Case Studies 3, 9 and 22 give an indication of what has been achieved.

All parts of the world have benefited at different times in this way. This is very much the public good domain of BC, as the benefits reach all who grow and benefit from the crop, without requiring them to make any intervention. Indeed it has been said that the benefits of classical BC are often obtained in spite of the farmers' actions (such as possible continued pesticide use), not because of them.

3.2. Food safety and farmers' and workers' health

One of the positive aspects of both classical BC and augmentative BC is that for them to work, farmers need to stop applying pesticides routinely, and either eliminate them or start to use them in a rational and integrated way so as not to interfere with the natural BC including established exotic BC agents and released or native augmentative BC agents. This reduction in pesticide use will have benefits in terms of reduced risks to farmers and farm workers who would otherwise apply the pesticides, and reduced associated human and medical costs where people are exposed to pesticides. The reduction in pesticide use can also have benefits in terms of reduced pesticide residues in food (which should facilitate access to more profitable and international markets; Case Study 23), as well as potentially reducing the use of foreign exchange to purchase pesticides.

3.3. Livelihoods

BC can affect livelihoods through job creation. In order to make augmentative BC products available in developing countries it is necessary to establish mass-production facilities which creates job opportunities and develops skills of workers, although the number of people involved is small. More important is the creation or retention of jobs in production systems which depend upon augmentative BC (Case Study 23).

For example, Kenya is a major producer of cut flowers for lucrative markets in the European Union (EU). In fact Kenya is the largest single supplier of cut flowers to the EU, accounting for 35% of all exports into the EU. The exports amounted to 93,000 tonnes in 2008 with a value of about $ 600 million (Kenya Flower Council 2009). Although cut flowers are not used as human or animal food, pesticide and quarantine standards apply, and so extensive use of chemicals is not possible in the plastic tunnel environment in the growing areas around Lake Naivasha, Kinangop, and Mt Kenya on about 2,000 hectares. The growers therefore depend on augmentative BC.

According to the Kenya Flower Council (2009) the industry is estimated to employ over 50,000 people directly, and 500,000 people indirectly through affiliated services to the industry. If each has four dependants, the total beneficiaries could be of the order of two million people or about 7% of the population. These opportunities in employment are in rural areas and so not only help to stem rural–urban migration but also contribute to poverty alleviation.

3.4. Environment and conservation benefits

Reduced pesticide use due to BC will also have environmental benefits, for example, in terms of reduced drift from agriculture to adjacent land, reduced run-off and contamination of above- and below-ground water sources, and reduced impact on biodiversity that passes through the crop and its surroundings.

Another important point is that the environment sector itself increasingly needs to deal with invasive alien species that affect biodiversity. Plants in particular have enormous potential to transform ecosystems (Case Study 8), but invertebrates can also have major impact (Case Study 13). In these cases, BC, particularly classical BC, is one of the few options available to land managers. Solutions to pest problems in the environment sector can often be found in the agriculture sector (in the form of BC and other management options). Many pest problems are common to the environment and agriculture or forestry. The application of BC developed to address agricultural problems has had significant benefits in the environment sector and will continue to do so.

3.5. Research and capacity building

As has been pointed out in section 1.3, there are good pragmatic reasons for working with a competent local partner in carrying out BC surveys and research in source countries. When added to the moral obligation in the spirit of ABS under the CBD, there is a compelling case for local partnerships, involving shared research and capacity building. Some of these local partners will become the leaders in developing BC options for their country in the future.

Amongst the actual or potential pragmatic benefits to the BC programme of working with local partners, BC practitioners will recognise:

- Local scientists' knowledge regarding collecting sites, local taxonomic expertise (or lack of it), local plants, farming methods, etc.;
- Assistance where language may be a problem;
- Interface with local authorities regarding permits and permissions;
- Straightforward arrangements for use of vehicles and field assistants;
- Laboratory and field facilities;
- Well-informed local advice where security may be an issue for whatever reason;
- Local back-up in the event of accident or illness.

Conversely, as well as an injection of cash, local partners expect to learn new skills and expertise by participating in surveys, participating in joint publications when appropriate, and acquiring new biodiversity information on plant hosts, pests and natural enemies, etc.

Initial surveys, particularly where there is a wide geographic range to survey (Section 1.3) are by their nature rapid, so the opportunities for shared research are limited. Equally, supplying a known BC agent, which has already been used, is a straightforward activity, involving little or no opportunity for research or generating new information (Case Studies 21, 24). However, opportunities will arise when in-country studies are undertaken. Joint research can become a reality, there may be infrastructure benefits, there will be informal training opportunities, and there may be formal training opportunities. If the collaboration works well, it is likely to expand to related topics and other pests over time (Case Study 25). Such collaboration is encouraged.

3.6. Commercial benefits from improved production

Large countries with large agricultural economies will show much greater commercial benefits from BC than small countries with small agricultural economies. Thus the biggest benefits tend to relate to widespread weeds and insect pests of important crops in countries such as the USA, Canada and Australia. The benefits in developing countries would need to be evaluated in the local context (see e.g. considerations in section 2.3.3). Furthermore, although it is widely accepted that classical BC has generated substantial commercial benefits from improved production, regrettably there are relatively few well-documented studies to show this, partly because, when successful, the results are often considered self-evident and not worth measuring and documenting.

