SHORT COMMUNICATION

BIOLOGICAL AND HABITAT INTERVENTIONS FOR INTEGRATED PEST MANAGEMENT SYSTEMS

CONLONG DE[1,2] and RUTHERFORD RS[1]

[1]*South African Sugarcane Research Institute, Private Bag X02, Mount Edgecombe, 4300, South Africa*
[2]*Department of Conservation Ecology and Entomology, Faculty of AgriSciences, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa*
Des.conlong@sugar.org.za Stuart.Rutherford@sugar.org.za

Abstract

Conventional Integrated Pest Management (IPM) systems control pests through informed use of cultural and biological control and host plant resistance characteristics to minimise pesticide interventions. Successful IPM is based on a thorough knowledge of the target pest's life cycle, and its ecological and behavioural interactions with its environment and natural controlling factors. A number of new interventions can be added to the IPM arsenal. These include habitat management, which increases the efficacy of conservation, inoculative and augmentative biological control; use of plant and insect pathogens and symbionts on target pest populations to make potential host plants more or less suitable for colonisation; and the impact of these on adult fertility and offspring sex ratios makes their exploitation, in combination with interventions such as Sterile Insect Technology (SIT), a real and practical possibility.

Modern IPM is not only about insect/plant interactions, but about holistic agro-ecosytem interactions, in which knowledge about plants, pathogens, endophytes, symbionts and insects are combined to provide crop protection in an area-wide, environmentally friendly manner.

The full chapter on which this short communication is based is now published (Conlong and Rutherford, 2009).

Keywords: habitat management, Sterile Insect Technology, endophytes, *Wolbachia*, host plant resistance, cultural controls

Introduction

Integrated Pest Management (IPM) is described as a 'knowledge intensive' approach to farming (Bartlett, 2002), with the basic building block regarded as sound knowledge of ecology (Landis *et al.,* 2000; Dofour, 2001; Gurr *et al.,* 2004). The four phases of arthropod pest management and their interactions (Zehnder *et al.,* 2007) should form the basis of all IPM programmes.

SASRI has for many years attempted to control *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (Carnegie, 1974). Good cultural control measures (Carnegie, 1981; Carnegie and Smaill, 1982), and resistant varieties have been developed (Keeping, 2006). However, it still remains a pest throughout the sugar industry (Webster *et al.,* 2005), necessitating a refocusing of control efforts into area-wide integrated pest management (AW-IPM) (Klassen, 2005). This marries the more conventional control options with ecologically based new technologies, such as delineation of within-species populations, chemical ecology, habitat management, sterile insect technology (SIT), and utilising plant endophytic pathogens and *Wolbachia* to produce a workable IPM strategy.

Ecology

Conlong (2001) found behavioural, host plant and natural enemy differences between populations of *E. saccharina* occurring in South and West Africa, with them seemingly coming together in Uganda. These differences between different populations of a morphologically similar species made it an ideal candidate for molecular systematic analyses. Assefa *et al.* (2006), using cytochrome c oxidase subunit 1 (CO1), separated the African species into three groups (west, south and Ethiopian). Two of these groups (west and south) were found in Uganda. Genetic diversity between these groups was larger than that of related species of other lepidopterans. IPM programmes, which use classical biocontrol and/or translocation of natural enemies (Schulthess *et al.,* 1997) as management options, can be enhanced with such techniques to identify cryptic species, or populations of species, most closely related to each other, leading to more informed decisions on natural enemy selection against problem pest species.

Habitat management

Understanding the role of the plant in managing insect populations is very important, as it has attributes that attract and repel insects (Cortesero *et al.,* 2000; Wäckers *et al.*, 2005). An example comes from biological control efforts against *E. saccharina*. It has been puzzling why parasitoids of *E. saccharina*, abundant in indigenous host plants (Conlong, 1990), are never found in *E. saccharina* infested sugarcane, even if adjacent to indigenous host plants. Smith *et al.* (2006) showed that the crop and indigenous host plants emit different volatile profiles, and these different profiles are more evident when plants are attacked by *E. saccharina.* Prior to this discovery, it was hypothesised that a 'barrier' prevented natural enemy movement between the two habitats, prompting early habitat management work.

