BSES Limited

FINAL REPORT – SRDC PROJECT BSS280

OVERSEAS SUGARCANE QUARANTINE AND EMERGENCY RESPONSE PLANNING

by

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SD05017

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SUMMARY

The aim of this trip was for Dr Mohamed Sallam, BSES entomologist, to gain experience in sugarcane biosecurity and to learn about sugarcane pest and disease problems in the United States. In addition, Dr Sallam participated in the International Conference on Lepidopterous Cereal Stem and Cob Borers in Africa (ICLCBA), which took place at the International Centre of Insect Physiology and Ecology (ICIPE) in Nairobi, Kenya.

During a 10-week visit to the Department of Entomology, Louisiana State University (LSU), Dr Sallam interacted with sugarcane entomologists, quarantine workers and sugarcane grower groups. Knowledge gained included quarantine measures in place to ensure that the movement of the Mexican rice borer (*Eoreuma loftini*) towards Louisiana is hindered, IPM strategies to combat the sugarcane borer (*Diatraea saccharalis*), and the general cane-growing system in Louisiana.

Dr Sallam also visited the Institute of Food and Agricultural Sciences at the University of Florida (IFAS/UFL), where a team of entomologists and botanists is working on combating invasive insect and plant pest species. Knowledge gained there included learning about several insect pests of sugarcane in Florida, such as whitegrubs, wireworms and the yellow sugarcane aphid, and methods for their control.

The ICLCBA conference at ICIPE, Kenya, was attended by 44 scientists working on the ecology, biology, taxonomy and management of gramineous moth borers in Africa. Dr Sallam gave a presentation on sugarcane biosecurity in Australia and ran the final system-wide-initiative discussions at the end of the meetings.

During this Travel and Learning project, Dr Sallam also prepared a Pest Incursion Management Plan dossier on Mexican Rice Borer and collected field and laboratory specimens of Old and New World borer species to enrich the borer DNA database at BSES and of their parasitoids to provide additional material for a PhD project at the University of Adelaide.

In addition, Dr Sallam promoted Australian sugarcane research work and highlighted the role of BSES/SRDC biosecurity initiatives. Scientists from all parts of the world commended the Australian approach in dealing with exotic threats, and future opportunities for further cooperation with LSU, ICIPE and the South African Sugarcane Research Institute (SASRI) have been created.

Learnings have been communicated through a seminar at BSES Meringa and a *BSES Bulletin* article to be published in 2006. They will also be the subject of COMPASS, *GrubPlan* and Joint Operations Group meetings in 2006.

1.0 BACKGROUND

During the International Congress of Entomology (Brisbane, September 2004), I was invited by Professor Gene Reagan to visit the Entomology Department at Louisiana State University (LSU) to exchange knowledge on sugarcane biosecurity.

Dr Reagan is concerned about the spread of the Mexican rice borer (MRB), *Eoreuma loftini* (Lepidoptera: Crambidae), through Texas and towards Louisiana. At LSU, a team of entomologists is working on the ecology, biology and spread of MRB. Dr Reagan is exerting heavy pressure on the Louisiana Department of Agriculture and Forestry (LDAF) to tighten their quarantine measures regarding sugarcane being transported from Texas to Louisiana. Dr Reagan was impressed with BSES' work on quarantine and was keen to learn more about our approach to fill any gaps they might have in dealing with the borer threat.

I was interested to learn about the research conducted on MRB and the quarantine measurements in place to deal with that threat. There was also a need to develop a Pest Incursion Management Plan specifically for *Eoreuma loftini*, given that we did not include that species in our previous biosecurity project (BSS249). In addition, I was interested in participating in the International Conference on Lepidopterous Stemborers in Africa, which would bring together scientists who are working on borer management from different parts of the world, especially from Africa.

My visit to LSU took place between 1 August and 14 October 2005. During that time, I also conducted a short visit to the Institute of Food and Agricultural Science of the University of Florida (IFAS/UFL). From 14 October to 29 October, I visited the International Center of Insect Physiology and Ecology (ICIPE) in Nairobi, Kenya.

2.0 OBJECTIVES

The overall aim of this project was to improve the ability of the Australian sugar industry to manage an incursion of an exotic pest. This Travel and Learning project allowed me to visit Louisiana State University, USA and attend a conference on moth borer pests in Nairobi, Kenya.

Specific objectives were to:

- Participate for 10 weeks at Louisiana State University to gain hands-on experience in methods of detection, incursion management, containment and eradication systems for North and South American cane borers - especially Mexican rice borer.
- Attend the International Conference on Lepidopterous Stemborers in Africa (24-28 October 2005) and present a paper on Australia's preparedness for incursions.
- Explore the potential for collaborative work on sugarcane quarantine, emergency response and stemborer biology and management with Louisiana State University and the International Centre of Insect Physiology and Ecology in Kenya.
- Communicate knowledge gained to Australian organizations (AQIS, QDPI&F, Northwatch and Plant Health Australia) through NAQS update sessions, and to cane growers through *GrubPlan*, Compass and RPAC workshops.

All objectives have been met satisfactorily. Although, the main delivery of COMPASS has recently been through the on-line version, I will present my learnings at any meeting in northern Queensland. 'In person' delivery of information is still on-going through *GrubPlan* workshops and growers have access to information on biosecurity via the BSES internet site.

3.0 ITINERARY

Date	Depart	Arrive
30/07/2005	Cairns	Sydney
30/07/2005	Sydney	Los Angeles
30/07/2005	Los Angeles	Dallas
30/07/2005	Dallas	Baton Rouge
Started work at LSU from 1/8/05 until 22/9/05 - work included short visits to research stations in Texas		
22/09/2005	Baton Rouge	Fort Pierce - Florida
Visited University of Florida and gave a seminar at IFAS (22-27/9/2005)		
27/09/2005	Fort Pierce - Florida	Baton Rouge
Resumed work at LSU from 30/9 until 14/10/05		
14/10/2005	Baton Rouge	Dallas
14/10/2005	Dallas	Chicago
14/10/2005	Chicago	London
15/10/2005	London	Nairobi - Kenya
Started work at ICIPE - Nairobi from 17-29/10/05		
29/10/2005	Nairobi	Johannesburg
30/10/2005	Johannesburg	Sydney
31/10/2005	Sydney	Cairns
Resumed work at BSES on 1/11/05		

4.0 GENERAL INTRODUCTION

4.1 Sugarcane in Louisiana

Louisiana was the first American state to plant sugarcane and produce granulated sugar. The industry goes back to the mid 1700s when sugarcane was first planted in New Orleans by the Jesuit (Society of Jesus) priests. Since then, sugarcane plantations have expanded throughout southern Louisiana, and currently cane is planted over 450,000 acres (182,112.5 ha) in 24 of the 64 parishes (counties). This constitutes about 40% of the sugarcane area in the United States, and produces about 1.5 million tonnes of raw sugar per year. Sugarcane is also planted in Texas, Florida and Hawaii. Sugar beet is planted in cooler parts of the USA, such as North Dakota, Minnesota, Wyoming, California and Michigan, and this provides approximately the same amount of sugar as the sugarcane industry. Even with a total production of 7.7 million tonnes of raw sugar per year, the

United States still imports one-fifth of its total domestic consumption of sugar (about 1.5 million tonnes).

In Louisiana, sugarcane is planted around August-September and harvested in September-January. Due to climatic conditions in Louisiana, sugarcane is severely set back during winter months (December-January) when temperatures normally fall below 0°C and may remain this way for a number of days. This freeze kills all the shoots that have germinated during September-December. Later in March-April, the buds that have not germinated become active and produce shoots. These then form the crop. Whole-stalk planting is the preferred method used to make sure there are enough viable eyes in the soil to germinate. The Australian billet planter was tried in Louisiana, but the crop failed, as, after the freeze, there were no viable buds to compensate for the winter loses.

Sugarcane in Louisiana is planted as single rows on preformed/raised beds at 1.8 m centre to centre. This ensures controlled traffic of field machinery and minimizes the chances of water logging. The planting ratio can be as low as 3:1 (one-third of a crop is used to plant another crop), and this is partly due to the need for enough planting material to ensure good germination. However, mechanical planting of whole stalks is also responsible for this high ratio. Hand planting is practiced in several farms, and this results in a more economical ratio (as high as 10:1).

Sugarcane in Louisiana is mechanically harvested using either combine or soldier harvesters. Combine harvesting is the same system used in Australia and is now implemented in almost 90% of cane farms in Louisiana. Combine harvesters have gradually replaced soldier harvesters, which could only cut erect plants efficiently. Soldier harvesters were widely used in the past - they cut the plants at the base, two rows at a time, remove the tops, and stack the stalks behind the machine in what is called a heap row. The cane in the heap rows is then burnt and transported to the mill. The name ‘soldier harvester’ was derived from the method in which erect cane plants enter the machine upright as soldiers. In the 1990s, and with the introduction of the high-yielding variety (LCP85-384) that naturally tends to lodge, it was not feasible to continue using soldier harvesters and they were gradually replaced with combine harvesters that are capable of cutting lodged cane. Combine harvesting is more expensive, since they cut only one row at a time, but they have reduced burning as cane can be cut green. This has minimized the risk of fire to the environment, as well as to the public. Soldier harvesters are still used to cut cane for planting.

The variety LCP85-384 is currently planted over 89% of Louisiana sugar farms. Cane growers quickly expanded their plantings of this variety because its tonnage and sugar yield were about 30% higher than previous varieties. However, the same variety is also susceptible to moth-borer infestation. More recently, sugarcane rust gradually started to become a major problem in this variety. A breeding program conducted by the Agricultural Research Service (ARS), a section of the United States Department of Agriculture (USDA), is currently underway specifically to produce borer-resistant varieties. In addition, another breeding program is undertaken by Louisiana State University (LSU). Each year, a meeting takes place between LSU, USDA, American Sugarcane League (ASCL) and the Sugarcane Commodity Group based at Thibodaux, Louisiana, where varieties from both programs are evaluated. Due to continuous efforts by LSU, susceptibility to borers is becoming an important selection criterion for cultivars, especially now that more than 80% of the Louisiana crop is considered highly susceptible. Professor Gene Reagan at LSU continues to exert pressure on all cane groups to discard varieties susceptible to borers, even if they are high-performing cultivars. However, cane growers are willing to adopt any high yielding variety, even if it is borer susceptible, and they mainly rely on chemical control to suppress borer infestation.

4.2 Sugarcane moth borers in USA

4.2.1 Sugarcane borer: *Diatraea saccharalis* (Lepidoptera: Crambidae)

Sugarcane borer has been the major pest problem in sugarcane fields in USA since its introduction into Louisiana in the 1800s. The importance of this pest has declined recently in Texas, and this can be attributed the introduction of the efficient parasitoid (*Cotesia flavipes*) into Texas from India in the 1970s, along with the registration of the effective and environmentally acceptable insect growth regulator (tebufenozide) for use in cane fields. In Louisiana, several attempts to establish *Cotesia flavipes* in cane fields have not been successful. It was originally thought that harsh climatic conditions during winter kills all parasitoid stages, but recent studies showed that *C. flavipes* is capable of over-wintering in Louisiana, but it is incapable of finding the first borer generation in spring as the caterpillars are below ground level.

The chemical tebufenozide is currently the main management tool in Louisiana, aided by a rigorous risk assessment/monitoring program that ensures quick detection of infestations at an early stage. BSES has an established Incursion Management Plan for this pest (available on http://www.bses.org.au/bses_01.asp?page_id=1000).

4.2.2 Mexican rice borer: *Eoreuma loftini* (Lepidoptera: Crambidae)

MRB invaded the United States in 1980. It was first detected in Arizona and later in Texas. A comprehensive classical biological-control program was followed through the 1980s and 1990s in Texas and relied on importing natural enemies from other countries to manage the introduced pest. However, MRB proved very difficult to manage using biological or even chemical control. This is because the larvae tunnel into the stem soon after hatching and then fully pack the tunnels with compact frass (Figure 1); thus, they escape contact with insecticides and make it difficult for natural enemies to gain access inside the stem.

E. loftini has expanded its range from the Lower Rio Grande Valley of Texas and is currently approaching Louisiana. The spread towards Louisiana is estimated at 15 miles/year, which means that, unless aided (or hampered) by human factors, the pest is likely to cross the Texas-Louisiana border in the next 2 years, and will invade the first cane field 3 years later.

E. loftini is mainly a pest of sugarcane (Figure 2), but it also attacks rice (Figures 3 and 4); hence, the invasion of Louisiana by MRB is expected to have a severe negative impact on both industries. While in Louisiana, I compiled a detailed Incursion Management Plan for this species (Appendix 1) that will be added to the Incursion Management Plans on the BSES website.

Figure 1 A sugarcane stalk infested by Mexican rice borer showing the tunnels packed with frass

Figure 2 Sugarcane infested with Mexican rice borer

Figure 3 Checking rice fields at Ganado, TX for Mexican rice borer infestation

Figure 4 Mexican rice borer larva in rice stems

5.0 ENTOMOLOGY DEPARTMENT AT LSU

During my visit to LSU, I had several discussions with sugarcane scientists (Figure 5), quarantine workers and sugarcane groups, and I gave a seminar at LSU on the Australian quarantine approach. In addition, I attended several variety meetings in which cultivars were either accepted or dropped. I also visited the USDA sugarcane research station at Houma and the Texas A&M University campus at Beaumont, and collected larval stages of both borer species (*Diatraea saccharalis* and *Eoreuma loftini*) and their parasitoids to add to our DNA database. I also participated in pheromone trapping of borers (Figure 6) and in planting variety trials (Figure 7). Following are the details of the main activities in which I participated and the major learnings gained.

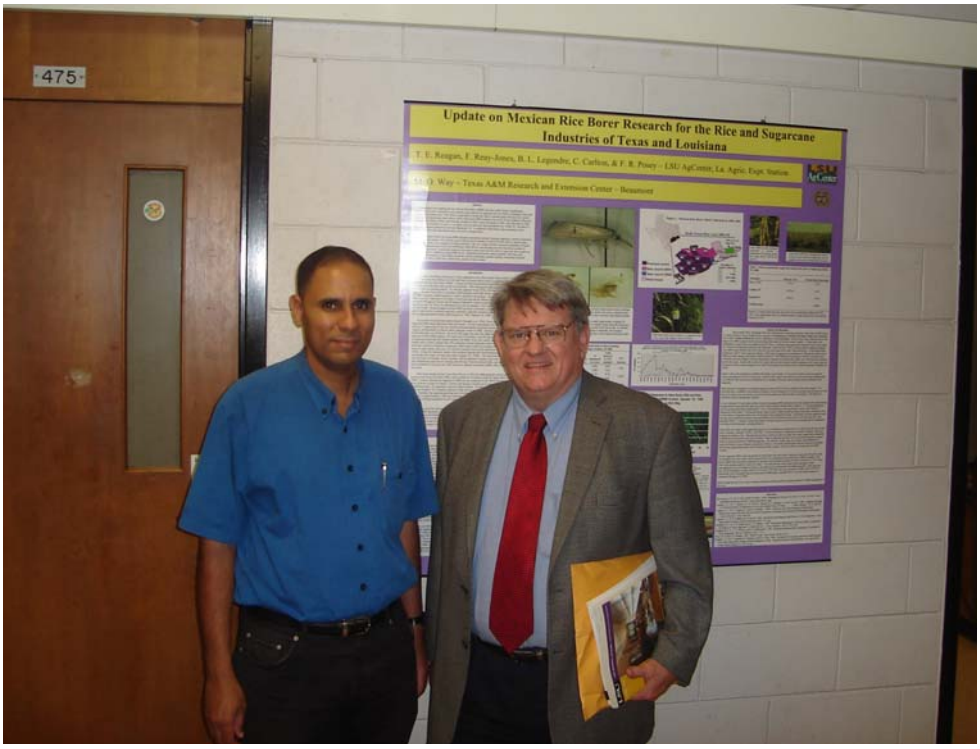


Figure 5 Professor Gene Reagan and I at Louisiana State University

Figure 6 **Checking a pheromone trap in rice fields at Beaumont Texas A&M University station**

Figure 7 **Helping to plant a variety trial in Louisiana**

5.1 Discussions with Louisiana Department of Agriculture and Forestry (LDAF)

I met several staff from LDAF during my visit to LSU. LDAF is equivalent to DPI&F in Queensland, as it operates on the state level. Mr Tad Hardy from LDAF attended my seminar and he also gave a seminar at LSU that I attended. LDAF runs several programs and oversees regulations dealing with all agricultural issues in Louisiana. I was able to collect the following material that summarizes their activities in Louisiana and work links with USDA.

5.1.1 Sugarcane quarantine in Louisiana - formal policy

Any person desiring to import sugarcane plants, plant parts or tissue into Louisiana must first make application to the Louisiana Department of Agriculture & Forestry to obtain a permit to import sugarcane. No sugarcane material may enter Louisiana without such a permit.

I. From foreign sources

All sugarcane plants, plant parts and tissue grown in, originating from or shipped from any source outside of the United States is prohibited entry into Louisiana unless said sugarcane has been held in federal quarantine facility for a period of no less than twelve (12) months immediately following its importance and found to be free from injurious insect pests and diseases of sugarcane. Upon arrival in Louisiana, sugarcane will be handled as described in section IV B and C.

II. Sugarcane from Hawaii, Puerto Rico and domestic world collections

All sugarcane plants, plant parts and tissue grown in, originating from or shipped from Hawaii, Puerto Rico or any domestic world collection are prohibited entry into Louisiana unless said sugarcane has been held in a federal quarantine facility for a period of no less twelve (12) months immediately following its importation and found to be free from injurious insect pests and disease of sugarcane. Upon arrival in Louisiana, sugarcane will be handled as described in section IV B and C.

III. Sugarcane from other domestic resources

All sugarcane plants, plant parts and tissue grown in, originating from or shipped from any other domestic source outside of Louisiana must meet the following conditions. Adherence to these conditions will be certified by state officials in the state of origin through inspection and or/Compliance Agreement between the shipper and state officials in the state of origin.

A. All plants and plant material, including that used as a source of tissue to be shipped, must be inspected visually for signs of injurious insects and symptoms of disease, including but not limited to leaf scald, mosaic, smut, dry top rot and sugarcane yellow leaf. Any material found to have signs of injurious insects or symptoms of leaf scald, mosaic, smut, dry top rot or any other systemic disease is prohibited.
B. All plants and plant material, or plant material used as a direct source of tissue to be shipped must undergo diagnostic procedures to confirm the presence or absence of leaf scald, mosaic, ratoon stunting disease (RSD) and other diseases

of economic concern. Diagnostic procedures used must be specific to the diseases of concern and must be conducted in a manner approved by the state entomologist. Any material positive for these diseases is prohibited.

C. All plants and plant material, including that used as a source of tissue to be shipped, must undergo diagnostic procedures to confirm the presence or absence of sugarcane yellow leaf virus. Diagnostic procedures used must be specific to sugarcane yellow leaf virus and must be conducted in a manner approved by the state entomologist. Any material testing positive for this disease must be handled and shipped in a manner described in section IV D below.

D. Direct shipments of tissue culture plantlets derived from genetic material originating outside of Louisiana are prohibited unless the plants from which meristem tissue used to produce the plantlets was shown to be free of leaf scald, mosaic, smut, sugarcane yellow leaf virus and RSD and has been maintained in a protected location prior to being used as a source of tissue culture. Plantlets must be maintained in a protected location prior to shipment.

IV. Treatments

All sugarcane plants, plant parts and tissue grown in, originating from or shipped from any other domestic source outside of Louisiana must, in addition to the conditions set forth in section III A-C above, meet the following conditions. Handling and treatment of sugarcane as specified below will be accomplished through establishment of a Compliance Agreement between the person(s) responsible for the sugarcane material and the Louisiana Department of Agriculture & Forestry.

A. Prior to shipment, all sugarcane stalk tissue will be cleaned of leaf tissue and inspected for signs of injurious insects, soaked in water for 40-48 hours, then will undergo a ‘long hot-water treatment” for three (3) hours at 50°C. Treated material will be handled in a sanitary manner, will not be exposed to untreated cane, and will be prepared for immediate shipment. Adherence to treatment requirements will be certified by state officials in the state of origin and/or through a compliance agreement between the shipper and state officials in the state of origin.

B. Upon arrival in Louisiana, stalk tissue will be planted and maintained in a greenhouse at the USDA/ARS/SRRC/Sugarcane Research Unit at Houma, Louisiana designated to hold only imported material and screened with 32 x 32 or finer mesh screening to protect from insect pests for a minimum of four (4) months with no overlapping shipments. Plants will be visually inspected on a regular basis for signs of disease or insects and must undergo diagnostic procedures to confirm the presence or absence of leaf scald, mosaic, sugarcane yellow leaf virus and RSD before release from the greenhouse. Any plants showing signs or symptoms of disease or insects or testing positive for leaf scald or RSD will be destroyed by appropriate methods to render pathogens and plant tissue non-viable.

C. Initial planting of clones from IV B above will be restricted to state and federal experimental farms.

D. Plant material that tested positive for sugarcane yellow leaf virus in III C above must be subjected to meristem propagation to eliminate the virus. Plantlets must be tested and found free from the virus prior to release from the laboratory. All meristematic tissues not used for propagation will be autoclaved before disposal.

V. Sugarcane originating in Louisiana

All sugarcane plants, plant parts and tissue grown in, originating from and shipped from any location in Louisiana into another state, with the exception of Hawaii and Porto Rico, and returning to Louisiana must meet the following conditions. Adherence to the following conditions will be certified by state officials in the state of origin through inspection and/or Compliance Agreement between the shipper and state officials in the state of origin.

A. The Louisiana shipper/provider is responsible for contacting the receiving state to confirm conditions to be met to ship Louisiana sugarcane material into that state.
B. All plants and plant material, including that used as a source of tissue to be shipped, must be held in a manner to prevent any exposure to sugarcane plants or tissue from any source or origin other that Louisiana.

At present, there is a 18,000 ha sugarcane plantation in Texas, and currently there are no regulations to stop transportation of sugarcane from Texas to Louisiana. Mr Tad Hardy from LDAF told me that currently a cane sample is checked for borer damage at the source in Texas prior to shipping it to Louisiana mills, and another sample is inspected at the destination. However, Tad acknowledged that some trucks may not have been inspected; Dr Gene Reagan has been exerting pressure to make sure all trucks carrying cane into Louisiana are inspected. In addition, recent pheromone trapping indicated the occurrence of MRB adult moths in a cane plantation in Jefferson County, about 30 miles from the borders with Louisiana. Dr Reagan lobbied to prevent shipping cane from that farm to Louisiana, and, against the grower's will, cane had to be ploughed out and destroyed on the farm.

5.1.2 Quarantine and surveillance programs at LDAF

In addition to the program surveying for Mexican rice borer, LDAF conducts specific quarantine programs that deal with exotic invasive species. After attending Tad Hardy's seminar, I compiled this list of LDAF programs based on printed material that he distributed.

Sweet potato program - Sweet potato weevil (SPW), *Cylas formicarius* (Coleoptera: Curculionidae), is one of the world's most damaging pests of field and stored sweet potatoes, and therefore constitutes a major quarantine significance. SPW was recorded for the first time in the United States in Louisiana in 1875, and it is now distributed throughout the South East, Hawaii and Puerto Rico. The SPW program at LDAF involves platform inspection (spot checks), seed-bed and field inspection and destruction, marketplace inspection, and pheromone trapping.

Gypsy moth trapping program - Gypsy moth, *Lymantria dispar* (Lepidoptera: Lymantriidae), is a major pest of forest trees. It was accidentally introduced into the United States in the late 1860s, and is currently distributed throughout the North East of the United States. LDAF program is mainly training oriented, where quarantine personnel are trained on deploying, maintaining and checking traps state-wide.

Phytophagous snail program - Any plant material originating from an area infested by any species of phytophagous snails, including the European brown garden snail, needs to be accompanied by a certificate of nursery inspection. LDAF program includes state/federal inspection of samples and overseeing treatment of isolated infestations.

Pine shoot beetle inspection program - Pine shoot beetle, *Tomicus piniperda* (Coleoptera: Curculionidae), is a recent arrival in the United States from Europe as it was first recorded in 1992 in Ohio. Currently it is widely distributed in northern states, and is considered a major pest of pines. LDAF program includes routine and compliance-specific inspections of Christmas trees, with data reported annually to the Animal and Plant Health Inspection Service (APHIS), the equivalent of the Australian Quarantine and Inspection Service (AQIS).

Burrowing nematode survey program and other nursery pests - The main species LDAF is concerned with is the burrowing nematode *Radopholus similis*. Materials containing soil, sand and plant parts produced below soil level are regulated. This program also inspects and surveys for lethal yellowing of palms and oak wilt.

Post-entry quarantine program - Site-specific inspections on imported plants for a 2-year period is conducted.

Citrus disease program - This program mainly inspects for citrus canker, *Xanthomonas campestris* pv *citri*, where regulated material includes all plants and plant parts of calamodin orange (*Citrus mitis*), pummelo (shaddock) (*Citrus maxima*), citrus citron (*Citrus medica*), satsuma (*Citrus reticulata*), grapefruit (*Citrus paradisi*), sour orange (*Citrus aurantium*), kumquat (*Fortunella japonica*), sweet orange (*Citrus sinensis*), lemon (*Citrus limon*), tangelo (*C. paradisi x. C. reticulata*), lime *(Citrus aurantifolia*), temple orange *(C. reticulata x. C. sinensis*), mandarin orange (tangerine) *(Citrus reticulata)*, trifoliata orange (*Poncirus trifoliata*), and any other article or means of conveyance that presents a risk of disease spread. Only regulated materials certified for interstate movement under Federal Citrus Canker regulations may be moved in from Florida. Limited permit fruit is prohibited. Another viral disease of citrus, tristeza, also necessitates inspections and movement regulation of citrus nursery stock and budwood.

Japanese beetle survey program - Japanese beetle, *Popillia japonica* (Coleoptera: Scarabaeidae) is originally from Japan and was detected for the first time in the USA in New Jersey in 1916. It is currently found east of a line running from Michigan, southern Wisconsin and Illinois south to Alabama. This species is a very damaging pest of ornamental trees, shrubs and turf grass. LDAF program include deploying, maintaining and checking traps state-wide and reporting results annually to APHIS.

Giant salvinia program - *Salvinia molesta* is a noxious aquatic weed that rapidly dominates slow-moving freshwaters. It competes with native species and creates problems for anglers. It is currently distributed throughout most of the southern states. LDAF activities include routine and compliance specific inspections and state and federal identification of samples

Karnal bunt survey program - Karnal bunt is a disease of wheat caused by the smut fungus *Tilletia indica*. It invaded the USA in the 1980s, and LDAF participated in a national survey on that species. Currently LDAF cooperates with the Grain Division within USDA in conducting annual samples and reporting results to APHIS.

Tropical soda apple survey program - Tropical soda apple (*Solanum viarum*) is a serious weed problem in perennial grass pastures. It has recently invaded the USA from South America, and currently occurs in several southern states. LDAF conducts annual state-wide surveys and sample identification.

Plum pox survey program - Plum pox is a viral disease of stone fruit that invaded USA in the 1990s. LDAF conducts sample collections and reports data to APHIS.

Phytosanitary certification program - LDAF conducts site and product inspections for material to be exported.

Solid wood packing materials program - LDAF conducts site inspections and provides federal certificates to industry.

Sudden oak death program - Sudden oak death is caused by the fungus *Phytophthora ramorum*, which was first detected in California in 1995, and is currently found along the west coast of USA. LDAF conducts an annual state-wide survey.

Cotton-related programs - LDAF is involved in occasional trap surveys in conjunction with the boll weevil eradication program. LDAF also conducts routine inspections of cotton equipment entering and leaving the state.

CAPS program (Cooperative Agricultural Pest Survey) - LDAF conducts specific surveys to inspect for khapra beetle, pink hibiscus mealybug, bakanae (fungal disease of rice) and other listed high-threat pests and diseases.