The programmes of weed BC which Australia has undertaken over many years are a welcome exception to this tendency. Page & Lacy (2006) compiled an analysis of the costs and benefits of all weed BC programmes undertaken by Australia – both successful and unsuccessful – and estimated an annual benefit:cost ratio of 23.1, and that "based on this ratio and where an annual investment in weed biocontrol of approximately [Aus]$ 4.3 million is continued into the future, it is expected that weed biocontrol projects may provide, on average, an annual net benefit of [Aus]$ 95.3 million of which [Aus]$ 71.8 million is expected to flow to the agriculture sector."

One of the Australian programmes most directly affecting agriculture was the successful classical BC of the commonest biotype of skeleton weed, Chondrilla juncea L. (Asteraceae), a weed of arable wheat production, using BC agents from the Mediterranean region. Marsden et al. (1980) estimated the cost of the programme, when converted to 2004/05 Australian dollars, to be Aus$ 12.7 million, with an annual benefit:cost ratio of 112.1, based on increased wheat yield worth Aus$ 70 million per year and reduced weed control costs of Aus$ 10.4 million per year, but not considering reduced harvesting costs, increased soil nitrogen, increased soil moisture uptake, improved condition of dairy cattle, and reduction in management and machinery problems in vineyards and citrus orchards, which were all significant benefits.

The financial benefits of classical BC of insect pests are perhaps even less documented, with only a few notable exceptions (Greathead 1995). For example, successful programmes against insect pests in the USA have produced some substantial benefit cost ratios. Alfalfa weevil, Hypera postica (Gyllenhal) (Coleoptera: Curculionidae), was controlled at a cost of US$ 1 million, producing savings of US$ 77 million, discounted over 32 years, and Rhodes grass scale, Antonina graminis (Maskell) (Hemiptera: Pseudococcidae), was controlled in Texas for just US$ 200,000 giving savings of $ 194 million discounted over five years.

There are many more examples of successful classical BC and augmentative BC programmes, which have generated benefits in agriculture, forestry and the environment (Case Studies 1, 3-5, 7, 9, 11, 13, 19, 22-24, 26 and 27 all illustrate examples), but the benefits are seldom quantified. Whole industries would have closed down locally without the support of BC (Case Studies 3, 7, 22-24). Species would have become extinct, and habitats irreversibly changed (Case Study 13).

4. Control of genetic resources used in biological control

BC agents themselves are not patented as they are naturally occurring living organisms. Once released and established in a target country, a BC agent is in the public domain, and anyone can collect it from the field for their own purposes. Thus the implementer no longer has control over that GR, and anyone can try and find ways to make money from it. There are one or two minor examples of this in classical BC, but rather more in augmentative BC, albeit poorly documented. The augmentative BC company that develops a new BC agent invests in its development, and should accept responsibilities for benefit sharing if it is an introduced BC agent. In spite of the efforts of the original company to protect its know-how, experience shows that other companies will be able to develop their own production systems and sell the same BC agent in competition. Companies which exploit a BC agent originally developed by another company do not make the same investment in developing the product, and since the BC agent was locally obtained will be under no obligation to share any benefits with the original source country.

The implementing agency for a classical BC introduction will often collect BC agents back from the field in order to redistribute them to other parts of the country. This is normal practice, particularly where the area infested by the pest is large, but there is nothing to prevent entrepreneurs doing the same and selling the BC agents for a profit, and at least one BC company in the USA has been established that operates by rearing and collecting BC agents for sale to implementing agencies at a profit. Equally, a BC agent may be introduced as part of a classical BC programme, but once established in the target country, it may be practical to use it as part of an augmentative BC programme (e.g. Case Study 5).

BC agents will spread on their own once established in a country, and spread to the limits of suitable climate and food availability. Living organisms do not respect national boundaries, so BC agents can easily spread from one country to another across a common border without human assistance (e.g. Case Study 28). This is the main reason why importing countries are encouraged to consult with their neighbouring countries when considering the release of new BC agents for classical BC. Countries to which BC agents spread may thus obtain the benefits of a BC agent without being involved in research or implementation.

Furthermore, just as pests may be accidentally transported over large distances and become established on different continents, the same can happen to natural enemies. Some examples seem to be purely fortuitous, usually facilitated by transport of plant material infested with pests and natural enemies together (Case Study 26), others may be assisted by deliberate introductions which bridge an intercontinental gap (Case Study 27). The examples currently known do not indicate the source country, although molecular techniques now available could be used to identify the country of origin if this information were needed. In any case, these BC agents have spread without deliberate assistance, and in this situation the receiving country has benefited.

