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General News

Progress on Tackling Glassy-Winged Sharpshooter Invasions in California and the South Pacific

Glassy-winged sharpshooter, *Homalodisca coagulata*, is a major agricultural pest in California, USA. Inordinate densities of this exotic xylophagous cicadellid have developed in most of California where it feeds and reproduces on more than 300 species of plants. *Homalodisca coagulata* is native to the southeastern USA and northeastern Mexico. The insect invaded and established in southern California in the late 1980s, presumably immigrating from the donor range on imported ornamental plants. After undergoing a prolonged lag period, populations exploded in the early to mid 1990s and the insect rapidly increased its range, spreading from southern California north through the Central Valley and into areas around Sacramento in northern California.

Female *H. coagulata* lay eggs on the underside of leaves. Typically, individual eggs are laid side by side under the leaf epidermis which the female cuts with her ovipositor. The number of eggs in an egg mass can range from approximately two to 15 eggs with around 7–10 eggs per egg mass being common. There are five nymphal instars and adult insects are quite large, around 2 cm in length, and have an obvious enlarged head that contains well developed musculature and mouthparts.

The major threat this insect poses to agricultural crops, urban ornamental plantings, and some native plant species is through its ability to vector a xylem-dwelling bacterium, *Xylella fastidiosa*. The bacterium is contained within the mouthparts of immature and adult insects. Each time nymphs moult, bacteria are lost from the buccal cavity and must be reacquired from feeding on infested host plants. Adult *H. coagulata* are infective for life but transmission efficiency declines with age. *Xylella fastidiosa* is a xanthanomid-type bacterium. It replicates in the xylem and produces gummy xanthum-like secretions. These secretions and high bacterial densities in xylem clog water-conducting vessels thereby impeding water flow which results in the development of 'scorch-like' symptoms in susceptible hosts, which ultimately leads to death because of water stress. In California, one of the most important crops at risk from this novel vector–pathogen combination is grapes. Wine, table, and raisin grapes are multi-billion dollar commodities in California. Substantial disease damage, subsequent crop losses, and greatly increased pest management costs for *H. coagulata* control to wine producers in southern California, and table and raisin grape growers in the Central Valley do not bode well for California's premier wine-growing regions of Napa, Sonoma, and Mendocino counties which are currently free of infestation but are now well within striking distance of *H. coagulata*.

Sharpshooter Booms in the South Pacific

High densities of *H. coagulata* are not only present in California. In 1999, the pest was detected in Tahiti (French Polynesia in the South Pacific Ocean). Initial eradication attempts were apparently unsuccessful as large populations were later detected there in 2001 and in Mo'orea in 2002. In 2003 and 2004, populations were discovered on the islands of Huahine, Bora Bora, and Raiatea (all infested islands are part of the Society Islands group). *Homalodisca coagulata* populations in Tahiti are much higher than those observed in California. There are at least four reasons for this.

1. *Homalodisca coagulata* breeds year round in Tahiti as opposed to California where there are only two generations a year, spring and summer. In California, overwintering adults enter a reproductive quiescence during the late autumn and winter and sporadic egg laying occurs during warm periods over winter. Reproductive quiescence is not observed in Tahiti owing to the mild year round climate. Population fluctuations seem to be driven more by the wet and dry seasons with *H. coagulata* being more common in the wet season.

2. There is no effective natural enemy fauna in French Polynesia attacking *H. coagulata* so population growth is largely unchecked.

3. There are no aggressive xylophagous (native or exotic) competitors excluding *H. coagulata* from resources in French Polynesia.

4. Feeding studies with generalist predators such as endemic spiders indicate that *H. coagulata* nymphs and adults are toxic to these upper trophic level organisms. Incredibly, this insect may actually be creating its own natural enemy free space thereby promoting its invasion success in French Polynesia. Mechanisms underlying toxicity to native French Polynesian spiders are unknown but may result from symbiotic bacteria that are harboured in mycetomes, or perhaps *X. fastidiosa*, if this bacterium is present in French Polynesia.

Consequently, densities of *H. coagulata* are so high in the Society Islands, that its densities in California appear inconsequential, and the amount of excreta 'raining' from trees in Tahiti and Mo'orea have earned the pest the common local name *meuche pisseuse* ('pissing fly').

In 2004, *H. coagulata* was detected in Hawaii and populations have reached high densities on Oahu, approaching levels similar to those seen in French Polynesia. Clearly, *H. coagulata* has demonstrated high invasion ability and a propensity to spread globally, most probably transported long distances as egg masses on ornamental plants moved from infested areas (this life stage is largely immune to insecticides unlike nymphs and adults which are quite susceptible to systemic and foliar insecticide applications). In the South Pacific, this insect must be considered a major biosecurity risk and proactive incursion management strategies should be adopted by at risk nations. For example, New Zealand and Australia have climates that would favour *H. coagulata* establishment and both countries have major agricultural industries, including grapes, which would be adversely affected if the pest established in these countries.