Eldana saccharina has a hierarchical preference in choosing a host plant habitat to oviposit in, selecting sugarcane only after Cyperaceae (Conlong *et al.,* 2007) and maize (Keeping *et al.,* 2007). Both the latter have *E saccharina* population controls in place- natural enemies in the Cyperaceae (Conlong 1990, 1997) and genetically engineered Bt toxins in maize (Keeping *et al.,* 2007). Further evidence to promote habitat management was the repellent properties of *Melinis minutiflora* Beauv. to cereal stemborers, and its attractant properties to their parasitoids (Khan *et al.* 1997a,b; 2001). Kasl (2004) showed that *E. saccharina* was repelled by this grass, and that *Xanthopimpla stemmator* (Thunberg) (Hymenoptera: Ichneumonidae) parasitised more *E. saccharina* pupae in sugarcane in the presence of this grass, than in sugarcane only. *Eldana saccharina* populations and damage were halved in *M. minutiflora* field plots compared to pure sugarcane control plots (Barker *et al.,* 2006).

The success of these trials led to the development of a farm based habitat management plan, incorporating indigenous host plants and Bt maize as 'pull' plants and *M. minutiflora* as the 'push' component. In addition, it incorporates *E. saccharina* resistant sugarcane varieties suited to soil types and environmental conditions (Figures 1 and 2). An added aspect is planting buckwheat, which attracts adult parasitoids and predators into the environment by providing pollen and nectar to enhance indigenous natural enemy activity (Wäckers *et al.,* 2005; Zehnder *et al.,* 2007).

Induced plant resistance

In addition to ecological knowledge, host plant resistance is regarded as another basic requisite for IPM (Maxwell, 1985). Keeping and Meyer (2002) demonstrated sugarcane resistance enhancement by incorporating silicon into soil. The use of plant elicitors to induce resistance (Zehnder *et. al.,* 2007) shows much promise in IPM. Stout *et al.* (2002), review the concept of inducing resistance of plants to insect herbivores. Many of these elicitors have a two-fold benefit: they induce resistance, and attract predators and parasitoids into crop fields, increasing foraging populations (James *et al.,* 2005).

The fourth trophic level

Fungal endophytes

In *Cyperus papyrus* L., *Beauveria bassiana* is a major mortality factor of *E. saccharina* (Conlong 1990). In trials testing the efficacy of *B. bassiana* as a dip to kill *E. saccharina* in sugarcane setts to be used for planting, no colonisation of existing borings by this fungus was demonstrated (unpublished results[1]). When *E. saccharina* bores into sugarcane; however, a reddish discoloration around the boring is caused by *Fusarium* spp. This fungus was aggressive, not allowing colonisation by *B. bassiana* (personal communication[2]). Following on from this and work of Schulthess *et al.* (2002), McFarlane and Rutherford (2005) isolated endophytic *Fusarium* spp. from sugarcane. These species elicited different responses from *E. saccharina*. Some were beneficial to the borer, showing similar attraction as demonstrated by Schulthess *et al.* (2002). Others were antagonistic, with *E. saccharina* growth retarded, and being repelled (McFarlane and Rutherford, 2005, 2006).

The most attractant *Fusarium* isolate to *E. saccharina* is *F. pseudonygamai* (McFarlane and Rutherford 2005, 2006). In an IPM approach against *E. saccharina,* hot water treatment or treatment with fungicides of seedcane could reduce infestation by *F. pseudonygamai*, thereby reducing *E. saccharina* infestation. Alternatively, the facilitation of endophytic colonisation of sugarcane by antagonistic *Fusarium* species (McFarlane and Rutherford 2005; 2006) could afford more sustainable environmentally friendly protection against *E. saccharina*, as these may restrict colonisation of sugarcane by isolates beneficial to *E. saccharina.*

Wolbachia

In reviews on *Wolbachia,* infection symptoms such as feminisation of genetic males, parthenogenesis induction, male embryo killing and cytoplasmic incompatibility (CI) of related strains of arthropods are regarded as useful characters for population regulation (Werren, 1997; Floate *et al.,* 2006; Bourtzis, 2007). These alter reproductive success of their

[1] DE Conlong, South African Sugarcane Research Institute, Private Bag X02 Mt Edgecombe 4300. South Africa.
[2] M Morris, Plant Health Products (Pty) Ltd, PO Box 207, Nottingham Road. 3280, South Africa. mike@plant-health.co.za