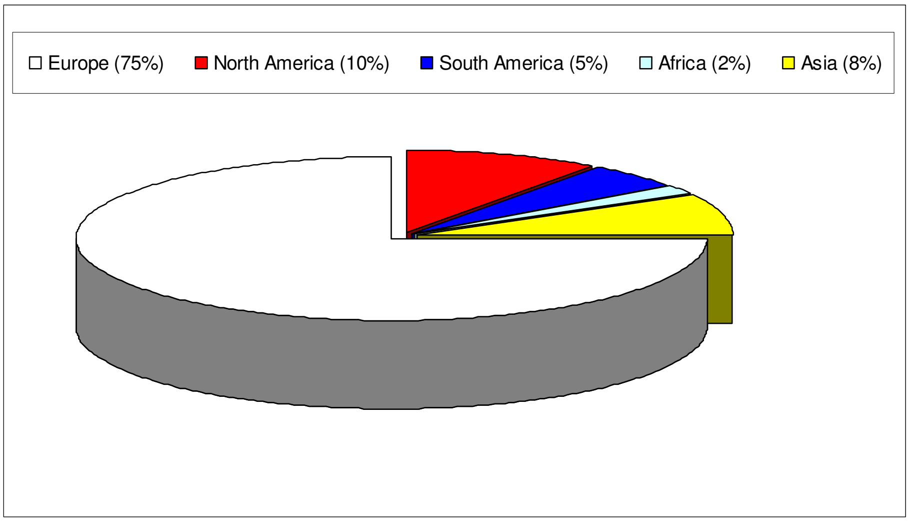
5. Selling genetic resources-based products

The history of commercial mass production and sale of natural enemies spans a period of less than 50 years (Bolckmans, 1999). In some areas of agriculture, such as fruit orchards, maize, cotton, sugarcane, soybean, vineyards and greenhouses, it has been a successful, environmentally and economically sound, alternative for chemical pest control. Success of commercial BC is primarily dependent on the quality of the natural enemies, which are produced by mass-rearing companies (van Lenteren, 2003a). Augmentative, commercial BC is applied on 0.16 million km2, which is 0.4% of land under cultivation (the total world area with agricultural activity is estimated to be 44.4 million km2).

Today, more than 150 natural enemy species are on the market for BC, but only 30 species are generally used and form more than 90% of the value of the BC market. Of all commercialised species of natural enemies, about 45% are of alien origin (van Lenteren & Tommasini 2003). Worldwide, some 30 larger commercial producers are active (Bolckmans, 2008), of which 20 are located in Europe. ‘Larger’ means that more than five people are employed. In addition to the larger producers, some 100 small commercial producers are active. The producers of natural enemies are usually very small companies consisting of 2–10 people. Fewer than five companies employ more than 50 people. The largest company has currently (2009) about 600 people employed. Producers have started to organise themselves in different associations. In Europe, producers are organised in the International Biocontrol Manufacturers Association (IBMA). In North America, the Association of Natural Biocontrol Producers (ANBP) serves the companies in Canada and the USA. The Australian producers created the Australasian Biological Control.

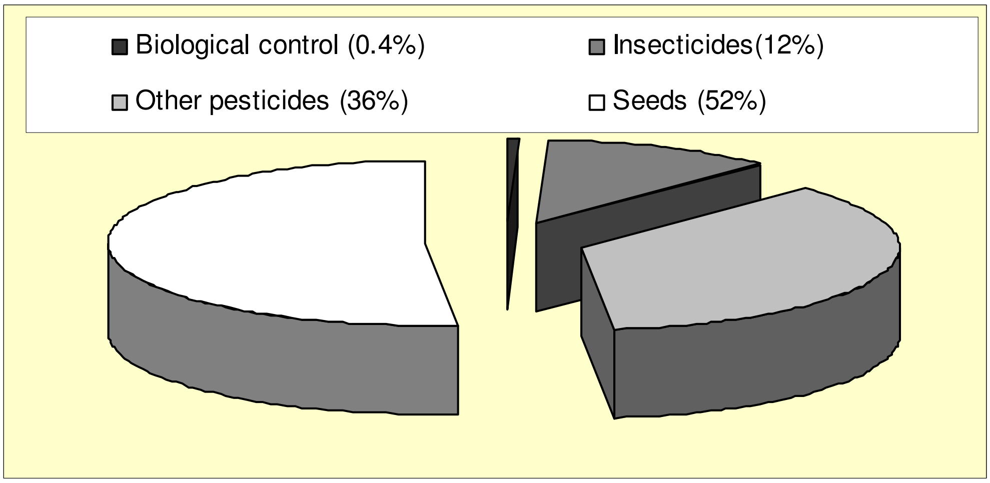
The total market for natural enemies at end-user level for greenhouses in 2008 was estimated at about $ 225–300 million (Bolckmans 2008). The most important markets are The Netherlands, the UK, France and Spain, followed by the USA. Together, these countries account for about two-thirds of the total market (Bolckmans 1999). Nevertheless, Africa, Asia and Latin America represent significant and growing markets (Fig. 4). The market for field crops is only a small fraction of the greenhouse market. With an average net profit margin of around 3–5%, the total commercial augmentative BC industry profit is under $ 15 million per year.

Fig. 4. The 2008 market share of commercial augmentative biological control by regions.