5.2 Seminar on Australian quarantine

On 26 August, I gave a seminar at LSU on the Australian approach in dealing with invasive borer species. I highlighted the effort taken by BSES and SRDC in developing Pest Incursion Management Plans for the moth borers, and presented Pest Categorization tables and Pest Threat Index figures. Professor Gene Reagan advertised the seminar widely, and representatives from Louisiana Department of Agriculture and Forestry (LDAF), American Sugarcane League (ASCL) and many other scientists attended the seminar. Very positive comments were voiced by attendees for the Australian quarantine approach. I was requested to list recommendations “from an Australian perspective” on what else LDAF/USDA/LSU could do to delay the arrival of MRB in Louisiana. I suggested that the following points should be considered:

- A contingency plan needs to be established between LSU, LDAF and ASCL that details the steps to be taken immediately an incursion is detected in Louisiana.
- Sugarcane should not be transported from Texas to Louisiana. A sugarcane mill currently being built in Lacassine, Louisiana, could be moved further west to the borders with Texas.
- A training/awareness campaign should take place on pest recognition, quarantine measurements and contingency planning. Growers and cane workers should attend the training and all be familiarized with the threat posed by the pest.

- A memorandum of understanding between LDAF and ASCL is to be signed, whereby a minimum percentage of tolerant varieties is to be planted on each farm in Louisiana (since 89% of the crop is of one variety that is highly susceptible).
- An Emergency Use Permit for controlled-release and systemic soil insecticides, such as Confidor® CR, should be issued. Chemicals can be allowed only in restricted areas bordering Louisiana.
- The stemborer parasitoids *Sturmiopsis parasitica* (Diptera: Tachinidae) from Africa, and *Cotesia* sp. (Hymenoptera: Braconidae) from Australia could be tested on MRB in a quarantine facility. Successful parasitoids could be granted permission for release in Texas and Louisiana.

Most organophosphates have been banned in American fields. In addition, American entomologists were not keen on recommending imidacloprid in cane fields because of conflicts with 'green' groups regarding problems with chemical run-off.

Figure 8 Laboratory rearing of *Diatraea saccharalis* larvae at LSU

5.3 Pheromone trapping

I participated in pheromone trapping of moth borers (Figure 6) during my visit at LSU. In recent years, LSU AgCenter has joined forces with Texas A&M University to monitor the dispersal of MRB through the Texas rice belt. The two organizations cooperate with the

Louisiana Department of Agriculture and Forestry (LDAF) and the Texas Department of Agriculture (TDA), both are State departments equivalent to DPI&F in Australia, and they both conduct pheromone trapping of MRB in their respective states. Figure 9 shows the dispersal of MRB during recent years through Texas and towards Louisiana.

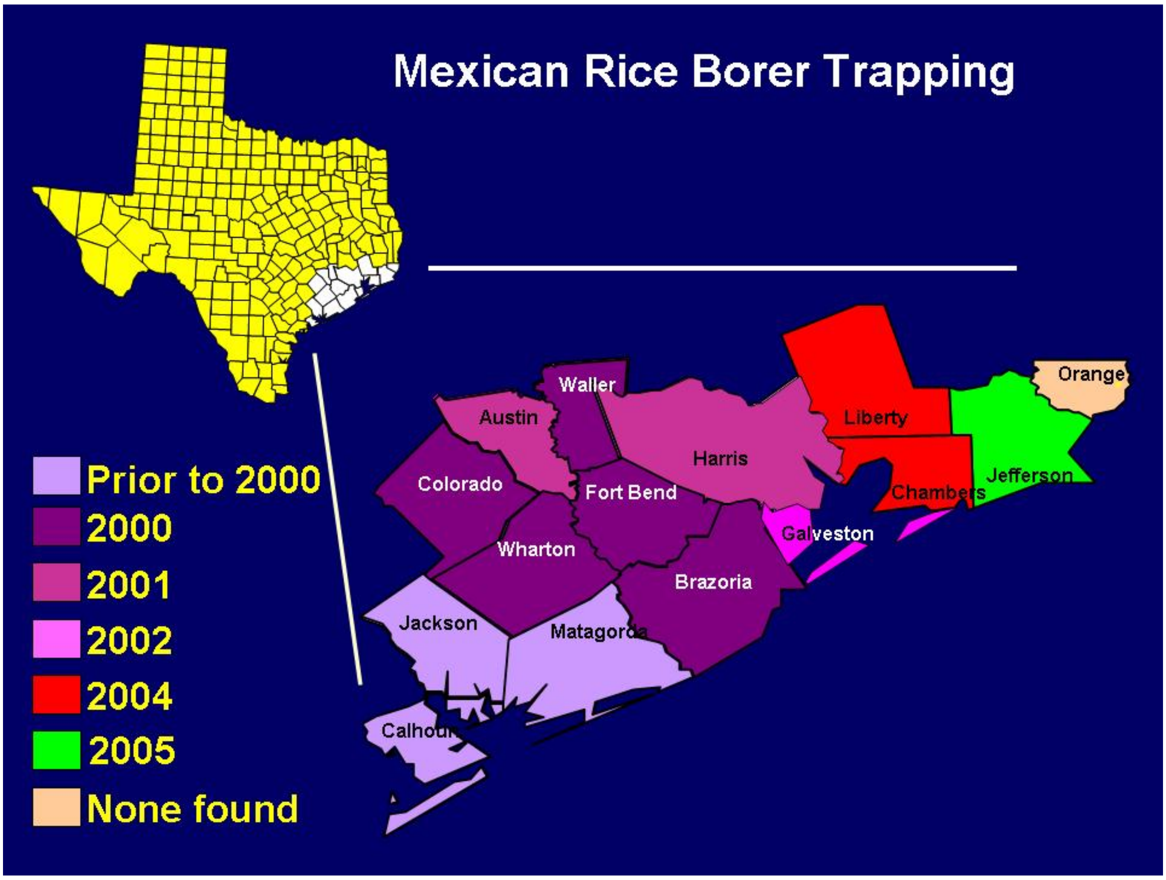


Figure 9 Dispersal of Mexican rice borer through Texas to 2005

Pheromone trapping is conducted in areas adjacent to sugarcane and rice plantations and near sugarcane mills. Bucket-type pheromone traps (Figure 6) are placed in each monitoring site across cane and rice growing areas of Texas and Louisiana. The traps are baited with a synthetic female *E. loftini* sex pheromone lure (Luresept, Hercon Environmental, Emigsville, PA), which is replaced every 3 weeks. An insecticidal strip (Vaportape II, Hercon Environmental, Emigsville, PA) is placed in the bucket to kill trapped insects and prevent them from damaging each other. Insecticidal strips are replaced every 6 weeks. The traps are attached to a metal pole 1 m above the soil surface and are usually separated by about 100 m from each other.

6.0 UNITED STATES DEPARTMENT OF AGRICULTURE (USDA), HOUMA

During my visit to LSU, I visited Dr Bill White, the sugarcane entomologist for the Agricultural Research Service (ARS/USDA), based at Houma. Dr White runs several plant-breeding and pest-management projects.

One of his project goals is to broaden the germplasm base of cane varieties in Louisiana through the introduction of genes from wild relatives of cane, as well as improve the current cultivars through the conventional breeding programs. Dr White is developing two recurrent populations designed specifically to accumulate genes for increased stalk-borer tolerance, while at the same time maintaining good sugar content. He is also developing molecular markers to assist breeders eliminate undesirable plants early in the selection process.

Dr White is also working to develop an overall crop management program that relies on reduced burning at harvesting, reduced chemical control, enhanced biological control and host-plant resistance. If needs be, highly restricted use of selective and efficient pesticides can be conducted. He has cooperated with Dr Reagan to establish the moth-borer parasitoid *Cotesia flavipes* in Louisiana, but these efforts failed. More work is still being done to overcome the limitations of this failure.

While at ARS/USDA Houma, I collected laboratory-reared *Diatraea saccharalis*, *Diatraea evanescens* and *Eoreuma loftini* larvae. These specimens will be sent to BSES Indooroopilly to add to our DNA database. I also collected samples of the Texas population of *Cotesia flavipes*, and these were given to Ms Kate Muirhead, a PhD student at the University of Adelaide working on the genetic variability of this parasitoid.

7.0 INSTITUTE OF FOOD AND AGRICULTURAL SCIENCES/UNIVERSITY OF FLORIDA (IFAS/UFL)

I visited the Institute of Food and Agricultural Sciences/University of Florida (IFAS/UFL) during 22-27 September. I first visited Dr Gregg Nuessly, the entomologist based at Belle Glade station (UFL), to exchange knowledge on sugarcane pests and their management in Queensland and Florida. I later visited IFAS/UFL station at Fort Pierce, where a group of scientists are working to combat exotic plant and animal pest species that have invaded Florida.

7.1 Sugarcane in Florida

Commercial sugarcane growing commenced in southern Florida during the 1920s, and cane currently occupies an area of approximately 450,000 acres around the southern edge of Lake Okeechobee, producing about 1.8 million tonnes of raw sugar annually. Cane is planted during September-January and harvested during October-March. Due to the warm and humid climate of Florida, sugarcane does not usually suffer freezing during winter months and productivity is slightly higher than in Louisiana, with an average CCS of up to 12 units compared to 11 in Louisiana.

Based on a discussion with Dr Nuessly, key sugarcane pests in Florida are:

Sugarcane borer, *Diatraea saccharalis* (Lepidoptera: Crambidae) - As is the case in Louisiana and Texas, the sugarcane borer is a key pest of sugarcane in Florida. However, the importance of this pest has declined during the last decade. Reasons for this decline are not fully understood, but the use of the parasitoid *Cotesia flavipes* and the development of tolerant varieties may have contributed to this decline. Currently, regular pest monitoring forms the basis of the IPM program for the borer. Fields are scouted every 2 or 3 weeks from March through November. Usually, no chemical control is recommended if 50% or more borers are parasitized.

White grub, *Ligyrus subtropicus* (Coleoptera: Scarabaeidae) - A range of whitegrub species belonging to the genera *Ligyrus*, *Cyclocephala*, *Phyllophaga* and *Anomala* attack sugarcane crops in Florida. However, *Ligyrus subtropicus* is the most damaging. Whitegrubs generally feed on the roots, causing yellowing of the leaves followed by stunted growth and then stool tipping. *Ligyrus subtropicus* infestation usually starts around the edges and slowly spreads throughout the field. No insecticides are registered for canegrub control in USA, therefore growers try other management methods such as disking infested fields, reducing the number of ratoon crops and flooding the soil with about 50 mm of water during August.

Lesser cornstalk borer, *Elasmopalpus lignosellus* (Lepidoptera: Pyralidae) - This species is a pest of sugarcane in Florida especially in sandy soils. *E. lignosellus* is also an important pest of beans, corn, peanuts, and peppers. Larvae tunnel inside the plant and feed below soil level, so insecticidal control is difficult to achieve.

Wireworms - There are at least 12 species of wireworms in southern Florida, but only *Melanotus communis* (Coleoptera: Elateridae) damages sugarcane. Wireworms are mainly a pest of plant cane, although they may also affect ratoons. *M. communis* larvae feed on buds and root primordia, as well as the shoots and roots after germination. Damage by wireworms results in poor cane patches in the field. Growers in Florida use flooding for about 6-8 weeks, depending on infestation levels, for wireworm control. In some cases, growers may grow a rice crop to reduce infestation.

Yellow sugarcane aphid, *Sipha flava* (Hemiptera: Aphididae) - Infestation by the yellow sugarcane aphid (YSA) results in yellowing/reddening and ultimately death of the leaves, while heavy infestation reduces crop yield and sugar content. The use of tolerant cane varieties offers a good management strategy, in addition to a large number of natural enemies that help maintain YSA population in check. Chemical control is also available and is recommended in situations of high infestation.

Sugarcane leafhopper, *Perkinsiella saccharicida* (Hemiptera: Delphacidae) - This pest originated in New Guinea, and was first recorded in Florida in the early 1980s. Feeding by nymphs and adults causes desiccation of leaves and growth of mould on the honey dew produced by the insect.

Table 1 shows the insecticides available for use in Florida sugarcane.

Table 1 Insecticides available for use in Florida sugarcane

Active ingredient	Re-entry interval (hours)	Pre-harvest interval (days)	Trade name and formulation	Rate per acre
Sugarcane borer				
*Carbofuran	48	17	Furadan 4F	1.5 pint
*Cyfluthrin	12	15	Baythroid 2 (2EC)	2.1 oz
*Esfenvalerate	12	21	Asana XL (0.66EC)	5.8-9.6 oz
Tebufenozide	4	14	Confirm 2F	6.0-8.0 oz
Lesser cornstalk borer				
*Carbofuran	48	17	Furadan 4F	1-1.5 pint
Wireworms				
*Ethoprop	48	At planting	Mocap 10G	20-40 lb
*Ethoprop	48	At planting	Mocap 20G	19.5 lb
*Phorate	48	At planting	Phorate 20G Thimet 20G	19.5 lb 19.5 lb
Aphids				
*Carbofuran	48	17	Furadan 4F	1-1.5 pint

* Denotes a restricted-use compound
Reproduced with kind permission from IFAS/University of Florida

7.2 Invasive species in Florida

The state of Florida is not new to exotic introductions. In fact, most food and industrial crops grown in Florida are introduced species. It is also estimated that 31% of uncultivated plants in Florida are exotic, amounting to more than 1300 well-established exotic plant species. However, only 10% of these are considered invasive weeds. In Florida, as is the case in Australia, wetlands such as swamps, lagoons and marshes are important ecosystems that harbour several species of birds, fish and aquatic plants. Exotic plant species in Florida wetlands spread rapidly and compete with native flora and fauna. It is also estimated that more than 270 exotic insect species have invaded Florida during the last 20 years.

At the Fort Pierce IFAS station/UFL, a team of entomologists and botanists are working on combating invasive animal and plant pest species that have invaded Florida. During my visit to that station, I met Dr Ronald Cave who studies invasive arthropods, particularly the cycad aulacaspis scale (CAS) and the Mexican bromeliad weevil. I also met Dr William Overholt and his student Mr Rodrigo Diaz, who study the biological control of invasive weed species, particularly hymenachne and Brazilian peppertree in Florida.

The approach used by IFAS/UFL in combating invasive pest species relies largely on classical biological control, where key natural enemies of the introduced pest are collected from its original home and introduced into the area it invaded. The followings are notes on major invasive insect and weed species in Florida, along with a brief reference on their classical biological control strategy.

Cycad aulacaspis scale (CAS), *Aulacaspis yasumatsui* (Hemiptera: Diaspididae) - This species is native to Asia where it attacks cycads. CAS was first recorded in Miami, Florida in the mid 1990s on ornamentals cycads, and is currently spreading rapidly further north within Florida. The pest is impacting on cycad production, which is an important income source in Florida, and is also threatening the survival of several rare cycad species. Currently a classical biological control program uses an imported parasitoid, *Coccobius fulvus* (Hymenoptera: Aphelinidae), and an imported predator, *Cybocephalus nipponicus* (Coleoptera: Nitidulidae), both from Thailand, against CAS. The imported parasitoid achieves levels of parasitism of 30-40%. Dr Cave is still searching for natural enemies in Asia, and is currently looking at the performance of *Arrhenophagus chionaspidis* (Hymenoptera: Encyrtidae) from China.

Mexican bromeliad weevil, *Metamasius callizona* (Coleoptera: Curculionidae) - *M. callizona* is a serious pest of bromeliads and was first recorded in Florida in 1989. The pest probably arrived in Florida with a bromeliad shipment from Mexico. Since then, *M. callizona* has spread into several counties within Florida. A parasitic fly, *Lixophaga* sp. (Diptera: Tachinidae), was imported from Honduras where it attacks closely related weevil species. Host range tests show that the fly does not attack any species other than *Metamasius* weevils, and Dr Cave is in the process of applying for a permit to release the parasitoid in Florida.

Brazilian peppertree, *Schinus terebinthifolius* (Anacardiaceae) - Brazilian peppertree is a native of South America that was introduced into Florida in the mid 1800s as an ornamental plant. *S. terebinthifolius* proved to be a highly destructive species, as it has replaced vast areas of mangrove communities in southern Florida. Certain herbicides are available for the control of this tree (i.e. glyphosate), but their use is very restricted. Dr Overholt is looking at a specific herbivorous thrips from Brazil (*Pseudophilothrips ichini*) and another wasp native to northern Argentina (*Heteroperreyia hubrichi*) that feed on *S. terebinthifolius*. Releases will not be made in Florida until host range studies have been completed. Dr Overholt also used microsatellite DNA to trace the origin of the Florida population, and, because there are distinct populations in eastern and western Florida, concluded that there were two separate introductions.

Hymenachne (West Indian marsh grass), *Hymenachne amplexicaulis* (Poaceae) - Hymenachne is native to South America and the West Indies and has spread to most countries of the Neotropics. It was first recorded in 1957 in Palm Beach county, Florida. It may have been intentionally introduced as a forage crop, a similar situation to Australia where the Department of Primary Industries (QDPI) introduced it as a fodder grass. Hymenachne invades ponds, river banks and flood areas, it blocks waterways and causes significant water loss. Mr Diaz is looking at the performance of an exotic herbivorous bug, *Ischnodemus variegatus* (Hemiptera: Blissidae), for the control of hymenachne in Florida (Figure 10).

Figure 10 Inside the IFAS/University of Florida quarantine facility with Rodrigo Diaz, PhD student working on biological control of hymenachne. These are his experimental cages where he is testing *Ischnodemus varigatus* on stems of hymenachne

7.3 Quarantine facilities at IFAS/UFL

Work on invasive species at IFAS/UFL is conducted in two quarantine facilities, one in Fort Pierce and the other in Fort Lauderdale, Florida. These containment facilities are carefully constructed to minimize the possibility of escape of natural enemies whilst they are being studied. The important features of the two facilities are:

- Entrance to a containment facility is through a series of two vestibules with well-sealed interlocking doors, such that no two doors can be open at the same time.
- Containment areas are constantly under negative air pressure. This means that when any doors are opened, the flow of air will be into the containment area rather than towards the outside.
- All waste water leaving the facility is sterilized with heat to kill any organisms that may enter a drain.
- All solid waste from the facility is sterilized in an autoclave at high pressure and temperature before removal.
- Either there are no windows, or if windows do exist, they are permanently sealed and are high strength (double-paned or Lexan).
- Air leaving the facility passes through very fine high efficiency particulate air (HEPA) filters.
- There are no perforations in the walls. All electrical conduits, lights, outlets and switches are mounted on the wall, rather than in the wall as is typical in normal construction. All perforations in the ceilings and floors, as well as all joints between walls, ceilings and floors, are sealed with silicone.

- The operation of each containment facility is monitored by a quarantine officer or containment director who is responsible for the physical integrity of the construction and for making certain that scientists and staff working in the facility follow operating procedures.
- Shipments received directly from overseas are opened in a maximum security room by the quarantine officer and the scientist leading the project. Plant material, undesirable insects and packing material are immediately destroyed in an autoclave. Import permits are checked and a record of what and how many natural enemies were received is filed.
- Access to containment areas is limited to only those scientists and technicians who work in the facility, and have been trained on containment operating procedures.
- The two new facilities in Fort Pierce and Fort Lauderdale are both constructed to withstand category III hurricanes. If a category III hurricane is predicted, all quarantined organisms will be moved from greenhouses to the central sections of the buildings. A stronger hurricane would require that all quarantined organisms are destroyed or moved to another approved facility (time permitting).

8.0 INTERNATIONAL CENTRE OF INSECT PHYSIOLOGY AND ECOLOGY, KENYA

After my visit to Louisiana and Florida, I flew to Kenya, Nairobi to attend the International Conference on Lepidopterous Cereal Stem and Cob Borers in Africa (ICLCBA). This took place at the International Centre of Insect Physiology and Ecology (ICIPE) from 24-28 October 2005.

ICIPE is a world-recognized entomological institution that studies a wide range of entomological issues. ICIPE consists of four major divisions, Human Health, Animal Health, Plant Health and Environmental Health. ICIPE conducts scientific research in the areas of insect behavioural and chemical ecology, molecular biology, biotechnology and insect population ecology.

8.1 Conference program

One of the major study areas within the Plant Health department is gramineous moth borers. Currently at ICIPE, the International Foundation for Science (IFS) and the Institute of Research and Development (IRD) have combined efforts and are collaborating with the existing Wageningen Agricultural University program (WAU). The main aim of the joint project is to review the taxonomic status of all sub-Saharan gramineous borer species. Both IRD and IFS organized and sponsored the ICLCBA conference at ICIPE. The conference agenda and abstracts are in Appendix 2. The main issues discussed at the conference were:

1. Moth borer taxonomy;
2. Moth borer field and behavioural ecology;
3. Moth borer sex pheromones;
4. Moth borers natural enemies;
5. Parasitoid taxonomy;

6. Parasitoid ecology and dynamics;
7. Introduction and exchange of borer natural enemies;
8. Habitat management in small-scale farming environments.

Major conference learnings were the notable spread and impact of the moth-borer parasitoid, *Cotesia flavipes* (Hymenoptera: Braconidae), in sub-Saharan Africa after its introduction from Pakistan in 1993. Other borer parasitoids are being tested in quarantine facilities in Africa and some are already being released in selected sites. Another introduced borer parasitoid, *Xanthopimpla stemmator* (Hymenoptera: Ichneumonidae) (Figures 11 & 12), is showing good results of spreading and colonizing new habitats.

Figure 11 Laboratory rearing of borer parasites at ICIPE

Figure 12 Rearing *Xanthopimpla* at ICIPE

Ms Kate Muirhead, a University of Adelaide PhD student who I am supervising, also attended the conference with SRDC funding. Kate presented her results on populations of *Cotesia flavipes* based on samples that we had collected from several parts of the world. Based on DNA studies, the Australian *Cotesia* population is very likely to be a separate species; it was important to determine this in advance of any application for the importation of *C. flavipes*.

Other work presented at the conference focused on revision of the taxonomy of all borer species in sub-Saharan Africa. A clearer picture, based on DNA techniques, is emerging on the different population structure of borers in several African countries.

Finally, a number of studies focused on habitat management, where trap cropping and mixed vegetation strategies were discussed. Regionally based recommendations are made according to the specific complex of borer species, climatic conditions and endemic wild grasses.

8.2 Paper presentation at ICLCBA

I presented a paper at the conference: A review of sugarcane stemborers and their natural enemies in Asia and Indian Ocean islands: An Australian perspective. The paper (Appendix 3) lists all native and introduced natural enemies used for biological control programs of moth borers in Asia and Indian Ocean Islands, with implications for Australia, and was an output from BSS249 Preparedness for borer incursion. .

8.3 Round-table discussions at ICLCBA

I was requested by the ICLCBA organizers to coordinate the conference round-table discussions and to facilitate the final 'system-wide initiative' session. During the conference, I arranged for two simultaneous round-table discussions; the first on moth borer ecology and their habitats, and the other on borer natural enemies, their use and exchange within African countries. At the end of the two sessions, I requested scientists in the two groups to convene for an 'all encompassing' session, in which issues for the final system-wide initiative were determined. On the last day of the conference, I coordinated a discussion on future work in light of the conference findings. The points that I compiled during that session are:

- An inter-African training course in borer/host-plant/parasitoids faunistics and systematics is to be conducted, along with the creation of a coordinated research network with standardized sampling protocols (in both farmer fields and wild habitat).
  - <u>Training subjects</u>: systematics, morphology, molecular markers;
  - Sampling methodology to be placed on ICIPE web page;
  - <u>Where</u>: ICIPE; South Africa (University of the North West – ARC Biosystematics) – IITA. Trainer could travel between stations;
  - <u>Who are the trainers</u>: Insect and plant taxonomists from South Africa; local scientists; IRD;
  - <u>Funding</u>: French government / IFS;
  - <u>Who to be trained</u>: graduate students working on cereals; personnel involved in collecting and sampling;
  - <u>When</u>: According to season – 2007.

- Construction of a website to contain biological and ecological data from all regions and to include DNA data in the future (A 'live/dynamic' database where people access and put in information through the use of a password). This could be a part of the already existing Stemborer Information System. ICIPE; IRD and University of North West (South Africa) to play a central role in constructing trophic network database with back up samples in both organizations.
  - <u>Who</u>: A team work: Isaac Njaci; Eric Muchugu from ICIPE, to develop the structure of the database, with help from an ecologist (Dr Bruno Le Rü);
  - Validating the system;
  - Interactive system to be further developed and decided on (PHP for example);

- Information to be collected from people in their respective countries. A representative in each country to coordinate adding information.

- Improve knowledge on borer habitat, gain in yield versus parasitism rates, and effect of other factors (mainly soil types and fertilizers).
  - Long-term data needed;
  - Exclude natural enemies from the system then assess damage (with and without natural enemies);
  - Work on soils, fertilizers, etc, to continue as a part of exclusion trials;
  - Variations with habitat management results to be tested.

- Training required on standard field methodologies and experimental design.
  - This should be a part of all surveys.

- Management of Bt maize in light of new information.
  - <u>Who</u>: Joint project between ICIPE and CYMMIT.

- Development of a predictive population dynamics model.
  - <u>Who</u>: Dr Nanqing to coordinate with Dr Stephane Dupas, IRD;
  - Coordinate with agricultural companies and industries;
  - <u>When</u>: 2006.

- Develop markers for borers and parasitoid identification in as many regions as possible.
  - <u>Who does it</u>: ICIPE; IRD and SASRI to coordinate with representatives in their respective countries;
  - Possible link to the Consortium for the Barcode of Life program (CBOL) - (Dr Jean-Francois Silvain, IRD).

- Facilitating the exchange of sample materials.
  - Mailing to be paid for by the receiver if possible;
  - Record GPS on the label when sampling;
  - Sample host plants as well, and preserve roots and flowers properly with a reference number (code);
  - Samples to be sent in as little ethanol as possible;
  - Samples can be sent with travelling scientists/students;
  - This file will be e-mailed to everybody, feedback expected.

- Test the Australian *Cotesia* population on African borers:
  - <u>Who</u>: Kate Muirhead, University of Adelaide.
  - <u>When</u>: 2006 –2007.
  - <u>Where</u>: Quarantine facility in Pretoria can be used for this work.
  - <u>Funding</u>: Australian Research Council – partly.

8.4 Specimen collection

During the first week in Nairobi, I collected laboratory-reared larvae of the four borer pest species from sub-Saharan Africa: the crambid *Chilo partellus* (Figure 13), the pyralid *Eldana saccharina,* and the noctuids *Sesamia calamistis* and *Busseola fusca*. In the field, I collected larvae of *Sesamia calamistis* and *Chilo partellus* from two areas of eastern Kenya, Muhaka and Msangatamu.

Figure 13 Rearing *Chilo partellus* at ICIPE

In addition, I had asked conference attendees, prior to the conference, to bring specimens of moth borer parasitoids with them from their respective countries. Ms Muirhead and I received specimens of the borer parasitoids *Cotesia flavipes* and *Cotesia sesamiae* (Hymenoptera: Braconidae) from several African and Asian countries (Figure 14).

Figure 14 Ms Muirhead and I in the *Cotesia* breeding room at ICIPE

Stemborer specimens will be sent to BSES Indooroopilly to add to the DNA database developed under BSS249, whilst Kate will use the parasitoid specimens for her PhD work.

9.0 OVERALL LEARNINGS AND RECOMMENDATIONS

Overall, I learnt a good deal on canegrowing systems in Louisiana, as well as quarantine measures in the USA. I am now up-to-date on world-wide stemborer research. This knowledge is essential to enhance our preparation for a potential incursion of a sugarcane stemborer.

I believe that Australia leads the world in sugarcane quarantine and incursion preparedness. This trip made me realize the importance Australia places on quarantine compared to other countries, and it is certainly encouraging to see that Australia has first-class quarantine regulations and capacity. In addition, several scientists in America and Kenya commended BSES as a leading organization in sugarcane research and extension, and were impressed with our preparedness for pest and disease incursions that we have developed with funding from SRDC, ACIAR, QDPI&F and BSES.

In sugarcane production, I could see that the Australian growers are fairly efficient, although there is certainly room for improvement. Generally, Australia runs an efficient sugarcane industry, especially when our cost of production is as low as 7 cents/pound, while it can be as high as 14 cents/pound in the USA. One fact that helps the American sugar industry remain competitive, apart from price subsidies, is farm size. A system that encourages larger corporations with vast sugarcane areas all running centrally reduces production costs.

Another observation was the controlled-traffic system followed in Louisiana, where cane is planted on preformed bed at 1.8 m (centre to centre). Adoption of controlled traffic in Australia is inevitable, but several challenges lie ahead of us to refine the system and deliver regionally based solutions. In conclusion, I feel that the ‘New Farming System’ initiative is a vital step towards a more efficient and competitive industry. There is high potential for system improvement, but more work is required to overcome several problems with the proposed system especially in Far North Queensland, and developing better ways of reaching out to growers should be explored.

10.0 COMMUNICATION OF LEARNINGS

The learnings from this project have been communicated to BSES staff and some keen canegrowers in the north through a seminar that I gave on 7 November 2005 at BSES Meringa. I gave a PowerPoint presentation (Appendix 5) on cane production in Louisiana, as well as borer management in both the USA and in Africa.