Ecological Mechanisms that Increase Invasiveness and Threats to Other Nations

High density populations of *H. coagulata* in invaded regions present major threats to agriculture, and perhaps more importantly native biodiversity for three major reasons.

First, addition of *H. coagulata* to a new ecosystem permanently changes the vector ecology and disease prevalence of areas with endemic sharpshooters and *X. fastidiosa*. This is the case in California, where *X. fastidiosa* is endemic and there is a suite of native sharpshooters that vector the pathogen. *Homalodisca coagulata* has permanently changed the dynamics of *X. fastidiosa* transmission in California through its vector efficiency, parts of plants it can feed on, and high number of species that are utilized for feeding and reproduction. In areas such as French Polynesia and Hawaii where *X. fastidiosa* is not endemic, the bacterium could be present in ornamental plants imported from the Americas. *Xylella fastidiosa* is native to the New World and some species of imported ornamental plants from this region could act as 'silent reservoirs', by harbouring bacterial populations without exhibiting disease symptoms. Establishment of a competent vector in areas with silent reservoirs could result in the movement of *X. fastidiosa* out of reservoirs into susceptible uninfected hosts. If acquisition and dissemination occurs in such areas as described, this would increase the risk of exposure to native plant species that have no evolutionary association with *X. fastidiosa*. Such ecologically naïve plants could be highly susceptible to infection following feeding by infected *H. coagulata* nymphs and adults.

Second, high density populations of *H. coagulata* present an abundant food source for invasive upper trophic level organisms, such as mymarid parasitoids that use *H. coagulata* egg masses for reproduction. *Gonatocerus ashmeadi* is native to the home range of *H. coagulata*, and the egg parasitoid invaded and established in California independent of deliberate human assistance. *Gonatocerus ashmeadi* can utilize native California congenerics, such as *H. liturata*, for reproduction and such exploitation may have been essential to its establishment in southern California as it presumably was imported into the state in parasitized *H. coagulata* egg masses. Museum records suggest that *G. ashmeadi* established in California sometime before 1978, and populations of this parasitoid probably preceded *H. coagulata* by over a decade, therefore it had to have utilized *H. liturata* before *H. coagulata* established in California. In 2003, an undescribed species of *Gonatocerus* which is closely allied to described species from Argentina was reared from *H. coagulata* egg masses collected from Irvine County in southern California. How this undescribed *Gonatocerus* species arrived in southern California is unknown. Successful establishment was most likely facilitated by high densities of an exotic invader (i.e. *H. coagulata*), that allowed small founding parasitoid populations to readily locate and exploit suitable resources needed for rapid establishment and proliferation thereby reducing the likelihood of stochastic events eliminating founders. Because abundant hosts were present at its time of arrival, establishment barriers were eased. Environmental resistance to invasion by this parasitoid would have been much greater if highly abundant resources in the form of an unexploited pest population were absent. Therefore, invasions by upper trophic level organisms that establish because of high exotic pest populations may threaten endemic organisms through the development of novel food web linkages with native species that could result in undesirable nontarget species impacts and trophic perturbations.

Third, high density populations of *H. coagulata* greatly increase the chances of accidental exportation from heavily infested areas because of the greater probability of contamination of goods being moved from infested areas to non-infested areas. This is particularly evident in Tahiti where large numbers of *H. coagulata* are attracted to lights at night, especially around airport hangars and cargo loading areas where they can drop into loading bins after colliding with lights. Additionally, yellow logos on the sides of aircraft and yellow painted propeller tips attract large numbers of vagile adults to aircraft where they have been observed to fly into open doors and cargo holds.

California: the Biocontrol Story So Far

Homalodisca coagulata has the potential to derail California's agricultural economic trajectory akin to the impact that cottony cushion scale, *Icerya purchasi*, had on the state's fledgling citrus industry in the late 1880s. The economic cost to California caused by *H. coagulata–X. fastidiosa* is immense. Oleander leaf scorch has been estimated to cause damages in excess of US$52 million on 2000 miles of freeway median planting. In 2000, $6.9 million were made available to supply pesticides to projects focused on area-wide spraying of *H. coagulata* habitats in an effort to manage populations migrating into vineyards in Temecula and Bakersfield. Grape growers in Riverside and San Diego counties in 1998 and 1999 accrued estimated losses of $37.9 million because of *X. fastidiosa* related diseases that resulted from *H. coagulata* vectoring.