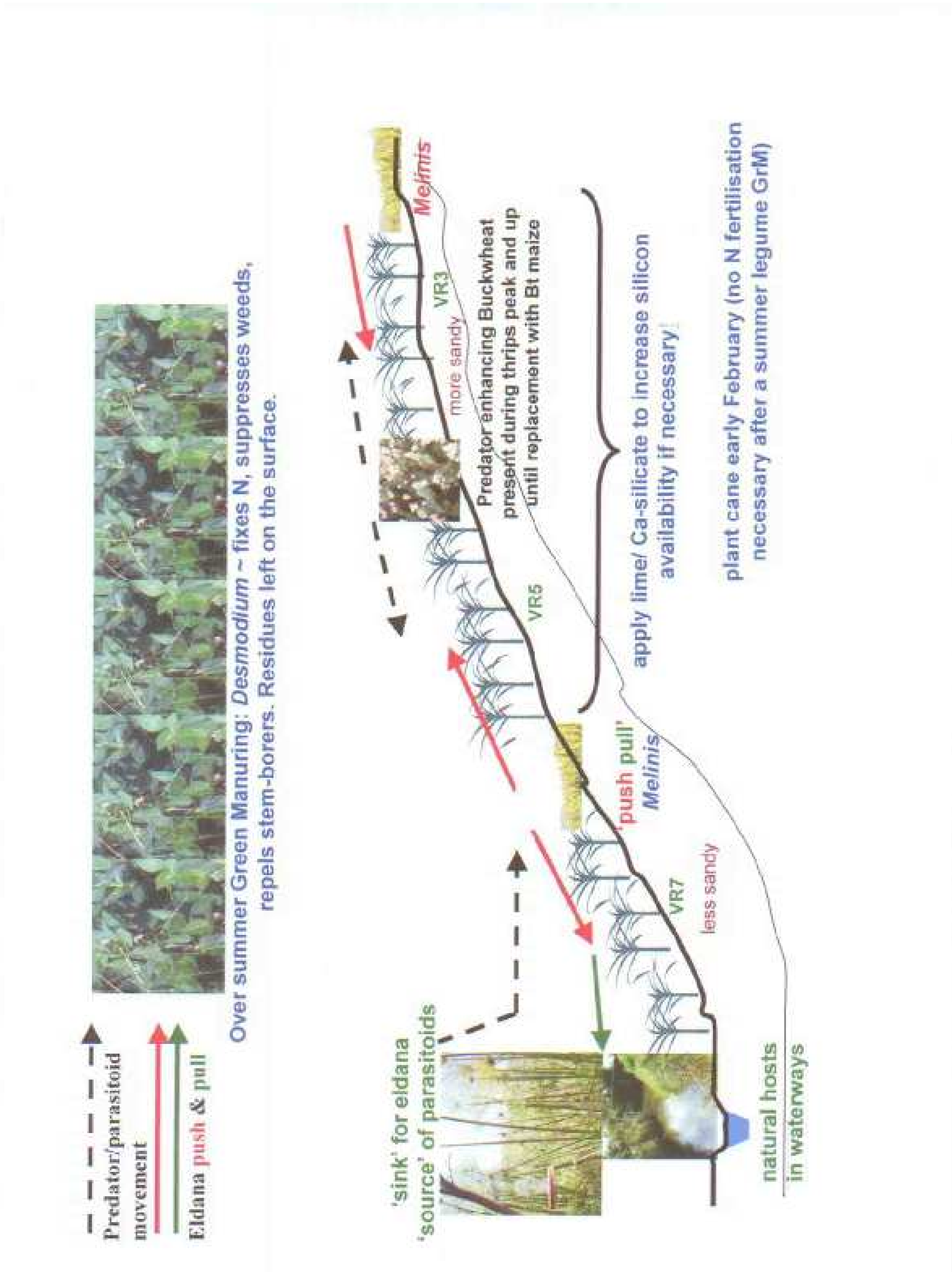

Figure 1. Conceptual diagram for a habitat management based IPM approach to control thrips (Thysanoptera: Thripidae) at planting, and *Eldana saccharina* infestation in older sugarcane: Management just prior to planting and at planting. (VR3, VR5, VR7= sugarcane varieties recommended for the particular soil and environmental conditions of the planting site, and resistant to *E. saccharina*) (From Conlong and Rutherford, 2009).

