We conclude that the augmentation of natural enemies by mass-releases of ladybird beetles should be considered as a component of an integrated control strategy for *D. plantaginea* in the future. Augmentative release in combination with conservation biological control measures and cultivation of resistant apple varieties could lead to a more sustainable control strategy against *D. plantaginea*, in particular in regions (e.g. Belgium) where insecticide-resistance has evolved.

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CHILO SACCHARIPHAGUS BOJER (LEPIDOPTERA: CRAMBIDAE) IN MOZAMBICAN SUGARCANE-A CASE FOR AUGMENTATION OR CLASSICAL BIOCONTROL, OR BOTH?

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In 1999, the spotted stalk borer *Chilo sacchariphagus* Bojer (Lepidoptera: Crambidae) was identified from bored sugarcane at two estates in Sofala Province, Mozambique. This borer, originating from Southeast Asia, is a major sugarcane pest in the Indian Ocean Islands of Mauritius, Madagascar and Reunion. It is the first time it has been recorded as a pest on mainland Africa, and poses a threat to the sugar industries of Mozambique and surrounding countries.

In 2000, a biological control programme against it was requested. As a result, regular surveys of infected sugarcane were implemented in order to determine the levels of infestation, seasonal occurrence and presence of any indigenous parasitoids attacking the different life stages of this borer. It soon became apparent that less than 1% of the larval and pupal stages were attacked by indigenous parasitoids, with a *Stenobracon* sp. (Hymenoptera: Braconidae) and *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae) occasionally being found from parasitised large instar larvae. No pupal parasitism was recorded. In contrast, in excess of 90% of *C. sacchariphagus* egg batches were parasitised by *Trichogramma bournieri* Pintureau and Babault (Hymenoptera: Trichogrammatidae).

In 2001, releases of a pupal parasitoid *Xanthopimpla stemmator* Thunberg (Hymenoptera: Ichneumonidae), an indigenous natural enemy of *C. sacchariphagus* obtained from Mauritius (who originally obtained their population from Sri Lanka) commenced, as it was recognised that an empty niche existed for an effective pupal parasitoid. In addition, the South African Sugarcane Research Institute had a strong laboratory colony of this parasitoid. Population reductions of *C. sacchariphagus* of up to 60% were measured in the release fields within a year of releases commencing. Two years after releases, *X. stemmator* adults were collected from surrounding fields, as were parasitised pupae. It is thus apparent that *X. stemmator* is established on its aboriginal host at both sugar estates.

The decision now is whether to pursue the classical biocontrol approach, as used with *X. stemmator*. A larval parasitoid, *Cotesia flavipes* Cameron (Hymenoptera: Braconidae), has been reported as effective against *C. sacchariphagus.* A collection of this parasitoid from a population of *C. sacchariphagus* in Southeast Asia most closely related to the Mozambican population, could be imported into Mozambique in order to fill the empty larval parasitoid niche which is available in this new outbreak area, and thus increase parasitoid biodiversity. Alternatively, *T. bournieri* could be reared on a factitious host for release at times of the year when its population is low, in order to augment the field population already there, to make it a more effective parasitoid.

In the light of information already obtained about the population dynamics of *C. sacchariphagus* and its parasitoid complex in Mozambique, arguments for the single use of both approaches will be presented and discussed, as well as a case for the complementary use of both approaches together.

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AUGMENTING LEAFROLLER PARASITOIDS IN APPLE ORCHARDS

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The obliquebanded leafroller, *Choristoneura rosaceana* (Harris), and three-lined leafroller, *Pandemis limitata* (Robinson) (Lepidoptera: Tortricidae), are important pests of apples in southern British Columbia, Canada. The two sympatric and generally bivoltine leafroller species overwinter as second or third instar larvae in bark crevices and begin to feed on apple foliage and blossoms when the latter are in the pink stage of bud development. The larvae shelter within blossoms or rolled leaves and fruit damage is caused when the sheltering leaf is tied to the fruit and larvae feed on the surface of the apple.