Like the cottony cushion scale problem over a century ago, state and federal agencies, and affected commodity boards have made research funds available for work on *H. coagulata* and *X. fastidiosa*, and classical biological control is seen as a feasible means for permanently suppressing *H. coagulata* densities to much lower levels, perhaps to densities similar to those seen in the home range where populations of this insect are orders of magnitude lower than currently observed in California.

Classical biological control of *H. coagulata* is being vigorously pursued in California and the programme is a joint effort between the University of California at Riverside (UCR), the California Department of Food and Agriculture (CDFA), and the US Department of Agriculture – Agricultural Research Service (USDA-ARS). Consequently, there are currently in excess of 70 research programmes on *H. coagulata* or *X. fastidiosa*. Because of the serious nature of the problem and the vast sums of money at stake, the National Academy of Sciences (NAS), a US society of distinguished scholars engaged in scientific and engineering research with a mandate to advise the Federal Government on scientific and technical matters, has subjected these research programmes to evaluation and assessment. Biological control of *H. coagulata* in California was reviewed extremely favourably by NAS.

On the biological control front, UCR is leading the effort in foreign exploration of the home range of *H. coagulata* for mymarid egg parasitoids. Studies are being undertaken in biological control laboratories at UCR on the developmental and reproductive biology of imported parasitoid species, their searching and oviposition behaviours, factors affecting sex ratio allocation, attack rates under field and laboratory conditions, pest and parasitoid phenology in citrus orchards, utilization of nutritive resources in the field, and the risk exotic natural enemies released for *H. coagulata* control pose to native nontarget sharpshooters (many of which are also serious pest species because of their propensity to vector *X. fastidiosa*).

CDFA is leading mass rearing, establishment and redistribution of parasitoid species in California. USDA-ARS is assisting CDFA with mass rearing efforts and USDA-ARS scientists from Weslaco Texas have been investigating the feasibility of new-association biological control by studying in quarantine host utilization behaviours and host ranges of sharpshooter parasitoids collected from South America. Studies on generalist predators and their role in biological control in citrus and urban ecosystems are being run by project leaders out of the University of California at Berkeley (UCB) and the USDA-ARS Cotton Research Laboratory in Phoenix Arizona. In 2004, The French Polynesian Government funded and launched a classical biological control programme against *H. coagulata*. The goal of the programme is to establish mymarid egg parasitoids in French Polynesia that have been released in California. The biological control programme is a joint effort being led by UCR and the UCB Gump Research Station on Mo'orea in cooperation with French Polynesian scientists based in Tahiti.

In 2001 and 2002, *G. triguttatus* from Texas and *G. fasciatus* from Louisiana, respectively, were established in California to complement the omnipresent *G. ashmeadi*. By 2004, over 90 separate recoveries of egg masses parasitized by *G. triguttatus* or *G. fasciatus* had been made in 23 sites over seven Californian counties suggesting these control agents are establishing and becoming widespread. *Gonatocerus ashmeadi* and *G. triguttatus* are solitary endoparasitoids with one adult parasitoid emerging per *H. coagulata* egg. *Gonatocerus fasciatus* is a gregarious endoparasitoid with more than one adult emerging per host egg. All three parasitoids are biparental with female biased sex ratios. Under no choice conditions, these three parasitoids exhibit significant differences in successful host egg age utilization. *Gonatocerus ashmeadi* has greater offspring output from host eggs 3 days of age, *G. triguttatus* from eggs 4 days of age, and *G. fasciatus* from eggs 2 days of age. When host eggs of varying ages that are all susceptible to attack are presented simultaneously *G. ashmeadi* (1–4 days utilized most effectively) and *G. triguttatus* (3–6 days utilized most effectively) utilize eggs across presented age categories with equal efficiency and show no preferences. *Gonatocerus fasciatus* however, is highly restricted to very young host eggs just 1–3 days of age. Beyond this age, egg parasitism drops to extremely low levels. This may occur because *G. fasciatus* is considerably smaller than *G. ashmeadi* and *G. triguttatus* because of its gregarious habit (the more adults produced per host egg the smaller the parasitoid) and its ovipositor may not be strong or long enough to penetrate a host chorion that is increasing in strength as it matures. The day-degree requirements and demographic statistics of these three parasitoids are currently being studied to determine the likely impact they could have on the target and the climatic suitability for the parasitoids in areas in which *H. coagulata* has already invaded and established or has the potential to invade.