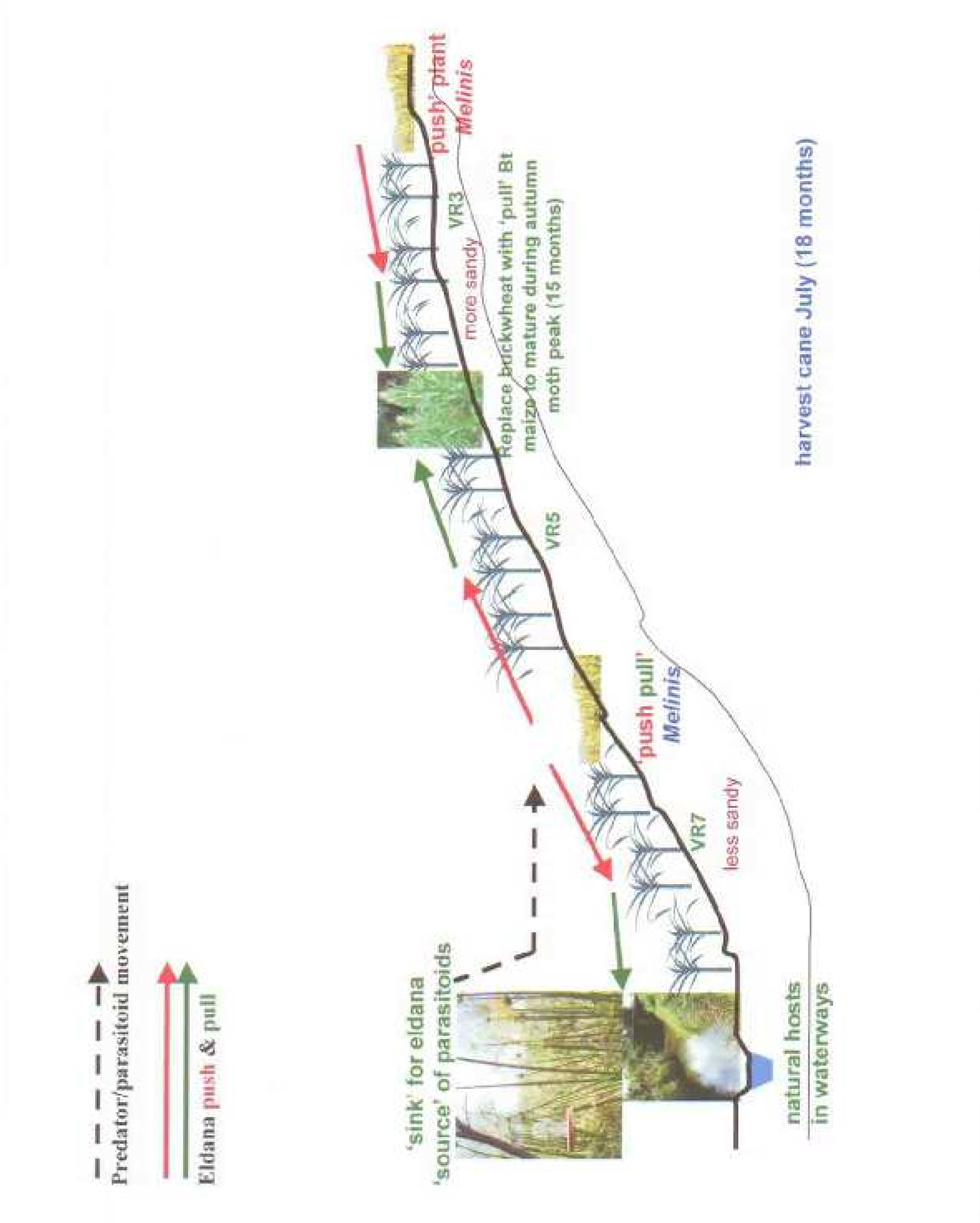

Figure 2. Conceptual diagram for a habitat management based IPM approach to control thrips (Thysanoptera: Thripidae) at planting, and *Eldana saccharina* infestation in older sugarcane: Management from planting to harvest. (VR3, VR5, VR7= sugarcane varieties recommended for the particular soil and environmental conditions of the planting site, and resistant to *E. saccharina*). (From Conlong and Rutherford, 2009).

hosts (Floate, 2007). *Wolbachia* thus have potential as a 'new' biological control agent (Bourtzis, 2007; Floate, 2007), because they enhance productivity of natural enemies (Werren, 1997). In addition, *Wolbachia*-induced CI directly suppresses populations of economic and public health importance, and can be used as a tool to spread genetically modified strains into wild populations and as an expression vector, after a genetic transformation system for this bacterium is developed (Bourtzis, 2007).