Compare the $ 300 million spent on commercial biological pest control with the $ 8,016 million spent on chemical control of insects and the $ 33,390 million spent on chemical control of all pests in 2007 (Crop Life International 2008), the $ 30,000 million spent on seeds in 2006 (Laird & Wynberg 2008) and the $ 607,000 million spent on pharmaceuticals (calculated from data in Laird & Wynberg 2008). Augmentative BC is a relatively small activity (Fig. 5) undertaken by small and medium-sized enterprises (SMEs) and with modest profits.

Fig. 5. Relative market value of selected biodiversity-related crop production sectors.



Classical BC is a smaller activity in terms of turnover, although it can have a substantial impact for stakeholders, but as discussed in section 2.1.3, with no realised cash benefits for the implementers.

6. Conclusions

Based on this overview of the use and global exchange of BC agents and the benefits derived, it may be concluded that:

- All countries benefit normally on a multilateral rather than bilateral basis;

- To a large extent, classical BC is developing public good as its products – naturally occurring living organisms- are not subject to restrictive intellectual property rights, and so benefits accrue to farmers and the society;
- The use of augmentative BC can generate monetary benefits where the implementing agency is a commercial company, however profit margins are relatively low so that it may be appropriate to concentrate on sharing other types of benefits. Benefits accrue to source countries through capacity building in many cases.
- There are no negative effects or liabilities for the source country through allowing BC agents to be exported.

III. CURRENT PRACTICES OF EXCHANGE OF GENETIC RESOURCES

1. Current terms and modalities for exchange of genetic resources

1.1. Informal networks

There is an informal cooperative network of BC practitioners around the world, involving scientists working with government agencies, intergovernmental organisations, international agricultural research centres, universities, industry groups, etc. IOBC is one manifestation of this but much of the network operates at the personal level and based on the recognition that BC practitioners can assist each other on a multilateral basis and will try and do so (Case Studies 9, 10, 11, 20, 24). This is a well-established community of practice based on free multilateral exchange of BC agents. It includes BC against pests of plantation crops, where the target country might even be seen as a competitor of the source country; the source country has already benefited, or expects to benefit in turn, when it needs access to a BC agent (Case Study 15).

This network is particularly effective when it comes to providing known BC agents, e.g. from a country where they have already been introduced (see section 2.2.5), and redistribution of a recently introduced BC agent within a country.

1.2. Information on biological control agents

An important issue is knowing what BC agents have been used, where, and how successfully. This information is often, but not always, available in the published literature, although finding it may be a problem if the literature is large. One short cut is the use of databases, such as those consulted for Annex 1. As noted there, these are not necessarily up to date or publicly available. If they could be kept up to date and publicly available, this would improve access to known GR for use in BC.

Two international organisations represent the augmentative BC industry and can provide information: the International Biocontrol Manufacturers Association (IBMA) covering mainly European producers of natural enemies and the Association of Natural Biocontrol Producers (ANBP) for the North American producers. These organisations provide information about the availability of natural enemies, but the most recent information about species available for certain crops in certain areas can often be better obtained directly from the producers, whose contact details are available from IBMA or ANBP.

Once a BC agent's identity is rigourously established all other sources of information can be used for research and for a better understanding of this organism. The vast amount of data available in published literature and through internet-based databanks become accessible, often free of charge, such as gene banks (e.g. National Center for Biotechnology Information), literature services (CABDirect, AGORA/HINARI/OARE, AGRIS, AGRICOLA), collections of journals and their archives (JSTOR, AJOL, Bioline International, etc.), and other compilations of specialist information, e.g., CABI Crop Protection Compendium, Encyclopaedia of Life.

1.3. Gaining access to biological control agents

BC agents are not literally available off the shelf. They are living material, normally in situ, and if they have not been previously used in BC are of largely unknown value. They need to be collected from the field, studied, cultured (usually) and sent by hand, air-freight, or post to the target country. Access and permission to export currently depend on national regulations, the legislation for which may or may not address ABS issues.

We have not undertaken a comprehensive survey of the current situation country by country, with regard to the processes by which access to BC agents are regulated and how benefit sharing is handled.

1.4. Effects of legal or technological tools on use and exchange of genetic resources

Patenting and know-how. The BC sector does not patent BC agents. Classical BC does not consider patents anyway, as the objective is to release the organism to establish itself in the target country, thereby becoming a public good. Augmentative BC companies may establish patents on rearing processes, but more usually handle this by keeping the relevant know-how secret. It may be possible to patent individual strains of invertebrate BC agents in future, a process already being developed for microorganisms, but there are no examples as yet. Possible examples might include an acaricide-resistant predatory mite, or a predator selected for heat tolerance. However, the relatively low income and profits of augmentative BC firms (Section 2.5) makes patenting less likely as the high development cost will often not be justified by the expected sales.

Licensing production. The larger augmentative BC companies are already able to license production to smaller companies, and this provides one way to facilitate setting up new companies in new countries to supply new markets. This could include the source country.

Inter-company supply. Commercial augmentative BC companies can and do buy BC agents from each other on occasion.