Most commercial agricultural environments in which *H. coagulata* thrives are unfavourable habitats for natural enemies because weed suppression removes potential shelter and floral resources that hymenopterous biological control agents can use. In the laboratory it has been demonstrated that honey-water and buckwheat (*Fagopyrum esculentum*) flowers significantly increased longevity of male and female *G. ashmeadi*, *G. triguttatus*, and *G. fasciatus* up to 94.6%, 92.4% and 93.1%, respectively, compared with water. These results indicate that resource procurement maybe extremely important for enhancing parasitoid survival in agroecosystems. Increased longevity of female parasitoids resulting from resource procurement may enhance biological control of *H. coagulata* because increased female longevity may increase encounter rates with *H. coagulata* egg masses and subsequently increase parasitism. Field studies are planned to investigate conservation biological control of *H. coagulata* more thoroughly.

What Next?

In September 2004, *G. ashmeadi* colonies were established in quarantine in Tahiti. Before parasitoids are released from quarantine they will be subjected to extremely rigorous host-specificity testing to determine the potential risk the parasitoid poses to indigenous sharpshooter species in French Polynesia. To achieve this, the native 'at-risk' fauna needs to be identified and egg laying ecology determined by field surveys as the cicadellid fauna of French Polynesia is poorly studied. Efforts are underway to remedy shortcomings in knowledge of Tahitian sharpshooters, enabling a thorough list of nontarget species to be drawn up and decisions made on the need for testing them. It is likely that the nontarget risk posed by *Gonatocerus* species will be low. French Polynesia has no native sharpshooters in the tribe Proconiini, and from exhaustive field studies in the home range of *H. coagulata*, *G. ashmeadi*, *G. triguttatus* and *G. fasciatus* have only been reared from proconiin sharpshooters, a cicadellid tribe unique to the New World.

Biological control of *H. coagulata* is being considered in Hawai'i. However, this project is likely to proceed with extreme caution because of the past history of unwanted nontarget impacts on some of Hawai'i's unique insect fauna. In February 2005, *H. coagulata* and management of this pest will be the focus of an entire session at the annual meeting of the Hawai'ian Entomological Society.

In southern California, the key parasitoid attacking *H. coagulata* is the self-introduced *G. ashmeadi*, and despite the establishment of two additional parasitoid species (*G. triguttatus* and *G. fasciatus*) to complement resident native egg parasitoids (e.g. the trichogrammatids *Ufens* spp. and *Zagella* spp. and *G. morrilli* and *G. novofasciatus*), overall parasitoid impact on *H. coagulata* still remains low. In southern California, the spring generation of *H. coagulata* eggs sustains an average parasitism rate of just 12%, while the summer generation of eggs suffers an average parasitism rate of 19%. At certain periods during summer when densities of host egg masses are low, parasitism rates will reach 100% for short periods. Of the egg masses discovered by *Gonatocerus* spp., 17% on average have at least one egg parasitized in spring, compared to 30% of discovered egg masses utilized at some level in summer. Parasitism rates, especially of eggs of the spring generation of *H. coagulata,* need to increase substantially to bring the pest under effective control.

Interestingly, even though one of the key natural enemies of *H. coagulata*, *G. ashmeadi*, was established in California well in advance of *H. coagulata* arriving, it did not prevent the pest establishing, reaching high densities, and spreading over wide areas. Establishment of two exotic *Gonatocerus* spp. in California has so far had no obvious impact on *H. coagulata* populations, but it may still be too early to assess the ultimate impact *G. triguttatus* and *G. fasciatus* will have. One aspect that deserves attention is assessment of potentially adverse interactions between competing parasitoid species. An argument that periodically surfaces in the biological control literature is: 'how many natural enemy species should be released to control an arthropod pest?' The self-establishment of *G. ashmeadi* may have prevented a more effective natural enemy (e.g. *G. triguttatus*?) from realizing its full potential following deliberate release in California. Clearly, there is much more that needs to be done (e.g. life table studies of *H. coagulata* and detailed field studies on the role of brochosomes (particles produced by the Malpighian tubules of cicadellids) covering *H. coagulata* egg masses on parasitism rates) and careful evaluation before factors influencing the success of biological control of *H. coagulata* will be fully understood.

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A Minute Wasp to Tackle a Big Job: Control of Silverleaf Whitefly

The Australian Government Departments of Environment and Heritage, and Agriculture, Fisheries and Forestry have granted permission for the release of a tiny parasitic wasp in Australia. After extensive testing in quarantine in Brisbane, *Eretmocerus hayati* will be released in southeast Queensland to control silverleaf whitefly (SLW), *Bemisia tabaci* Biotype B. It will be the battle of the midgets.

SLW is a small (around 1 mm long), white, sucking insect related to aphids. It can be distinguished from other closely related whitefly by the tent-like way it holds its wings. Females produce between 50 and 300 eggs, depending on the host plant, and these are laid on the underside of leaves. A generation lasts between two and three weeks and there are four juvenile stages (three nymphs and a pupa from which the adult emerges). Only the first instar is mobile but it moves only a short distance from its egg. Therefore, older instars tend to occur on older leaves with eggs on new leaves. A crop under attack can host billions of whitefly.