The confirmation of *Wolbachia* presence in *E. saccharina* from Kenya, Uganda and Tanzania opens the use of *Wolbachia* in the SASRI IPM strategy. Cytoplasmically inherited *Wolbachia* infections can spread through uninfected populations due to CI (Werren, 1997). Could this be achieved in the uninfected South African population? If so, a female biased field population can be expected. This would complement sterile insect technology, especially F1 male sterility.

Links with Sterile Insect Technology (SIT)

The area wide integrated pest management (AW-IPM) concept was introduced when locust plagues and vector borne diseases had to be controlled (Klassen, 2005). This concept makes sense, as insects don't consider international, provincial, or farm boundaries. Their distributions are constrained by biotic and abiotic factors. Klassen (2005), Dyck *et al.* (2005) and Vreysen *et al.* (2007) review AW-IPM development and show its links with SIT.

For Lepidoptera, doses of radiation are too high if full sterility is the desired outcome (Carpenter *et al.,* 2005), as these doses affect other life functions, making them less fit than their wild counterparts. This does not make them unsuitable for SIT, as inherited sterility is another option (Carpenter *et al.,* 2005), which allows the radiation dose to be adjusted lower to produce partially sterile but more fit males who, when mated with wild females, have radiation induced deleterious effects passed on to their F1 generation. This results in reduced egg hatch with F1 offspring sterile and male biased (Carpenter *et al.,* 2005). Radiation biology studies on *E. saccharina* show it to be a candidate for inherited sterility.

Conclusion

Modern IPM is not only about insect/plant interactions, but about holistic agro-ecosytem interactions, where increased knowledge about environment, plants, pathogens, endophytes, symbionts and insects all combine to provide crop protection in an environmentally friendly manner. As knowledge about and interactions between chemistry of induced plant resistance, chemical ecology, endophytic fungi and *Wolbachia,* SIT, and phylogenetics and phylogeography of arthropods becomes more easily available, it is hypothesised that these will become important components of AW-IPM, minimising the impacts of synthetic pesticides. IPM practitioners are encouraged to consider the complete ecology of the perceived pest, and to use ecological concepts and theory in its management to provide sustainable, environmentally friendly control rather than the knee-jerk reaction of pesticide spraying.

REFERENCES

Assefa Y, Mitchell A and Conlong DE (2006). Phylogeography of *Eldana saccharina* Walker (Lepidoptera: Pyralidae). *Annales de la Société Entomologique de France* 42: 331-337.

Barker AJ, Conlong DE and Byrne M (2006). Habitat management using *Melinis minutiflora* (Poaceae) to decrease the infestation of sugarcane by *Eldana saccharina* (Lepidoptera: Pyralidae). *Proceedings of the South African Sugarcane Technologists' Association* 80: 226-235.

Bartlett A (2002). ICT and IPM. *Farmers, FAO and Field Schools: Bringing IPM to the grass roots in Asia*. United Nations Food and Agriculture Organisation, Bangkok.

Bourtzis K (2007). *Wolbachia*-induced cytoplasmic incompatibility to control insect pests? In: Vreysen MJB, Robinson AS and Hendrichs J (Eds). *Area-Wide Control of Insect Pests: From Research to Field Implementation.* Pp 125-135. Springer, Dordrecht, The Netherlands.

Carnegie AJM (1974). A recrudescence of the borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae). *Proceedings of the South African Sugarcane Technologists' Association* 48: 107-110.

Carnegie AJM (1981). Combatting *Eldana saccharina* Walker, a progress report. *Proceedings of the South African Sugarcane Technologists' Association* 55: 116-119.

Carnegie AJM and Smaill RJ (1982). Pre-trashing as a means of combating the borer *Eldana saccharina* Walker. *Proceedings of the South African Sugarcane Technologists' Association* 56: 78-81.

