Study Brief 4: Impact

Safeguarding the environment, food security and livelihoods from invasive species using biological controls

R. Shaw, A. Witt, M. Cock, K. Pollard, S. Thomas and D. Romney

Summary

Non-native invasive species, such as insect pests and Needs, have a huge impact on livelihoods, food production and biodiversity around the world. Classical biological control (CBC) by the introduction of exotic biological control agents from the area of origin of an introduced pest provides a sustainable and cost-effective control method that minimises the use of pesticides. It has been practised widely for more than 100 years, with many successes. Developed countries have used this tool far more than developing countries which are often dependent on donor assistance and expert help to implement such projects. CABI supports national programmes to implement CBC programmes, and has been involved in some very successful programmes. There is a shortage of comprehensive impact studies, but we outline three examples from programmes where CABI has played a role, and tabulate results from a further five selected studies. Increased donor support to develop and implement CBC in support of farmer livelihoods and food security is needed — cost-benefit analyses have clearly shown that the returns on donor investments in CBC programmes are significant.

Project objectives

Biological control of pests, including weeds provides a sustainable and effective approach to some apparently insurmountable problems. The objective in the CABI projects reviewed was to implement classical biological control (CBC) by the introduction of exotic biological control agents. The desired impact is to bring the target insect pest or weed under effective natural control so that additional control measures for that pest, such as pesticides, are no longer necessary. This will reduce crop losses, strengthen food security, protect livelihoods, and support local and national economies, while at the same time protecting the environment and human health. It is relatively rare for the impact of biological control to be well documented after the release of the biological control agents. This project set out to find concrete evidence confirming beneficial impacts.

Findings

Biological control by the introduction of natural enemies has been practiced globally for more than 100 years, and CABI has been directly involved in supporting this approach for over 80 years. By considering a series of local, regional and global projects over at least the last 30 years, the benefits of this approach would become evident.

Targets for CBC are pests (insects, weeds or other organisms) that have been accidentally or deliberately introduced into a country or region and, freed of their natural enemies that keep them in check in their area of origin, have increased in numbers to become a severe problem. The process of CBC involves surveying in the area of origin of a pest to find out what natural enemies affect it there, studying selected natural enemies to assess their safety for use as biological control agents, transferring them to the target country, culturing and release of the natural enemy, and monitoring and evaluation of their impact.

CABI is often directly involved with the first four stages, working in collaboration with local or international partners in the area of origin of a pest, and supporting national programmes to implement CBC in the target country. However, in the past it has been unusual for CABI to be directly involved in the evaluation of the impact of a CBC programme, as this would be the responsibility of the national programme. Understandably, the evaluation stage is often not prioritized, especially if by this stage it is considered self-evident that CBC has solved the pest problem. Nonetheless, a number of studies have aimed to assess the impact of such interventions.

CBC is more widely practiced than most people realize. In a 2009 assessment, it was found that globally[7], 108 introductions of biological control agents involving about 2,685 species have been made. These introductions and their effectiveness are summarized in the following table.

Income per capita Group (after World Bank classification)	**Low**	**Lower middle**	**Upper middle**	**High (not OECD)**	**High (OECD)**	**Unclass-ified**
No. of countries practising biological control	25	35	43	23	25	15
No. of biological control agent introductions	333	796	1260	889	3637	193
No. of introductions of biological control agents / country	13	23	29	39	145	13
No. of biological control agent species	52	169	243	172	530	57
No. of biological control agent species / country	2	5	6	7	21	4
No. of biological control agents established	132	294	493	259	1440	55
% of introduced biological control agents that become established	40%	37%	39%	29%	40%	28%
No. of biological control agents providing at least some control	52	107	229	122	556	25
% of established biological control agents that give control	39%	36%	46%	47%	39%	45%

The success rates are similar in both developed and developing countries, but biological control has been practiced least in the least developed countries, and very much more in OECD countries, leading to a corresponding greater number of successes. This bias is even greater if biological control of weeds is considered alone.

Impact

When considering benefits to the environment or returns on investment, it is important to note that CBC is self-sustaining solution. The introduced natural enemies reproduce on their target pest and disperse to seek out further populations of the pest to attack; before long a new equilibrium is established in which the pest is maintained by its specialized natural enemies at low levels, normally below the threshold at which they would cause economic or environmental damage. Thus, benefits will continue to accrue indefinitely, although in most economic analyses these benefits are discounted over a period of some years.