This report, upon acceptance by SRDC, will be distributed to AQIS, QDPI&F/Northwatch program and Plant Health Australia (PHA). In addition, I will give an overview of this project at the Joint Operation Group (DPI&F, AQIS, BSES) quarantine meeting that is scheduled for 2 February 2006 at DPI&F Cairns.

Knowledge gained will be communicated to cane growers through COMPASS and *GrubPlan* workshops. GrubPlan workshops are scheduled for June-July 2006, after grub-monitoring results are available.

An article has been prepared for the *BSES Bulletin* (Appendix 4), and is scheduled for publication in early 2006.

11.0 PROSPECTS FOR FUTURE WORK

Biosecurity is one of the six key areas identified in the BSES Strategic Plan that need to be addressed if we are to have a competitive and sustainable Australian sugar industry. We must continue our world-class effort. The initiative should involve further training of industry personnel, NAQS operational staff and island communities on the importance of sugarcane quarantine and pest and disease detection.

One area that requires more experience on the ground is weed management, and a BSES/SRDC Biosecurity initiative should develop contingency plans against major exotic weed species. It could also be involved in managing established exotic weeds such as hymenachne, similar to the work conducted at the University of Florida.

In addition, more cooperation is required with the South African Sugarcane Research Institute (SASRI) in the area of borer management. Good opportunities for consultancies and scientific cooperation were created with LSU, ICIPE and SASRI. During the ICLCBA conference, I discussed the possibilities of reviving a cooperation plan that BSES has developed with SASRI with Dr Des Conlong. He was happy to test Australian pathogens on South African whitegrub species, and for us to test pathogens and parasitic nematodes from South Africa on Australian whitegrub species. He indicated that this work could easily be conducted in a quarantine facility in Pretoria. Dr Conlong was also keen on testing the Australian population of *Cotesia* sp. on South African borer species. Exchange of this material is being arranged.

Overall, this visit has greatly expanded my knowledge of sugarcane biosecurity, and quarantine in general. I regard the knowledge I gained during this trip as an asset to myself as well as to the Australian sugar industry.

12.0 ACKNOWLEDGMENTS

I thank SRDC and BSES for providing me with the opportunity to visit Louisiana and Nairobi and for their commitment to enhancing sugarcane biosecurity. Thanks are also due to BSES Indooroopilly, especially Dr Peter Allsopp and Dr Ross Gilmour, for their support during that trip.

I thank Professor Gene Reagan at LSU for extending the invitation to visit his department, and giving me time and access to conduct further travel and learning within USA. Francis Reay-Jones and Waseem Akbar, PhD students at LSU, were also very helpful during my visit. Dr Bill Overholt and Dr Gregg Nuessly are also thanked for their time and hospitality.

Finally, many thanks are due to BSES Meringa staff who maintained interest in my news and kept in continuous contact with me while I was overseas; they were also keen to attend my seminar and learn about my travel experience in the USA and Kenya.

APPENDIX 1 – Pest Incursion Management Plan Dossier for Mexican rice borer

Eoreuma loftini (Dyar) (Lepidoptera: Crambidae)

Chilo loftini Dyar 1917.
Acigona loftini Bleszynski 1967, 1969.
Eoreuma loftini Klots 1970.

Types
Glenndale, Arizona, bred from Mexican cane, in US National Museum.

Common Name
Mexican rice borer (MRB).

Distribution
Mexico, Texas (USA).

Host Plants
Sugarcane, rice.

Symptoms
Eggs can be detected on the underside of the leaves, mainly dry ones. Adult emergence holes can also be seen on infested stalks. Infested plants suffer poor growth and their leaves turn yellow. Heavily infested plants ultimately die, and evidence of larval feeding can be seen on the stalks.

Evidence of larval feeding by Mexican rice borer (Dr Francis Reay-Jones, LSU)

Economic Impact

Legaspi *et al.* (1999) estimated the collective damage done by both *Eoreuma loftini* and *Diatraea saccharalis* in the lower Rio Grande Valley of Texas to approximately equal 20% of sugarcane internodes annually. Based on a raw sugar value of US$420/t, 20% bored internodes results in a loss of US$1,181.04/ha. Most of this damage is attributed to *E. loftini*, since it then comprised more than 95% of the sugarcane stalkborer population in Texas (Legaspi *et al.* 1999).

Sugarcane infested with Mexican rice borer

Morphology

Misidentification of this species as *Eoreuma morbidella* was reported by Agnew *et al.* (1988). The two species can be separated using the male genitalia.

Eggs

Eggs are globular and cream in colour. The eggs are laid in masses of 5-100, usually between layers of dry leaf tissue near the plant base (Legaspi *et al.* 1997).

Egg mass (Legaspi *et al.* 1997)

Larvae

Larvae are also cream in colour with four parallel purple- red lines along the body. The head capsule is orange-brown.

Larva (Legaspi *et al.* 1997)

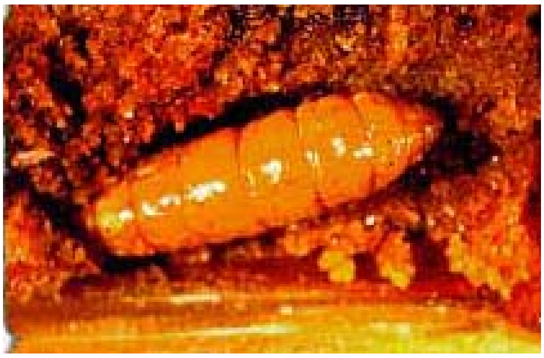
Larvae undergo 5-6 molts and they measure about 2-2.5 cm in length when fully grown.

Early larval instars feed on and inside the leaf sheaths, producing a red or purple hole. Larvae tunnel into the stem both vertically and horizontally in a girdling fashion, which may lead to stalk breakage. Tunnels are packed with frass and are, therefore, well protected from chemical and biological control agents. Mature larva construct a pupation cell near the stalk surface and protect it by one or two layers of transparent leaf tissue (Legaspi *et al.* 1997).

Split stem of sugarcane showing larval tunnel packed with frass (with permission from LSU)

Pupae

Pupae are about 2 cm long and are orange-brown with small tubercles (projections) at the posterior of the abdomen (Legaspi *et al.* 1997).



Pupa (Legaspi *et al.* 1997)

Adult moths

The moth is about 1.25-2.0 cm long and creamy white. The adult is distinguished from other stalkborers by a dark spot in the centre of each forewing and the absence of other wing markings (Legaspi *et al.* 1997).

Adult (Legaspi *et al.* 1997)

The following is the description by Dyar (1917): apex of fore wing acute, whitish straw-color, the veins light, edged on each side by a line of fine brown scales, which diffuse in the interspaces; a small black discal dot; a row of terminal black dots in the interspaces, connected by a slender line; fringe interlined with brown. Hind wing white with a slender brown line on apical half. Expanse 23 mm. The male is much smaller, expanse, 15 mm. The species is allied to *C. multipunctellus* Kearfott, but is not as white and is more distinctly and clearly marked. It looks very much like *Platytes densellus* Zeller, but the front is strongly tuberculate, which is not the case in that species.

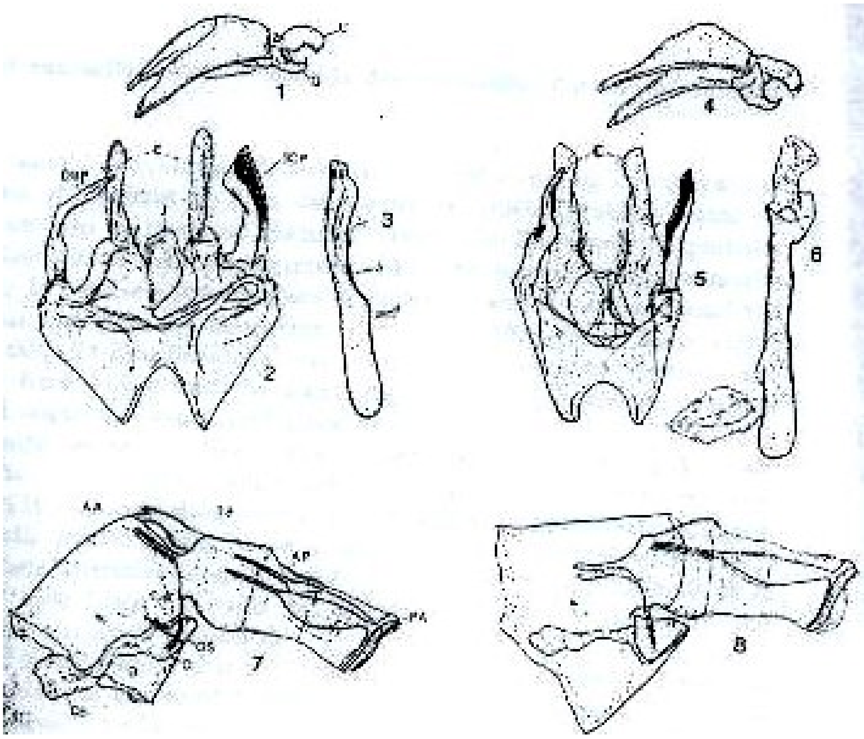
Agnew et al 1988 gives the following description to male and female genitaliae for *E. loftini* and *E. morbidella*.

Male genitalia

In male *E. lofini* (Figure 2 below), the sinistral costal process in truncate, broadened distally, and partially spiculate. The dextral process is slightly constrictes medially and bent inward at that point. The apex is bluntly pointed. The male of *E. morbidella* differs primarily in the shape of the sinistral costal process (SCP), which is tapered, not truncate, while the dextral prcess (DCP) is more narrowed and slightly sigmoid in shape. The aedeagus (A) of *E. morbidella* (5) broadens distally (6), unlike that of *E. loftini* (3).

Female genitalia

The females of *E. loftini* and *E. morbidella* can be separated, but with more difficulty. The most useful character is ostiolar sclerite (OS). This structure in *E. loftini* has finger like extensions produced laterally (7) while in *E. morbidella* it is shield-shaped (8). In addition, the ductus bursa (D) usually appears more constricted in *E. morbidella* than in *E. loftini.*



(1-3) *Eoreuma loftini* (Dyar) male. (1) Uncus (U) and gnathos (G). (2) Valvae includeing cuculli (C), dextral costal process (DCP), sinistral costal process (SCP), juxta (J), and vinculum (V). (3) Aedeagus. (4-6) *Eoreuma morbidella* (Dyar) male. (4) Uncus and gnathos. (5) Valvae. (6) Aedeagus. (7) *E. loftini* female, papillae anales (PA), apophysis posteriors (AP), eighth tergite (T8), apophysis anterioris (AA), ostium (antrum) (O), ostiolar sclerites (OS), ductus bursae, and corpus bursae (CB). (8) *E. morbidella* female. The ductus bursa (D) usually appears more constricted in *E. morbidella* than in *E. loftini*.

Detection Methods

Light trapping can be used to detect adults. Checking leaves for egg masses, especially dry leaves, gives a good indication of presence. Stalk splitting to look for larvae and pupae in tunnels is a good method of detection. Pheromone traps (see later) are also useful indicators of moth activity.

Biology and Ecology
Laboratory studies showed mean developmental times in the laboratory at 27°C to be: eggs incubation period, 6-7 days; larval duration, 28.5 days; pupal duration, 6 days; adult life span, 7 days; total about 48.5 days.

Mean total fecundity increases from about 260 eggs per female at 20°C to a maximum of more than 400 eggs per female at 26°C, and then declines to about 350 at 29°C and 32°C. The maximum daily oviposition rate of about 188 per female occurs at 29°C.

Four to six generations per year are common in the field. Larvae undergo diapause during autumn and winter months, and are able to tolerate freezing (Legaspi *et al.* 1997).

In the field, Spurgeon *et al.* (1999) found that larval age distributions were fairly stable throughout the sampling periods, with young larvae comprising a high portion of the total population.

Most larvae and tunnels are located in the lower internodes regardless of the plant stage. Ring *et al.* (1991) found that internodes were most prone to attack during the first 70 days after initial formation.

Reay-Jones *et al.* (2003) state that high levels of sodium and magnesium salt stress (15-30-cm soil depth) are usually associated with higher MRB damage in most cultivars.

Natural Enemies
Due to the cryptic nature of MRB, biological control has not proven very effective. A few parasitoid species have been recorded on MRB in Texas and Mexico, but the overall impact is not clear.

***Alabagrus stigma* (Brulle) = *Agathis stigmatera* (Cresson) Hymenoptera: Braconidae):** This species is a larval endoparasitoid that was introduced from Peru into the United States (Meagher *et al.* 1998).
***Allorhogas pyralophagus* (Hymenoptera: Braconidae):** This species is a gregarious larval ectoparasitoid that was introduced from Mexico into USA, where it is established and is responsible for variable levels of parasitism (Meagher 1998; Harbison *et al.* 2001).
***Lydella jalisco* Woodley (Diptera: Tachinidae):** This species is a solitary larval endoparasitoid of MRB that was introduced into USA from Mexico as part of a classical biological control program. Laboratory studies by Lauziere *et al.* (2002) showed that survival is greater at cooler temperatures; adult emergence was 62.5% at 20°C, compared to 9.5% at 35°C. The lower temperature threshold for larval development was 14.5°C.
***Chelonus sonorensis* Cameron (Hymenoptera: Braconidae):** This species is an egg-larval parasitoid native to Southern USA and Mexico.
***Digonogastra solitaria* Wharton & Quicke (Hymenoptera: Braconidae):** This is a solitary larval ectoparasitoid, native to the American continent.

In addition, eight species of Trichogrammatidae did develop on MRB eggs in laboratory studies, with *Trichogramma retorridum* (Girault) being the most effective. However, the concealed location of *E. loftini* egg masses in the field places limitations on parasitization (Browning & Melton 1987).

Pathogens: laboratory and field studies showed that MRB larvae are susceptible to infection by the entomopathogenic fungus, *Beauveria bassiana* (Balsamo) Vuillemin (Deuteromycotina: Hyphomycetes) (Legaspi *et al.* 2000).

Management

Chemical control

Confirm® (tebufenozide), an insect growth regulator (IGR), is currently the only insecticide widely used against *E. loftini* in Texas. However, of approximately 18,200 ha planted to sugarcane in south Texas, Legaspi *et al.* (2000) estimated that only about 80 ha are treated - this is because chemical control is widely regarded as ineffective.

Farming practices

Good irrigation is a very important farming practice to minimize the chances of adults being attracted to cane plants, and to minimize damage due to water stress (Reay-Jones *et al.* 2005).

Pheromone trapping

Shaver *et al.* (1990) states that 0.63-10.0 mg of (Z)-13-octadecenyl acetate, (Z)-11-hexadecenyl acetate and (Z)-13-octadecenal at the ratio of 8:1:1.3 are effective in capturing MRB males over a 112-day period. These are formulated in rubber septa.

Bucket-type pheromone traps are used in Louisiana. The traps are baited with a synthetic female sex pheromone lure (Luresept, Hercon Environmental, Emigsville, PA), which is replaced every 3 weeks. An insecticidal strip (Vaportape II, Hercon Environmental, Emigsville, PA) is placed in the bucket to kill trapped insects and prevent them from damaging each other. Insecticidal strips are replaced every 6 weeks. The traps are attached to a metal pole 1 m above the soil surface and are usually separated by about 100 m from each other (Gene Reagan, personal communication).

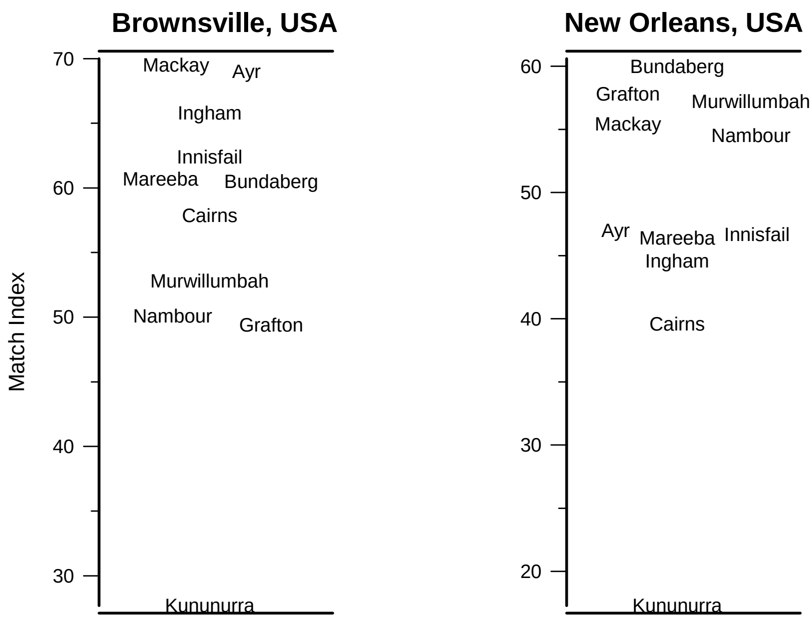
Pheromone trap for detecting Mexican rice borers

Plant resistance
Studies in the USA showed that the cultivar HoCP85-845 lost some of its apparent resistance under heavy infestation, while CP70-321 was the most resistant. Results indicated that cultivar LCP85-384 was more susceptible than NCo310, traditionally the most susceptible cultivar commercially produced in Texas. In 2001, LCP85-384, which now represents 89% of the production area in Louisiana, had the greatest moth production per hectare (17,052), which is significantly higher than HoCP85-845 (3,038) (Reay-Jones *et al.* 2003).

Setamou *et al.* (2002) studied the impact of snowdrop lectin (*Galanthus nivalis* Agglutinin, GNA) expressed in transgenic sugarcane on MRB, and recorded a significant reduction in adult emergence, female fecundity and the pupal weight of the following generation.

Means of Movement
The most likely means of entry by this species into Australia would be by the introduction of infested planting material from Central America and southern USA.

Phytosanitary Risk
Entry potential: Medium – isolated from Australia, but readily transferred on infested planting material.
Colonization potential: High in all sugarcane growing areas – especially Central and southern districts of Queensland.
Spread potential: High, unless strict control imposed over movement of infested material.
Establishment potential: High, except for the Ord (see Match Indexes for climates at Brownsville and New Orleans and principal Australian areas below).



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APPENDIX 2 – ICLCBA program and abstracts

Conference Program

Sunday 23 October 2005
Arrival of participants

Monday 24 October 2005
09:00-10:00 Registration

Inaugural Session
Chair: Paul-André Calatayud, IRD/ICIPE, Kenya

10:00-10:10 Introduction and opening remarks, Prof. Christian Borgemeister, Director General, ICIPE
10:10-10:20 His Excellency Mr Hubert Fournier, Ambassador of France in Kenya
10:20-10:30 Dr Jean-François Silvain, Head of IRD Research Unit, France
10:30-11:00 Tea/Coffee Break
11:00-11:30 IFS: 30 years of young scientist support, Dr Jean-Marc Leblanc, IFS/IRD, Sweden

12:00-14:00 Lunch Break

Chair: Jean-François Silvain, IRD/CNRS, France

14:00-14:20 Diversity of lepidopteran stem borers in eastern Africa revisited, Bruno Le Rü, IRD/ICIPE, Kenya

14:20-14:40 History of the systematics of African Noctuid stem borers of monocot plants, Pascal Moyal, IRD/CNRS, France

14:40-15:00 A review of sugarcane stemborers and their natural enemies in Asia and Indian Ocean islands: An Australian perspective, Mohamed N. Sallam, BSES Limited, Australia

15:00-15:30 Tea/Coffee break

Chair: Stéphane Dupas, IRD/CNRS, France

15:30-15:50 Mitochondrial DNA sequence variation among populations of African sugarcane stalk borer *Eldana saccharina* (Lepidoptera : Pyralidae), Yoseph Assefa, University of KwaZulu-Natal, South Africa

15:50-16:10 Phylogeographic pattern and regional evolutionary history of the maize stalk borer *Busseola fusca* (Lepidoptera: Noctuidae) in subsaharan Africa, Michel Sezonlin, IRD/IITA, Benin

16:10-16:30 Phylogeography of *Busseola fusca*: What are microsatellite data telling us? Jean-François Silvain, IRD/CNRS, France

Chair: Mohamed N. Sallam, BSES Limited, Australia

16:30-16:50 From population to species: morphological and molecular diversity in East African stem borer species of the genus *Manga* Bowden (Lepidoptera: Noctuidae). 1 - Morphological diversity, Pascal Moyal, IRD/CNRS, France

16:50-17:10 From population to species: morphological and molecular diversity in East African stem borer species of the genus *Manga* Bowden (Lepidoptera: Noctuidae). 2 - Molecular diversity, Pascal Moyal, IRD/CNRS, France

17:10-17:30 Genetic variation in the *Cotesia flavipes* complex of parasitic wasps: towards the effective biological control of stemborer pests in Australia Kate A. Muirhead, The University of Adelaide, Australia

18:00-20:00 Cocktail

Tuesday 25 October 2005

Chair: Paul-André Calatayud, IRD/ICIPE, Kenya

09:00-09:20 Combined use of trap and repellent plants in a 'push-pull' strategy to control cereal stemborers (Lepidoptera: Pyralidae; Noctuidae) in Africa, Zeyaur R. Khan, ICIPE, Kenya

09:20-09:40 Vetiver grass (*Vetiveria zizanioides*), a component of a habitat management system for *Chilo partellus* in maize Johnnie van den Berg, North-West University, South Africa

09:40-10:00 Will Bt-maize solve the stem borer problem in Africa?, Johnnie van den Berg, North-West University, South Africa

10:00-10:30 Tea/Coffee Break

Chair: Des E. Conlong, South African Sugarcane Research Institute, South Africa

10:30-10:50 Genetic diversity of *Sturmiopsis* parastica Curran (Diptera: Tachinidae) Yoseph Assefa, University of KwaZulu-Natal, South Africa

10:50-11:10 The use of PCR-RFLP and multiplex PCR on Polydnavirus markers for a faster identification of *Cotesia sesamiae* (Hymenoptera: Braconidae) and *C. flavipes*, Stéphane Dupas, IRD/CNRS, France

11:10-11:30 Experiments on scope for genetic enhancement of the parasitisation potential of four native strains of *Trichogrammatoidea* sp. nr. *lutea* in Kenya, Joseph M. Baya, ICIPE, Kenya

12:00-14:00 Lunch Break

Chair: Bruno Le Rü, IRD/ICIPE, Kenya

14:00-14:20 Distribution and importance of lepidopterous cereal stemborers in Kenya, Josephine Songa, Kenya Agricultural Research Institute, Kenya

14:20-14:40 Predicting spatial patterns of cereal stem borers under current and future climate scenarios in East and Southern Africa, Eric I. Muchugu, ICIPE, Kenya

14:40-15:00 Distribution and relative importance of cereal stemborers and their natural enemies in the Amhara State of Ethiopia, Melaku Wale, Amhara Regional Agricultural Research Institute, Ethiopia

15:00-15:30 Tea/Coffee Break

Chair: Fritz Schulthess, ICIPE, Kenya

15:30-15:50 The synchrony of stemborer and parasitoid populations of coastal Kenya Nanqing Jiang, ICIPE, Kenya

15:50-16:10 Biogeography and ecological characteristics of East African noctuid stem borers, Bruno Le Rü, IRD/ICIPE, Kenya

16:10-16:30 The role of wild grasses on densities of lepidopteran stem borer pests along altitudinal gradient in Kenya, Georges O. Ong'amo, IRD/ICIPE, Kenya

16:30-16:50 Diversity and abundance of wild host plants (Poaceae, Cyperaceae, Typhaceae) of Lepidopteran stem borers in two cereal growing localities from Kenya Nicholas A. Otieno, ICIPE, Kenya

Wednesday 26 October 2005
Chair: Rose Ndemah, IITA, Cameroon

09:00-09:20 Who chooses the host plant - the moth or the larva?, Des E. Conlong, South African Sugarcane Research Institute, South Africa

Chair: Pascal Moyal, IRD/CNRS, France

09:20-09:40 Differences in ovipositional response between wild and laboratory-reared *Busseola fusca* (Lepidoptera: Noctuidae), Gerald Juma, IRD/ICIPE, Kenya

09:40-10:00 Sexual dimorphism of antennal and tarsal chemosensilla and chemosensory equipment of the ovipositor in the African stalk borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), Paul-André Calatayud, IRD/ICIPE, Kenya

10:00-10:30 Tea/Coffee Break

10:30-10:50 Sex pheromone, reproductive isolation and populations in Lepidoptera Brigitte Frérot, INRA, France

Chair: Brigitte Frérot, INRA, France

10:50-11:10 Specific Mate Recognition System of an African stem borer: *Busseola fusca*, Anne-Emmanuelle Félix, INRA/IRD, France

11:10-11:30 Reproductive compatibility and variation in survival and sex ratio of West and Eastern African strains of *Cotesia sesamiae*, a larval parasitoid of cereal stem borers in Africa, Saka Gounou, IITA, Benin

11:30-11:50 Performance of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) on stem borers of cereals and wild crops, Meshack Obonyo, ICIPE/IRD, Kenya

12:10-14:00 Lunch Break

14:00 – 17.00 Round table discussions

Thursday 27 October 2005

Chair: Adenirin Chabi-Olaye, IITA, Benin

09:00-09:20 Host suitability studies, introduction and establishment of the exotic stem borer parasitoid *Cotesia flavipes* in Zimbabwe, Peter Chinwada, University of Zimbabwe, Zimbabwe

09:20-09:40 *Trichogramma bournieri* (Hymenoptera : Trichogrammatidae) and *Chilo* sacchariphagus (Lepidoptera : Crambidae) in sugarcane in Mozambique - a new association, Des E. Conlong, South African Sugarcane Research Institute, South Africa

09:40-10:00 Suitability of the Egg Parasitoid *Trichogramma bournieri* Pintureau & Babault (Hymenoptera: Trichogrammatidae) for the control of East African Stemborers, Yaovi Anani Bruce, ICIPE, Kenya

10:00-10:30 Tea/Coffee Break

Chair: Nanqing Jiang, ICIPE, Kenya

10:30-10:50 Differences in calyx fluid proteins of two *Cotesia sesamiae* (Hymenoptera : Braconidae) biotypes : implications to biological control of *Busseola fusca* (Lepidoptera : Noctuidae), Catherine W. Gitau, ICIPE, Kenya

10:50-11:10 Role of micro-organisms in host-parasitoid coevolution process: Example of a cereal stemborers parasitoid in Kenya: *Cotesia Sesamia* Antoine Branca, IRD/CNRS, France

11:10-11:30 A model for the study of Wolbachia induced Cytoplasmic Incompatibility in arrhenotokous haplodiploid populations, Antoine Branca, IRD/CNRS, France

11:30-11:50 Tritrophic interactions between lepidopterous stemborers, storage beetles and mycotoxin producing fungi in pre-harvest maize, Fritz Schulthess, ICIPE, Kenya

11:50-12:10 The effect of grassy field margins on soils, stemborer attacks and yield of maize in the humid forest of Cameroon, Rose Ndemah, IITA, Cameroon

12:10-14:00 Lunch Break

Chair: Charles Omwega, ICIPE, Kenya

14:00-14:20 Relationships of soil fertility proprieties and stemborers damage to yield in maize-based cropping system in Cameroon, Adenirin Chabi-Olaye, IITA, Benin

14:20-14:40 Effect of nitrogen fertilizer and pesticide on maize stemborer population and parasitism with maize growth in Zanzibar, Abdalla I. Ali, ICIPE, Kenya

14:40-15:00 Maize-legumes-cassava intercropping in the control of maize cob borers with special reference to *Mussidia nigrivenella*, Komi Agboka, IITA, Benin

15:00-15:30 Tea/Coffee Break

Chair: Fritz Schulthess, ICIPE, Kenya

15:30-15:50 Effect of intercropped maize and trap cropping on stem borer damage and yield, Amalia Sidumo, Eduardo Mondlane University, Mozambique

15:50-16:10 Impact of wild grasses planted as border rows on stemborer infestations in Uganda, Teddy O. Matama-Kauma, Namulonge Agricultural Research Institute, Uganda

16:10-16:30 Habitat management affecting infestation of maize by stem borers and borer parasitism, Difabachew Belay, ICIPE, Ethiopia

Chair: Bruno Le Rü, IRD/ICIPE, Kenya

16:30-16:50 Economics of biological control of cereal stem borers in Kenya Anderson K. Kipkoech, ICIPE, Kenya

16:50-17:10 Impact of the parasitoid *Cotesia flavipes* Cameron (Hymenoptera : Braconidae) on the spotted stemborer *Chilo partellus* (Swinhoe) (Lepidoptera : Crambidae) in Eastern Uganda, Samuel Kyamanywa, Makerere University, Uganda

Friday 28 October 2005

Chair: Bruno Le Rü, IRD/ICIPE, Kenya

09:00-09:20 Losses caused by stem borers to transplanted sorghum crops in northern Cameroon, Bertrand Mathieu, CIRAD-CA, Cameroon

Chair: Rose Ndemah, IITA, Cameroon

09:20-09:40 Assessment of the impact of natural enemies on stem borer infestations and yield loss in maize using selected insecticides in Mozambique, Domingos Cugala, Eduardo Mondlane University, Mozambique

09:40-10:00 Release, establishment and spread of *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) in Tanzania, Beatrice Pallangyo, National Biological Control Programme, Tanzania

10:00-10:30 Tea/Coffee Break

Chair: Fritz Schulthess, ICIPE, Kenya

10:30-10:50 Release and establishment of *Cotesia flavipes* (Hymenoptera : Braconidae) an exotic parasitoid of *Chilo partellus* (Lepidoptera : Crambidae) in Eastern and Southern Africa, Charles Omwega, ICIPE, Kenya

10:50-11:10 Yield Loss due to the stemborer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) at different nitrogen application rates to maize Victor Mgoo, Sokoine University of Agriculture, Tanzania

11:10-11:30 Towards transgenic stem borer resistant maize in Kenya Stephen Mugo, CIMMYT, Kenya

12:00-14:00 Lunch Break

Chair: Mohamed N. Sallam, BSES Limited, Australia

14:00-15:00 System wide initiative discussion

15:00-15:30 Tea/Coffee Break

15:30-17:00 Discussion about perspectives - Closing remarks by Jean-François Silvain (IRD/CNRS, France)

19:00-23:00 Closing dinner

Conference abstracts

Diversity of lepidopteran stem borers in eastern Africa revisited

Bruno P. Le Rü [(1)], G.O. Ong'amo [(1)], P. Moyal [(2)], L. Ngala [(1)], B. Musyoka [(1)], Z. Abdullah [(3)], D. Cugala [(4)], B. Defabachew [(5)], T. A. Haile [(6)], T. Kauma Matama [(7)], V.Y. Lada [(3)], B. Negassi [(8)], K. Pallangyo [(9)], J. Ravololonandrianina [(10)], A. Sidumo [(4)], C. Omwega [(11)], F. Schulthess [(11)], P.-.A. Calatayud [(1)] & J.-F. Silvain,[(2)]
[(1)] Unité de Recherche IRD 072, ICIPE, Nairobi, Kenya. [(2)] Unité de Recherche IRD 072, CNRS, Laboratoire Populations, Génétique et Evolution, BP1, 91198 Gif - sur - Yvette cedex, France, [(3)] Ministry of Agriculture, Plant protection division, P.O. Box 1062, Zanzibar, Tanzania [(4)] Eduardo Mondlane University, Faculty of agronomy and forestry engineering, Av. J. Nyerere, Campus Universitario 1, Maputo, Moçambique, [(5)] Ethiopian Agricultural Research Centre, Melkasa, P.O. Box 436, Ethiopia, [(6)] University of Asmara, P.O. Box 1220, Asmara, Eritrea. [(7)] National Agricultural Research Organisation (NARO), Namulonge Agricultural Res. Inst. P.O. Box 7084, Kampala, Uganda, [(8)] Ministry of Agriculture, DARHRD Agricultural Research, P.O. Box 4627, Asmara, Eritrea [(9)] Biocontrol Programme, P.O. Box 30031, Kibaha, Tanzania [(10)] Ministère de l'Agriculture, Service de la protection des végétaux, B.P. 1042, Antananarivo 101, Madagascar, [(11)] ICIPE, PO Box 30772, Nairobi, Kenya.

