



## Review

# Current status and potential of conservation biological control for agriculture in the developing world

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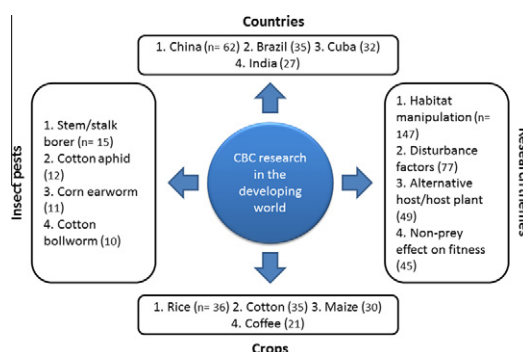
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## HIGHLIGHTS

- ▶ A total of 390 literature records from 53 different crops and 53 nations were found.
- ▶ Most research focused on habitat management and changes in disturbance regimes.
- ▶ No CBC records were found for several key staple crops and cash crops.
- ▶ 70% of pests with high incidence of insecticide resistance have been overlooked.
- ▶ Many nations have high insecticide use and import, but little CBC research attention.

## GRAPHICAL ABSTRACT



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## ABSTRACT

Conservation biological control (CBC), often described as the field of biological control with the greatest potential for use in developing world agriculture, has received only marginal, scattered research attention outside Western Europe or North America. As a consequence, pesticide overuse remains rampant in many cropping systems, while in others, a complete lack of safe, affordable and effective pest control options leaves farmers vulnerable in face of herbivore attack. In this study, we describe the current status of CBC research in a wide variety of agro-production systems outside North America, Australia, New Zealand, Japan and Western Europe. We summarize information on (1) a variety of CBC themes related to natural enemy biology and ecology, (2) factors that either disrupt or enhance natural enemy efficacy, and (3) field evaluation of CBC schemes. A total of 390 CBC-related literature records from 53 different crops were considered. Most records were from China, Brazil, or Cuba, while no CBC references were found from several developing countries. CBC research primarily focused on habitat management, with 71 records on general habitat manipulation and 80 records on the effects of inter- or cover-crops on natural enemy abundance or efficacy. The effects of deliberate modification of disturbance regimes, through alterations in pesticide use or tillage, on natural enemies were well-characterized in many cropping systems. For each of the CBC themes, research progress was assessed and opportunities were identified to translate current findings into practical solutions. On a crop level, most research was targeted at rice,

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maize and cotton. No CBC records were found for key staple crops such as yams, taro, sago or breadfruit; fruits such as papaya, pineapple and avocado; or forage crops. Also, millet, lentils, barley and plantain, all crops grown mainly in the developing world, received limited CBC research attention. CBC research has been done on myriad arthropod pests, including species with high levels of insecticide resistance such as *Chilo suppressalis* (Lepidoptera: Crambidae) and *Helicoverpa armigera* (Lepidoptera: Noctuidae). However, almost 70% of pests with high incidence of insecticide resistance have been overlooked. Lastly, we contrast country-specific CBC research advances with the national level of insecticide use and importation, and identify lucrative opportunities for countries to save funds through targeted research investment. Based upon our delineation of the current status of CBC, we indicate potential for well-orchestrated regional research projects to pursue higher levels of CBC integration into current pest management schemes. This work constitutes a first step in drawing a roadmap for developing-world research that provides local farmers with safe, low-cost means to control damaging insect pests, safeguard harvests and secure their livelihoods.

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## 1. Introduction

Arthropods provide many valuable ecosystem services, including the natural control of agricultural pests (Daily, 1997). In the United States alone, the annual value of these biological control services is estimated at \$4.5 up to \$17 billion (Pimentel et al., 1997; Losey and Vaughan, 2006), and this value may still be much higher for small-scale agriculture in the developing world. Such natural pest control services are delivered through a diverse community of arthropod predators, parasitoids and entomo-pathogens that are present in the vegetation in or around farm fields. The deliberate manipulation of agro-ecosystems to enhance the survival, fitness, and behavioral performance of these natural enemies, and to improve their resulting pest control action, is termed conservation biological control (CBC) (Barbosa, 1998; Landis et al., 2000). Through vegetation manipulation, CBC can provide control of both primary and secondary pests, while reducing the likelihood of pest outbreaks and resurgences (e.g., Naranjo and Ellsworth, 2009). Also, CBC practices do not lead to the development of insecticide resistance, a process that prevents closure of yield gaps in many developing world crops (Godfray et al., 2010). Lastly, CBC does not bring about human health risks, as compared to many chemically-defined insecticides.