Carrier issues. Possible options for transferring BC agents between countries and within-country include hand-carrying by plane, air freight, courier services, postal services, road transport and customer collection. Most transport pathways are controlled by postal or aviation regulations, and at any given time may be restricted or blocked because of these regulations, which are primarily intended to minimise phytosanitary or security risks. Courier and airline companies may be reluctant to carry live material, especially if the procedures are unfamiliar to the staff at a particular office. Commercial companies also do not like to see a 'suspicious box' at the check-in, even when all required permits accompany it. Last-minute requirements can lead to significantly increased costs. Thus, major bottlenecks are beginning to appear as some commercial carriers are refusing to ship live arthropods and some countries require inspection of live animals, including arthropods, at a limited number of ports of entry.

2. Conclusions

Current practices for exchange of GR for BC have been working mostly quite effectively, although bedding in new systems based on new legislation has caused significant delays and problems in some cases. Certainly there is room for improvement, but the current system has been working and many have benefited.

The multilateral free exchange ethos for BC contributes substantially to public good around the globe. Existing arrangements in the BC sector seem to ensure unrestricted access to BC agents on the one hand and benefit sharing based on joint research and capacity building, on the other hand. The existing multilateral free exchange ethos and effective global networking of BC practitioners is a foundation that deserves special consideration with regard to ABS.

IV. STAKEHOLDERS' VIEWS

1. Perceptions, awareness of users and providers on access and benefit sharing

1.1. The users of biological control agents

Much of the classical BC community has been unaware of the potential of ABS to affect their activities. For example, and typical of published material, one of the most recent text books (Van Driesche et al. 2008) which includes practical guidance on foreign exploration including the need for export permits, does not mention ABS, although the pragmatic need for a good local collaborator is recognised. Other members of the classical BC community have been more aware, as shown by the establishment of the IOBC Global Commission on ABS, and the growing trend towards implementing good practice with regard to local collaboration.

There is concern within the BC community that ABS could stop its activities, and hence that this FAO/IOBC initiative is important. The BC community would like continued free exchange, and fear that without it BC and the resultant public good will be greatly reduced, slowed down, and in some cases stopped altogether.

In Australia 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 (Barratt, B.I.P. (2009, in press) Access and benefit-sharing for biological control: What does it mean for New Zealand?).

Current practices for obtaining exotic BC agents in Canada and the USA have been in place for a long period of time. Normally BC agents 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 BC agents originated.

On the other hand, the augmentative BC community has been more aware of the issues, perhaps because augmentative BC does generate some modest commercial profits. Larger augmentative BC producers are now willing to consider benefit sharing in the form of knowledge sharing, training, provision of natural enemies, and other ways. In the event that a natural enemy obtained from a source country becomes a commercially successful BC agent, shared activities and capacity building would seem to be a more pragmatic approach than the payment of 'royalties' to the country of origin, given the relatively small profits and profit margins in the augmentative BC industry (Section 2.5).

Both the classical BC and augmentative BC communities recognise that some countries that were restrictive with regard to access to BC agents are now opening up, and mechanisms to implement regulations are becoming clearer and adjusting to facilitate some purposes, e.g. research including BC (Case Study 17). However, at the same time others are passing new legislation which is not necessarily designed with BC in mind, and they will become restrictive in the short to medium term, until mechanisms for access can be clarified or improved (Case Study 18).

The attitudes and views of these players reflect a mixture of positions regarding ABS, ranging from some who have not really been aware of the issues, to those who have been aware but frustrated as to how to implement them. To a lesser or greater degree all players have deliberately or otherwise adopted a non-formal position in line with the spirit of the CBD, and aligning quite closely with recent ABS and academic research initiatives (e.g. Biber-Klemm & Martinez 2006). This approach, recently exemplified by the outputs of the 2008 workshop at the Zoological Research Museum Alexander Koenig, Bonn (Anonymous 2009) suggests one model that could be applied quite easily to the BC research approach, providing the in-country mechanisms are in place and functional (Section 4.2).

1.2. The biological control agent source countries

Many GR providers have simply not considered BC in the context of ABS, and when asked may respond that they were not considering BC in framing the national legislation and procedures. On the other hand, national BC research groups may appreciate the value of multilateral free exchange of BC agents, but find that their participation in this process is restricted by ABS legislation.

It should also be remembered that in the context of BC, countries that are providers are also users of BC (Section 2.1.1). Therefore it is likely to be in the national interest to maintain multilateral exchange of BC agents (Case Study 15).

In preparing this report, we have not been able to undertake a full review of the perceptions and practice around the world with regard to BC and ABS, but have contacted a range of countries to try and establish what the situation currently is, to demonstrate the diversity of approaches that the ABS community has used for this sector. This information is presented in Section 3.1.3.

2. Initiatives of key players

There is only a limited pool of key players in BC. For classical BC, the norm is for national institutes of the concerned countries to take a major role . This is likely to be supported, particularly for developing countries, by international agricultural research centres, such as CABI, icipe and sometimes the CGIAR (Consultative Group on International Agricultural Research) centres, and occasionally universities.