Below we summarize impact from a selection of programmes in which CABI has been involved:

Target	Country / period of CABI activity	Agent / Intervention	Result / Impact	CABI role	Main partners*
Cassava mealybug, *Phenacoccus manihoti*	Mainland Afro-tropical Region 1977-1992	*Anagyrus lopezi*	Complete control. Benefit: cost ratio 149:1[4].	Share in survey, research and supply of biological control agents; share in release programme (East Africa)	IITA, CIAT, NHM
Mango mealybug, *Rastrococcus invadens*	Western and Central Africa 1986-1991	*Gyranusoidea tebygi Anagyrus mangicola*	Fruit production increase 142%[2]. In Benin, each mango farmer gained US$ 328 per year. Benefit: cost ratio 145:1[2].	Survey, research and supply of biological control agents	IITA
Orthezia scale, *Orthezia insignis*	St Helena 1992-1993	*Hyperaspis pantherina*	Complete control enabling recovery of the threatened endemic gumwood trees ecosystem[5].	Collection, supply and release of known biological control agents	–
Banana skipper, *Erionota thrax*	Mauritius, Hawaii, Guam, Saipan, Papua New Guinea 1971-1973	*Ooencyrtus pallidipes, Cotesia erionotae*	Complete control. In PNG yield loss reduced from 30% to 0%[6] and prevention of banana losses kept 6-15K subsistence farmers and 28K rural poor above the poverty line[7].	Survey, research and supply of biological control agents	ACIAR / CSIRO (for PNG)
Mile-a-minute weed, *Mikania micrantha*	India, Taiwan, China, Fiji, Papua New	*Puccinia spegazzinii*	Established in Fiji and PNG. Initial	Survey, research and supply of	–

	Guinea 1978-present		assessments in PNG show that *Mikania* cover decreased from 100% to 40%[8].	biological control agents	
Leafy spurge, *Euphorbia esula*	USA and Canada 1960-1998	*Aphthona nigriscutis, A. czwalinae* and *A. lacertosa*	Reductions in plant cover from 100% to 10%, allowing native vegetation to recover[9]. Total impacts from leafy spurge control in the Upper Midwest USA estimated US$ 58.4 million annually[9].	Surveys, research and supply of biological control agents	USDA-ARS
Rubber vine, *Cryptostegia grandiflora*	Australia 1986-1995	*Maravalia cryptostegia*	Reduction in regeneration from 178 seedlings per hectare to almost zero[10]. Benefits from this programme estimated between AS$ 295 million and AS$ 527 million[1]. Benefit: cost ratio 108.8:1[1].	Surveys, research and supply of biological control agents	QDL
Water hyacinth, *Eichhornia crassipes*	Old World tropics 1968-1996	*Neochetina eichorniae, N. bruchi* and *Niphograpta albiguttalis*	In Benin, increase income of US$ 30.5 million per year[11]. Benefit: cost ratio of 124:1[11].	Share in survey, research and supply of biological control agents; share in some release programmes (Zambia, Sudan, etc.)	CSIRO, IITA

* Other than national implementing agencies

The literature on the impact of CBC is disappointingly scant. At one extreme, there is no documented Follow-up at all; at the other extreme very rarely is there an attempt to make a formal cost-benefit analysis. Sometimes, there has been an attempt to quantify the impact of the pest before control, but often this is glossed over with terms like, reduced yield, very damaging, heavy defoliation, dense cover, etc. Often the impact of the CBC agents is characterized similarly: reduced density, good control, yields improved. One reason for this is that when CBC is successful, it can be very successful, such that the degree of impact is self-evident, and hence not considered worth measuring. Nevertheless, we have selected from the available studies to highlight the impact of some of the programmes to which CABI has contributed.

African food security protected from devastating crop losses by biological control of cassava mealybug

Cassava is of South American origin, but is now grown as an important staple in many parts of the tropics, including most of tropical Africa. It is grown by poor farmers, many of them women, often on marginal land. For these people and their families, cassava is vital for both food security and income generation.