Eretmocerus hayati is a tiny parasitic wasp, less than 1mm long. The female lays her eggs under a SLW nymph. The wasp larva, when it hatches, bores into the nymph slowly developing along with the whitefly. Once the whitefly enters the final development stage the parasite kills the whitefly and completes its development and the adult finally emerges through a hole it chews in the surface of the whitefly.

Despite its size, SLW is considered one of the major global pests of vegetables, cotton and ornamental production. It is found across Europe, Asia, Africa, the Americas and several Pacific Countries and is known to attack more than 600 plant species. It arrived unnoticed in Australia in 1994, probably from the USA, and carried with it resistance to many insecticides.

SLW liked it in Australia, spread quickly and is now causing severe problems in Queensland, northern New South Wales (NSW) and parts of Western Australia. It is a major problem for vegetable and soyabean producers in most parts of Queensland and for cotton growers in the state's Central Highlands where it threatens the viability of cotton production. The large quantities of honeydew produced cause 'sticky cotton' which can bring a cotton gin to a standstill. Sooty mould, which grows on honeydew, necessitates the costly washing of produce and fouls cotton. The pest is still spreading with a recent outbreaks occurring in the Carnarvon area of Western Australia and the Darling Downs of Queensland.

Outbreaks cost growers dearly. In 2000, more than Au$6 million extra was spent on SLW control in the coastal strip from northern NSW to the Burdekin in Queensland. In 2001/02, it caused an extra $3 million to be spent on control on cotton in Queensland's Central Highlands.

The only means of control currently available to growers is pesticides and the capacity of SLW to develop resistance makes reliance on chemical control unsustainable. This makes biological control an attractive option. After a long search for a suitable potential biocontrol agent, Dr Paul De Barro and his team at CSIRO Entomology began evaluating *E. hayati*. This wasp, originally from Pakistan, has been used successfully against SLW in the Lower Rio Grande in south Texas – an area very similar climatically to coastal and Central Highland areas of Queensland. In the Rio Grande, the numbers of SLW have been reduced to a level where they are readily managed by existing programmes.

The process of finding and getting approval for the release of a potential biological control agent is long and complicated with each step requiring unanimous approval from 21 independent agencies representing all Federal and State Departments of Environment and Agriculture. Once permission is given to import a potential agent into quarantine in Australia, the long and sometimes tedious process of assessing its suitability begins. This is to ensure that the agent attacks only the pest it is intended to control and that it will not move on to other species.

It is hoped that once this agent becomes established it will have the same effect here as it had in the Rio Grande and growers will be able to manage SLW more easily.

The research on SWF was completed by CSIRO Entomology and the Queensland Department of Primary Industries and Fisheries and supported by Growcom, Horticulture Australia Ltd, the Grains Research and Development Corporation and the Cotton Research and Development Corporation.

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Egypt Unearths Prospective Agent for Cotton Pest

A virus of local origin may provide a new tool for control of *Spodoptera littoralis* (Egyptian cotton leafworm) on cotton in Egypt. IPM has been implemented in the country's cotton-growing areas for many years. Against *S. littoralis,* measures include collecting egg masses, microbial pesticides (although the pest is not susceptible to all strains of the most commonly used biopesticide, *Bacillus thuringiensis* [*Bt*]), insect growth regulators, and pheromone-mediated mating disruption and mass trapping. Nevertheless, even with these measures and chemical sprays where they fail, *S. littoralis* remains the main threat to cotton growing in Egypt. Joint research involving the French organization IRD (Institut de Recherche pour le Développement, Paris) the University of Cairo at Gizeh (Egypt), the University of Quebec at Laval (Canada) and the University of Montpellier II (France) has been evaluating the potential of the densovirus MlDNV as a new biological control to add to the IPM toolkit.

Between 400,000 and 500,000 ha in Egypt are planted with cotton, accounting for one-sixth of all cultivated land. The cotton sector employs over one million people and is a crucial foreign exchange earner. It has seen changes in recent years, with a transition from government to private control. Egypt retains its position as a foremost producer of quality cotton, although exports are under threat from changes made to trade agreements at the beginning of 2005.

Spodoptera littoralis is one of the most intensively studied insects in Egypt. It attacks not only cotton but also cereal crops and lucerne, the country's principal fodder crop. In cotton, it is a major constraint to production because it causes both yield loss and quality degradation.