IOBC is the only professional organisation that covers classical BC. BC falls within FAO's mandate as it is an essential part of agriculture, and on several occasions FAO has supported the implementation of classical BC programmes through its Technical Cooperation Project rapid-response mechanism, e.g. pink hibiscus mealybug (Maconellicoccus hirsutus Green) in the Caribbean, brown peach aphid (Pterochloroides persicae (Cholodkovsky)) in Yemen, mango mealybug (Rastrococcus invadens Williams) in Togo.

The augmentative BC industry is beginning to address policy-level issues relating to access to and use of BC agents. IBMA organised a side-event on BC and ABS during the Ad Hoc Open-ended Working Group on Access and Benefit Sharing (WGABS 7) meeting in Paris, 7 April 2009 (www.cbd.int/doc/?meeting=abswg-07), and plans to attend further such meetings, which IOBC may also become involved in.

In October 2008, IOBC established its Global Commission on Biological Control and Access and Benefit Sharing, with the mission to provide scientific advice to oversee and advise the design and implementation of an ABS regime that ensures practical and effective arrangements for the collection and use of BC agents which are acceptable to all parties (IOBC 2008). This mission will be realised by:

- Increasing scientific knowledge in the area of BC and ABS;
- Documenting the potential for negative consequences of adopting strict regulations about ABS of BC agents;
- Transferring the knowledge concerning the question of ABS to the scientific community, stakeholders and international parties;

- Developing linkages/agreements with international partners (CBD, FAO, CABI, ANBP, IBMA, and CGIAR);
- Promoting the development and application of new international conventions on BC and ABS which respect the CBD.

This initiative has already led to collaboration with FAO and this report. This report, involving many of the key players, is the first time that the classical BC community has prepared a formal position on the ABS issue.

BC is only one research-based activity that requires access to GR but is not expected to generate monetary returns that can be shared. Academic research, especially taxonomic research on biodiversity, has similar issues. There is a growing concern and consensus that it should be recognised that non-commercial academic research is not expected to generate monetary benefits, and therefore benefit sharing needs to focus on non-monetary benefits based on joint research and capacity building (SCBD 2002; Biber-Klemm & Martinez 2006; Anonymous 2009).

Broadly speaking the same arguments can be applied to classical BC and partially to augmentative BC, so this academic research initiative is an important model for BC and one which many BC practitioners have already been trying to implement informally.

3. Conclusions

- BC creates and sustains public good – food security, food quality, reduced pesticide use, human (farmer and worker) health, invasive alien species control, protection of biodiversity, and maintenance of ecosystem services.
- The benefits of classical BC accrue to the growers, and all growers benefit equally – this includes smallholders, plantation owners and export crop producers.
- Classical BC agents can spread accidentally or deliberately to adjacent countries that will also benefit.
- Those who implement classical BC cannot gain any direct financial benefit from the process, and measuring the economic, social and environmental benefits is not always undertaken.
- Direct benefits of augmentative BC accrue to the producers and the growers who buy and apply the BC agent. There is great scope for non-monetary benefit sharing, including capacity building, shared research, technology sharing.
- Access procedures need to be clear, straightforward and facilitate access. At this stage expectations regarding benefits need to be realistic.

V. OVERALL RECOMMENDATIONS

ABS regulations should recognise the specific features of BC:

- Countries providing BC agents are themselves also users of this technology;
- Many BC agents are exchanged, but have little recoverable monetary value;
- Organisms are not patented, so can be used by anyone at any time;
- Classical BC information and to a degree augmentative BC information are publicly shared;
- There are societal benefits for all, such as environmental and public health benefits, and reduction in pesticide use;
- BC is widely used in both developing and developed countries, often using the same BC agents;
- Most use of BC relates to food and agriculture.

In view of these specific positive features, the following recommendations are made:

1. Governments should build on the existing multilateral practice of exchange of natural enemies for BC on a complementary and mutually reinforcing basis, which ensures fair and equitable sharing of the benefits of BC worldwide.
2. ABS regulations should encourage further development of the BC sector, by facilitating the multilateral exchange of BC agents.
3. Countries are encouraged to have a single point of contact to facilitate survey missions, provision of information, institutional linkages and taxonomic support, and provide advice on compliance with regulations for BC, including ABS.
4. ABS in relation to BC will normally be based on non-monetary benefit sharing, e.g. capacity building, shared research programmes and/or technology transfer, as already practised by several organisations and the industry.
5. A document describing best practices for ABS in relation to BC will be helpful for the BC practitioners. This could include guidelines for joint research that are equitable, but not restrictive. BC organisations would be expected to follow these guidelines.
6. To improve transparency in the exchange of BC agents, mechanisms should be supported globally to establish and allow free access to database information on BC agents including source and target countries.
7. In the case of a humanitarian or an emergency situation for food security, governments should cooperate within FAO to fast track action in the exchange of BC agents.

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Case Study 1. 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:

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Case Study 2. 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 without exaggeration 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 22).

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 3).

Prepared by Fabian Haas & Matthew J.W. Cock

Sources:

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Case Study 3. 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 2). 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 specimens of the three parasitoids 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 2), 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 classical BC of P. manihoti – an unanticipated benefit to Brazil, one of the source countries for BC agents of P. manihoti.