Carpenter JE, Bloem S and Marec F. (2005). Inherited Sterility in Insects. In: Dyck VA, Hendrichs J and Robinson AS (Eds). *Sterile Insect Technique. Principles and Practice in Area-Wide Integrated Pest Management*. pp 39-68. IAEA Springer, The Netherlands.

Conlong DE (1990). A study of pest-parasitoid relationships in natural habitats: An aid towards the biological control of *Eldana saccharina* Walker (Lepidoptera: Pyralidae) in sugarcane. *Proceedings of the South African Sugarcane Technologists' Association* 64: 111-115.

Conlong DE (1997). Biological control of *Eldana saccharina* Walker in South Afrcian sugarcane: Constraints identified from 15 years of research. *Insect Science and its Application* 17: 69-78.

Conlong DE (2001). Biological control of indigenous African stemborers: What do we know? *Insect Science and its Application* 21: 267-274.

Conlong DE and Rutherford RS (2009). Conventional and New Biological and Habitat Interventions for Integrated Pest Management Systems: Review and Case Studies using *Eldana saccharina* Walker (Lepidoptera: Pyralidae). Chapter 10, pp 241-261. *In* Peshin R and Dhawan AK (Eds). *Integrated Pest Management: Innovation-Development Process,* Vol.1. Springer, Dordrecht, The Netherlands. ISBN 978-1-4020-8991-6 (Print); 978-1-4020-8992-3 (online). DOI 10.1007/978-1-4020-8992-3_10.

Conlong DE, Kasl B and Byrne M (2007). Independent kids, or motherly moms? Implications for integrated pest management of *Eldana saccharina* Walker (Lepidoptera: Pyralidae). *Proceedings of the International Society of Sugar Cane Technologists* 26: 787-796.

Cortesero AM, Stapel JO and Lewis WJ (2000). Understanding and manipulating plant attributes to enhance biological control. *Biological Control* 17: 35-49.

Dufour R (2001). Biointensive Integrated Pest Management (IPM). Fundamentals of Sustainable Agriculture. http://www.atta.ncat.org/atta-pub/ipm.html (HTML). http://www.atta.ncat.org/atta-pub/PDF/ipm.pdf (PDF).

Dyck VA, Hendrichs J and Robinson AS (Eds) (2005). *Sterile Insect Technique. Principles and Practice in Area-Wide Integrated Pest Management*. pp 39-68. IAEA Springer, The Netherlands.

Floate KD (2007). Relevance of *Wolbachia* bacteria in biocontrol programs. *In* van Lenteren JC, de Clercq P and Johnson MW (Eds.). *Proceedings of 11th meeting of the Working Group Arthropod Mass Rearing and Quality Control. 28 October - 1 November 2007, Montreal, Canada.* Bulletin IOBC Global No 3, 177 pp. Ponsen and Looijen, Wageningen, The Netherlands. pp 51-54.

Floate KD, Kyei-Poku GK and Coghlin PC (2006). Overview and relevance of *Wolbachia* bacteria in biocontrol research. *Biocontrol Science and Technology* 16: 767-778.

Gurr GM, Wratten SD and Altieri MA (Eds) (2004). *Ecological Engineering for Pest Management. Advances in Habitat Manipulation for Arthropods.* CSIRO Publishing, Collingwood, Victoria 3066, Australia.

James DG, Castle SC, Grasswitz T and Reyna V (2005). Using synthetic herbivore-induced plant volatiles to enhance conservation biological control: Field experiments in hops and grapes. In: Hoddle MS (Ed). *Proceedings of the Second International Symposium on Biological Control of Arthropods. Volume 1.* Davos, Switzerland. September 12-16, 2005. United States Department of Agriculture. FHTET-2005-08.

Kasl B (2004). Stimulo-Deterrent Diversion Approaches to Decrease *Eldana saccharina* Walker (Lepidoptera: Pyralidae) Infestation in Sugarcane. Unpublished PhD dissertation. University of the Witwatersrand, Johannesburg, South Africa. 215 pp.

Keeping MG (2006). Screening of South African sugarcane cultivars for resistance to the stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae). *African Entomology* 14: 277-288.