A new pest, the cassava mealybug, *Phenacoccus manihoti* was first observed in Africa in the 1970s. Unchecked by natural enemies, it found ideal conditions to multiply explosively devastating cassava crops, causing crop losses of up to 80%. It quickly spread throughout all cassava producing regions in Africa, and threatened the food security of over 200 million people.

Up until its discovery in Africa, the mealybug had never been recorded causing damage anywhere in the world. CABI was a partner in the international survey programme which covered almost the entire Neotropical Region, until the mealybug and associated natural enemies were discovered in a small area of Paraguay, Bolivia and Brazil. A parasitic wasp, Anagyrus lopezi, was introduced and released in Africa in 1981 and by the end of the decade it had been spread to all mealybug infested areas. All over the cassava belt of Africa the wasps reduced the mealybug population by 95% and today, cassava grows with little mealybug damage. For the farmers of Africa, the economic impact has been exceptional and the biggest benefits can be seen in the Democratic Republic of Congo, Nigeria, Ghana, Tanzania, Mozambique and Uganda. An economic analysis of the programme showed that benefits to all 27 African countries involved, accumulated over 40 years, amounted to US$94 billion, with an annual gain of US$235 million and a benefit-cost ratio of 149:1[4]


Cassava mealybug (*Phenacoccus manihoti*) on cassava leaf and its key biological control agent, *Anagyrus Iopezi*. (G. Goergen, IITA, from Invasive Species Compendium).

African food supplies and cash crop incomes safeguarded thanks to the biological control of mango mealybug

In the wetter parts of West Africa, a large proportion of households are rural. Almost all have mango trees growing around their homes. Mangoes are grown, amongst other things, as a cash crop for the domestic market. The annual national crop in Benin has been estimated at US$65 million[2]. The fruit is high in sugar and vitamins, especially vitamin A. In towns, it is a valuable dessert fruit and, in rural areas, it can replace whole meals during working days in the field. Almost all producers interviewed (99%), said they consumed mango fruits, and most (87%) underlined the added importance of mango for combating diseases. The trees are also valued for their shade, and thus facilitate social functions.

Rastrococcus invadens, otherwise known as the mango mealybug, is native to South-East Asia. In the 1980s, it became a problem in West Africa where it caused serious damage to fruit trees, in particular mango and citrus. By the mid-1990s, mango mealybug had invaded most of West and Central Africa.

Although it does not cause significant direct feeding damage to plants, the honeydew it produces falls onto leaves and fruit below, leading to the formation of a black sooty mould. This mould prevents growth and restricts photosynthesis resulting in a decrease in fruit production. For example, in Benin, the annual yield losses of mango as a result of the mango mealybug were estimated to be 89%[2].

Surveys by CABI in India found two promising parasitic wasps, *Gyranusoidea tebygi* and *Anagyrus mangicola*, which caused significant mortality to the mango mealybug. After safety testing in quarantine and mass rearing of the wasps, *G. tebygi Nas* released in Benin between 1988 and 1993. The second parasitic wasp, *A. mangicola*, was later released between 1991 and 1993 to provide additional control for localized “hotspots”. After release and establishment of these agents, fruit production was seen to dramatically increase and current estimates of the benefits of the biocontrol programme over 20 years in Benin amount to US$531 million[2]. This combination of biocontrol agents has also been successfully used for control of the mango mealybug in other affected African countries. A benefit-cost ratio of 808:1 has been estimated when including benefits of the biocontrol programmes throughout the Sub-Saharan Africa[3].

The target for biocontrol, Rastrococcus invadens (G. Georgen, IITA, from Invasive Species Compendium). Symptoms of a Rastrococcus invadens infestation on mango leaves; the sooty mould on the leaf uppersurfaces contrasts sharply with the leaf with mango mealybug that has been turned over (P. Neuanschwander, IITA, from Invasive Species Compendium).

Valuable Australian ecosystems and millions of dollars saved from invasive rubber vine invasion using biological control

Rubber vine, *Cryptostegia grandiflora*, is a perennial woody climber or vine which may also grow as a sub-shrub in open situations. Native to south-west Madagascar, rubber vine was introduced into Australia in the 1860s as an ornamental plant and has since spread dramatically throughout Queensland. At the time, rubber vine was described as the single biggest threat to natural ecosystems in tropical Australia and by 1991 it was estimated to be present across 34 million hectares in Queensland, and spreading. Rubber vine can smother trees and pastures and will often form impenetrable thickets along streams, out-competing native flora, decreasing biodiversity, and increasing erosion due to decreased ground cover. The livestock industry is severely affected as it restricts access to water, reduces grazing, increases mustering problems, and is toxic (albeit rarely eaten as it is quite unpalatable).