Prepared by Fernando L Cônsoli & José Roberto Postali Parra

Sources:

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Case Study 4. 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 BC 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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Case Study 5. 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 BC agent for classical biological control from several different sources, but subsequently the established population was mass produced, distributed and sold as a BC agent for augmentative biological control.

Prepared by José Roberto Postali Parra & Fernando L Cônsoli.

Sources:

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

Case Study 6. 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 m3 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.

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 BC 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 BC agents 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.

Case Study 8. 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 BC 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 BC agents 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 BC agents 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 BC agents 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.

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 classical BC BC agent 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.

Case Study 10. 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 BC 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.

Case Study 11. 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 BC 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.

Case Study 12. Sourcing natural enemies within Europe for biological control of houndstongue

Houndstongue (Cynoglossum officinale L.; Boraginaceae) is a biennial or short-lived perennial, native to Europe and Asia Minor. It is a widespread but relatively uncommon plant in Europe associated with open well-drained light soils. Introduced into North America in the mid 19th century, it now occurs in most Canadian provinces and states of the adjacent north-west USA. This rangeland weed hinders the establishment of forage species in new pastures and can dominate clearings in forests. The barbed nutlets become attached to cattle causing irritation and potential market loss. A biological control programme was started in 1988 because chemical and cultural control methods against large infestations are often neither feasible nor economic.

Surveys of natural enemies of this weed in Europe were carried out by CABI's centre in Switzerland, and subsequently selected species were studied with regard to their biology and host specificity. It soon became apparent that in order to obtain reasonable numbers of insects for culture and study, the isolated and uncommon houndstongue plants of western Europe were not adequate, and often in protected habitats, and so for practical reasons collection efforts concentrated on the larger populations of houndstongue available further east, particularly in Austria, Hungary and former Yugoslavia.

Thus, although the BC agents were widespread in Europe and in principle BC agents could have been collected from a range of countries within Europe, the populations used for research and supply to North America actually came from these countries further east rather than around the CABI centre in western Switzerland. The BC agents were not at risk in situ, but they were sufficiently rare to limit their access in parts of their range.

Prepared by Matthew J.W. Cock

Source:

De Clerck-Floate, R.A.; Schwarzlaender, M. (2002) Cynoglossum officinale L., houndstongue (Boraginaceae). Pp. 337-343 in Mason, P.G.; Huber, J.T. (eds) Biological control programmes in Canada, 1981–2000. CABI Publishing, Wallingford, UK.

Case Study 13. 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. (www.fs.fed.us/foresthealth/technology/pdfs/2ndSymposiumArthropods05_08V1.pdf).

Case Study 14. 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 treatment 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 BC agents. 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.

Case Study 15. 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 national scientist. The chairman of this committee did raise the question of why Kenya should help Latin America with BC agents and then answered it himself – because Kenya equally expects to benefit from BC 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 BC agents 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.

Case Study 16. 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.

Case Study 17. 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 classical BC (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 classical BC 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 BC agents in India in collaboration with Indian partners, with a view to exporting the BC agents 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 (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 Robert Tanner, CABI.

Case Study 18. 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.

Case Study 19. 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 BC agents were easy to make – so much so that it was simpler to try a BC agent 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.

Case Study 20. 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 BC agent release being made in Hawaii in 1926. More recently, New Zealand has led research, and seven invertebrate BC agents 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 BC agents. 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

Source:

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.

Case Study 21. Fast-track biological control of orthezia scale in St Helena implemented with no research in intermediate source country

An earlier case study (Case Study 13) 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 Hawai'i 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.

The BC 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 BC agent 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.
(www.fs.fed.us/foresthealth/technology/pdfs/2ndSymposiumArthropods05_08V1.pdf).

Case Study 22. 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, BC agents were found in three South American countries (Paraguay, Brazil and Bolivia) following extensive surveys (Case Study 2). 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. Many 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 (108)!

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.

Case Study 23. 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 is 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.

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.

Case Study 24. 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 BC 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 BC agent, 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.

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 classical BC 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 classical BC approach against invasive exotic species, the expertise in this region is primarily rooted in the augmentative BC (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 BC agents 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 classical BC against plant species native to Central Asia and invasive in North America.
- To support Prof. Khamraev's working group in facilitating transfer of the knowledge of Prof. Khamraev, who is close to retirement, to the next generation.
- 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 classical BC 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 BC agents 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.

Case Study 26. 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 BC 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.

Case Study 27. 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:

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Case Study 28. 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 BC agent by one country can have impacts in a neighbouring country where ecozones are similar.

Prepared by Peter G. Mason

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ANNEX 1: LISTS OF BIOLOGICAL CONTROL INTRODUCTIONS

Classical BC and, to a lesser extent, augmentative BC have been widely practiced over many years. In support of the preparation of this report, we compiled a list of as many biological control introductions as possible, by extracting data from databases and, to a limited extent, the published literature as follows:

Classical Biological Control

- Insects used as BC agents against insects for classical BC. CABI developed and has maintained the BIOCAT database for many years, which is intended to include basic information about all insects introduced to control other insects (Greathead & Greathead 1992). It was maintained by Dr David Greathead after he retired until his untimely death in 2006. CABI is now organising bringing the database back up to date for the last 3-4 years, and hopes to make it freely available via the internet once resources are available. For this review, we used the database as it stood up to 2006, which already includes 5,558 records, and the great majority of all insect introductions.