Over thirty species of parasitoids have been identified from these two leafroller populations in organically managed apple orchards in western Canada. Up to 25 % parasitism was recorded in the spring generation of overwintered leafroller hosts and up to 68 % in the summer generation. It would be advantageous to better understand the biology of this complex in order to allow augmentation of leafroller parasitism in orchards where previous pest management practices have deterred parasitoid establishment.

Laboratory bioassessments of common key leafroller parasitoids indicate that several species in the complex should contribute towards significant suppression of host populations in the field. Female *Apophua simplicipes* (Cresson) (Hymenoptera: Ichneumonidae) are long lived, parasitize a large number of obliquebanded leafroller larvae and act as predators of, and induce escape reactions in early instars of both leafroller species. The parasitoid emerges from the ultimate and penultimate host instar; however, feeding is significantly reduced in late instar parasitized hosts. *Apanteles polychrosidis* Viereck (Hymenoptera: Braconidae) parasitizes both leafroller species and emerges from third to fourth instar hosts, thereby killing the leafroller before it causes significant fruit damage. Both endoparasitoid species were mass reared and introduced as adults into separate commercial orchards under spring conditions, when wild members of these species would still be developing in overwintered leafroller hosts. Spring release was chosen to target generally higher population densities of host larvae in susceptible instars prior to significant damage occurring to the fruit. Potted trees, infested with early instar obliquebanded leafrollers, were used to monitor parasitoid activity in each orchard. *Apophua simplicipes* parasitized 7 to 29% of the sentinel larvae in the orchard in which this parasitoid was released and 21 and 9 % of wild leafrollers collected on release and non-release trees respectively. *Apanteles polychrosidis* parasitized 6 to 9 % of the sentinel larvae in the two orchards in which it was released and 7 % of wild leafrollers collected on release trees.

Releases of both parasitoid species were also carried out under fall conditions in commercial and research orchards, when leafroller hosts would be entering diapausing locations in bark crevices. Spring collections of wild leafroller larvae will be carried out in 2005 to assess augmentation of the two parasitoid species in overwintering host populations.

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EVALUATION OF CERTAIN EXOTIC APHID PARASITOID SPECIES AGAINST CEREAL APHIDS UNDER LABORATORY, FIELD CAGE, AND OPEN WHEAT FIELD CONDITIONS

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Aphids are the most serious insect pests attacking cereal crops, particularly wheat, barley and corn in many countries worldwide. Aphid parasitoids' importation and colonization have a great potential as a classical and effective biological control method. Through an Egyptian/American collaborative project carried out during 1997-2001, four cereal aphid exotic parasitoid species were imported from different countries to provide additional mortality factors to the indigenous ones, against key cereal aphid species in Egyptian and American wheat fields. A search for exotic cereal aphid parasitoid species or biotypes was carried out in Syria, Morocco, and Iran, in localities near the reported areas of the origin of cereal species and from habitats of climatic patterns similar to those in Upper Egypt and Southern California, USA. *Aphidius matricariae* Haliday (Syria), *Diaeretiella rapae* M'Intosh (Morocco), *Aphidius rhopalosiphi* De Stefani (Hymenoptera: Aphidiidae) and *Aphelinus albipodus* Hayat & Fatima (Hymenoptera: Aphelinidae) (Iran) were the parasitoid species introduced and evaluated under laboratory, field cage and open field conditions. Identification of the exotic species was confirmed by Dr. P. Stary, Institute of Entomology, Academy of Science of the Czech Republic. For each species, no. of parasitoids released, timing of release, wheat cultivar, wheat plant growth stage and location were recorded. The exotic parasitoid species showed different performances under several tested conditions. Generally, slight significant differences among the developmental periods of the released parasitoid species under the field cages at different environmental locations were recorded. *A. matricariae* parasitized significantly greater numbers of the oat-cherry aphid species, *Rhopalosiphum padi* L. (Homoptera: Aphididae) than the numbers parasitized by *D. rapae* and *A. rhopalosiphi* not only under the laboratory conditions (22+2ÚC and 50-60% R.H.) but also under field cages and in open fields, as well when compared with the indigenous *A. matricariae*.