Keeping M and Meyer J (2002). Effect of four sources of silicon on resistance of sugarcane varieties to *Eldana saccharina* (Lepidoptera: Pyralidae). *Proceedings of the South African Sugarcane Technologists Association* 77: 99-103.

Keeping MG, Rutherford RS and Conlong DE (2007). Bt-maize as a potential trap crop for management of *Eldana saccharina* Walker (Lepidoptera: Pyralidae) in sugarcane. *Journal of Applied Entomology* 131: 241-250.

Khan ZR, Chiliswa P, Ampong-Nyarko K, Smart LE, Polaszek A, Wandera J and Mulaa MA (1997a). Utilization of wild gramineous plants for management of cereal stemborers in Africa*. Insect Science and its Application* 17: 143–150.

Khan ZR, Ampong-Nyarko K, Chiliswa P, Hassanali A, Kimani S, Lwande W, Overholt WA, Pickett PA, Smart LE, Wadhams LJ and Woodstock CM (1997b). Intercropping increases parasitism of pests. *Nature* 388: 631-639.

Khan ZR, Pickett JA, Wadhams LKJ and Muyekho F (2001). Habitat management strategies for the control of cereal stemborers and striga in maize in Kenya. *Insect Science and its Application* 21: 375-380.

Klassen W (2005). Area-Wide Integrated Pest Management and the Sterile Insect Techniques. *In* Dyck VA, Hendrichs J and Robinson AS (Eds). *Sterile Insect Technique. Principles and Practice in Area-Wide Integrated Pest Management*. pp 39-68. IAEA Springer, The Netherlands.

Landis DA, Wratten SD and Gurr GM (2000). Habitat Management to Conserve Natural Enemies of Arthropod Pests in Agriculture. *Annual Review of Entomology* 45: 175-201.

Maxwell FG (1985). Utilisation of host plant resistance in pest management. *Insect Science and its Application* 6: 437-442.

McFarlane SA and Rutherford SR (2005). *Fusarium* species isolated form sugarcane in KwaZulu-Natal, and their effect on *Eldana saccharina* (Lepidoptera: Pyralidae) development *in vitro. Proceedings of the South African Sugarcane Technologists' Association* 79: 120-123.

McFarlane SA and Rutherford SR (2006). Attraction of *Eldana saccharina* (Lepidoptera: Pyralidae) to certain *Fusarium* isolates in olfactory choice assays. *Proceedings of the South African Sugarcane Technologists' Association* 80: 196-198.

Schulthess F, Cardwell KF and Gonou S (2002). The effect of endophytic *Fusarium verticellioides* on infestation of two maize varieities by lepidopterous stemborers and coleopteran grain feeders. *Phytopathology* 92: 120-128.

Schulthess F, Bosque-Perez NA, Chabi-Olaye A, Gonou S, Ndemah R and Goergen G (1997). Exchange of natural enemies of lepidopteran cereal stemborers between African regions. *Insect Science and its Application* 17: 97-108.

Smith JM, Conlong DE, Byrne M and Frerot B (2006). Response of *Goniozus indicus* (Hymenoptera: Bethylidae) to sugarcane and *Cyperus papyrus* volatiles. *Proceedings of the South African Sugarcane Technologists' Association* 80:250-255.

Stout MJ, Zehnder GW and Baur ME (2002). Potential for the use of elicitors of plant resistance in arthropod management programmes. *Arch. Insect Biochem. Physiol.* 51: 222-235.

Vreysen MJB, Robinson AS and Hendrichs J (Eds) (2007). *Area-Wide Control of Insect Pests: From Research to Field Implementation.* Springer, Dordrecht, The Netherlands.

Wäckers FL, van Rijn PCJ and Bruin J (Eds) (2005). *Plant-Provided Food for Carnivorous Insects: A Protective Mutualism and its Applications.* Cambridge University Press. Cambridge, UK.

Werren, J.H. (1997). Biology of *Wolbachia. Annual Review of Entomology* 42: 587-609.

Webster TM, Maher GW and Conlong DE (2005). An integrated pest management system for *Eldana saccharina* in the Midlands North region of KwaZulu-Natal. *Proceedings of the South African Sugar Technologists Association* 79: 347-358.

Zehnder G, Gurr GM, Kühne S, Wade MR, Wratten SD and Wyss E (2007). Arthropod pest management in organic crops. *Annual Review of Entomology* 52: 57-80.