CABI’s surveys in the native range revealed a rust pathogen, *Maravalia cryptostegiae*, to be a promising biological control agent. This pathogen infects the leaves of rubber vine causing premature leaf drop and as a result a reduction in vigour and seed production. After extensive studies under quarantine facilities, the rust pathogen was released in Australia from 1993-1995. Since then, the populations of rubber vine across Queensland have declined significantly (by up to 90% at some sites) and the benefits of this programme are believed to be between AS$ 295-528 million[1] from reduced weed control and mustering costs, and increased carrying capacity and cattle production. This cost does not, however, include the many benefits to the ecosystem, including those to a World Heritage conservation area which was previously under threat. Rubber vine is also a problem in several other countries in the tropics, including parts of eastern and southern Africa, Brazil, Mexico and Cuba, so there is scope to control it in these countries, by releasing this very effective pathogen biological control agent.

Rubber vine smothering a Eucalyptus forest in Australia, 1994 (Ian Purvis CSIRO)

The rust pathogen, *Maravalia cryptostegiae*, on the leaves of rubber vine (Harry Evans, CABI)

The wider context

Because many pests have been introduced into several countries, often in different regions and continents, there is plenty of scope to repeat successful CBC programmes in other countries or regions. The Australian vedalia beetle, *Rodolia cardinalis*. has been released in more than 40 countries, including many developing countries, and is more or less guaranteed to provide improved CBC of cottony cushion scale, a potentially devastating pest of citrus and other crops. Following its success in West Africa, *Anagyrus lopezii* has been released throughout the cassava belt of Africa, controlling cassava mealybug in almost all situations, and is now being released in South-East Asia where the cassava mealybug has spread in recent years.

CABI is currently developing several CBC initiatives in Africa to support and safeguard livelihoods: *Opuntia stricta* in Kenya, a serious pasture weed affecting valuable pasture species and livestock health; *Chromolaena odorata* in Tanzania, Central African Republic and DR Congo, having adverse impacts on biodiversity, and crop and pasture production; *Parthenium hysterophorus* in Tanzania, an introduced weed having severe effects on crop and pasture production, human and animal health and biodiversity; *Mimosa pigra* in Zambia affecting grazing, fishing, biodiversity and crop production. Other invasive plants which will be targeted in Africa include *Lantana camara*, *Pistia stratiotes*, and other cactus species. In South-East Asia *Mikania micrantha*, *Mimosa diplotricha* and *Acacia nilotica* are being targeted for biological control.

The implementation of CBC in low-income countries depends entirely or almost entirely on donor assistance, often linked to the availability of CBC agents as spin-offs from high- and middle-income country research. CBC research targeted at pests primarily of concern to low-income and lower middle-income countries is rare, and in the case of weed CBC, the long-term nature of the research and the need to carry out costly surveys and evaluation can make this superficially unattractive to donors. Nevertheless, targeted CBC research has been shown to have enormous potential benefits to these countries, which don’t have the resources for expensive chemical and mechanical control programmes. Increased donor support to develop and implement CBC in support of famer livelihoods and food security is needed — cost-benefit analyses have clearly shown that the returns on donor investments in CBC programmes are significant.

Written and other outputs

Impact studies for the examples given above:

1. Palmer, B. and Vogler, W. (2012) *Cryptostegia grandifolia* (Roxb.) R. Br. — rubber vine. In: Julien, M., McFadyen, R and Cullen J. (eds) Biological Control of Weeds in Australia. CSIRO, Canberra, Australia, pp 190-197.
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5. Fowler, S.V. (2004) Biological control of an exotic scale, *Orthezia insignis* Browne (Homoptera: Ortheziidae), saves the endemic gumwood tree, *Commiclendrum robustum* [Roxb.) DC. (Asteraceae) on the island of St Helena. Biological Control 29, 367-374.
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Donors and partners

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