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CHOOSING (OR CREATING) PARASITOIDS FOR TEPHRITID FRUIT FLY CONTROL

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Inundative releases of mass-reared fruit fly braconid parasitoids have significantly suppressed Mediterranean fruit fly (*Ceratitis capitata* (Wiedmann)), *Anastrepha suspensa* (Loew) and *A. ludens* (Loew) (all Diptera: Tephritidae) populations, with reductions of up to 95%. The combination of inundative parasitoid releases and the Sterile Insect Technique (=SIT) is synergistically efficacious, and inundative parasitoid releases, unlike SIT, can be fully integrated with insecticide bait-sprays. Rearing methods and expenses vary with species, but production methods that reduce costs make the technique practical under more circumstances. These include the following:

1) Choice of optimal parasitoid. The numbers of parasitoids available for inundative release has recently expanded. While efficacy is paramount, reproductive potential under mass-rearing conditions, and ultimately cost, is an important consideration for its use in integrated control programs. With any particular parasitoid, those species with a higher r are "competitors" for inclusion in augmentative releases. Other characteristics to considered are: 1) host vulnerability as a function of ovipositor length; 2) optimal macro and micro-environments; 3) host range and stage attacked; and 4) capacity to forage well at declining host densities.

2) Multispecies rearing through serial exposure. Depending on species, parasitism of larvae in mass-rearing facilities is often ~50%. However, the unparasitized pupae remaining can be exposed to pupal parasitoids to increase production and provide a means of attacking immature fruit flies that escaped braconid parasitism. For example, the diapriid *Coptera haywardi* (Oglobin) is an endoparasitoid tephritid specialist that does not hyperparasitize braconid larval parasitoids. Serial parasitism can double production and in field cage trials *C. haywardi* killed substantial numbers of buried pupae.

3) Creation of parthenogenic strains. Sex ratios of mass-reared braconids are typically 50%. If quality female parasitoids could be reared in thelytokic strains then the production costs would be automatically halved. Such strains might be created by exploiting sex ratio-distorting microbial endosymbionts. Bacteria in the genus *Wolbachia* can produce sex-ratio distortions in Hymenoptera through induced diploidy. Collection and screening of naturally-occurring infested insects may provide thelytokic females. In some parasitoid genera, parthenogenic and bisexual females occur sympatrically, but there

have been few surveys searching for thelytoky. At present, we have one parthenogenic line of a figitid species, a possibly parthenogenic, but uncolonized, braconid and a braconid colony that has extreme female biases. *Wolbachia* infections are largely transmitted vertically through female offspring but horizontal transmission, both intra and inter specific, can occur during super- and multi- parasitism. Infections can also be passed through microinjection and we hope to develop both a *Wolbachia* "library" and means of transmission.

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LONG-TERM EFFECTS OF NATURAL ENEMY AUGMENTATIVE RELEASES ON VINE MEALYBUG PEST POPULATIONS

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Vine mealybug (VMB), *Planoccocus ficus* (Signoret) (Homoptera: Pseudococcidae) is one of the key pests of grape growing areas in South Africa, the Mediterranean and more recently California in the USA. The cryptic behavior and waxy excretions produced by this pest result in inefficient control when using conventional pesticides. In order to develop an alternative, environmentally safe pest management tool, the mealybug parasitoid, *Coccidoxenoides perminutus* (Timberlake) (Hymenoptera: Encyrtidae) was laboratory-reared and mass-released in VMB infested vineyards with low, medium and high pest infestation levels situated in three environmentally different grape-growing areas in the South-Western Cape Province in South Africa. Mass-releases were done for a four-year period in release plots which were left without pesticide treatment during this period and compared with control plots where VMB were controlled with the use of conventional pesticides. Control and release plots were separated by buffer plots aimed at limiting the spread of mass-released parasitoids from the release plots to the control plots. A physical monitoring system with known levels of error coupled with degree-day information for VMB was used to determine the start date and number of natural enemies that needed to be released in each of the areas. Mass releases were done at monthly intervals starting during the beginning of summer in each of the areas and continued until the end of summer.