Densoviruses are a small group of DNA viruses that infect arthropods. Densovirus MlDNV was isolated for the first time in 1995, in Egypt, from another leaf-feeding noctuid, *Mythimna loreyi*, on maize[1]. Results of subsequent field research plus genome analyses indicated its potential as a component of biological pest control strategies, attacking an array of pest species, on a variety of host plants, and in all seasons. The research team characterized the biology, virulence and propagation of the virus in relation to population fluctuations of insect pests. It was found in seven noctuid species, including *S. littoralis*. It was isolated throughout Egypt, from cotton plantations in the Nile Delta in Lower Egypt to lucerne and clover fields in Upper Egypt and the oases in the West. Moreover, it occurred at all times of the year, with large infections developing in *Agrotis ipsilon, A. segetum, A. spinifera* and *Spodoptera exigua* in winter and spring, and *Heliothis armigera*, *Autographa gamma* and *S. littoralis* in summer and autumn.

Characterization, partial cloning and sequencing of the densovirus MlDNV genome provided information on the mechanisms that govern the virus's multiplication[2]. Samples collected in different parts of Egypt were all shown to be the same species of densovirus, MlDNV, although some corresponded to genetically distinct strains. This genetic biodiversity could explain the wide distribution of the virus and its high virulence in different species of noctuid. One strain has been selected for development for biocontrol of *S. littoralis*, and it is hoped it can be used for other pests in the long term.

Potential nontarget effects are being investigated. In-vitro cell-infection experiments showed that the virus was unlikely to infect mammals and other nontarget species in agricultural areas including earthworms and snails. Further research is continuing in Egypt to verify the harmlessness of the virus for nontarget insect species, with a view to its authorization. Such ratification would be the first step towards the development of a densovirus-based biocontrol agent.

[1]Fédière, G., El-Sheikh, M.A.K., Abol-Ela, S., Salah, M., Massri, M. & Veyrunes, J.C. (1995) Isolation of a new densonucleosis virus from *Mythimna loreyi* Dup. (Lep. Noctuidae) in Egypt. *Bulletin of the Faculty of Agriculture, Cairo University* 46, 693–702.

[2]Fédière, G., El-Far, M., Li, Y., Bergoin, M. & Tijssen, P. (2004) Expression strategy of densonucleosis virus from *Mythimna loreyi* (*Ml*DNV). *Virology* 320, 181–189.

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Why Food Producers Disregard Augmentation

Augmentative biological control has the potential to be one of the cornerstones of sustainable agriculture, yet there has been limited use of the technology in commercial crop protection, particularly in the USA. Limited use has been ascribed to lack of farmer knowledge, failures in government policies, poor public perception, etc. But is the technology itself also wanting? A recent paper in the journal *Biological Control*[1] analyses the success of augmentative biological control in field food crops, discusses how the results might explain limited adoption of the technology, and suggests whether the future could bring about a reversal in the situation.

Augmentative or inundative biological control involves releasing large numbers of artificially reared natural enemies with the aim of augmenting existing natural enemy populations, or inundating a pest population with natural enemies. The aim is to suppress pest populations to non-damaging levels.

The review, which deals with releases of predators and parasitoids in agricultural food crops, focuses on three key questions about augmentation:

- Does it work?
- Is it cost effective?
- What ecological factors affect it?

The first two questions are key to farmer decision-making. For decades, broad-spectrum chemical pesticides have been the mainstay of crop protection, and this has been the baseline against which other technologies are measured. The augmentative approach has to compete with chemicals in terms of the degree (and predictability) of efficacy as well as cost. Farmers tend to be risk-averse. They depend on being able to market their crop, and decisions are weighted in favour of reliability of result. This is particularly important in the context of food production for a market (public) that has high demands in terms of quality and acceptable pest damage. Farmers also have to make a living. Despite growing pressure for environmentally benign agriculture, consumers still expect cheap food.

The third question aims to identify common factors affecting the success of augmentation, and to ascertain whether conclusions can be drawn about which factors might be manipulated to improve success.

Using the AGRICOLA database the authors identified more than 140 published scientific case studies on augmentation from which they selected a subset included in the review. Most selected papers pertain to the USA, although Brazil, Canada, France and Switzerland are also represented. A key part of the review is a critique of various methods used in published studies of augmentation. For this reason alone, the paper is an invaluable aid to anyone setting out to assess the efficacy of augmentation. Stringent requirements for inclusion in the review ensured that the selected studies could be interpreted in a scientifically rigorous way. However, the authors note that this stringency led to some types of augmentation being excluded and that: “The review therefore applies best to small plots in open field situations” rather than greenhouses or entire agroecosystems.