Despite being one of the oldest forms of pest control, with records dating back to 300 BC (see Huang and Yang, 1987), CBC has only received limited attention (Ehler, 1998). With the onset of the pesticide era, chemical insecticides came to replace the action of naturally occurring natural enemies. By displacing natural biological control agents from farm fields, pesticides thus quickly divorced agricultural production from ecology (Robertson and Swinton, 2005). Similarly, the spectacular achievements with importation biological control projects in the 1980s may have reduced interest in CBC. However, the volume of CBC research has steadily increased and some related tactics are being adopted in cropping systems in Europe and North America (e.g., McLeod et al., 2004; Jonsson et al., 2008; Naranjo and Ellsworth, 2009; Nilsson, 2011). Despite these evolutions, the potential for the management of pest insects using CBC has yet to be fully exploited, especially for control of indigenous crop pests that have large natural enemy complexes.

In many parts of the developing world, CBC is believed to be the area of biological control with the greatest scope for pest control in multiple crops (e.g., Waage and Schulthess, 1989; Yaninek and Cock, 1989; Tamo et al., 1997; Gurr et al., 2011). Lower consumer expectations regarding cosmetic standards for harvested produce, relatively diverse agro-ecosystems, and the low resource base supporting local production systems all make CBC an attractive pest management solution for local farmers (Neuenschwander, 2010). In systems where pest losses are high, better pest

management through enhancement of biological control services can raise crop yields more than most other types of crop research (Pretty et al., 2011). However, a range of problems impede the development and implementation of CBC in developing countries. Often, adequate ecological information describing the action of indigenous natural enemies and an assessment of ways to exploit them is missing (Yaninek and Cock, 1989; Legg et al., 2003). Also, instead of being seen as an opportunity to advance CBC, the predominance of generalist predators is frequently thought an impediment to effective biological control (Cherry et al., 2003). Consequently, pesticide use in many parts of the developing world remains high and interferes with natural biological control services. In the Latin American horticultural sector, for example, dependence on pesticides is at worrying levels, with the bulk of growers naming insecticides as their sole pest management tool (Nunes et al., 2005; Wyckhuys et al., 2011). In other systems, farmers seem to be falling back into the pesticide treadmill. The classic Peruvian Canete Valley success, in which insecticide applications in cotton fields were reduced from 16 to 2–3 per crop (Doutt and Smith, 1971; Barducci Boza, 1972), had completely degenerated within 30 years, with a return to pesticide-dominated pest control (Way and van Emden, 2000). Even in Southeast Asia, where increased understanding of agro-ecosystem functioning led to far-reaching management and policy changes in the 1990s, pesticide use is increasing and associated pest problems are mounting once again (Bottrell and Schoenly, 2012). For those systems, there is a need to seriously assess the potential of CBC as a complementary or alternative pest management tactic. In other parts of the developing world, such as Sub-Saharan Africa, farmers do not have the financial means to use insecticides and insects continue to cause vast yield losses and imperil food security (Neuenschwander, personal communication). In those systems, CBC could constitute an equally attractive pest management option, representing a low-cost means to promote resident natural enemies and contribute to pest control.

In some countries, such as Cuba, CBC has received a fair amount of research attention and occupies a prominent place in pest management schemes (Vázquez et al., 2008). Also, in a small set of subsistence crops, farmers have historically learned to manage their pests with limited use of insecticides (Jago, 1991; Way and van Emden, 2000; Wyckhuys and O'Neil, 2007a). These cases should be documented to help guide the development of CBC practices for other crops in the tropics and in the developed world.

Agricultural production systems tend to lower the abundance and efficacy of natural enemies through increased levels of disturbance (i.e., pesticide use, tillage), simplification of landscapes, or use of monocultures (Letourneau, 1998). CBC tactics, as tools to correct these problems, have been categorized into those that reduce natural enemy mortality, provide supplementary resources

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