- Mites used as BC agents, and biological control of mites. There was no obvious source for this information, apart from the basic reviews of biological control (e.g. Clausen 1972, Cock 1985, Cameron et al. 1989, Waterhouse & Sands 2001, Mason & Huber 2002, Neuenschwander et al. 2003). Sources such as these and other literature searched yielded 168 introductions. This section is probably both the most incomplete and the one with the greatest overlap with the list of augmentative BC BC agents.

- Nematodes used as BC agents of insects. This information was taken from Hajek et al.'s (2005) catalogue of pathogens and nematodes for classical BC of insects and mites, and comprised 29 introductions.

- Snails and planarians used as BC agents for snails. A list of 90 introductions was compiled from some of the sources listed under mites above, and from a more general literature survey.

- Arthropods used as BC agents for control of weeds were taken from Julien & Griffiths (1998) World catalogue of weed BC agents, which covers the period up to the end of 1996, and includes 1,160 releases (including pathogens). This was supplemented by a literature search and personal contacts focussed on Australia, Canada, New Zealand, South Africa and USA – the five countries which consistently invested most in weed biological control – which produced a further 131 new releases.

- No other taxonomic groups of invertebrate BC agents were found.

In this way, we were able to compile a reasonably complete dataset of all classical BC introductions using invertebrates. In the interests of supporting transparency regarding the exchange of BC agents, it is recommended that this list should be completed and kept up to date and made publicly available to regulatory bodies, researchers and practitioners. This will involve additional work, e.g. to clarify dependent territories and islands in a national sense, rather than a zoogeographic / ecological sense.

Annex 1, Table 1. An example of the information in the BIOCAT database: 43 introductions of Rodolia cardinalis to control Icerya purchasi.

Country	**Date**	**Result**	**Reference**[1]
Antigua	1966, 70, 73	Established	Waterhouse 1993
Ascension	1977	Not known	Cock 1985
Bahamas	1934	Complete control with other BCA(s)	Koch 1989
Barbados	1943	Established	Greathead 1971
Bermuda	1902	Substantial control	Greathead 1976
Cayman Islands	1961	Complete control	Altieri et al 1989
Chile	1939	Established	OPIE 1986
Cyprus	1938,39	Some impact	OPIE 1986
Ecuador	1978	Substantial control?	Waterhouse 1993
Egypt	1890-92	Some impact	Chiu et al 1985
Ethiopia	1947-71	Substantial control	Greathead 1976
France	1912	Complete control	Beingolea 1967
Greece	1927	Failed to establish	Rao et al 1971
Guam	1926	Not known	Greathead 1971
Hawaii	1890	Substantial control with other BCA(s)	Cock 1985
Hong Kong	1961	Not known	Greathead 1978
Israel	1912	Substantial control	Cock 1985
Italy	1901, 21, 23	Temporarily established	Nafus & Schreiner 1989
Kenya	1917	Complete control	Altieri et al 1989
Madagascar	1951	Failed to establish	Greathead 1971
Malta	1911	Substantial control	Greathead 1971
Montserrat	1964-66	Substantial control	Haimonot & Crowe 1979
New Zealand	1894	Complete control with other BCA(s)	Mendel et al 1992

Peru	1932	Substantial - complete control	Cock 1985
Philippines	1956	Failed to establish	Greathead 1976
Portugal	1897	Established	Greathead 1978
Puerto Rico	1932-33	Complete control	CAB 1980
Sao Tome	?	Failed to establish	Greathead 1971
Senegal	1954	Substantial control	Greathead 1976
South Africa	1892	Complete control	Greathead 1976
Spain	1922-24	Substantial control	Cock 1985
Sri Lanka	1918, 20	Complete control	Koch 1989
St Helena	1896, 1898	Complete control	Altieri et al 1989
St Kitts-Nevis	1966	Failed to establish	Waterhouse 1993
Switzerland	1924-29	Not known	Greathead 1971
Taiwan	1909	Established	Beardsley 1955
Uruguay	1916	Complete control with other BCA(s)	Marco 1959
USA	1888-89	Complete control	Greathead 1976
USA	1893	Complete control	Greathead 1976
USSR	?	Complete control	Greathead 1971
Venezuela	1941	Complete control with other BCA(s)	Clausen 1978
Yugoslavia	1910-11	Established	Beardsley 1955

1These are not included in the references to this report.

Augmentative Biological Control

A similar database was compiled, building on Lenteren (2003) and information provided by the augmentative BC industry. In the time available, this is considered reasonably comprehensive for Europe (Annex 1, Table 2), which is the largest market. Further work will be needed to complete the compilation and checking of a comprehensive list of all BC agents used in augmentative BC worldwide.

Annex 1, Table 2. Listing of all commercial augmentative biological control agents available in Europe - updated from van Lenteren(2003).

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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