The basic approach for the review was developed in part from a study of classical biological control by Stiling[2]. For some studies, determination of the efficacy of augmentation was based on author assessment of whether pest densities or crop damage were suppressed to specified target levels. Pest populations were reduced to target densities in five of 31 studies analysed. In six cases, the impact was described as ‘mixed’ because the results varied (between sites or years, or depending on the market). Augmentation was described as failing in the remaining 20 (64%) cases. Seven studies explicitly compared augmentation and conventional pesticide application. In these, pesticide treatments achieved target pest densities in most (but not all) cases. Augmentation was typically less effective.

Economic data for both augmentation and pesticide use were frequently inadequate for analysis. Few studies presented costs of augmentation versus conventional pesticide application or explicitly included cost–benefit analyses. The review authors note that information on costs should always be included in studies of augmentation. Without such information, adoption of any technology is doomed, however effective. For studies that included appropriate data, analysis showed that pesticides were usually more cost-effective. However, in some case, costs/benefits of augmentation were comparable to those of chemical control, and integrating chemical and biological control showed potential for greatest net benefit in a few systems.

The review authors conclude that augmentative biological control:

- Was usually less effective than treatment with conventional pesticides.
- Was often more expensive than the chemical alternative, and sometimes much more so.

Under these circumstances, it is not hard to see why farmers persist in favouring chemical control. Can anything be done? Do the answers to the third question provide any insights?

To identify ecological factors limiting augmentation, the review authors again relied on the views of the authors of the original studies (some of which fell into the 'failing' category in terms of efficacy, see above). Twelve factors emerged as affecting success, with "environmental conditions unfavourable for the natural enemy" the most frequently cited, followed by "natural enemy dispersal", "natural enemy predation", "availability of pest refugia", and "mutual interference/cannibalism". Some factors clearly warrant further research to mitigate their effects, particularly through the release of multiple enemy species. Integration of the augmentative approach with other pest management methods (cultural and chemical) also has the potential to overcome limitations, although few studies investigated this.

The review authors conclude that poor efficacy is currently a major shortcoming of augmentation, and consequently this technology is not likely to replace broad-spectrum pesticide use in food crops in the USA, in the short term at least. Acceptance of this perhaps unpalatable conclusion, however, sets a clear challenge for researchers. The crucial question is whether augmentation can achieve pest suppression comparable to applications of one or more of the pesticides available for pest control, and if not, why?

This paper identified factors limiting the adoption of augmentation, but the authors acknowledge some shortcomings in their methods that may make the picture more hopeful. New technologies in rearing and release of natural enemies will hopefully tip the balance in favour of augmentation. In addition, the growth of organic agriculture, the withdrawal of cheap 'high-risk' pesticides and the introduction of more environmentally benign and more expensive chemicals levels the playing field. Integration of augmentative biological control with other pest management measures is seen as the most promising avenue.

Willingness to recognize shortcomings and to try and rectify them is a sign of maturity in any applied science. This review is the latest in a series of significant publications which illustrates how biological control stakeholders (researchers and practitioners) are examining all areas of the discipline with a view to improving the performance of this well founded and exacting science.

[1]Collier, T. & Van Steenwyk, R. (2004) A critical evaluation of augmentative biological control. *Biological Control* 31, 245–256.

[2]Stiling, P. (1993) Why do natural enemies fail in classical biological control programs? *American Entomologist* 39, 31–37.

Towards a Green and Pleasant Land: Biocontrol in UK Agriculture

It is becoming axiomatic that less pesticide is good – good for the environment and good for health. Government and consumers alike are pressing for less pesticide use in UK agriculture. But how realistic is the goal? As the article above ('Why food producers disregard augmentation') indicates, 'alternative' pest management strategies are not necessarily as effective or cost-effective as chemical control – in which case farmers are unlikely to implement them when left to their own devices. This is part of the reason that, despite intensive research into development of various biological alternatives to chemical pest control, these strategies represent in total less than 1% of a global pest control market worth some US$30 billion. What can the UK do to break the mould?

A UK£1 million project funded by the RELU (Rural Economy and Land Use) programme, supported by Research Councils UK, Defra (Department for Environment, Food and Rural Affairs) and SEERAD (Scottish Executive Environment and Rural Affairs Department), is to look at the obstacles to and opportunities for biological control strategies in UK agriculture. 'Re-bugging the system: promoting adoption of alternative pest management strategies in field crop systems' is a collaborative project involving Imperial College, London, the Game Conservancy Trust and Rothamsted Research and will focus on UK cereal systems.

To aid in the further development and commercial uptake of alternative strategies, information will be gathered in UK cereal systems concerning:

- Social benefits of reduced pesticide use, compared with current costs of chemical control.
- Constraints to and incentives for adoption of alternative technologies.
- Social, economic and environmental/technical factors determining the current level of pesticide 'lock in'.