Accurate knowledge of the stem borers found in the wild habitat is considered essential in the design and development of control strategies. A survey was carried out in Eastern Africa (Eritrea, Ethiopia, Kenya, Madagascar, Mozambique, Tanzania, Uganda, Zanzibar) between January 2003 and April 2005 to appraise the Lepidopteran stem borers guild in wild host plants. Seventy eight species of wild host plants belonging to Poaceae, Cyperaceae and Typhaceae families were found infested. However there was variation in stem borer species diversity among these plants, with Panicum maximum Jack being the richest. 23,994 larvae belonging to 135 species of lepidopteran stem borers have been collected, 43 Noctuidae belonging to 9 genera, 64 Pyraloidea belonging to Crambidae and Pyralidae families, 25 Tortricidae and 3 Cossidae. Host plants of at least 110 of these stem borer species have never been reported previously. The noctuid larvae represent 72.4 % of the total collection with 64.8, 3.6 and 4.0 % found on Poaceae, Cyperaceae and Typhaceae respectively. The Crambidae, Pyralidae, Tortricidae and Cossidae represent 22.8, 2.0, 2.5 and 0.1 % respectively of the total collection, with 92.6% of the Crambidae and Pyralidae collected from Poaceae, and 99.7% of the Tortricidae collected from Cyperaceae. The wild host-ranges of the 5 main stem borer pests in East Africa are recorded. The lepidopteran stem borers guild is far more diverse than previously reported.

History of the systematics of African Noctuid stem borers of monocot plants

Pascal Moyal
IRD/CNRS, Laboratoire Populations Génétique Evolution- Avenue de la terrasse, Gif-sur-Yvette cedex, France

From the description of the genus *Sesamia* in 1852 to the last diagnoses of African species, the history of the systematics of the difficult group of African Noctuid stem borers is recounted. The misidentifications that confused the taxonomy of these taxa and the new light shed when genitalia observation was first used are described. Some difficulties that still remain to classify the 157 species described by now are emphasized and possible improvement by the combined use of morphological and molecular analyses is stressed.

A review of sugarcane stemborers and their natural enemies in Asia and Indian Ocean islands: An Australian perspective

Mohamed N. Sallam
BSES Limited, PO Box 122, Gordonvale, QLD 4865, Australia

This paper provides a review on stemborer pests of gramineous crops in Asia and Indian Ocean Islands which have the potential to invade Australia. Information on the geographical distribution, host plants and potential of invading Australia is provided for 24 stemborer species with special reference to those mainly attacking sugarcane. A literature review of all natural enemies of 18 key pest species is provided. About 800 records of parasitoids, predators and pathogens of these pests are listed, with information on the host stage they attack, host plant or crop where they were recorded and country of record. The list includes all records of indigenous natural enemies, as well as introduced ones that are recorded to have established in the country of introduction. This information will facilitate quick decision making in case of a sudden detection of an exotic borer in Australia. A knowledge of possible biological control options is essential to determine which natural enemies are to be considered for introduction following an incursion. Efforts from biological control programs attempted overseas are highlighted to provide insight into the complexity of this approach, and to assist in arriving at a correct decision within an acceptable length of time. The Braconid, *Cotesia flavipes*, stands out as a promising candidate for introduction into Australia following a borer incursion. Studies are currently being conducted on a native *Cotesia* species in Australia, which may be able to parasitize larvae of exotic borers, therefore minimizing the need for other parasitoids introductions.

Mitochondrial DNA sequence variation among populations of African sugarcane stalk borer *Eldana saccharina* (Lepidoptera : Pyralidae)

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Eldana saccharina Walker is an indigenous insect that is widely distributed throughout sub-Saharan Africa. Studies have shown that populations from west Africa have distinct behavioural differences compared to populations from east and southern Africa. In addition, the parasitoids guilds attacking these populations in the different regions are markedly different. The parallel geographical variation in these patterns between several widespread populations of *E. saccharina* evoked the hypothesis of diversification. A molecular analysis on the Cytochrome Oxidase c subunit I (COI) region of the mitochondrial DNA was conducted on populations of *E. saccharina* from western, eastern, northern and southern Africa to evaluate this hypothesis. The phylogenetic tree constructed by use of Neighborhood Joining (NJ) and unweighted pair-group method with arithmetic average (UPGMA) clustered the 30 specimens in to three groups. Results presented of the current study thus reveal the presence of genetic variation in *E. saccharina* populations, which is related to geographic variation. This is discussed.

Phylogeographic pattern and regional evolutionary history of the maize stalk borer *Busseola fusca* (Lepidoptera : Noctuidae) in subsaharan Africa.

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We used partial mitochondrial DNA sequences (cytochrome b) to study the phylogeographic and demographic history of *Busseola fusca* (Lepidoptera : Noctuidae) one of the major cereal pest in subsaharan Africa. 489 individuals of this species collected in 98 localities in southern, central, eastern and western Africa countries were sequenced. Nested clade phylogeographical analysis (NCPA) separated *B. fusca* populations in three mitochondrial main clades (W, KI, KII) and identified a certain amount of genetic structure within each of them. Besides, this analysis showed that KI and KII clades are partly sympatric and well separated from the West African clade (W). Mismatch distribution analysis and the negative values of Tajima D index are consistent with a demographic expansion hypothesis for these three clades. Significant genetic differentiations were revealed at various hierarchical levels by analysis of molecular variance (AMOVA). Hypotheses about the geographic origin of the three main clades are provided.

Phylogeography of *Busseola fusca*: What are micosatellite data telling us?

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The noctuid stem borer *Busseola fusca* occurs throughout sub-Saharan Africa, where it is considered as a major pests of maize and sorghum. Populations occurring in western and eastern Africa have slightly different ecological preferenda. A phylogeographic study based on the analysis of Cytochrome b sequences revealed three separated clades. We developed and used seven microsatellite loci for a genetic analysis at the nuclear level. Preliminary results showed a strong genetic structuration between populations from West Africa and populations from Central, South and East Africa. Western populations seemed to form an homogeneous group. Central, South and Eastern populations are more diverse and can be grouped into different geographic units. We are now looking for fine-scale genetic and geographic structuration.

From population to species: morphological and molecular diversity in East African stem borer species of the genus Manga Bowden (Lepidoptera: Noctuidae). 1- Morphological diversity

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Larvae of noctuid stem borers were collected in wild monocot plants in Eastern Africa, from Ethiopia to Mozambique, and reared to adult stage. Three species of the African genus *Manga* Bowden (Lepidoptera: Noctuidae) were found, in host plants belonging only to the Poaceae family. *M. melanodonta* (Hampson) was collected in stems of *Panicum maximum* Jacq., *Setaria megaphylla* (Steud.) Dur. et Schinz and *Setaria plicatilis* (Hochst.) Hack; *M. nubifera* (Hampson), and *M. fuliginosa* n. sp, both only in stems of *P. maximum*. The second species was in the past sunk as synonym of *M. melanodonta*, but the present study shows it has to be considered as a different species. The new species is described as well as features not yet known of the other species (female habitus and male and female genitalia of *M. melanodonta* and *M. nubifera*), and also the larva, which was similar for the three species. The *Manga* genus is revised, the different species are presented and *M. bisignata* Laporte is sunk as synonym of *Busseola quadrata* Bowden.

From population to species: morphological and molecular diversity in East African stem borer species of the genus Manga Bowden (Lepidoptera: Noctuidae). 2- Molecular diversity

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The diversity of *Manga* species collected in East Africa, from Ethiopia to Mozambique, was studied at the molecular level using the mitochondrial gene Cytochrome b. A complex history made of successive fragmentation events was revealed. The combination of three forces appeared to have shaped this diversity: the main paleo-climatic events (succession of dry and humid periods), the geological barriers, particularly the Rift valley, and specialization on new host plants. A molecular clock proved to be acceptable for all species except for the species that first diverged, *Manga fuliginosa*. The dates of the major paleo-climatic events of the last 5 million years appeared to correspond to the observed divergence events when using an evolution rate of 1.15% per million year, with a correction for *M. fuliginosa*. The isolation by the Rift valley favoured diversification in some instances, and the adaptation of *Manga melanodonta* to new host plants enabled the colonization of humid environments. A scenario of the evolution of the group is proposed, from its origin in Austral Africa about 5 million years ago and its northward expansion, until the recent migrations of *Manga nubifera* during the last million year.

Genetic variation in the *Cotesia flavipes* complex of parasitic wasps: towards the effective biological control of stemborer pests in Australia

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The *Cotesia flavipes* species complex of parasitic wasps are economically important worldwide for the biological control of lepidopteran stemborer species associated with gramineous crops. The complex currently comprises three species: *C. flavipes* Cameron, *C. sesamiae* (Cameron) and *C. chilonis* (Matsumura). The absence of clear diagnostic characters to separate the species and inaccurate identification have confounded past efforts to assess the impact of specific introductions. Moreover, small- and large-scale geographic populations have exhibited differences in host/habitat preference and host range. Molecular markers are being developed to characterise genetic variation and phylogenetic relationships among worldwide populations of the *C. flavipes* complex, and correlate these with host and/or habitat preference. The status of *C. flavipes*-like species in Australia will be determined for the preparedness of stemborer incursion into Australia. Genetic differentiation between populations may have potentially important implications for host utilisation and thus, the diagnosis of appropriate strains for biological control against specific host species.

Genetic diversity of *Sturmiopsis parastica* Curran (Diptera: Tachinidae)

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The African sugarcane stalk borer, *Eldana saccharina* Walker, is reported to show high levels of genetic differentiation in its indigenous range. This evoked the hypothesis that one of its biological control agents, *Sturmiopsis parasitica* Curren, might have undergone genetic differentiation in response to the differentiation in its host. This thought was supported by the fact that in West Africa, *S. parasitica* parasitised predominantly *E. saccharina*, while in Zimbabwe it was found only from *Busseola fusca* Fuller. To confirm this hypothesis, mitochondrial DNA sequences in cytochrome oxidase I were sequenced. Phylogenetic analysis of the sequences using maximum parsimony clustered the specimens into two groups. The genetic divergence observed suggests the presence of intraspecific polymorphism in *S. parasitica*. These results are presented and discussed.

The use of PCR-RFLP and multiplex PCR on Polydnavirus markers for a faster identification of *Cotesia sesamiae* (Hymenoptera: Braconidae) and *C. flavipes*

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C. sesamiae and *C. flavipes* (Hymenoptera: Braconidae) are the two main larval parasitoids of cereal stemborers in Subsaharan Africa. One is endemic and the other was introduced. The two species exhibit very similar ecological niches, especially in lowland areas. It can be feared that the introduced insect drive to extinction it's indigenous homologue. To address this hypothesis, a better characterizaton of their ecological niche and long term field surveys are needed. Polydnavirus are obigatory symbionts used by the wasp to regulate their host's physiology during parasitization. *C. sesamiae* and *C. flavipes* harbor different viruses, named CsBV and CfBV respectively. Their genome is integrated in the genome of the wasp and they can be used to distinguish the two species. Sequences differences between CsBV and CfBV were observed in the polydnavirus gene CrV1. Two fast and cost effective molecular techniques were developed to distinguish the two viruses. The first is a classic PCR-RFLP technique. The second is a multiplex PCR technique. It is based on differences in PCR amplimer size due to the specificity of the reverse primer annealing at different position in the two species of virus. Both allowed the fast distinction between *C. flavipes* and *C. sesamiae* from extracted DNA as well as from pieces of tissue from the abdomen. The method costs less than one US $ per insect. It could be used for the survey of future biological control introductions.

Experiments on scope for genetic enhancement of the parasitisation potential of four native strains of Trichogrammatoidea sp. nr. lutea in Kenya

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The African bollworm, *Helicoverpa armigera*, is reckoned as an important cob borer on maize, besides causing substantial yield losses on sorghum in several countries in Eastern Africa. The scope for genetic enhancement of the parasitisation potential of promising native strains of *Trichogramma* for mass production and inundative release for *Helicoverpa* biocontrol in the region was assessed in the laboratory. Adults of four chosen Kenyan strains of the commonly occurring trichogrammatid species, *Trichogrammatoidea* sp. nr. *lutea* Girault, were cross-mated in reciprocal combinations. Significant differences were observed between inbred and reciprocal crosses in fecundity and progeny female ratio, besides in overall progeny production and progeny adult longevity. Genotypic and phenotypic variance-covariance matrices generated for six life-history traits and their fitness components showed high positive correlations for most traits in both inbred and reciprocal heterogamic crosses. Fecundity and number of female offspring were the most important factors in the heterogamic crosses. Significant differences occurred between homogamic crosses and most reciprocal heterogamic crosses in the major biological attributes. These results confirm the scope for seeking genetic enhancement through inter-population crossing among native trichogrammatid species for improving the field impact potential.

Distribution and importance of lepidopterous cereal stemborers in Kenya

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Stemborer densities, species composition and parasitism as well as damage to maize plants and yield were evaluated in small scale farmers' fields in Central, Eastern, and Western Kenya during 5 seasons, and in Coastal Kenya over 8 seasons. In Central and Eastern Kenya, *Chilo partellus* was the dominant species with less than 1 borer/ plant, followed by *S. calamistis* and *B. fusca* with densities of less than 0.1/plant. In Central Kenya, the density and the relative importance of *Ch. partellus* increased across the seasons, while in

Eastern Kenya they decreased while that of *B. fusca* increased. There was no consistent trend for *S. calamistis* . In Western Kenya, *B. fusca* was the dominant species, with a density of less than 0.1 per plant. Eastern Kenya had the highest parasitism, followed by Central and Western. Parasitism was mainly on *C. partellus* , with larval parasitoids *C. flavipes* and *C. sesamiae* being the most common in Eastern and Central, while in Western, *C. sesamiae* was dominant. The most common pupal parasitoid was *Dentichasmias busseolae*.

Predicting spatial patterns of cereal stem borers under current and future climate scenarios in East and Southern Africa

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The management of both pests and natural enemies species requires an understanding of the factors determining their distribution. Statistical models offer methods for formulating the species habitat link and means for predicting where species should occur. This paper describes an integrated approach to species habitat mapping in east and southern Africa region using generalized regression analysis and spatial prediction (GRASP). The approach uses separate statistical models for each stem borer and parasitoid species to predict the species richness and abundance in each grid cell in a geographic information system (GIS). Allocation of these grid cells to species composition allows "hot-spots" of feasible areas for bio-control to be defined. Examples of use of this information for pest management are presented. This paper explores species habitat under different global climate change scenarios.

Distribution and relative importance of cereal stemborers and their natural enemies in the Amhara State of Ethiopia

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The distribution and relative importance of lepidopteran and coleopteran stemborers and their natural enemies were studied in cereal growing zones of the Amhara State of Ethiopia from 2003/04. In eastern Amhara, the species composition was 91% *C. partellus* , 8% *B. fusca* and 1% *S. calamistis* . in western Amhara, sorghum was only attacked by *B. fusca* while on maize, 61% were *B. fusca* and 39% *S. calamistis* . Borer density generally increased significantly with crop growth stage. On maize, *S. calamistis* was most abundant at the flag leaf or early tasseling. In eastern Amhara, *C. partellus* parasitism by *Co. flavipes* varied among districts ranging from 5% to 39%. In western Amhara, unidentified nematodes extensively infected medium sized *B. fusca* larvae during the wet months. Taylor's power law showed aggregated distribution for *C. partellus* and random for *B. fusca*.

The synchrony of stemborer and parasitoid populations of coastal Kenya

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The spatial synchrony of the exotic stemborer *Chilo partellus* , and the indigenous *Sesamiae calamistis* and *Chilo orichalcociliellus*, the indigenous and introduced larval parasitoids *Cotesia sesamiae* and *Co. flavipes*, respectively, was studied using 3-year data collected in coastal Kenya. Spatial correlation function (SCF) and spatial cross-correlation function were applied. An autoregressive model was used to study the effect of climatic stochasticity or population density-dependent factors on the stemborer and parasitoid populations. It appeared that *Ch. partellus* populations are not stabilized yet. Although, their niches overlap on several plant species, the periodic cross-correlation between *Ch. partellus* and *Ch. orichalcociliellus* with distance showed that these two species may differ in their mobility (dispersal). *Co. sesamiae* showed to have more impact on the spatial pattern of *S. calamistis* than on the other stemborer species. By contrast, for *Ch. partellus* and *Ch. orichalcociliellus*, the spatial pattern were closely linked with *Co. flavipes*.

Biogeography and ecological characteristics of East African noctuid stem borers

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Surveys were carried out in Kenya, Tanzania and Uganda to establish the ecological characteristics such as host plant range and preference, feeding behaviour, reproductive strategies of African noctuid stem borers. Fifty wild plant species belonging to Poaceae, Cyperaceae and Typhaceae were found to harbour stem borers in the six vegetation mosaics surveyed. A total of 37 noctuid species belonging to 9 genera were identified from a total of 14116 larvae collected. Eighteen new species were found. The species diversity varied among vegetation mosaics [*Zambezian miombo* woodland (alpha = 0.88) and Guineo-Congolian mosaic (alpha=3.22)] and host plants [*Cynodon aethiopicus* (alpha= 0.14) and *Cyperus latifolius* (alpha =1.59)]. Most borer species were found in the wetter parts of the vegetation mosaics and appeared to be specialist feeders: 25 species were monophagous and among the oligophagous species there was a marked preference for one or two host plants.

The role of wild grasses on densities of lepidopteran stem borer pests along altitudinal gradient in Kenya

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Presence of non-crop hosts of stemborers in the cereal-growing areas has always been considered detrimental in serving as a stemborer reservoir. Surveys to determine the role of these hosts on the dynamics of stemborer pest populations was carried during the cropping and non-cropping seasons along varying altitudinal gradients in Kenya. A total of 35 wild plant species were found infested by the end of survey from which 45 stemborer species [Noctuidae (26), Crambidae (14) and Pyralidae [5]] including the four important pest species; *Busseola fusca* (Fuller), *Sesamia calamistis* Hampson (Noctuidae), *Chilo partellus* (Swinhoe) and *Chilo orichalcociliellus* (Strand) (Crambidae) were recovered. Contrary to the earlier reports, *B. fusca* was recovered only from *Sorghum arundinaceum* (Desv.) and *Phragmites mauritianus* Kunth unlike *S. calamistis* and *C. partellus* which each occurred in more than four non-crop hosts. However, the total larvae of respective pest species were very low and may not sustain pest populations in the subsequent generation

converse to reports from West Africa where *S. calamistis* and *Eldana saccharina* Walker are the main pest species. These results support the increasing evidence which suggests that the host range of economically important stemborers vary between location and seasons. Importance of the non-crop hosts as well as the diversity of stemborer species along the altitudinal gradient is discussed.

Diversity and abundance of wild host plants (Poaceae, Cyperaceae, Typhaceae) of Lepidopteran stem borers in two cereal growing localities from Kenya

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Wild Habitats are currently assumed to constitute important refuge for lepidopteran stemborer pests during non-cropping season. However, information on the diversity and abundance of potential wild hosts of stem borers, a vital understanding of the role of wild habitat on the pest dynamics, is limited. A study was done in two ecologically different localities: Kakamega in western Kenya (Guineo-Congolese mosaic) and Muhaka in Kenya coast (Inhambane mosaic) to assess the diversity and abundance of wild host plants in the cropping and non-cropping seasons. There was no evidence in variation in diversity and abundance of wild host plants between cropping and non-cropping seasons in Kakamega, wild host plants covered 2% and maize 43% of the surface and. In Muhaka, diversity of wild host plant species varied between the cropping and non-cropping seasons. Plant cover also varied between 12% to 16% higher than that of maize which had 2%. Implication of these results is discussed.

Who chooses the host plant – the moth or the larva ?

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Eldana saccharina Walker has a wide host range encompassing four plant Families. Morphological studies show *E. saccharina* female moths have a prehensile ovipositor, with sensory hairs at its tip enabling oviposition in cryptic positions. Cage studies show that females will oviposit on plants, in leaf curls, behind leaf sheaths and cracks in stalk rinds, mostly in dead or mature tissues. However, they also oviposit under plant pots, on plant pot rims, and in the corners of cages, away from any host plants. Freshly eclosed *E. saccharina* larvae, in contrast, showed distinct preferences for plant leaf and sheath material of a number of host plants. They chose green plant material over dead plant material, and plant material from sedges above material from sugarcane, above material from indigenous grasses. These results are discussed in the context of host plant selection by stalk borer adults and the subsequent survival of their larvae on the plants selected.

Differences in ovipositional response between wild and laboratory-reared *Busseola fusca* (Lepidoptera: Noctuidae)

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The stem borer, *Busseola fusca* (Fuller)(Lepidoptera: Noctuidae), is an important pest of maize and sorghum in East Africa. In order to understand how the insect selects its host plant for oviposition, it has been necessary to verify first if the laboratory-reared *B. fusca* differ from natural population in ovipositional response. We carried out experiments to investigate the ovipositional response towards different supports including maize plant, their original host plant, as well as towards extracts of the plant surface. Wind tunnel studies were also undertaken to study the attraction of female moths to maize volatiles. Further, responsiveness of the antennal olfactory receptors to known components of plant volatiles was studied using electroantennographic techniques. In all the studies, a population of *B. fusca* caught from the wild and laboratory mass-reared moths were used. The laboratory-reared insects have lost the host plant specificity for oviposition, accepting an artificial support totally outside their original host plant, showing no oviposition preference for artificial stems imbibed with plant extracts and fewer exhibiting an oriented flight behaviour toward maize plants under wind tunnel conditions. However, the laboratory-reared females conserved the same antennal sensitivity towards host plant volatiles than wild ones. All the results indicate that laboratory-reared *B. fusca* insects differ from wild population in the host plant specificity and this limits their representativeness of the species in the wild. Therefore it is important to use wild insects in future studies on host plant selection process for oviposition.

Sexual dimorphism of antennal and tarsal chemosensilla and chemosensory equipment of the ovipositor in the African stalk borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae)

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The number and the distribution of chemosensilla located on different organs of *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) males and females were described using scanning electron microscopy, selective staining, and contact electrophysiology. The antennae as well as the fifth tarsomere of the prothoracic legs of both sexes bear contact chemosensilla identified as of the uniporous chaetica type and chemosensilla belonging to the multiporous trichoidea type. A sexual dimorphism was found in the number and the size of sensilla on the antennae and the fifth tarsomere. The distal part of the ovipositor possesses uniporous contact chemosensilla of the chaetica type. The possible involvement of these sensory structures in *B. fusca* oviposition site selection is discussed.

Sex pheromone, reproductive isolation and populations in Lepidoptera

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Sex pheromones released by females mediate reproduction in most of the moth species. They were largely studied for the last 30 years with the aim of providing new tools for monitoring the species damaging crops. The first identifications from *Bombyx mori* and *Cydia pomonella*, have associated a single component as a sex pheromone of each species leading to the thought that each species was

characterised by its own specific component. However the idea did not last very long and a short time later, it was clearly demonstrated that the moth sex pheromone was a complex blend of different components and that the stimulation of male reproductive behaviour depended on both the quality and quantity of the pheromone released. Through the examination of Lepidopteran female pheromone components, it has been discovered that they are composed of a limited number of molecules and that different species can produce the same pheromone blend. Thus the specificity of the sexual communication relied on mechanisms other than blend quality and quantity. The processes ranging from diel periodicity to courtship behaviour will be described. In contrast, within the same species, different pheromone populations have been discovered for a long time. Recent advance in pheromone collection allowed the study of individual production and evidenced that pheromone population can be correlated with host plant specialisation, addressing questions on polyphagia and species notion.

Specific Mate Recognition System of an African stem borer: *Busseola fusca*

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Busseola fusca, Hübner (Lepidoptera: Noctuidae) is the most important African stem borer damaging maize and sorghum. Pheromone identification already conducted on wild *B. fusca* populations showed no marked differences in the female sexual pheromone. This pheromone is a blend of Z11-14: Ac., major and E11-14: Ac. and Z9-14: Ac., minors and a new component revealed by INRA Z11-16: Ac. E11-14: Ac. and Z9-14: Ac. vary from 5 to 10% but the biological effect is unknown. Molecular biology studies (IRD) have shown the existence of mitochondrial haplotypes. There exist three different populations within the same species: in the East, type II, major and I, minor and in the West (type west). *B. fusca* used for this study originated either from the ICIPE mass rearing or from the wild. The ICIPE population bearing two haplotypes: I and II was used for determination of the response windows in males using a wind tunnel. The wild populations were only subject to pheromone identification and haplotype characterisation. Male attraction behaviour is typical in Lepidoptera: after a lock-on, a zigzag pathway was attributed to losses of scent and turn back towards the female; after the male attempted to copulate. Attraction tests with synthetic lures showed that variations from 5 to 10% of minor components have biological effects on male mate finding. Cross mate behaviours between ICIPE population and wild insects from Kitale (type I) did not show reproductive isolation. The haplotypes ratio was the same whatever the origin of the strain, ICIPE or wild (37% of type I). No correlation between molecular markers and either female pheromone polymorphism or male behaviours could be identified. Due to a lack of insects, we could not formulate conclusions on the putative reproductive isolation within the haplotypes I and II. Mating behaviour was studied to decipher each step that could account for reproductive isolation. The mating behaviour was described as very simple, without any particular events or male pheromone emission.