VMB infestation levels as well as crop loss assessments were done during the season and at harvest respectively. Season-long monitoring was done in order to determine the presence of natural enemies as well as percent parasitism in each of the three areas. Biological control of this pest was not hampered by the presence of ants in the first two areas, but the third had high incidence of *Anoplolepis custodiens* (Smith) and *A. steingroeveri* (Forel) (Hymenoptera:

Formicidae), both aggressive and difficult to control pugnacious ant species. Analysis of the above data sets indicated differences in season-long VMB infestation levels between release and control plots for the four-season period and higher VMB infestation levels were found in the control plots compared to the release plots and similar findings were made during crop loss assessments. Crop losses were lower in the release plots compared to the controls. Higher numbers of the parasitoids were found in the release plots compared to the control plots. The plots where ants hampered bio-control had lower percent parasitism compared to the plots which did not have ants. VMB infestation levels gradually decreased during the four-year period in all three areas in both the control and release plots, possibly due to the movement of released parasitoids from release plots to the surrounding control plots. The lowest decline in VMB season-long population levels were encountered in the plots which had the highest VMB infestation levels as well as ant presence. A cost analysis was done for each of the three areas and this information indicated that mass releases of natural enemies against VMB was more cost-effective in the areas which had no ant interference and displayed lower initial VMB infestation levels.

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IMPROVING KNOWLEDGE AND MANAGEMENT OF NATIVE NATURAL ENEMIES FOR BIOLOGICAL CONTROL OF COLORADO POTATO BEETLE

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Several native natural enemies of Colorado potato beetle (*Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae) (CPB)) provide biological control of this key pest of potatoes, tomatoes, and eggplant in North America. These native predators and parasitoids of CPB present a spectrum of biological opportunities and management options which range from conventional augmentation (laboratory mass-rearing and release), through field-based augmentation (in-situ natural enemy nursery) to conservation biocontrol tactics involving habitat modification to favor natural enemy populations and to "welcome" the natural enemies by providing critical resources to retain and propagate them within the agroecosystem.

Two species are more or less generalist predators, *Podisus maculiventris* (Say) (Heteroptera: Pentatomidae), and the polyphagous *Coleomegilla maculata* (De Geer) (Coleoptera: Coccinellidae). Both of these species are generalists in terms of habitat and also in their catholic feeding habits, which include significant consumption of plant juices and pollen respectively. This limits the usefulness, for these species, of simple augmentative tactics which may result in insufficient specialization in prey or in habitat, to meet the desired function of pest suppression. Instead it requires consideration of manipulation of predator movement and/or provision of properly-timed trophic supplements.

Three specialist natural enemies of CPB are less known, in part because of challenges in rearing. *Lebia grandis* Hentz (Coleoptera: Carabidae) is a carabid predator and parasitoid of *Leptinotarsa* which is well-synchronized with the CPB life-cycle but which is apparently limited both by conventional cultural practices and by climatic factors. We have succeeded in developing *Lebia* rearing techniques both for research and for augmentation objectives. The first instar carabid, the host-seeking life-stage, is short-lived and sensitive to climatic extremes. This puts a premium on tailoring cultural and chemical practices to favor the predator-parasitoid in the agricultural setting. Two specialist tachinid species, *Myiopharus doryphorae* (Riley) and *M. aberrans* (Townsend) (Diptera: Tachinidae), can be abundant in the field especially in the late season. Building on discoveries of the overwintering stage of the flies, which is within the adult chrysomelid host, we hope to develop in-field sorting techniques to favor the survival of tachinid-parasitized, compared to nonparasitized, host beetles.

Each natural enemy has specific requirements which limit the success of a conventional "lab rear and release" augmentation paradigm. This is turn requires species-specific modifications in biocontrol tactics, to include possible combinations of lab- and field-based rearing and conservation tactics.