Reproductive compatibility and variation in survival and sex ratio of West and Eastern African strains of *Cotesia sesamiae*, a larval parasitoid of cereal stem borers in Africa

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The reproductive compatibility between three different strains of *Cotesia sesamiae* from Nigeria and Kenya was studied. All the three strains were self compatible with the percentage of success ranging from 20 to 45%. Cross-compatibility among strains was very high. The numbers and sex ratio of progenies in all possible crosses and backcrosses were similar. Cross-mating between the Eastern Nigerian and Coastal Kenya strains had the highest reproductive success. F1 hybrids between the Kenyan and the Nigerian strains performed poorly compared to their parents and the other hybrids. The significance of the revealed interspecific variations is discussed in relation to their adaptation to various climate conditions in the biological control of cereal stemborers.

Performance of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) on stem borers of cereals and wild crops

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The braconid larval parasitoid *Cotesia flavipes* was introduced into Kenya from Asia for the control of the invasive crambid stemborer *Chilo partellus* . In Africa, maize fields are often surrounded by land occupied by wild gramineous plants, which harbour borer species not found on crops. The purpose of this study was to assess the suitability of some of these 'wild' borer species (i.e., two populations of *S. nonagrioides* from East and West Kenya, *Busseola phaia*, *Sciomesa piscator*) as well as *Busseola fusca*, *Sesamia calamistis* and *C. partellus* , which attack cereals, for the development of *C. flavipes*; to study the foraging behaviour of the parasitoid; to identify plant volatiles that could mediate host finding by *C. flavipes*. All species were equally acceptable to *C. flavipes* but only *C. partellus* , *S. calamistis* and the *S. nonagrioides* West population were suitable. *C. flavipes* females were significantly more attracted to volatiles from stemborer-infested than uninfested plants irrespective of borer or plant species. This was probably due to the richer profile of chemicals and especially in green leaf volatiles and terpenoids of stemborer-infested plants. It can be concluded that the unsuitable borer species used in the present experiment form a reproductive sink.

Host suitability studies, introduction and establishment of the exotic stem borer parasitoid *Cotesia flavipes* in Zimbabwe

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Cotesia flavipes Cameron was first released in Zimbabwe in 1999. First recoveries of the parasitoid were made in 2004 with parasitism levels not exceeding 3.5%. By 2005, parasitisam levels had gone up to 23.2% at Bushu, 5.2% at Muzarabani, 23.1% at Musikavanhu. Recoveries were made from non-release areas indicating that the parasitoid is spreading. These releases were predictable from a laboratory study where populations of the crambid stemborer, *Chilo partellus* (Swinhoe) from five release sites (Muzarabani, Sanyati, Musikavanhu, Mamina and Bushu) and one of the noctuid stemborer, *Busseola fusca* (Fuller) were evaluated for their suitability as hosts of *C. flavipes*. Successful parasitoid development occurred only on *C. partellus* but there were no significant differences in parasitism levels among the five populations of the stemborer. Significantly smaller brood sizes (13.0 adults) were, however, produced on Muzarabani *C. partellus* compared to the Sanyati, Musikavanhu, Mamina and Bushu populations. The numbers of *C. flavipes* adult female progeny per brood were lowest (13.5%) on Muzarabani *C. partellus* brood compared to the other four populations where females comprised 73.8-77.7% of the adults in each brood. Total parasitoid egg-adult development did not differ among the five *C. partellus* populations, ranging from 18.1 to 18.5 days.

Trichogramma bournieri **(Hymenoptera : Trichogrammatidae) and *Chilo sacchariphagus* (Lepidoptera : Crambidae) in sugarcane in Mozambique – a new association**

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Chilo sacchariphagus Bojer, a sugarcane stalk borer indigenous to South East Asia, and the nearby Indonesian Islands, was found in African sugarcane in Mozambique in 1999. Prior to a classical biocontrol programme being implemented against it, intensive pre-release surveys for the presence of any indigenous natural enemies on life stages of the borer were completed. Negligible parasitism of larval and pupal stages was recorded. In contrast, egg batches found were heavily parasitised. Parasitoid adults emerging from the eggs were found to be only the indigenous *Trichogramma bournieri* Pintureau and Babault. Aspects of the biology of *T. bournieri* on *C. sacchariphagus* eggs in Mozambican sugarcane are presented, and the potential of using this egg parasitoid against *C.* sacchariphagus in an augmentation biocontrol programme is discussed.

Suitability of the Egg Parasitoid *Trichogramma bournieri* Pintureau & Babault (Hymenoptera: Trichogrammatidae) for the control of East African Stemborers

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The trichogrammatid *Trichogramma bournieri* (Pintureau & Babault) is a polyphagous parasitoid of eggs of several cereal stemborer species in eastern Africa. The effect of host species, host age and time of host deprivation on the performance of the parasitoid was studied in the laboratory. Host acceptance and suitability were tested using five stemborer species. The noctuids *Sesamia calamistis* Hampson, *Sesamia nonagrioides* Tam & Bowden, *Busseola fusca* Fuller and the pyralids: *Chilo partellus* Swinhoe and *Eldana saccharina* Walker were successfully parasitized by *T. bournieri*. Parasitism and sex ratio (expressed as proportion of female progeny) did not differ among species, except for *E. saccharina*, which yielded the lowest values. With increasing duration of host deprivation from 0 to 12 days, longevity increased for the parasitoid, whereas average life-time fecundity decreased per female, indicating resorption of eggs.

Differences in calyx fluid proteins of two *Cotesia sesamiae* (Hymenoptera : Braconidae) biotypes : implications to biological control of *Busseola fusca* (Lepidoptera : Noctuidae)

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The braconid *Cotesia sesamiae* is an indigenous larval of the noctuid *Busseola fusca*, a serious pests of cereals in sub-Saharan Africa. The importance of *C. sesamiae* varies considerably between regions for reasons still not well understood. In Kenya, *C. sesamiae* occurs as two biotypes with different abilities to develop in *B. fusca*. In contrast to western Kenya population, the *C. sesamiae* population from coastal Kenya, where *B. fusca* is not abundant, does not complete development in this host and all its eggs get encapsulated hours after oviposition. Recent studies showed that calyx fluid of the two strains is involved in suppression of the immune system of *B. fusca*, and the proteins are likely to be genetically different. This study compared proteins found in the calyx fluid of these two *C. sesamiae* populations using 2d-Gel electrophoresis. There were more protein spots in protein gels with calyx fluid samples from western Kenya *C. sesamiae* biotype (Chisq = 7.00; df = 1; P = 0.0082) than the coastal Kenya biotype. Implications of using *C. sesamiae* as a biocontrol agent of *B. fusca* in Africa are discussed in this paper.

Role of micro-organisms in host-parasitoid coevolution process: Example of a cereal stemborers parasitoid in Kenya: *Cotesia sesamiae*

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The parasitoid *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae), one of the principal biological control agents of cereal stemborers in Kenya, is associated with two types of symbiotic micro-organisms potentially affecting its fitness: polyDNAvirus and Wolbachia bacteria. In *C. sesamiae*, Wolbachia is responsible for cytoplasmic incompatibility between infected males and healthy female. DNA sequencing showed the presence of different Wolbachia strains. Their mutual incompatibility can lead to reproductive isolation between parasitoid populations carrying different bacteria strains. PolyDNAvirus are symbiotic viruses of the parasitoid implicated in immune reaction suppression of the host larvae. *Busseola fusca* is the only host among the main Kenyan stemborers capable of an immune response. We observed a strong correlation between polyDNAvirus genotypes and *B. fusca* occurrence, suggesting an adaptive specialization due to the virus. The distribution of Wolbachia strains was also correlated to polyDNAvirus distribution in Kenya. The reproductive isolation caused by the bacteria may reinforce the adaptive specialization associated with polyDNAvirus.

A model for the study of Wolbachia induced Cytoplasmic Incompatibility in arrhenotokous haplodiploid populations

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Wolbachia is an endocytoplasmic bacteria responsible of various reproduction modification in arthropods. In several species, Wolbachia induces a phenomena call cytoplasmic incompatibility (CI) :crosses between Wolbachia infected male and healthy female are incompatible. In haplodiploid species reproducing with arrhenotokous parthenogenesis, CI induces a male-biased sex-ratio because incompatible crosses give only males. Here, we computed a stochastic model to evaluate respective influences of demographic and biological parameters on Wolbachia fixation probability and on the sex-ratio bottleneck occuring during a Wolbachia invasion.

Losses caused by stem borers to transplanted sorghum crops in northern Cameroon
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In northern Cameroon, the extension of dry season transplanted sorghum beyond its traditional area (typical vertisol), toward vertic soils close to rainfed crop fields, resulted in an increase of damage by stem borers (mainly *Sesamia cretica*). In surveys conducted from 2001-2003 in two sites, *Sesamia* spp. were shown to cause significant yield losses in 25% of the plots sampled, with up to 450 kg ha-1 grain loss. Loss assessment experiments were extended to 17 sites during the following two years (2003-2005). This enabled to clarify *Sesamia* spp. populations' dynamics on transplanted sorghum, by analysing losses incurred according to transplanting dates and distance from rainy season fields. The prospect for the use of these results for integrated management of *Sesamia* spp. on sorghum is discussed.

Tritrophic interactions between lepidopterous stemborers, storage beetles and mycotoxin producing fungi in pre-harvest maize
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An overview is given on the interactions between lepidopterous stemborers, storage beetles and mycotoxin-producing fungi in pre-harvest maize. In some areas in Africa humans are chronically exposed to mycotoxins such as aflatoxins, produced by *Aspergillus* spp., and fumonisins, produced by *Fusarium verticillioides*, which have carcinogenic and immunotoxic properties that cause, as anti-nutritional factors, unthrifty growth and immune suppression in young mammals. Surveys in field grown maize in West Africa showed that aflatoxin levels and infestations of the ear by storage beetles increased exponentially and linearly, respectively, with grain damage by stemborers. In addition, plants infected by the endophytic form of *F. verticillioides* had higher egg loads by borers and higher survival and fecundity of their offspring than clean plants. Thus, insects are not only vectors of the fungus but are also attracted by infected plants. Consequently, solving the pest problem would also solve the fungal problems and vice-versa.

The effect of grassy field margins on soils, stemborer attacks and yield of maize in the humid forest of Cameroon
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Two field trials were undertaken during two consecutive seasons in the humid forest zone of Cameroon to investigate the effect of nitrogen fertilizer and border rows with the elephant grass *Pennisetum purpureum* or *Panicum maximum* on soil water, plan nutrients, stem borer infestations, parasitism and maize yield. Soil humidity was significantly higher under grass borders than under the maize. Nitrogen uptake by maize tended to be highest in plots surrounded by elephant grass. *B. fusca* numbers and stem tunnelled were 2 times and grain weight 2-2.5 times higher in fertilized plots. In the first season only, P. purpureum increased egg batch parasitism. Multiple regression showed that *B. fusca* numbers and plant damage significantly decreased with egg parasitism, plant K and P, but increased with plant N, while yield decreased with pest infestation and plant damage but increased significantly with egg parasitism. The implication of the findings for the feasibilty of this habitat management technology to farmers in southern Cameroon is discussed.

Relationships of soil fertility proprieties and stemborers damage to yield in maize-based cropping system in Cameroon
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Field trials were designed to investigate the effect of N fertilisation and mucuna fallow on maize yield and borer attacks in the humid forest zone of Cameroon. A traditional maize-cassava-groundnut systems was compared with a maize-cassava + 120 Kg N ha-1, a rotation system in which maize-cassava followed a mucuna fallow as well as with a maize monocrop grown after mucuna fallow and with a maize monocrop grown with 120 Kg N ha-1. Average egg batch densities of *B. fusca* were generally higher in monocrops compared to mixed cropping. Between intercrops, there were no differences in egg batch densities for both after a mucuna fallow and with 120 Kg N ha-1. The average yield losses due to borers were 2-5 times higher in the maize-cassava-groundnut system compared to both a maize-cassava after mucuna fallow and maize-cassava grown with 120 Kg N ha-1.

Effect of nitrogen fertilizer and pesticide on maize stemborer population and parasitism with maize growth in Zanzibar
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Stemborer density and species composition were investigated in four regions of Zanzibar during two seasons. Overall, *Chilo partellus* was the dominant species with densities of 1.0~1.5/plant, followed by the indigenous *Sesamiae* calamisits and *Chilo orichalcociliellus*, with about 0.6 and 0.2/plant, respectively. Mean parasitism of *Ch. partellus* by *Cotesia flavipes* was ca 10% in all regions, and that of *S. calamisitis* by *C. sesamiae* about 5%. Grain yield was lower in southern and west Zanzibar corresponding to the higher percentage of internodes and tunnel damaged. Results of nitrogen treatments carried out in the southern region showed that under natural infestations, borer density increased while percentage of bored internodes and tunnel decreased with nitrogen level.

Yield loss due to the stemborer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) at different nitrogen application rates to maize
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Field trials were conducted at Kibaha and Morogoro in eastern Tanzania during two seasons to evaluate the effect of nitrogen fertilization (0, 50, 75, 100 kg [N]/ha) on pest abundance, plant damage and yield loss of maize due to stemborers. In general, ear and grain weights increased linearly with nitrogen level. In the infested plot, grain weight increased 2.5 and 1.8 fold from 0 to 100 kg [N]/ha in the short and long rainy season, respectively, at Kibaha, and 1.4 and 1.6 times at Morogoro. Yield loss decreased with an increase in nitrogen application and the effect was stronger under high than low borer infestation levels. The results show the beneficial effect of nitrogen on the plant's ability to compensate for borer damage. Analysis of economic benefits of applying fertilizer and insecticide treatment indicated that using insecticides is not profitable under high-pest-low-soil fertility conditions.

Maize-legumes-cassava intercropping in the control of maize cob borers with special reference to *Mussidia nigrivenella*

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Effects of intercropping maize with cowpea, lima bean, soybean, three leguminous cover crops (*Tephrosia vogelii*, *Canavalia ensiformis*, *Sesbania rostrata*) and cassava on the infestation of *Mussidia nigrivenella* and other cob borers were studied. Field experiments were conducted in four different locations in Benin using four by two pattern of maize/legumes or cassava planting. Intercrops reduced the number of eggs (>25%) and larvae of *M. nigrivenella* (17.9-53%) compared with the monocrop. Maize/*C. ensiformis* and maize/*T. vogelii* proved to be the most effective combinations for reducing *M. nigrivenella* populations in the different locations. Yield loss and cob damage were significantly affected by the intercrops and varied between 0.9 and 46.8%, and they were significantly correlated with the number of insects in the cob. No parasitized larvae were found in any of the locations.

Impact of wild grasses planted as border rows on stemborer infestations in Uganda

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Field trials to evaluate the impact of grassy border rows on stemborer infestations in maize were set up at two sites in Uganda during three cropping seasons. Four grass species were chosen and compared with a control without grasses. In the first season, *Busseola fusca* was the major stemborer followed by *Chilo partellus* while in the subsequent season *C. partellus* became the dominant species. Maize with *Pennisetum purpureum* and *Panicum maximum* borders had lower infestations compared to the control. At harvest stem damage was significantly higher on maize surrounded by Sorghum arundinaceum than on sole maize and maize surrounded by other grass species. These results were not consistent during the three seasons suggesting that grassy border rows are not a reliable technology for the control of stemborers.

Combined use of trap and repellent plants in a 'push-pull' strategy to control cereal stemborers (Lepidoptera: Pyralidae; Noctuidae) in Africa

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The lepidopteran stemborers [*Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) and *Busseola fusca* Füller (Lepidoptera: Noctuidae)] cause major yield losses in subsistence maize production throughout Sub Saharan Africa. A 'push-pull' or stimulo-deterrent diversionary strategy for minimizing damage due to stemborers has been developed in maize-based farming systems for small- and medium-scale farmers of eastern Africa (www.push-pull.net). This strategy involved selection of plant species that could be employed as trap crops to attract stemborer colonization away from the cereal plants, or as intercrops to repel the pests. The two most successful trap crop plants Napier grass, *Pennisetum purpureum*, and Sudan grass, *Sorghum vulgare sudanensis* attracted greater oviposition by stemborers, than cultivated maize. The intercrops giving maximum repellent effect were molasses grass, *Melinis minutiflora* and two legumes, silverleaf, *Desmodium uncinatum* and greenleaf *Desmodium intortum*. 'Push-pull' trials, using the trap crops and repellent plants, significantly reduced stemborer attack and increased levels of parasitism of borers on protected plants, resulting in a significant increase in maize yield. The trap crop and intercrop plants also provide valuable forage for cattle, often reared in association with subsistence cereal production. Intercropping maize with *D. uncinatum* and *D. intortum* not only reduced stemborer colonization on maize but also significantly reduced parasitization of maize by *Striga hermonthica*, a parasitic weed of cereals in Africa. There has been considerable take-up of the habitat management system by farmers in eastern Africa and many farmers in different agro-ecologies in Kenya and Uganda have adopted this technology resulting in increased maize and milk production.

Vetiver grass (*Vetiveria zizanioides*), a component of a habitat management system for *Chilo partellus* in maize

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Apart from its well known soil conservation properties, vetiver grass (*Vetiveria zizanioides*) is reported to be repellent to many insect species. However, infestation of vetiver by pests of other crops has been recorded and concerns were raised about vetiver grass being a refuge for insect pests. In South Africa vetiver grass which is known in Africa for its soil conservation properties is often used as a barrier between crop fields to limit soil erosion. This plant species is therefore common on contours in hilly areas where resource-poor farming activities are practiced. This paper addresses the benefits that vetiver may have in control of pests. *Chilo partellus* , a lepidopterous stem borer of grasses is a pest that is often mentioned in vetiver literature. This insect is a serious pest of maize, rice and other grain crops in Asia and throughout East and Southern Africa where it can cause total crop failure. These observations prompted research on insect/vetiver grass interactions to determine the response of stem borer moths and larvae when they encounter *V. zizanioides* plants. The response of moths to vetiver grass, which could be either positive or negative, would determine if vetiver grass could be used as trap crop for *C. partellus* in an integrated pest management system. Wild grasses such as Napier grass (*Pennisetum purpureum*) is successfully used in habitat management systems in East and Southern Africa. Studies were therefore conducted to determine preference of female moths for vetiver grass compared to maize and to determine the suitability of vetiver, Napier grass and maize for survival of stem borer larvae. Two-choice preference bioassays and larval survival experiments were conducted. Results indicated that vetiver grass was highly preferred for oviposition but that larval survival on vetiver grass was extremely low. Thus, vetiver has potential as trap crop component in a habitat management system for *C. partellus*. This technology could also have application in rice pest management.

Habitat management affecting infestation of maize by stem borers and borer parasitism

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Effect of intercropping of maize with haricot bean and push-pull on infestation of maize by stem borers and parasitism was studied in a field experiment during the 2004 cropping season at Melkassa. Intercropping had no effect on pest and plant variables as a result of low pest infestation. The land equivalent ratio was higher in inter- than mono-crop. Intercropping maize and sorghum with bean at a 2:1 ratio gave the highest economic value. In the push-pull trials, yield was negatively related to borer infestation and stem damage. Highest yields per plot was recorded from plots with very good establishment of Napier grass and desmodium at neutral pH. Establishment of desmodium and Napier grass varied from site to site, and poor establishment was observed in plots with lower pH. In most cases pH was lower in the control plots than plots with push-pull plants.

Economics of biological control of cereal stem borers in Kenya

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The Asian braconid larval parasitoid *Cotesia flavipes* was released in Kenya 1993 for the control of the invasive cereal stemborer *Chilo partellus*. This study assesses the economic impact of the introduced parasitoid. Temporal data on parasitism and pest density were obtained from ICIPE data bank while socio-economic data were collected through administration of questionnaire to 300 farmers. Economic impact of the project was calculated as the value of the yield loss abated. Yield loss abated was calculated based on the percentage reduction in stem borer density by the parasitoid. Average annual parasitism increased from the time of introduction to 18-35% parasitism by 2004 leading to 33.7% reduction stem borer density. The Project will accumulate a Net Present Value of US $ 180.7 million in economic benefits in 20 years. The internal rate of return was 78% signifying high return to investment. Introduction of egg and pupal parasitoids is required to push yield loss to insignificant level.

Impact of the parasitoid *Cotesia flavipes* Cameron (Hymenoptera : Braconidae) on the spotted stemborer *Chilo partellus* (Swinhoe) (Lepidoptera : Crambidae) in Eastern Uganda

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A study was conducted in Kumi and Iganga district of eastern Uganda to monitor the impact of the exotic parasitoid *Cotesia flavipes* Cameron (Hymenoptera:Braconidae) on stemborer population dynamics, its spread to other areas and the associated yield advantages from the classical biological control programme. On farm trials were conducted in two sub-counties at each district. One sub-county was a release site and the other a non-release site of *C. flavipes*. Two fields were established at each sub-county. Destructive sampling of maize plants/sorghum initiated 3-5 weeks after plant emergence and continued until harvest to determine stemborer density. Four stemborer species were found on sorghum and maize and they were *Chilo partellus* , *Busseola fusca*, *Eldana saccharina* and *Sesamia calamistis* in decreasing order of abundance. *C. flavipes* was recovered from all field sites and was the most abundant stemborer parasitoid even at non-release sites. Parasitism rates on *C. partellus* ranged from 3.5% to 73.3% and were generally higher in Kumi than in Iganga district. Maize grain yields were significantly higher in parasitoid release than in non-release areas. The damage due to stemborer was also lower in the release than non-release site. The results show that the introduced parasitoid is beginning to have a negative impact on *C. partellus* population.

Assessment of the impact of natural enemies on stem borer infestations and yield loss in maize using selected insecticides in Mozambique

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The effect of natural enemies on the stem borers infestation and yield loss of maize was estimated using insecticide treatments. Field experiments were conducted at low, mid and high elevation zones which have distinct stem borer species composition. A selective organophosphate insecticide, Dimethoate, was used to exclude natural enemies from the plots. Cypermethrin insecticide was applied on other plots to suppress stem borers while untreated plots served as control. In all the study sites more stem borer larvae and pupae were collected from the plots where natural enemies were excluded. Parasitoids and parasitism levels as well as maize grain weight in the yield losses in unprotected plots were significantly high compared to exclusion plots. Yield losses increased from 28.9% in unprotected to 43.3% in exclusion plots. Thus, removing natural enemies from the maize plants led to an increase of stem borer population and yield losses.

Release, establishment and spread of *Cotesia flavipes* (Cameron)(Hymenoptera : Braconidae) in Tanzania

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In 2002, the Ministry of Agriculture and Food Security (MAFS), Tanzania and the International Centre of Insect Physiology and Ecology (ICIPE) initiated a classical biological control strategy against *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) by introducing a larval parasitoid, *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae). Baseline surveys were conducted in order to determine the distribution, abundance and damage severity of *C. partellus* , and to select suitable sites before releasing the parasitoid. By December 2004, about 2,000,000 cocoons of *C. flavipes* had been imported from ICIPE and released in 43 locations in four agro ecological zones including the eastern, lake, central and northern zones. Post release surveys were conducted between June 2003 and June 2005 to determine the establishment and spread of the parasitoid. Post release surveys revealed the recovery of *C. flavipes* in all release sites, and 144 new locations in six agro ecological zones including the southern highlands where the parasitoid was never released. In 2002 percentage parasitism ranged from 0.5 to 4% and by 2005 parasitism rates were up to 41.7% in some areas.

Release and establishment of *Cotesia flavipes* (Hymenoptera : Braconidae) an exotic parasitoid of *Chilo partellus* (Lepidoptera : Crambidae) in Eastern and Southern Africa

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Cotesia flavipes Cameron (Hymenoptera: Braconidae) was imported into Kenya in 1991 from Pakistan for control of *Chilo partellus* Swinhoe (Lepidoptera: Crambidae). First releases were made at the Kenya coast in 1993 and establishment from this release was documented in 1994. Additional foreign exploration for *C. flavipes* was conducted in the south of India in 1996, which resulted in additional importation of the parasitoid for additional releases in eastern and southern Africa. Region-wide releases commenced with releases in Mozambique in 1996; Uganda and Somalia in 1997. By 2005 many releases had been made in 9 countries in eastern and southern Africa with establishment being reported in 10 countries including Ethiopia where releases were never made. It took up to five years to detect establishment of the parasitoid from time of release.

Will Bt-maize solve the stem borer problem in Africa?

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South Africa is the only African country where Bt-maize, containing the Cry 1A(b) gene that encodes a protein with insecticidal activity against *Busseola fusca*, is used to control this pest. In the short history of Bt-maize in South Africa lessons were learnt that are of importance to the rest of Africa where releases of Bt-maize is envisaged. Research has shown that *B. fusca* is effectively controlled by Bt-maize but that poor control is often observed with post-anthesis infestations and in poorly-adapted maize hybrids. Late infestations result in survival of larvae and subsequent emergence of moths form diapause larvae inside Bt-plants. During surveys in South Africa several Lepidoptera species that feed on Bt-maize and are exposed to Bt-toxin was recorded. These were all Noctuidae and included the stem borers, *B. fusca* and *Sesamia calamistis*, two leaf feeders, *Acantholeucania loreyi* and *Helicoverpa armigera*, and a webworm, *Eublemma gayneri*. Cutworm, *Agrotis segetum*, also completed its life cycle on Bt-maize seedlings. Results on Lepidoptera diversity in Bt maize will be presented and the potential impact of Bt-maize on non-target Lepidoptera discussed.

APPENDIX 3 – Paper presented at ICLCBA

A Review of Sugarcane Stemborers and their Natural Enemies in Asia and Indian Ocean Islands: An Australian Perspective.

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Running title:	**Sugarcane borers, an Australian perspective (Sallam MN).**

Abstract
This paper provides a review on stemborer pests of gramineous crops in Asia and Indian Ocean Islands which have the potential to invade Australia. Information on the geographical distribution, host plants and potential of invading Australia is provided for 24 stemborer species with special reference to those mainly attacking sugarcane. A literature review of all natural enemies of 18 key pest species is provided. The paper lists a total of 276 species of parasitoids, predators and pathogens recorded on these pests, with information on the host stage they attack, host plant or crop where they were recorded and country of record. The list includes all records of indigenous natural enemies, as well as introduced ones that are recorded to have established in the country of introduction. This information will facilitate quick decision making in case of a sudden detection of an exotic borer in Australia. A knowledge of possible biological control options is essential to determine which natural enemies are to be considered for introduction following an incursion. Efforts from biological control programs attempted overseas are highlighted to provide insight into the complexity of this approach, and to assist in arriving at a correct decision within an acceptable length of time. The Braconid, *Cotesia flavipes*, stands out as a promising candidate for introduction into Australia following a borer incursion. Studies are currently being conducted on a native *Cotesia* species in Australia, which may be able to parasitize larvae of exotic borers, therefore minimizing the need for other parasitoids introductions.

Résumé
Les données sur la distribution géographique, les plantes hôtes et le potentiel d'envahir l'Australie sont présentées pour 24 espèces de foreurs de tiges, avec une importance particulière accordée a celles attaquant la canne à sucre. Une revue de la littérature de tous les ennemis naturels de 18 ravageurs majeurs est fournie. Un total de 276 parasitoïdes, prédateurs et pathogènes de ces ravageurs sont incorporés dans cette liste qui comprend des informations sur le stade de l'hôte attaqué, la plante hôte (cultivée ou non) et le pays où la collecte a eu lieu. La liste inclut toute collecte d'ennemis naturels indigènes, et aussi d'espèces introduites qui se sont établies dans le pays d'introduction. Ces informations faciliteront une prise de décision rapide en cas de détection d'un foreur exotique en Australie. La connaissance des possibilités de lutte biologique est essentielle pour déterminer les ennemis naturels à introduire après l'invasion d'un ravageur exotique. Les programmes de lutte biologique à travers le monde sont présentés pour montrer la complexité de cette approche et aussi pour aider la prise de décision dans un délai acceptable. Le Braconidae *Cotesia flavipes* (Cameron) apparaît comme un candidat prometteur pour une introduction en Australie après l'invasion d'un foreur exotique. Des études sont actuellement conduites en Australie sur une espèce indigène de *Cotesia* qui serait capable de parasiter des larves de foreurs exotiques, ce qui réduirait la nécessité d'introduire d'autres parasitoïdes.

Key words: Stemborers, sugarcane, Australia, natural enemies, *Chilo*, *Sesamia*, *Scirpophaga*, *Maliarpha*, *Acigona*, *Argyroploce*, *Cotesia*

Introduction
Lepidopterous stemborers are major pests of gramineous crops in most countries of the world (Harris 1990; Polaszek 1998; Kuniata 1999). Most stemborers attack a range of host plants such as maize, sorghum, millet, rice, sugarcane as well as a vast range of wild grasses, which were mainly their natural hosts before the development of subsistence farming and large scale monoculture. Fortunately, Australia does not harbour major stemborer species, however, species of *Chilo*, *Sesamia*, *Scirpophaga*, *Maliarpha*, *Acigona* and *Argyroploce* are widely distributed in countries to the north of Australia. A number of these mainly attack sugarcane while others attack maize, sorghum or rice, but can exploit sugarcane for their development. The incursion of any of these pests into Australia would result in severe consequences to the Australian sugar industry, especially when some of these pests reach the immediate north of the Australian continent. For example, one notorious pest of cane, *Sesamia grisescens* Warren (Lepidoptera: Noctuidae), occurs in Papua New Guinea (PNG), where infestation in the early nineties resulted in sugar production losses of up to 8.4 million US dollars (Kuniata & Sweet 1994). Measurements of preparedness for possible borer incursion into Australia have been formulated with details on steps to be taken once a pest is detected (Allsopp *et al.* 2000). One aspect of the preparedness for incursion is to pave the way for importation of a host-specific and efficient natural enemy. Hence, it is important to identify major borer species and their natural enemies in neighbouring countries to be able to recognize the most suitable candidate for importation into Australia in case of incursion.
Several successful attempts of classical biological control (CBC) of gramineous stemborers are well documented, such as the notable success of the establishment of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) in East Africa and Indian Ocean islands on a range of stemborer species (Rajabalee & Governdasamy 1988; Polaszek & Walker 1991; Overholt *et al.* 1997). However, not all attempts of stemborers CBC have resulted in the establishment of the introduced natural enemies or in any significant degree of control. For example, several attempts to introduce the tachinid *Lydella striatalis* (*Diatraeophaga striatalis*) from Java into the Indian Ocean islands for the control of *Chilo sacchariphagus* had no apparent success (Brenière *et al*. 1966; Appert 1973; Brenière *et al*. 1985; Polaszek 1998). In 1968, *Pediobius furvus* (Hymenoptera: Eulophidae) was introduced from Africa into Madagascar and Pakistan, but did not survive the cold season in Pakistan, though it was recorded to have established in Madagascar on *Sesamia calamistis* (Mohyuddin 1970). In South Africa, 13 species of stemborer parasitoids were introduced between 1977 – 1993 for the control of *C. partellus* and other borer species, but none seems to have established. Reasons responsible for the failure of a natural enemy to establish in a new geographical area could be harsh climatic conditions, competition from native species, inaccurate identification of the pest in focus or the natural enemy to be introduced, host incompatibility or the release of low numbers of the enemy in the area of introduction (Mackauer *et al.* 1990; Hopper & Roush 1993; Noyes & Hayat 1994; Kfir 1997; Schauff & LaSalle 1998). The theory that some natural enemies can be "habitat specific" rather than "host specific" has been postulated (Mohyuddin *et al.* 1981; Inayatullah 1983). For example, Carl (1962) found that *Co. flavipes* was unable to parasitize *Scirpophaga nivella* and *Chilo infuscatellus* in cane fields, though the parasitoid is recorded to attack *C. infuscatellus* in cane in Taiwan and India, therefore he suggested that "racial differences" between populations within the same species is responsible. Similarly, *Co. flavipes* was introduced into Pakistan from Japan in 1962 and was established in maize fields but was rarely recorded in cane fields. This led to importing other "sugarcane

adapted strains" from Thailand, Indonesia and Barbados, which resulted in parasitoid establishment (Mohyuddin *et al*. 1981; Mohyuddin 1990; Shami & Mohyuddin 1992). However, Potting *et al.* (1997) found no differences in host selection among six different geographical *Co. flavipes* strains, and attributed behavioural differences reported earlier to variations in the reproductive success of local strains on local host populations. Therefore, prior to any release attempts of a natural enemy, a study of its geographical distribution, host range and history of introductions is required. This paper reviews the distribution of key stemborer species in Asia and Indian Ocean islands that have the potential of invading Australia, and provides a catalogue of their old and new-association natural enemies recorded over the past 100 years. This information provides an overall picture of successful attempts of CBC against stemborers in Asia and Indian Ocean islands, thus will help in selecting the most suitable natural enemy in case of a pest incursion into Australia.

Moth borers can be loosely classified into three groups according to the part of the plant they usually attack: shoot borers; top borers or stalk borers, however a species may not be restricted to one part of the plant (Allsopp *et al.* 2000). The term "stemborer" is used here to include all species in those three groups. With the exception of *Emmalocera depressella* Swinhoe, which is a root borer, and *Angustalius malacellus* Duponchel, which feeds below soil level, all other species mentioned here feed inside the plant above ground level. Other sugarcane key borer species such as *Eldana saccharina* (Walker) and *Diatraea* spp. are major pests in Africa and central and South America respectively. Detailed information on biological control programs of *Eldana saccharina* can be found in Carnegie *et al.* (1985) and Conlong (1997). Information on biological control of *Diatraea* spp. can be obtained from Rodriguez-del-Bosque *et al*. (1990), Smith *et al.* (1993) and Smith (1994). The followings are brief annotations on key gramineous borer species in Asia and Indian Ocean Islands. Information on their economic importance, host range, geographical distribution and potential of invading Australia are presented.

Family: Crambidae

***Angustalius* (*Bleszynskia*) *malacellus* Duponchel**

Very little is known about this species which is an early-shoot borer that attacks sugarcane and corn. This species is recorded from Mauritius (Williams 1978), and Italy, where Zangheri & Furlan (1998) recorded a pest outbreak in the summer of 1997 on corn in Veneto. Larvae bore into the young shoots below soil level and cause dead heart (Williams 1978). No records of natural enemies are available on this species. Invasion potential into Australia is unknown.

***Chilo auricilius* Dudgeon**

This species is distributed in China, India, Sri Lanka, Burma, Hong Kong, Bangladesh, Nepal, Taiwan, Vietnam, Formosa, Philippines, Thailand, Indonesia, Moluccas, Celebes, Borneo (Bleszynski 1970; Chundurwar 1989; David & Easwaramoorthy 1990). Kumar *et al.* (1987) stated that the expansion of planting soft but high sugar varieties and excessive usage of nitrogen fertilizers caused this species to become a serious pest in the Bihar state of India. This species is also a major pest of sugarcane in western Uttar Pradesh (U.P.) in India since its appearance in 1954 (Atwal 1962; Rai *et al.* 1999). *C. auricilius* also feeds on rice and is one of its major pests in some parts of Bangladesh and India (Husain & Begum 1985; Neupane 1990). It is however regarded as a minor pest of rice in some parts of PNG (Li 1990). This species was known to mainly feed on sugarcane in Indonesia until (Hattori & Siwi 1986) reported it to feed on rice for the first time in Java and South Kalimantan. Other hosts also include maize and sorghum (Huang *et al.* 1985; Chundurwar 1989; Harris 1990). Incursion potential of *C. auricilius* into Australia is high, and it also has a high colonisation potential in all sugarcane growing areas (Sallam & Allsopp 2002a).

***Chilo infuscatellus* Snellen**

This species is a major pest of sugarcane, but also attacks maize, millet, sorghum, rice, barley, oat, juar, *Saccharum spontaneum*, *Panicum* spp., *Rottboellia compressa, Cynodon dactylon*, *Echinochloa colonum* and *Cyperus rotundus* (Bleszynski 1970). The pest is distributed in the Former USSR, Afghanistan, Tadzhikistan, Central Asia, China, Nepal, Korea, Taiwan, Pakistan, India, Bangladesh, Burma, Malaysia, Indonesia, the Philippines, Thailand, south Vietnam, Formosa, Sri Lanka, Java, Timor, Vulcan Island and PNG (Carl 1962; Bleszynski 1970; CAB 1972; Chundurwar 1989; Harris 1990; Neupane 1990). This species is considered a minor pest of sugarcane at Ramu and on Vulcan Island (PNG). In 1981- 1982, the larval parasitoid *Bracon chinensis* (Szépl), and an Indian strain of *Apanteles flavipes* were introduced to PNG but neither of them seem to have established (Li 1990). *C. infuscatellus* has a high incursion and colonisation potential in Australia (Sallam & Allsopp 2002a).

***Chilo orichalcociliellus* (Strand)**

This species is native to Africa where it attacks maize, finger millet, sugarcane, *Panicum maximum*, *Pennisetum purpureum* and *Sorghum* spp. It occurs in Kenya, Tanzania, Eritrea, Congo, Nigeria, Malawi, South Africa and Madagascar (Mathez 1972; Hill 1983; Polaszek 1998; Haile & Hofsvang 2001). *C. orichalcociliellus* may not be an economic pest of sugarcane. The importance of this pest species has been declining in Africa since the 1970s due to the invasion of the exotic *C. partellus* (Overholt *et al.* 1997) into Africa. No recent data is available on the impact of this pest on sugarcane, and no information is available on its biological control outside mainland Africa. *C. orichalcociliellus* has a medium potential of invading Australia (Sallam & Allsopp 2002a).

***Chilo partellus* (Swinhoe)**

C. partellus is indigenous to Asia where it is recorded in Afghanistan, Pakistan, India, Bangladesh, Cambodia, Indonesia, Laos, Nepal, Sri Lanka, Thailand, Vietnam and the Philippines. The first report of this species in Africa was from Malawi in 1932 (Tams 1932). Since then, the pest has colonized several Eastern and Southern African countries as well as Madagascar and Comoros (Ingram 1948; CAB 1989, Chundurwar 1989; Meijerman & Ulenberg 1996; Maes 1998), and there is evidence that it is gradually displacing *C. orichalcociliellus* in some parts of Africa (Ofomata *et al.* 2000). Hosts include pearl millet, finger millet, *Sorghum* spp., *Eleusinae coracaua*, *Panicum maximum* and *Pennisetum purpureum* (Chundurwar 1989). *C. partellus* is a major pest of maize, sorghum and rice in southern Asia but less important in sugarcane (David & Easwaramoorthy 1990; Neupane 1990). *C. partellus* has a medium potential of invading Australia but would have a high colonisation potential (Sallam & Allsopp 2002a).

***Chilo polychrysus* (Meyrick)**

This is a similar species to *C. auricilius* and confusion may exist where the two species overlap (Barrion *et al.* 1990). Li (1970) recorded this species as a minor pest of rice in Northern Territory, Australia, though the species identified then may have belonged to another unidentified species similar to *C. polychrysus* (T Edwards, personal communication). *C. polychrysus* occurs in China, India, Thailand, Malaysia, Indonesia, Burma, Bangladesh, Vietnam and PNG (Hattori & Siwi 1986; van Verden & Ahmadzabidi 1986). The morphological similarity to *C. auricilius* led to earlier erroneous records of *C. polychrysus* in the Philippines. Rice is the main host but it also attacks maize and sugarcane though maybe of limited importance in that crop (David & Easwaramoorthy 1990). Hosts also include *Oryza latifolia*, *Setaria* sp., *Cyperus* sp., *Eriochola* sp. and *Panicum* sp. (Kalshoven 1981). Frequent outbreaks of *C. polychrysus* in Malaysia were common in rice fields before the introduction of double cropping of short-maturing varieties (Khoo 1986). Li (1970) reports the braconid *Apanteles flavipes* and the chalcidid *Euchalcidia* sp. as larval and pupal parasitoids. The possibility of the Australian population surviving in sugarcane should be investigated (Sallam & Allsopp 2002a).

***Chilo sacchariphagus* (Bojer)**
This is a synonym of *C. venosatus* (*Proceras venosatus*) Walker. *C. sacchariphagus* is a major pest of sugarcane in China, India, Indonesia, Madagascar, Taiwan and Mauritius (where it was accidentally introduced from Java in 1850). *C. sacchariphagus* is also an important pest of sorghum in some parts of China (Chundurwar 1989). It also occurs in Reunion and the Comoros, Japan, Singapore, Sri Lanka, Malaysia, Thailand and the Philippines (Kalshoven 1981; Williams 1983; Facknath 1989; Leslie 1994; Ganeshan and Rajabalee 1997; Suasa-ard 2000). This species is a major pest of sugarcane, and it has been recently recorded for the first time on main land Africa from Mozambique (Way & Turner 1999). This species is oftenly treated as three "sub-species": *C. sacchariphagus stramineellus* (Caradja), *C. sacchariphagus sacchariphagus* (Bojer) and *C. sacchariphagus indicus* (Kapur). Incursion potential of *C. sacchariphagus* into Australia is medium, but the pest is readily transmitted on infected planting material and would have a high spread and colonisation potential in all sugarcane-growing areas (Sallam & Allsopp 2002a).

***Chilo suppressalis* (Walker)**
This species is reported mainly on rice from Zanzibar, Iraq, former USSR, China, Japan, Korea, Taiwan, Bangladesh, Brunei, Burma, India, Pakistan, Malaysia, Indonesia, Nepal, Philippines, Sri Lanka, Thailand, Vietnam and PNG. Also recorded from Hawaii and Spain where it was accidentally introduced (Subba Rao & Chawla 1964; Harris 1990). Li (1970) recorded this species on rice in the Northern Territory of Australia. Rice is the main host, however, David & Easwaramoorthy (1990) referred to this species as a minor pest of cane in Taiwan and Japan. Other hosts may include sorghum, *Panicum miliaceum*, *Echinochloa* spp., *Phragmites communis*, *Typha latifolia*, *Zizania latifolia* and *Z. aquatica* (Litsinger 1977; Ishida *et al.* 2000). Cuong & Cohen (2002) demonstrated that records of this species from non-rice host plants are doubtful. The pest is present in Australia but not in sugarcane areas; survival of the Australian population on cane plants is an area worth investigating.

***Chilo terrenellus* Pagenstecher**
This species is native to PNG where it attacks *Saccharum* hybrids, and has been recorded in Bismarck Archipelago and Vulcan Island (Bleszynski 1970; Li 1985a; Kuniata 2000). *C. terrenellus* was first recorded in Australia on the Torres Strait islands of Saibei and Dauan (Gough & Peterson 1984; Chandler & Croft 1986; Anon. 1996). The status of *C. terrenellus* in PNG has changed in the late 1980s due to the adoption of "Ramu stunt" resistant cultivars, which were also *Sesamia* susceptible. Since 1987, severe cane losses were sustained due to *Sesamia grisescens*, while losses in young cane shoots due to *C. terrenellus* are usually less than 10% (Li 1990). The probability of this species invading Australia is high as it is found on the Torres Strait islands to the immediate north of Australia (Sallam & Allsopp 2002a). Though the importance of *C. terrenellus* is less than that of *S. grisescens* in PNG (Kuniata 2000), its status may change if it invades Australia and could potentially cause significant damage to Australian cane.

***Chilo tumidicostalis* (Hampson)**
This species is found in Bangladesh, Burma, India, Nepal and Thailand (Bleszynski 1970; Miah *et al.* 1983; David & Easwaramoorthy 1990; Suasa-ard 2000), and is reported to feed exclusively on sugarcane. This species used to be a major cane pest in India but its importance declined in the 1980s (Kumar *et al.* 1987). Yet it unexpectedly became a key pest of cane in Thailand in the late 1990s (Suasa-ard 2000). Incursion potential of *C. tumidicostalis* into Australia is medium, however the pest would have a high spread and colonisation potential in cane-growing areas specially in North Queensland (Sallam & Allsopp 2002a).

Family: Noctuidae
***Sesamia calamistis* Hampson**
This species is recorded in South Africa, Malawi, Zimbabwe, Uganda, Tanzania, Kenya, Angola, Nigeria, Ivory coast, Cameroon, Senegal, Gambia, Ghana, Madagascar, Mauritius, Reunion and Zanzibar (Meijerman & Ulenberg 1996, Holloway 1998). Host plants include rice, maize, sorghum, millet, sugarcane, *Panicum maximum*, *Paspalidium paniculatum, Paspalum conjugatum*, *Paspalum urvillei* and several other wild grasses (Tams & Bowden 1953; Nye 1960; Harris 1962; Meijerman & Ulenberg 1996). Maize is the preferred host plant (Heinrichs 1998), but the species is frequently found on sugarcane in Africa though rarely of economic importance. Damage tends to be confined to young shoots and plants can compensate by tillering (Leslie 1994; Polaszek & Khan 1998). Entry potential of *S. calamistis* to Australia is medium, but will have a high colonisation potential in all sugarcane-growing areas (Allsopp & Sallam 2001).

***Sesamia cretica* Ledrere**
This species is recorded from France, Italy, Croatia, Greece, Morocco, Algeria, Egypt, Sudan, Ethiopia, Somalia, northern Kenya, northern Nigeria, Syria, Tadzhikistan, Iraq, Iran, Saudi Arabia, Yemen, India, Sri Lanka and Thailand. Host plants include cane, rice, millet, sorghum, Johnson grass, wheat, maize, oat, barley and Tomato (Meijerman & Ulenberg 1996; FitzGibbon *et al.* 1998; Holloway 1998). This species is a major pest of maize and sugarcane in Egypt, where it has been thought of as a shoot borer but was found to damage more mature stalks (Temerak & Negm 1979; El-Amin 1984; Soliman & Miham 1997). In Iran, *S. cretica* is reported to cause up to 70% damage during population outbreaks (Shojai *et al.* 1995). *S. cretica* has a medium entry potential to Australia but may have a high colonisation potential (Allsopp & Sallam 2001).

***Sesamia grisescens* Warren**
This species is geographically restricted to its native home (PNG), where it occurs from sea level to 1600 m above sea level. *S. grisescens* feeds on indigenous *Saccharum* species such as *S. robustum*, *S. spontaneum* and *S. edule*, along with *Panicum maximum* and *Pennisetum purpureum* (Young & Kuniata 1992; Lloyd & Kuniata 2000). *S. grisescens* has become a major cane pest in PNG due to planting of varieties resistant to Ramu Stunt but on the same time "*Sesamia*–susceptible". In PNG, *Apanteles* (*Cotesia*) *flavipes* occurs naturally where it parasitises medium - large *Sesamia* and *Chilo* larvae. In 1981-1982, an Indian strain of *C. flavipes* was introduced to PNG but apparently did not establish (Kuniata 1998; Lloyd & Kuniata 2000). The pupal parasitoid *Pediobius furvus* was imported from East Africa in 1991 and released in PNG against this pest where it gives variable parasitism rates. *S. grisescens* has a high entry potential into Australia, and will have a high colonisation potential in all Australian sugarcane-growing areas (Allsopp & Sallam 2001).

Sesamia inferens Walker
This species is a key sugarcane pest in Japan and a major pest of rice in India and Bangladesh (Husain & Begum 1985; Shahjahan & Talukder 1995; Kumar & Kaul 1997). It occurs in Pakistan, Sri Lanka, Taiwan, China, Korea, Burma, Nepal, Cambodia, Vietnam, Laos, Thailand, Philippines, Malaysia, Singapore, Indonesia, PNG and Solomon Islands (CIE 1967; David *et al.* 1991; Cheng 1994; Teetes *et al.* 1983; Hattori & Siwi 1986). *S. inferens* attacks wheat, maize, oats, millet, reed, Guinea grass, Johnson grass, Sudan grass and lemon grass. It is also reported to attack bananas and seedlings of oil palm (Shah & Garg 1986; Garg 1988; Hirai 1991; Alam *et al.* 1993; Li 1993; Jacob & Kochu 1995). Corn and upland rice are favoured hosts than sugarcane in South Eastern Asia (Kalshoven 1981). The entry potential of *S. inferens* and its colonisation potential in Australia are high due to its closeness to Australia (Allsopp & Sallam 2001).

Sesamia nonagrioides Lefebvre
This is a similar species to *S. calamistis*. It is distributed in the Azores, Canary Islands, France, Greece, Turkey, Israel, Iran, Italy, Portugal, Spain, Ghana, Ivory Coast, Nigeria, Togo and Sudan. It attacks maize, rice, sorghum, sugarcane and several wild grasses (Tams & Bowden 1953; Meijerman & Ulenberg 1996). Cane does not seem to be a preferred host (Hilal 1984, 1985). *Platytelenomus busseolae* (*Telenomus busseolae*) is recorded to be an active egg parasitoid of this pest in maize fields in Turkey (Sertkaya & Kornosor 1994). *S. nonagroides* has a medium entry potential to Australia (Allsopp & Sallam 2001).

Sesamia penniseti Tams & Bowden
This species is similar to *S. calamistis*, *S. nonagrioides* and *S. poephaga*, but mainly distributed in West Africa and more frequently found in forest localities than *S. poephaga* (Tams & Bowden 1953; Holloway 1998). Host plants include rice, sorghum, cane, corn, pearl millet, Guinea grass, elephant grass (Rao & Nagaraja 1969; Meijerman & Ulenberg 1996, Heinrichs 1998). *S. penniseti* has a medium entry potential to Australia (Allsopp & Sallam 2001).

Sesamia poephaga Tams & Bowden
This is a very close species to *S. calamistis* and *S. nonagrioides*. Host plants include Maize, sorghum, sugarcane, Guinea grass and *Pennisetum purpureum*, which is the usual food plant (Tams & Bowden 1953; Harris 1962). *S. poephaga* occurs in Ghana, Ivory coast, Kenya, Malawi, Nigeria, Sudan, Tanzania, Uganda, Togo, Zimbabwe, Comoros and Madagascar (Tams & Bowden 1953). This species may cause some significant damage to maize and sorghum, but it is less important on sugarcane. This pest has a low-medium entry potential to Australia (Allsopp & Sallam 2001).

Sesamia uniformis (Dudgeon)
This species is reported from Northern India, Pakistan and the Philippines (Rao & Nagaraja 1969). Host plants include rice, sorghum, wheat, corn, *Saccharum* hybrids and *Erianthus arundinaceus* (Rao & Nagaraja 1969). This species is perhaps a synonym of *S. cretica* (Polaszek 1998). Potential of invading Australia is medium (Allsopp & Sallam 2001).

Family: Pyralidae
Acigona steniellus (_Bissetia steniella_) Hamp
Little is known about this species which seems to have a restricted geographical distribution of only India and Pakistan and feeds exclusively on sugarcane (Halimie *et al.* 1994; Pandey *et al.* 1997b). *A. steniellus* has a low- medium potential of colonising and spreading in Australia. The impact of incursion of this species on sugarcane in Australia is difficult to predict.

Emmalocera (_Polyocha_) _depressella_ Swinhoe
This species feeds inside cane roots and underground parts of stems (Singh *et al.* 1996). It was recorded damaging sugarcane roots for the first time in Tamil Nadu (India) in a ratoon crop in 1989 (Alagesan *et al.* 1991), though it has been recorded earlier from other parts of India (Box 1953). *E. depressella* is also recorded from Pakistan (Khan & Jan 1994; Ashraf & Fatima 1996) and Bangladesh (Kundu *et al.* 1994). Sugarcane is the main host but it was also recorded for the first time feeding on sorghum in Karnal, India (Sardana 1999). Potential for incursion by this species into Australia is medium, but would rapidly colonise many cane growing areas and may have a high spread potential in Australia.

Maliarpha separatella Ragonot
This species is found on mainland Africa and Indian Ocean islands (Madagascar, Comoros, Mauritius and Reunion). It is also reported from Indonesia and PNG, and may occur in Burma and China (Young 1982; Li 1985a; Maes 1998; Ooi 1998). Though *M. separatella* is known to feed exclusively on rice, Li (1985a) recorded heavy damage to sugarcane in the Markham valley of PNG due to this species. Therefore the status and host range of this species in PNG need to be revised. Cook (1997) proposed that *M. separatella* is a complex of three closely related stemborers, and the species has a number of synonyms (*Enosima* (*Rhinaphe*) *vectiferella* Ragonot and *Anerastia* (*Ampycodes*) *pallidicosta*) Hampson (see Maes 1998). No natural enemies were reported from PNG. One active parasitoid of *M. separatella* in Africa is *Goniozus indicus*, which was introduced into Madagascar from Senegal in 1973 (Appert 1975). *M. separatella* has a high potential of colonising and spreading in Australia due to its presence in Indonesia and PNG.

Scirpophaga nivella (Fabricius)
This species is mainly a pest of rice. Its status in sugarcane is now doubtful since Lewvanich (1981) stated that it does not occur in cane, and mostly all records of this species in cane are referrable to *S. excerptalis*. The Checklist of the Lepidoptera of Australia (Nielsen *et al.* 1996) uses the name *chrysorrhoa* as an alternative species name for *S. nivella.* Under that name, Common (1960) indicates that it is found in Northern Australia and Northern NSW. This species is also recorded from Bangladesh, Borneo, Hong Kong, India, Indonesia, Malaysia, Pakistan, the Philippines, Singapore, Sri Lanka, Taiwan, Thailand and Vietnam (Cheng 1999; Arora 2000). The fact that *S. chrysorrhoa* in Australia is the same species as *S. nivella* in Asia requires examination. However, the Australian population has never been recorded in Australian cane fields.

Scirpophaga excerptalis Walker
S. excerptalis is a key pest of sugarcane in Asia (Shenhmar & Brar 1996a; Tanwar & Varma 1997). It is found in Bangladesh, Bhutan, China, India, Indonesia, Japan, Malaysia, Nepal, Pakistan, Philippines, PNG, Singapore, Sri Lanka, Taiwan, Thailand and Vietnam (Miah *et al.* 1983; Arora 2000; Kuniata 2000; Suasa-ard 2000). *S. excerptalis* is mainly a pest of sugarcane, but also attacks sorghum and several wild grasses (Arora 2000). *S. excerptalis* has for a long time been erroneously referred to as *S. nivella* (Lewvanich 1981). *S. excerptalis* has a high entry potential into Australia, and a high colonisation potential in all Australian sugarcane-growing areas.

Family: Tortricidae
***Tetramoera* (*Argyroploce*) *schistaceana* (Snellen)**
This species is an early-shoot borer of sugarcane that is found in Mauritius, Reunion, Sri Lanka, China, Taiwan, Japan, Vietnam, Malaysia, the Philippines and Indonesia (Williams 1978; Allsopp *et al.* 2000). Guo *et al.* (2000) recorded *T. schistaceana* as a dominant pest in sugarcane plantations in China, where it occurs coincidentally with *C. infuscatellus* and *C. sacchariphagus*. *T. schistaceana* is frequently controlled using *Trichogramma* and *Trichogrammatoidea* spp. in China, Taiwan and the Philippines (Pan & lim 1979; Liu *et al.* 1987; Alba 1991). The potential of this species to invade Australia is medium, but may be able to spread in all cane growing areas.

Lepidopterous borers in Australia
***Bathytricha truncata* (Walker) (Lepidoptera: Nocyuidae)**
This species is found in New South Wales and Queensland on rice, sugarcane, *Echinochlea* spp., *Typha* spp. and *Cyperus* sp. (Jones 1966). Larvae feed inside the growing point of young cane causing dead hearts. Bell (1934) also reports *Apanteles flavipes* (*nonagriae*) as a larval parasitoid collected in the Mackay district. One pupal parasitoid was identified as *Euplectrus howardi* (Eulophidae) (Jarvis 1927). Macqueen (1969) and Li (1970) mention that *B. truncata* had become economically important in Queensland due to the destruction of its natural enemies as a result of the use of dieldrin for soldier fly control. Recently this species is rarely seen in Australian cane fields.

***Ephysteris promptella* (Staudinger) (Lepidoptera: Gelechiid)**
Larvae of this species bore into young shoots, often killing them and causing dead hearts. Damage is restricted to ratoons and usually occurs under drought conditions. No natural enemies are recorded on this pest probably because it is an introduced species, possibly from Indonesia (Jarvis, 1927). The pest is also reported to attack maize and sorghum in South Africa (Drinkwater 1986).

Other species also include the pyralid *Fossifrontia* (*Polyocha*) sp., which caused dead hearts in cane ratoons and gave similar damage symptoms to *B. truncata* or *E. promptella* (Jarvis, 1927). In addition, Sallam & Allsopp (2002b) recorded minor damage in a ratoon crop on the Atherton Tableland in the summer of 2000. Failed plants had about 20 larvae of *Oncopera* sp., possibly *Oncopera mitocera*, under each stool, but there was no evidence that the damage is caused by the larvae. In the laboratory, larvae fed on cane setts but never on the shoots and did not complete their life cycle, therefore the cause for failed ratooning was attributed to possible harvest damage.

The following table presents all records made of natural enemies of gramineous stemborers in Asia and Indian Ocean islands over the last century. A number of scientific names have been changed or revised and corrected over that period. For example, natural enemies of cane pests in India were listed by Butani in 1958 and later in 1972, during that period some names have changed and others that were erroneously applied to various species have been corrected. Information from the two lists is presented here to account for these inconsistencies. References were numbered from 1 – 154; the species name and country of record where followed by the reference number in cases of multiple entries or where plant hosts included crops other than sugarcane. A note is made on the status and origin of the natural enemy where relevant. Natural enemies of doubtful status or those recorded to exploit a certain host only in the laboratory were not included in this list. Some pests such as *C. partellus* and *S. calamistis* are widely distributed in main land Africa, while others such as *S. cretica* extend to Southern Europe, but only natural enemies recorded in Asia and Indian Ocean islands are presented here. Information on natural enemies of these pests in main land Africa can be found in (Polaszek 1998).

The table lists a number of 276 natural enemy species of 18 key pests of gramineous plants. The current list indicates that the majority of species recorded as biological control agents of stemborers in Asia are mainly native, and that successful CBC attempts were limited to only a few number of introductions. Two main parasitoids had the highest number of recorded introductions and establishments, and these are *Cotesia flavipes* and *Xanthopimpla stemmator*. Based on this work and several previous studies, *Co. flavipes* stands out as an efficient natural enemy of most of the key stem boring pests in the neighbouring countries. According to the table, *Co. flavipes* is capable of parasitizing 15 out of 18 stemborer pest species distributed in Asia and Indian Ocean islands. Though there are no records of *Co. flavipes* attacking *S. calamistis* in Mauritius, the parasitoid is recorded to attack that host in mainland Africa (see Ngi-Song et al 1995; Polaszek 1998; Sallam *et al.* 1999; Sallam *et al*. 2001). Other *Chilo* species, such as *C. orichalcociliellus*, are also attacked by *Co. flavipes* in corn in main land Africa (see Ngi-Song *et al.* 1995; Potting 1996). *Co. flavipes* is also recorded to parasitize a fairly wide range of stemborer species of the new world genus *Diatraea* in South America and southern USA (Rodriguez-del-Bosque *et al.* 1990; Overholt *et al.* 1997). However, the record of *Apanteles* (*Cotesia*) *flavipes* on *Scirpophaga excerptalis* is doubtful (see table), since female parasitoids are incapable of reaching host larvae inside the growing point, though may sting the host under laboratory conditions (Sallam, personal observation). *Co. flavipes* is also recorded on other *Scirpophaga* species in Asia, such as *S. innotata* and *S. incertulas* in rice fields (Nath & Hikim 1978; Reissing *et al.* 1986). *Co. flavipes* is a species originally native to the Indo Australian region, and it has been introduced into several countries for the control of pyralid and noctuid borers. Some remarkable successes of the establishment of this species are reported, for example, Appert *et al.* (1969) report a 2000 tons reduction in sugar losses in one state of Madagascar due to the control of *C. sacchariphagus* following the introduction of *Co. flavipes* in the late fifties. In Barbados, *Co. flavipes* was introduced from India in 1966 and recorded to have achieved parasitism levels of up to 80% against *D. saccharalis* (Simmonds 1969). The same parasitoid was also introduced into Brazil, where it is continuously mass released for the control of *D. saccharalis* in cane. Though the Brazilian approach does not strictly fit the definition of CBC given that the parasitoid is extensively used in augmentative releases, *Co. flavipes* resulted in a reduction in infestation levels by about 50% (Macedo *et al.* 1993).

A range of natural enemies attacking different host stages and with a variety of attack methods may be needed to achieve successful control of a target pest (Smith *et al.* 1993; Smith & Wiedenmann 1997). Primarily, a knowledge of the endemic natural enemy complex attacking an introduced pest in the country it invaded is required. This information is needed to identify which host stage is to be targeted for natural enemy introduction. For example, introducing egg parasitoids into South Africa had no impact on populations of *E. saccharina*, since a large proportion of eggs and neonate larvae are already eaten by predators (Conlong 1997). This agrees with van Hamburg & Hassell (1984), who showed that the impact of an additional mortality factor that targets a stage with already high natural mortality is negligible. Alternatively, the pupal parasitoid, *Xanthopimpla stemmator* Thunberg (Hymenoptera: Ichneumonidae) was introduced to Mozambique, where *C. sacchariphagus* was first confirmed to be attacking sugarcane in 1999, while no indigenous parasitoids were recorded attacking that host (Way & Turner 1999). Post release surveys showed a sharp reduction in the host population in all release fields (Conlong & Goebel 2002). Based on the list presented in the current study, *X. stemmator* is recorded on 8 key stemborers, therefore may act as an important candidate for introduction to Australia in case of incursion by any of its hosts. No direct competition between *Co. flavipes* and *X. stemmator* is expected as they attack different host stages and use different attack strategies. Both parasitoids were introduced to Mauritius where they contribute to the natural mortality of *C. sacchariphagus* in sugarcane (Ganeshan 2000).

Status of *Cotesia flavipes* in Australia

In Australia, the name *Apanteles nonagriae* is cited as a synonym of *Apanteles* (*Cotesia*) *flavipes* (Austin & Dangerfield 1992), however the two could be sibling species. Records of *A. nonagriae* in Australia go back as far as 1920 when Jarvis (1927) recorded it parasitising *Phragmatiphila truncata* Walker (*Bathytricha truncata*). The author refers to *P. truncata* larvae collected at Pyramid (South Mulgrave) in 1921 that yielded the parasitoid. He also mentioned that *A. nonagriae* has been previously recorded on *P. truncata* in New South Wales where it was responsible for 50% parasitism. In 1934, Bell recorded *Apanteles flavipes* (*nonagriae*) on *B. truncata* larvae in Mackay, Central Queensland. Later in 1970, Li recorded *Apanteles flavipes* (*A. nonagriae*) from *C. suppressalis* and *C. polychrysa* in rice fields in the Northern Territory. The occurrence of *Co. flavipes* in Australia is an area that requires more studies, especially when it is recorded to exploit most of the lepidopterous stemborers mentioned in this review. The fairly wide host range of *Co. flavipes* qualifies it to be a strong candidate in case of incursion of some of the most important borer species into Australia. Whether the Australian population is capable of exploiting the exotic stemborers or there is need to introduce another population is an interesting point to investigate. Future work should consider testing selected *Co. flavipes* populations on key borer species in the neighbouring countries; this information will help determine the most suitable population to be considered for introduction into Australia in case of a pest incursion.

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Table 1. Parasitoids, predators and pathogens recorded on sugarcane stemborers in Asia and Indian Ocean Islands

Parasitoids	Host attacked	Stage attacked	Host plant	Country	Reference	Remarks
Hymenoptera **Bethylidae** *Goniozus* (*cuttackensis* Lal) *indicus* Ashmead	Ci[18], Cp[22,100], Cs[22], Ctum[22], Si[22], Sn[22]	L	Sugarcane, rice[100]	India, Philippines[100]	18,21,22,100	
Goniozus indicus Ashmead	Cs	L	Sugarcane	India	18,21	
Goniozus indicus Muesebeck	Cp	L	Rice[76]	India[76]	76	
Goniozus sp.	Ci,[18] Cp[36], Ed[14], Sn[22]	L	Sugarcane, maize[36]	Philippines[18], Taiwan[18], India[14,18,22], Pakistan[36]	14,18,21,22,27,30,36	
Braconidae *Agathis stigmatera* (Brullé)(*Alabagrus stigma* Cresson)	Cs	L	Sugarcane	Mauritius	52,53,54,58	Introduced from Trinidad to Mauritius (1949-1951)[58]. Low parasitism levels recorded[54].
Allorhogas pyralophagus Marsh	As[126], Ca[126], Ci[126], Cp[146], Cs[52], Sn[144]	L	Sugarcane, sorghum[146]	India, Mauritius[52], Indonesia[144]	52,126, 144, 146	Originally from Mexico. Introduced to India and recorded to have been established in release sites[126]. Introduced to Indonesia in 1982, long term impact unclear[144]. Introduced into Mauritius but apparently unsuccessful[52]. A study in India failed to recover it from cane fields after release[47].
Apanteles sp.	Ca, Cs, Ctr[79,81], Ctum[22], Sc[64], Sn[18,117]	L	Sugarcane, maize[41, 64]	Indonesia[117], India[41], Reunion[64], Philippines[18], PNG[79,81]	18, 22,41,64,79,81,140,117	
Apanteles sp. nr *chilonis* Munikata	Ctr	L	Sugarcane	PNG	79,81	
Apanteles Baoris Wilkinson	Ca	L	Sugarcane	India	22	
Apanteles chilonis (Munakata)	Cp[123], Csup[62,63,70]	L	Rice[62,63,70]	India[123], Japan[62,63,70]	62,63,70,123	
Apanteles (*Cotesia*) *flavipes* Cameron (*nonagriae* Olliff. nec Viereck, *Stenopleura simplicis* Viereck)	Su, As, Sn	L	Sugarcane	India	22	
Apanteles (*Cotesia*) *flavipes* Cam.	Se, Sn	L	Sugarcane	Philippines, Thailand	4,135	
Apanteles flavipes Cam.	Cpc[69], Ctr[81]	L	Rice[69], sugarcane	Malaysia[69], PNG[81]	69,81	
Apanteles flavipes Cam. (*A. nonagriae* Oll.)	Csup	L	Rice	Australia (NT)	77	
Apanteles flavipes Cameron	Su	L	Sugarcane	India, Philippines	18,21	
Apanteles flavipes Cameron (*nonagriae* Ol. & Vier)	Sn	L	Sugarcane	India	21	
Apanteles pallipes Cameron	Si	L	Sugarcane	India	22	
Apanteles phytometrae Wilkinson	Ci	?	Sugarcane	India	22	
Apanteles ruficrus Hal.	Ca	L	Sugarcane, rice[154]	India, China[154]	101, 154	First record on this host in India[101]
Apanteles schoenobii Wilkinson	Cp	L	Sugarcane	India	22	
Apanteles scirpophagae Ashmead	Sn	L	Sugarcane	India	18,22	
Ascogaster sp.	Ed	L	Sugarcane	India, Pakistan	21,22	
Bracon albolineatus Cam.	Cp[71], Sc[94]	?	Sorghum[71], rice[94]	India[71], Mauritius[94]	71,94	First record in India[71], introduced to Mauritius for the control of *S. calamistis* but impact on pest unclear[94].
Bracon brevicornis Wesmael	Si	L	Sugarcane	India	22	
Bracon chinensis (*Amyosoma*, *Microbracon*) (*albolineatus* Cameron, *chilonis* Viereck)	Ci, Si, Sn	L	Sugarcane	India, Taiwan, Philippines	18,22	
Bracon chinensis Szepl.	Cs[58], Csup[69], Sc[58]	L	Sugarcane, rice[69]	Mauritius, Indonesia[69]	58,69,151	Introduced from Sri Lanka into Mauritius in 1939[58].
Bracon chinensis Szepligetti	Ci[18], Si[21], Su[18]	L	Sugarcane	India[18,21], Taiwan, Philippines	18,21	

Bracon chinensis Szépligeti	Cp		Sugarcane, maize[24,99]	Pakistan[24], Nepal[99], Sri Lanka	21,22,24,99	
Bracon famulus Bingham	Sn	L	Sugarcane	India	22	
Bracon hebetor Say	Si	L	Sugarcane	India	22	
Campyloneurus erythrothorax Szépl.	Cs	L	Sugarcane	Indonesia	69	
Campyloneurus mutator Fabricius	Ca, Ci, Ctum, Sn	L	Sugarcane	India	22	
Campyloneurus sp.	Ca, Cs	L	Sugarcane	Indonesia	116,140	
Chelonus heliopae Gupta	Cp	L	Sugarcane	India	22	
Chelonus narayani Subba Rao	Ed	?	Sugarcane	India	22	
Chelonus munakatae	Ci	L	Millet	China	80	
Chilonis sp.	Sn	L	Sugarcane	India	18,21,22	
Chelonus sp. (b)	Cp, Ed	L	Sugarcane	India, Pakistan	21, 22	
Cotesia (*Apanteles*) *flavipes*	Ci	L	Sugarcane, Vetiver grass (*Vetiveria zizamoides*)	India[18,21,22,98,133], Pakistan[90], Philippines[18], Taiwan[29], Thailand[135]	18,21,22, 29, 133, 90, 98, 135	A number of *C. flavipes* sugarcane adapted strains were imported from Indonesia, Thailand and Barbados, bred freely among themselves and released in Pakistan in 1983 and in the Punjab in 1982-1985. This resulted in successful establishment in sugarcane[91].
Cotesia (*Apanteles*) *flavipes* Cameron	Cp[2,18,19,71,93,97,98,99,128,133,136], Cs[8,13,52,53,54,58,69,89,94,109,135,151,152], Si [1,10,18,24,29,72,88,98,115]	L	Maize[2,19,93,99,128,136] sorghum[2,71,98,133], sugarcane, rice[98,115], cattail (*Typha angustata*)[24], *Saccharum spontaneum*[98], *Erianthus arundinaceus*[98], Job's tears (*Coix lachrymal-jobi*) L[97].	India[18,21,22,44,47,72,98,133,136], Pakistan[2,42,90,93], Nepal[99], Comoros[19], Sri Lanka[18], Taiwan[18,29], Mauritius [52,53,54,58, 94,109,151,152], Madagascar[8,13], Reunion[58], Thailand[135], Indonesia [69,89,138], Japan[1,10], Philippines[18]	1,2,8,10,13,18,19,24,29,44, 47,58,71,72,88,89,93,97,98, 99,115,133, 135,136	• It is suggested that a shipment of *Apanteles* sp. (possibly *Cotesia flavipes*) arrived in Mauritius from India in 1964[58]. Another theory suggests *Cotesia flavipes* was introduced into Mauritius in 1917, and later into the Reunion[7]. It is also possible that *C. flavipes* may have arrived with it's host around 1850 from India[58]. • Strain in Madagascar was originally introduced from Mauritius in 1960 – 1961, well established[8]. • A Japanese strain was introduced into Pakistan in 1962, well established[2]. • A hybrid between a sugarcane-adapted strain, from Indonesia, and a local maize-adapted strain did establish in sugarcane in the Sindh Province of Pakistan[90]. • An imported Thai strain in 1985 improved overall parasitism rates on both hosts in Indonesia[89].
Cotesia flavipes Cameron	As [91,96,124], Args[29], Ca[22,97,98,101], Csup[29,70], Ctum[16,17,134], Sg[74,75]	L	Sugarcane, *Sacciolepis interrupta*[98*], rice[29].	India [16,17,22,91,97,98,101,124,], Pakistan[96], Indonesia[91,116,138], Japan, Taiwan[29], Thailand[134], PNG[74,75].	16,17,22,29,70,74,75,91,96, 97,98, 101,116,124,138	• *C. auricilius* larvae in Indonesia used to encapsulate immatures of the Indonesian *C. flavipes*. A Thai strain was introduced to Indonesia in 1985 that resulted in high parasitism rates[91]. • Record of *C. suppressalis* in cane (ref 29) is probably a misidentification, or pest was found occasionally in cane. • An indigenous population in PNG is responsible for high levels of parasitism (up to 70%). Continuously mass released[74,75].

Cotesia (*Apanteles*) *sesamiae*	Sc	L	Sugarcane, maize [19,58], sorghum [12,19]	Mauritius, Madagascar, Reunion	6,12,19,52,53,58,109,151	Originally from East Africa, *C. sesamiae* was introduced into Mauritius in 1951 from Kenya, and later from Mauritius into the Reunion in 1953-1955. Well established [6,58]. It was also introduced from Uganda to Madagascar [19], well established.
Glyptomorpha (=*Stenobracon*) *nicevillei* Bingham	Se	L	Sugarcane	India	142	
Habrobracon hebetor L.	Scrt	L	Maize	Iran	127	
Hormiopterus (*Rhaconotus*) sp.	Cs	L	Sugarcane	Indonesia	69	
Iphiaulax famulus Bingham	Si, Su, Sn	L	Sugarcane	India, Philippines	18,22	
Iphiaulax sikkimenis Cameron	Sn	L	Sugarcane	India	22	
Iphiaulax sp.	Si, Sn	L	Sugarcane	India	22	
Iphiaulax spilocephalus Cameron	Cp	L	Sugarcane	India	21,22	
Macrocentrus jacobsoni Szépl.	Ci, Cs, Sn	L	Sugarcane	Taiwan	18	
Macrocentrus nicevillei Ashmead	Si	L	Sugarcane	India	22	
Merinotus sp.	Cp	?	Sugarcane	India	22	
Microbracon chilocida Ram.	Cp	?	Sugarcane	India	22	
Microbracon chinensis	Ci, Cs	L	Sugarcane	Taiwan	29,34	
Microplitis sp.	Cp	?	Sugarcane	India	22	
Phanerotoma hendecasiella Cam.	Ed	?	Sugarcane	India	18	
Pseudoshirakia sp.	Sc	L	Sugarcane	India	42,142	
Rhaconotus roslinesis Lal	Sn	L	Sugarcane	India	21	
Rhaconotus roslinensis Lal (=*caulicola* Muesebeck)	Cs, As	L	Sugarcane	India	21,22	
Rhaconotus schoenobii Roh.	Sn	?	Sugarcane	Philippines	18	
Rhaconotus scirpophagae Wilkinson	As[18,21,22], Ed[18], Sn[18,21,22,24,57], Cp[21,22], Se[60,95,142]	L	Sugarcane	India, Pakistan[24]	18,21,22,24,57,60,95,142	Recorded as the most common larval parasitoid on this host in Pakistan[24]. Parasitism levels of up to 33.42% were recorded in North Bihar, India[60].
Rhaconotus signipennis Walker	As, Cs, Sn	L	Sugarcane	India	22,125	
Rhaconotus sp.	Se	L	Sugarcane	India	103	
Shirakia schoenobii Vier	Si	L	Sugarcane	Taiwan	18	
Shirakia sp.	Sn	?	Sugarcane	India	21	
Shirakia yokohamensis Cam.	Sn	L	Sugarcane	Taiwan	18	
Spathius elaboratus Wilkinson	As	L	Sugarcane	India	121	New record.
Spathius sp.	Se	L	Sugarcane	India	142	
Stenobracon (*Bracon*, *Glyptomorpha*) *karnalensis* Lal	Sn	L	Sugarcane	India	21	
Stenobracon deesae Cameron	As, Ca, Ci[21,22,24], Cp[21,22,24], Cs[47], Ed[18], Se[60,95], Sn[21,24]	L, P(?)[95 *]	Sugarcane, maize[24]	India, Pakistan[24]	18,20,21,24,47,60,95,142	Low parasitism levels recorded in Pakistan on *C. infuscatellus* (5.1%)[24] and on *S. nivella* (<3.1%)[24], while higher levels were recorded in North Bihar, India (up to 54.23%)[60].
Stenobracon karnalensis Lal	Sn	L	Sugarcane	India	22	
Stenobracon nicevillei Bingham	As[22], Ci[22], Cp[20,21,22,99], Sn[21,22,57]	L	Sugarcane, (rice, maize & sorghum)[99].	India, Nepal[99].	20,21,22,57,99	Possibly a synonym of *S. maculata* Vier., a rice stemborer parasitoid in Taiwan.
Stenobracon sp.	Sn	L	Sugarcane	Indonesia	140	
Stenobracon trifasciatus Szépl.	Ci, Sn	L	Sugarcane	Taiwan, Indonesia	18,69,117	

[*] *Stenobracon deesae* Cam. is a larval parasitoid, this record could be a misidentification or possibly an error.

Tropobracon (*Shirakia*) *schoenobii* (Viereck)	Ca, Ci, Cp, Si	?	Sugarcane, rice	India	22	
Vipio sp.	Ca, Cp, Si, Sn	L	Sugarcane	India	22	
Vipio (*Stenobracon, Bracon, Glyptomorpha*) *deesae* (Cameron)	As, Ca, Ci, Cp, Ed, Sn	L	Sugarcane	India	22	
Ceraphronidae						
Ceraphron (*Calliceras*) *fijiensis* Ferriere	Si	?	Sugarcane	India	22	Possibly a hyperparasitoid on *Cotesia flavipes* (see Chaudhary & Chand 1972).
Ceraphron sp.	Ctr	L	Sugarcane	PNG	81	
Chalcididae *Bephratoides saccharicola* Mani	Sc	?	Sugarcane	India	21,22	
Brachymeria (*Chalcis*) sp.	Si	P	Sugarcane	India	22	
Euchalcidia sp.	Cpc	P	Rice	Australia (NT)	77	
Harmoniae sp.	Sc	L	Sugarcane	India, Pakistan	21,22	
Hyperchalcidia soudanensis Steffan	Cp	P	Rice, maize & sorghum	Nepal	99	
Hyperchalcidia sp.	Cp	P	Maize	Pakistan	24	
Neohybothorax sp.	Ed	?	Sugarcane	India	118	New record in India.
Trichospilus diatraea Chairman & Margabandhu	Cs	P	Sugarcane	India, Mauritius	18,21,22,52,53,58,151	Introduced into Mauritius from India in 1959, established[58].
Elasmidae						
Elasmus sp.	Sn	L	Sugarcane	Taiwan, Indonesia	18,140	
Elasmus zehntneri Ferr.	Se	L	Sugarcane	India, Indonesia, Pakistan, Philippines	18,21,22,24,60,69,103,141, 142,145,117	Mass released in Indonesia[145]. Low parasitism levels recorded in India and Pakistan [24,60].
Eucoilidae *Rhoptromeris* sp.	Se	L	Sugarcane	India	103	
Eulophidae *Anostocetus* sp.	Ctum, Sn	L	Sugarcane	India	21,22	
Aprostocetus sp.	Ci, Cp, Sn	P	Sugarcane	India	21,22	
Pediobius furvus (Gahan)	Cp, Sc [7,12,58,93], Sg[73,75,85]	P	Sugarcane, maize[19], rice[7], sorghum[12]	Comoros[19], Madagascar[12], Reunion[12], PNG[73,75,85].	7,12,19,58,73,75,85,93	Introduced into Madagascar and the Reunion from Uganda in 1968 - 1971, well established[12]. Later introduced from Madagascar to Comoros in 1969-1971, established[19]. Also introduced from Kenya into PNG, established, but parasitism levels are generally low[75].
Tetrastichus atriclavus Waterst	Cs	P	Sugarcane	Mauritius	52,54	Introduced into Mauritius, low parasitism levels recorded[54].
Tetrastichus ayyari Rohwer	Ci, Cp[12], Cs, Si, Sn	P	Sugarcane, sorghum[12]	India, Reunion[12]	12,21,22	
Tetrastichus israeli (M.&K.)	Csup[69], Sc[12], Si[69]	P	Rice[69], sorghum[12]	Indonesia[69], Reunion[12]	12,69	Introduced from India into Reunion in 1959[12].
Tetrastichus israeli Mani & Kurian (*Aprostocetus israeli* Mani)	Ca, Ci	P	Sugarcane, rice	India	22	
Tetrastichus schoenobii Ferriere	Ci, Sn[89]	E	Sugarcane	India, Indonesia [18, 89]	18,22,89	
Tetrastichus scirpophaga Mani	Sn	E	Sugarcane	India	22	
Tetrastichus sp.	Ci, Cs, Sn	P	Sugarcane	India, Indonesia	21,22,44,140	
Tetrastichus sp. (near *atriclavus* Waterst.)	Cs, Sc	P	Sugarcane	Mauritius	18,54,94	
Trichospilus diatraea Chairman & Margabandhu	Sc[12], Si[22]	P	Sugarcane, sorghum[12]	India, Reunion[12], Mauritius	12,22,151	Introduced from India into Mauritius in 1963-1964[151].
Eupelmidae *Eupelmus* sp.	Ca	L?	Rice	India	22	
Ichneumonidae						

Amauromorpha metathoracio schoenobii Viereck	Ca, Cs[18]	L	Sugarcane	India, Indonesia[18]	18,22	
Amauromorpha schoenobii Vier.	Si, Sn	?	Sugarcane	Taiwan	18	
Anomalon sp.	Sn	L	Sugarcane	India	22	
Brachycoryphus nersei Cameron	Ci	L, P	Sugarcane	India	22	
Centeterus alternecoloratus Cushman	Ca[22,25], Ci, Cp[25], Sn	P	Sugarcane, rice[25], maize [22,25]	India	22,25	Recorded as a key pupal parasitoids in India with up to 50% parasitism levels[25]. 33% parasitism levels recorded in Assam, India[25].
Cremastus sp.	As, Sn	L	Sugarcane	India	21,22	
Cremastus (*Trathala*) *flavo-orbitalis* (Cameron)	Ca, Cp	L	Rice[22], sugarcane	India, Sri Lanka	18,22	
Enicospilus antankarus Sauss.	Cs	?	Sugarcane	Mauritius	18	
Enicosphilus (*Enicospilus*) *terebrus* Gauld	Sg	L	Sugarcane	PNG	74,75	Low parasitism levels recorded in PNG[75].
Enicospilus sakaguchii Mats. & Uchida	Si	?	Sugarcane	Taiwan	18	
Enicospilus sp.	Sc	L	Sugarcane	Mauritius	18,94	
Exetastes longicornis Ishida	Sn	?	Sugarcane	Taiwan	18	
Gambroides dammermani Rohw.	Sn	?	Sugarcane	Philippines	18	
Gambroides javensis Rohw.	Sn	?	Sugarcane	Indonesia, Philippines	18	
Gambroides rufithorax Uchida	Cs	?	Sugarcane	Taiwan	18	
Gambroides sp.	Ca, Cs	P	Sugarcane	Indonesia	140	
Goryphus basilaris Holmgren (*Exetastes*, *Mesosternus longicornis* Ishida)	Cs, Sn	?	Sugarcane	India	22	
Goryphus (*Melcha*) *ornatipennis* Cameron	Cs	?	Sugarcane	India	22	
Goryphus sp.	Cs, Sn	L?	Sugarcane	India	21,22	
Gotra marginata Brulle (*Listrognathus marginatus* WLK)	Ci	L?	Sugarcane	India	21,22	
Habropimpla sesamiae Rao	Sc	P	Sugarcane	India	21	
Horogenes lineata Ishida	Ci, Si	?	Sugarcane	India, Taiwan	18,21	
Ichneumon unicinctus Brúlle	Sc	P?	Sugarcane	Mauritius	151	
Ischnojoppa luteator Fab.	Sn	P	Sugarcane	India	22	
Isotima javensis Rhower	Se[47,60,95, 103, 142], Sn[57,69,106,117]	L[57], P[69], PP[106]	Sugarcane	India, Indonesia[69,117]	47,57,60, 69,95, 103, 106,117,142	A key parasitoid of *S. nivella* in India[106]. Parasitism levels of 6.67 – 15.28% were recorded in India on *S. excerptalis*[60].
Isotima dammermani Rohwer	Sn	P	Sugarcane	India	22	
Isotima (*Melcha*, *Gambroides*, *Eripernimorpha*) *javensis* Rohwer	Sn	?	Sugarcane	India	22	
Isotima sp.	Ci[3,24], Sn[24]	L	Sugarcane	Pakistan[24], Philippines	3,24	Low parasitism levels recorded in Pakistan[24].
Kriegeria heptazonata Ashm.	Su, Sn	?	Sugarcane	Philippines	18	
Kriegeria sp.	Sn	?	Sugarcane	India	22	
Listrognathus (*Mesostenoideus*) *calvinervis* Cameron	Sn	L	Sugarcane	India	21	
Melcha ornatipennis Cameron	Ci, Sn[18]	P	Sugarcane	India, Burma[18]	18,21,22	
Meloboris sinicus (Holmgren)	Ci, Cs	L	Sugarcane	Taiwan	29,30,33	
Mesostenus longicornis Ishida	Ci, Sn	?	Sugarcane	India	18	
Metopius sesamiae Rao	Si	P	Sugarcane	India	21	
Pimpla predator Fabricius	Sn	P	Sugarcane	India	18	
Syzeuctus sp.	Sn	L	Sugarcane	India	22	
Temelucha philippinensis (Ashmead)	Se	L	Sugarcane	Thailand	135	
Temelucha sp.	Si[22], Se[103,124], Sn[22]	L	Sugarcane, rice[22]	India	22,103,142	
Trathala flavoorbitalis Cameron	Cp	L	(Rice, maize &	Nepal	99	

			sorghum)[99]			
Vulgichneumon leucaniae Uchida	Si	P	?	China	78	
Xanthopimpla citrina (*X. luteola*) (Hlmgr.)	Cs[18,52,94], Sc[18,58,94]	P	Sugarcane	Mauritius[18,52,94], Reunion[58]	18,52,58,94	Introduced from Sri Lanka into Mauritius in 1952-1953, and in 1953, 1960 from Mauritius to Reunion [58,94].
Xanthopimpla enderleini Krieg.	Si, Su	?	Sugarcane	Philippines	18	
Xanthopimpla (*Metopis*) *sesamiae* (Rao)	Si	?	Sugarcane	India	22	
Xanthopimpla nursei Cameron	Cp	P	Sugarcane	India	21	
Xanthopimpla pedator F.	Se	P	Sugarcane	India	95	
Xanthopimpla (*Pimpla*) *punctata* Fabricus	Ci	P	Sugarcane	India	22	
Xanthopimpla predator Fabricius	Cp	P	Sugarcane	India	21	
Xanthopimpla punctator (*predator* Fabricius) Linnaeus	Cp	P	Sugarcane	India	22	
Xanthopimpla sp.	Ca, Cs, Ctum[134]	P	Sugarcane	Indonesia, Thailand[134]	134,140	
Xanthopimpla stemmator Thunberg	Ca[116], Ci[30, 132], Cp [18,99], Cs[58], Csup[69], Sc [58,94], Si [18, 132], Sn[139]	P	Sugarcane, (rice, maize & sorghum)[99]	India, Sri Lanka[18], Nepal[99], Indonesia[69], Taiwan[30,132,139], Mauritius[58], Reunion[23]	18,23,30,52,53,54,58,69,94, 99,116,132,139,151	Introduced from Sri Lanka into Mauritius in (1939-1942) and few individuals released, well established[58]. Later in 1953, 1966 it was introduced from Mauritius into Reunion[58], well established.
Xanthopimpla stemmator Thunberg (*thoracalis Krieger*, *bimaculata* Cameron *maculifrons* Cameron, *nursei* Cameron, *fascialis* Szepligetti, *Habropimpla sesamiae* Rao)	Ci, Cp, Cs, Sn	P	Sugarcane	India	22	
Xanthopimpla stemmator Timberlake	Cp	P	Sugarcane, (rice, maize & sorghum)[99]	India, Pakistan[24], Sri Lanka[147], Taiwan[18]	18,21,24,99,147[*]	
Mymaridae *Anagrus* sp.	Cpc	E	Rice	Malaysia	69	
Pteromalidae *Dinarmus* sp	Sn	L?	Sugarcane	Indonesia	69	
Scelionidae *Gryon nixoni* Masner	Ctr	E	Sugarcane	PNG	81	
Platytelenomus busseolae Gahan	Scrt	E	Maize	Iran	127	
Platytelenomus sp. (? *hylas* Nixon)	Sc	E	Sugarcane	Mauritius	94	
Telenomus alecto Crawford	Ci	E	Sugarcane	India	22	Introduced from Colombia, well established in West Bengal.
Telenomus beneficiens Nixon	Cs	E	Sugarcane	India	21,22,45,110,111	
Telenomus beneficiens var. *elongatus* Ishida	Sn	E	Sugarcane	Taiwan	18, 35	The key egg parasitoid in cane fields in Taiwan[35].
Telenomus beneficiens (Zehntner)	Sn, Cs[28], Ci[28]	E	Sugarcane	Taiwan[28,] Indonesia [18,69,117], India[18], Philippines[18]	18,28, 69,117	
Telenomus beneficiens (Zehnt.) Nixon	Cs	E	Sugarcane	India	44	
Telenomus beneficiens (Zehntner) (Ceraphron)	Cs	E	Sugarcane	Mauritius[18], Taiwan[18], Indonesia[18], China[32]	18, 32	
Telenomus (*Ceraphron*, *Phanurus*, *Praphanurus*) *beneficiens* (Zehntner) Nixon	Ci, Sn	E	Sugarcane	India	21	
Telenomus dignoides Nixon	Ci, Cs, Se[4], Sn[21,22, 24,89]	E	Sugarcane	Indonesia[89], Pakistan[24], India, Philippines[4]	4, 21, 22, 24, 44, 45, 89	
Telenomus dignus Gah.	Csup[69], Se[4, 103,142], Sn[21,22]	E	Sugarcane, rice[69]	Indonesia, India, Philippines	4, 21,22, 69, 103, 142	
Telenomus globosus n. sp.	Cs	E	Sugarcane	India	15, 44	

[*] Apparently a misidentification of the host (*C. partellus*) (See Greathead 1971).

Telenomus (*Phanurus, Praphanurus*) *beneficiens* (Zehntner) (Ceraphron)	Ci, Sn	E	Sugarcane	India	22	
Telenomus rowani (Gahan)	Ci, Cs, Ctum[134], Se, Sn[21,22]	E	Sugarcane	Thailand[134], India[21,22]	21, 22, 134, 135	
Telenomus saccharicola Mani	Sn	E	Sugarcane	India	22	
Telenomus sp.	Ca, Ci, Cp[69], Cs[69,140], Ctr[81, 153], Sg[74,75], Si[21], Sn[22,57,140]	E	Sugarcane, rice[69]	Indonesia[140], India[21,22,57], Malaysia[69,140], PNG[81,153]	21, 22, 69, 74, 75, 81, 153, 140	An indigenous strain is used for augmentative releases in PNG[74,75].
Trichogrammatidae						
Trichogramma australicum Girault	Ci [18,22,61], Cs[18,52,53,54,58], Sc[18, 58], Ed[22]	E	Sugarcane	India[22], Indonesia[18], Taiwan[18], Pakistan[61], Mauritius[18,52,53,54,58]	18, 22, 52, 53, 54, 58, 61	Introduced from India into Mauritius in 1964, well established[58].
Trichogramma bactrea Nagaraja	Ci[40], Cs[40]	E	Sugarcane	India[40]	40	
Trichogramma batra batra	Args	E	Sugarcane	Philippines	4	
Trichogramma chilonis Ishii	Ca[89,129], Ci [4,9,40,66,84,90,91,143], Cp [37,40,99,143], Cs[27,30,56,44,45,111,112,113,114,122], Si[84], As[143], Ed[9], Se[103,142], Args[4,29]	E	Sugarcane, Sorghum[37,99], Rice & Maize[99].	India [37,40,44,45,103,111,112,113,114,120,122,129,142,143], Indonesia[91,89], Taiwan[27,29,30], China[84], Pakistan[9,90], Philippines[4,66], Nepal[99], Reunion[56].	4, 9, 29, 30, 37,40, 44, 45, 56, 66, 84, 89, 90, 91, 99, 103, 111, 112, 113, 114, 120, 122, 129, 142, 143	A strain from Taiwan is mass released in India[143]. Mass released in Indonesia[89] and Pakistan[9,90]. Widely mass released in India[40,111,129] * and the Punjab[143]. Augmentative early releases early in the season increased parasitism rates to almost 98% in Indonesia[91].
Trichogramma chilotraeae Nagaraja and Nagarkatti	Ci[4,40,86,135], Cs[135], Ctum[134], Se[135], Args[4]	E	Sugarcane	Philippines[4], Thailand[86,134,135], India[40]	4, 40, 86, 134,135	
Trichogramma confusum (*T. chilonis*)	Ci[38,82], Cs[38,82], Args[148]	E	Sugarcane	China[38,82,148]	38,82, 148	Mass released in China[38,82].
Trichogramma dendrolimi	Args	E	Sugarcane	China	148	
Trichogramma exiguum	Cp[67]	E	Sorghum[37,67]	India [37,67]	37,67	Different strains were introduced from Barbados, Colombia and the Philippines, well established in Delhi and Nagpur[37].
Trichogramma evanescens minutum Riley	Ci ,Cp[21], Cs[21], Su[21]	E	Sugarcane	India	21	
Trichogramma fasciatum (Perkins)	Se	E	Sugarcane	India	104	Introduced from Barbados.
Trichogramma flandersi Nagaraja & Nagarkatti	Ci	E	Sugarcane	India	40	
Trichogramma japonicum Ashmead	Ca[18], Ci[22], Se[103], Args[148]	E	Sugarcane	India[22,103], Taiwan[18], China[148]	18, 22,103, 148	Mass released in India[103].
Trichogramma minutum Riley	Ci[18], Ed[18]	E	Sugarcane	India[18]	18	
Trichogramma nagarkattii	Ci[59]	E	Sugarcane	China[59]	59	Mass released in China[59]
Trichogramma nanum Zhnt.	Ca[18], Ci [4,18], Cs[18]	E	Sugarcane	Malaysia[18], India[18], Indonesia[18], Philippines[4], Taiwan[18]	4, 18	
Trichogramma nr. *nana* (Zhnt.)	Cs[18,69]	E	Sugarcane	Indonesia[69], Madagascar[18], Taiwan[18]	18, 69	
Trichogramma nubilale Ertle & Davis	Ci[59], Cs[83], Args[83]	E	Sugarcane	China[59,83]	59, 83	Introduced from USA into China in 1983[83]. Mass released [59,83].
Trichogramma ostriniae	Args	E	Sugarcane	Taiwan[31], China[148]	31, 148	
Trichogramma plasseyensis Nagaraja	Ci	E	Sugarcane	India	40	
Trichogramma poliae Nagaraja	Ci	E	Sugarcane	India	40	
Trichogramma semblidis (Auriv.)	Ci	E	Sugarcane	India	40	
Trichogramma sp.	Se[5], Args[5,52]	E	Sugarcane	Mauritius[52], Philippines[5]	5	
Trichogramma sp. (near *nana* (Zehnt))	Sc, Args[94,151]	E	Sugarcane	Mauritius[94,151], Madagascar[18]	18, 94,151	
Trichogramma sp. nr. *plasseyensis* Nagaraja	Ctr	E	Sugarcane	PNG	81	
Trichogramma spp.	Ca[140], Ci[5], Cpc[69], Csup[69], Ctr[79,153]	E	Sugarcane, rice[69]	Philippines[5], Indonesia [69,140], Malaysia[69], PNG[79,153]	5, 69, 79, 140, 153	
Trichogramma spp. (? *australicum* Girault)	Cs[94], Sc[94], Args[151]	E	Sugarcane	Mauritius[94,151]	94, 151	
Trichogrammatoidea nana Zehnt.	Args	E	Sugarcane	Indonesia[102], Philippines[4]	4, 102	Mass released in Indonesia[102]. The main egg parasitoid in the Philippines, 91%

* David and Easwaramoorthy (1990) state that *T. chilonis* was formerly misidentified in India as *Trichogramma evanescens minutum*, *Trichogramma australicum* and *Trichogramma confusum*.

						parasitism rates recorded[4].
Trichogrammatoidea nana Zehntner	Ci	E	Sugarcane	India	21,22	
Diptera						
Chloropidae *Anacamptoneurum oblicunum* Becker	Si	?	Sugarcane	India	22	
Anacamptoneurum sp.	Si	?	Sugarcane	India	22	
Anatrichus erinaceous Loew	Si	?	Sugarcane	India	22	
Mepachymerus (*Stellocerus*) *tenellus* Becker	Ci	?	Sugarcane	India	22	
Mepachymerus (*Stellocerus*) *tenellus* Becker	Si	?	Sugarcane	India	22	
Empididae *Drapetis* sp.	Ci	L	Sugarcane	India	22	
Phoridae Phorid fly	Cp	?	Sugarcane	India	22	
Tachinidae *Carcelia* sp.	Cs[69], Sg[75,85]	L	Sugarcane	Indonesia, PNG[75,85]	69, 75, 85	Low levels of parasitism recorded in PNG[75].
Carcelia (*Senametopia*) sp.	Ctr	L	Sugarcane	PNG	81	
Diatraeophaga sp.	Cs	P	Sugarcane	Indonesia[69]	69	Mass released in Indonesia[69]
Diatraeophaga striatalis Tns.	Ca[116], Cs[18,40]	L, P[18]	Sugarcane	Indonesia [18,116], India[40]	18, 40, 116	Mass released in Indonesia[116]. Imported from java and released in Tamil Nadu, India, in 1979, later recovered from release sites[40].
Dichaetomyia pallitarsus (Stein)	Cpc	P	Rice	Malaysia	69	
Drino discreta Van der Wulp	Si	?	Sugarcane	India	22	
Exorista quadrimaculata Baranov	Ci	L	Sugarcane	India	22	
Lixophaga diatrae (*diatraeae*)	Ci	L	Sugarcane	Philippines[4]	4	Introduced to the Philippines from South America, resulted in low parasitism levels[4].
Pseudoperichaeta orientalis Wiedmann	Si	L	Sugarcane	India	22	
Schistochilus aristatum AlDr	Cs	?	Sugarcane	Indonesia	18	
Sturmiopsis inferens Townsend	Ca, Ci, Cp, Cs, Csup[69], Cpc [69], Si[22], As[39], Sn[22]	L	Sugarcane, rice[69]	India, Malaysia [69], Indonesia [89]	22, 26, 39, 51, 65, 69, 89, 106, 108	Mass released in Indonesia[89].
Sturmiopsis (*Winthemia*) *semiberbis* Bezzi	Ci, Cp, Si	L	Sugarcane	India	21	
Predators						
Anisolabiidae *Euborellia stali* Dohn.	Si	L	Rice	Philippines	11	
Anthocoridae *Blaptostethoides* sp.	Sg	E	Sugarcane	PNG	75	
Chelisochidae *Chelisoches morio* (F.)	Sg	E, L	Sugarcane	PNG	75	
Carabidae						
Hexagonia sp? *Insignis* (Bates)	Cs	E, (L?)	Sugarcane	India	44	
Chrysopidae						
Chrysopa sp.	Cs	E	Sugarcane	Indonesia	69	
Coccinellidae *Brumus* (*Coccinella*) *suturalis* Fabricius	Sn	E	Sugarcane	India	22	
Brumus suturalis F.	Sn	E	Sugarcane	India	21	
Menochilus sexmaculatus (Fabricius)	CP	L	Sorghum	India	68	
Forficulidae						

Forficula sp.	Ca	L	Sugarcane	India	22	
Formicidae *Anoplolepis longipes* Jerdon	Cs	E, (L?)	Sugarcane	India	44	
Camponotus compressus (F.)	Cs	E, (L?)	Sugarcane	India	44	
Camponotus rufogloucus (Jerdon)	Cs	E, (L?)	Sugarcane	India	44	
Irridomymex spp.	Sg	L, P	Sugarcane	PNG	44	
Monomorium aberrans Forel	Cs	E, (L?)	Sugarcane	India	44	
Monomorium sp.	Sn	L, P	Sugarcane	India	22	
Oecophylla amaragdina Fabr.	Cs	E, (L?)	Sugarcane	India	44	
Pheidole megacephala Fab.	Cs, Args[151]	E	Sugarcane	Reunion[56], Mauritius[151]	56, 151	
Pheidole sp.	Sg	L, P	Sugarcane	PNG	75	
Pheldiogeton sp.	Cs	E, (L?)	Sugarcane	India	44	
Solinopsis geminala (F.)	Cs	E, (L?)	Sugarcane	India	44	
Tetraponera refonigra Jerdon	Cs	E, (L?)	Sugarcane	India	44	
Glubionidae *Oedignatha* sp.	Cs	E, (L?)	Sugarcane	India	44	
Lycosidae *Hippasa greenalliae* (Blackwell)	Ci[49]	L	Sugarcane	India	49	
Paradosa sp.	Cs	E, (L?)	Sugarcane	India	44	
Oxyopidae *Oxyopes* sp.	Cs	E, (L?)	Sugarcane	India	44	
Pentatomidae *Amyotea* (*asopus*) *malabarica* (Fabricius)	Si	L	Rice	India	105	
Reduviidae *Acanthaspis quinquespinosa* Fabricius	Cp	L	Sugarcane	India	21, 22	
Salticidae *Carrhotus viduus* Koch	Cs	E, (L?)	Sugarcane	India	44	
Plexippus paykulli (Audouin)	Cs	E, (L?)	Sugarcane	India	44	
Staphylinidae *Paederus fucipes* Curtis	Cp	E	Maize	Pakistan	92	
Thomisidae *Runcinia* sp.	Cs	E, (L?)	Sugarcane	India	44	
Pathogens						
Bacillaceae *Bacillus thuringiensis* Berliner	Cp	L	Sorghum	India	137	
Heterorhabditidae *Heterorhabditis indicus* n. sp.	Se	L	Sugarcane	India	107	
Hypomycetes *Beauveria bassiana*	Sg, Ed[119]	L	Sugarcane	PNG, India[119]	73, 119	
Beauveria densa	Cp	L	Sorghum	India	137	
Hirsutella nodulosa Petch	Cs	L	Sugarcane	India	48, 50	
Beauveria nr. *bassiana*	Ci	L	Sugarcane	India	130	
Metarhizium anisopliae (Metschnikoff)	Cs[53], Sg[75], Ed[119]	L, P[75]	Sugarcane	Mauritius[53], PNG[75], India[119]	53, 75, 119	
Paecilomyces sp.	Cs	L	Sugarcane	Mauritius	53	
Mermithidae *Amphimermis* sp.	Ci	L	Sugarcane	Pakistan	24	
Hexamermis sp.	Cp	L	Sorghum	India	137	
Mermis sp.	Cs, Sc	L	Sugarcane	Mauritius	94	
Nosematidae						

Nosema furnacalis	Cs	?	?	China	149	
Nosema infuscatellus	Ci	L	Sugarcane	China	150	
Nosema sp.	Cp	L	Sorghum	India	46	
Protozoa						
Tetrahymena sp.	Cp	L	Sorghum	India	137	
Rhabditida						
Rhabditis sp.	Cp	L	Sorghum	India	137	
Panagrolaimus sp.	Cp	L	Sorghum	India	137	
Steinernematidae						
Neoaplectana sp.	Cp	L	Sorghum	India	137	
Viruses						
Cytoplasmic polyhedral virus	Sc	L	Maize, cane	Reunion	64	
Granulosis virus (GV)	Ci, Cs	L	Sugarcane	India	43, 44, 87	
Nuclear polyhedral virus	Sc	L	Maize, cane	Reunion	64	
Nuclear polyhedrosis virus	Si	L	Rice	India[55], Korea[131]	55, 131	

Args=*Argyroploce* (*Tetramoera*) *schistaceana*; As= *Acigona steniellus*; Ca=*Chilo auricilius*, Ci=*Chilo infuscatellus*; Cp=*Chilo partellus*; Cpc=*Chilo polychrysus*; Cs=*Chilo sacchariphagus*; Csup=*Chilo suppressalis*; Ctr=*Chilo terrenellus*; Ctum=*Chilo tumidicostalis*; Ed=*Emmalocera depressella*; Sc=*Sesamia calamistis*; Scrt=*Sesamia cretica*; Sg=*Sesamia grisescens*; Si=*Sesamia inferens*; Su=*Sesamia uniformis*; Se=*Scirpophaga excerptalis*; Sn=*Scirpophaga nivella*.

E = egg, L = larva, PP = pre pupa and P = Pupa. A question mark indicates an unknown or a doubtful status of record.

(1)Abdul Mannan & Iwahashi 1999; (2)Alam et al 1972; (3)Alba 1989; (4)Alba 1990; (5)Alba 1991; (6)Anon.1954; (7)Appert 1973;(8)Appert et al 1969; (9)Arakaki & Ganaha 1986; (10) Ashraf & Fatima 1996; (11)Barrion et al 1987; (12)Betbeder-Matibet 1989; (13)Betbeder-Matibet & Malinge 1968; (14)Bhatt et al 1996; (15)Bin & Johnson 1982; (16)Borah & Arya 1995; (17)Borah & Sarma 1995; (18)Box 1953; (19)Brenière et al 1985; (20)Butani 1957; (21)Butani 1958; (22)Butani 1972; (23)Caresche 1962; (24)Carl 1962; (25)Chacko & Rao 1966; (26)Chandra & Avasthy 1988 (27)Cheng 1986; (28) Cheng & Chen 1998; (29)Cheng et al 1987a; (30)Cheng et 1987b; (31)Cheng et al 1995; (32)Cheng et al 1997; (33)Cheng et al 1999a; (34)Cheng et al 1999b; (35)Cheng et al 1999c; (36)CIBC 1966; (37)Chundurwar 1989; (38)Dai et al 1988; (39)David et al 1989; (40)David & Easwaramoorthy 1990; (41)Devi & Raj 1996; (42)Dey 1998; (43)Easwaramoorthy & Jayaraj 1987; (44)Easwaramoorthy & Nandagopal 1986; (45)Easwaramoorthy et al 1983; (46)Easwaramoorthy et al 1987; (47)Easwaramoorthy et al 1992; (48)Easwaramoorthy et al 1996a; (49)Easwaramoorthy et al 1996b; (50)Easwaramoorthy et al 1998; (51)Easwaramoorthy et al 1999; (52)Facknath S 1989; (53)Ganeshan 2000; (54)Ganeshan & Rajabalee 1997; (55)Godse & Nayak 1983; (56)Goebel et al 2000; (57)Goel et al 1983; (58)Greathead 1971; (59)Guo 1988; (60)Gupta et al 1994; (61)Hashmi & Rahim 1985; (62) Imamura & Machimura 1976; (63)Imamura & Yamazaki 1975; (64)Jacquemard et al 1985; (65)Jaipal & Chaudhary 1994; (66)Javier & Gonzalez 2000; (67)Jotwani 1982; (68)Jotwani & Verma 1969; (69)Kalshoven 1981; (70)Kajita & Drake 1969; (71)Kishore 1986; (72)Kumar & Kalra 1965; (73)Kuniata 1994; (74)Kuniata 2000; (75)Kuniata & Sweet 1994; (76)Kurian 1952; (77)Li 1970; (78)Li 1981; (79)Li 1985a; (80)Li 1985b; (81)Li 1990; (82)Liu et al 1985; (83)Liu et al 1987; (84)Liu et al 1996; (85)Lloyd & Kuniata 2000; (86)Meenakanit et al 1988; (87)Mehta & David 1980; (88)Mia & Iwahashi 1999; (89)Mohyuddin 1986; (90)Mohyuddin 1991; (91)Mohyuddin 1992; (92)Mohyuddin et al 1972; (93)Mohyuddin 1990; (94)Moutia & Courtois 1952; (95)Mukunthan 1989; (96)Muzaffar & Inayatullah 1986; (97)Nair 1988; (98)Nagarkatti & Nair 1973; (99)Neupane et al 1985; (100)Nickel 1964; (101)Nigam 1984; (102)Pan & Lim 1979; (103)Pandey et al 1997a; (104)Pandya 1997; (105)Pati & Mathur 1986; (106)Pawar 1987; (107)Poinar et al 1992; (108)Rai et al 1999; (109)Rajabalee & Governdasamy 1988; (110)Rajendran 1999; (111)Rajendran & Gopalan 1995; (112)Rajendran & Hanifa 1996; (113)Rajendran & Hanifa 1997; (114)Rajendran & Hanifa 1998; (115)Rothschild 1970; (116)Samoedi 1989; (117)Samoedi & Wirioatmodjo 1986; (118)Sardana 1994; (119)Sardana 1997; (120)Sardana 2000; (121)Saxena 1992; (122)Selvaraj et al 1994; (123)Sharma et al 1966; (124)Shenhmar & Brar 1996b; (125)Shenhmar & Varma 1988; (126)Shenhmar et al 1990; (127)Shojai et al 1995; (128)Singh et al 1975; (129)Singhal et al 2001; (130)Sivasankaran et al 1990; (131)So & Okada 1989; (132)Sonan 1929; (133)Srikanth et al 1999; (134)Suasa-ard 2000; (135)Suasa-ard & Charernsom 1995; (136)Subba Rao et al 1969; (137)Sukhani 1986; (138)Sunaryo & Suryanto 1986; (139)Takano 1934; (140)Tan & Koh 1980; (141)Tanwar 1990; (142)Tanwar & Varma 1997; (143)Tuhan & Pawar 1983; (144)Ubandi & Sunaryo 1986; (145)Ubandi et al 1988; (146)Varma & Saxena 1989; (147)Vinson 1942; (148)Wang et al 1985; (149)Wen & Sun 1988; (150)Wen & Sun 1989; (151)Williams 1978; (152)Williams 1983; (153)Young 1982; (154)Zhang 1986.

APPENDIX 4 – Draft article for *BSES Bulletin*

Managing cane borers in Louisiana

Two moth borer species are a cause of concern to Louisiana cane growers in USA, and these are the Sugarcane Borer and the Mexican Rice Borer.

As a part of a wide Biosecurity initiative taken by BSES and SRDC, BSES entomologist Mohamed Sallam spent 10 weeks at Louisiana State University (LSU), learning about sugarcane pest problems in USA. Sallam says even though we have a major insect problem in Australia, and that is the canegrub, we're very lucky we don't have to deal with a moth borer problem, and we certainly want it to stay that way.

The Sugarcane borer invaded Louisiana in the 1800s, and since then it has remained the major cane pest problem. The Mexican Rice Borer, however, is not yet in Louisiana, but it is just at the borders with Texas, where the two borers together are responsible for 20% yield loss. Since its introduction to America in 1980, the Mexican Rice Borer has been moving steadily, damaging cane and rice fields in Texas, and making its way through the Rio Grande Valley towards Louisiana. The last thing cane growers want to see in Louisiana is an incursion by another borer species. However, scientists at Louisiana State University estimate that it is only a matter of a few years before the Mexican Rice Borer is established in Louisiana. The Mexican Rice Borer is a major pest of rice and sugarcane, and, in many cases, it seems to prefer cane to rice! At the moment, a thorough monitoring program is ongoing using pheromone traps to attract adult moths, and this is used to trace the movement of the pest. Chemical control does not work well against this pest, because the larvae tunnel into the stem as soon as they hatch, therefore they remain protected, even natural enemies find it difficult to access the larva in the stem because it packs the tunnel with frass. Currently in Louisiana, a plant-breeding program is underway to select tolerant varieties to borer damage, however, tolerant varieties are not producing as good tonnage and sugar as the currently used variety, which is highly susceptible to borer damage.

In Texas, where they have a small cane plantation (18000 ha), the crop is transported to Louisiana for milling, and this creates a problem as the borer may be easily transported with the crop. One of the regulations imposed by the Louisiana Department of Agriculture and Forestry (LDAF) is that cane should be inspected at the source and at the destination to make sure it's borer free, however, LSU scientists believe that no cane should be transported from Texas into Louisiana, otherwise the risk of incursion is very high, and the battle goes on..

Implications for Australia

At BSES, we have been developing Incursion Management Plans detailing the steps to be taken immediately an incursion by a cane pest or disease is detected. These plans are updated in light of new information on moth borer species from overseas. BSES has developed these plans for most borer species in the world. These plans tell us where the borer is, its biology, life cycle, economic damage and its control measures. The plans are developed specifically for each bore species, so that we know what to do quickly and minimize errors. These Incursion Management Plans are our insurance policy against exotic pests and diseases. They can make the difference between eradicating a pest or having to live with it for ever.

APPENDIX 5 – PowerPoint slides used in staff and industry presentations following the tour

Raised beds in preparation for planting

Opening the planting furrow (50-56 cm wide). Cane ends up about 7 cm below surface

Field loader (at the back) collects cane from heap row and transfers it to the planting wagon

Mechanical planter (drum planter) plants one row at a time

Cane planter from the back

Whole stalks in furrow

Covering the stalks

A cultipacker to level and compact the soil around the stalks

Dense germination in autumn

Heavy growth before winter

After the freeze (December-January)

First cultivation in March – cut soil away around the plant

Herbicide spraying (seven rows)

Liquid fertilizing

Second cultivation in April – brings more soil into the row

Cane after second cultivation

Cane in August

Soldier harvester

Soldier harvester in action – two rows at a time, resulting in two heap rows behind

Soldier harvester from one side

Heap rows are burnt

Transloading cane after burning to be transported to the mill

'Combine' harvesting in Louisiana

Trash blanketing after harvest