Research will focus on two strategies that can affect the activity of natural enemies and their effectiveness as biocontrol agents: habitat management and semiochemicals. They will be considered independently and together by assessing:

- The relative importance of natural enemy diversity and abundance (temporal and spatial) in pest control in cereal-based systems.
- The roles of semiochemicals in crop–pest–natural enemy interactions and new opportunities for practical exploitation.
- How to integrate habitat manipulation and semiochemical technologies.
- The effect of applying these alternative strategies on a landscape scale.

The key questions are how much land needs to be manipulated to create good habitat before you encourage beneficial insects sufficiently and over what scale of adoption, field/farm/landscape, such manipulations become effective and cost efficient. To answer these, the project will conduct one of the UK's largest-ever field studies. Field trials beginning this spring focus on the addition of 6-metre flower-rich mixed-grass strips at field margins. The effect of these on the impact of ground- and crop-active predators (hoverflies and predatory beetles), parasitoids (parasitic wasps) and entomopathogens (fungal diseases of insects) on cereal aphids will be monitored to identify the contribution that each species makes to cereal aphid control, and to what extent this is influenced by the scale of habitat manipulations. Later in the project, semiochemical manipulation designed to encourage natural enemies and deter pests within the crop will be added to the system and effects monitored.

As a groundbreaking initiative in the UK, the Re-bugging project has the additional objective of defining a framework within which future development of alternative technologies can take place, integrating scientific and socioeconomic research, to maximize impact and ultimate uptake.

Recognizing that the scientific literature is littered with good ideas that failed to make the lab-to-field transition, the Re-bugging project will address some possible obstacles to the adoption of alternative pest control technologies. Adverse policies, high costs and inappropriate marketing have been implicated elsewhere in their failure. To address how these might affect their success in the UK, the project will consider:

- The role and design of agri-environmental policy.
- Consumer demand for differentiated 'pesticide-reduced' food products and the feasibility of passing such a price signal to the farm gate.
- The potential for retailer-led initiatives (e.g. contractual requirements).

The ultimate objective of this project is to use the results of the scientific and economic research to create a robust bioeconomic model that takes into account all relevant agricultural, economic, political and environmental factors. The model will function at several levels:

- Aiding optimal policy design and adoption decisions.
- Forming the basis of a practitioners' decision-support system.
- As a vehicle for dissemination of research results.

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GM Arthropods: Trapped in a Policy Vacuum

Given the debacle associated with the introduction of genetically modified (GM) crops, many in the biological control sector have sought to distance themselves from biotechnology. Others believe that the new technology has the potential to complement and enhance biological control, and may be able to solve some intractable pest problems. Genetic modification using recombinant DNA can now be used, almost routinely, to transform pest and beneficial arthropods (i.e. insects and mites). Goals include:

- Mosquitoes (and other vectors) unable to transmit diseases.
- Sterile males or female-only lines for genetic control programmes.
- Disease-resistant honeybees.
- Silk moths producing new types of silk.
- Arthropods producing drugs or vaccines.
- Natural enemies with enhanced effectiveness for biological control.

Arguments persist on how realistic these goals are, or how safe the methods, but the greatest impediment to their implementation may not be science but lack of regulatory structure. A workshop in the USA in September 2004[1] led to an unambiguous call for public involvement in developing risk assessment and regulatory procedures on an international scale.

Research intended to underpin the process goes back to 1982, when the common fruit fly, *Drosophila melanogaster*, was first modified using a P-element vector. The first (contained field) release of a transgenic arthropod natural enemy was 9 years ago. It took place against the background of a series of consultations with stakeholders holding a variety of viewpoints, including a workshop[2] that explored the potential risks of a GM natural enemy release. A model system was designed to mitigate identified risk issues. A beneficial rather than a pest arthropod was considered likely to arouse less concern. The species was selected because a good deal was already known about the ecology and performance of (non-transgenic) genetically improved strains from their development and successful deployment against pests. Avoidance of a vector for the gene transfer was thought to minimize the risk of horizontal transfer, and the marker gene (a *lacZ* construct) had been used previously without significant concern in other releases.

A transgenic strain of the predatory mite *Metaseiulus occidentalis* (also called *Galendromus* or *Typhlodromus occidentalis*) was created by microinjection of plasmid DNA into or near the ovaries of adult female mites. The injected DNA contained a microbial gene (*lacZ* open reading frame) with a promoter (*Drosophila* heat shock protein 70) to initiate transcription, and was intended to serve only as a molecular marker. Many eggs of injected females acquired the injected DNA, some in the nuclear genome (stably transmitted through several generations) and some as large extra-chromosomal arrays, which were destroyed. The transgenic strain was released into an experimental site on the campus of the University of Florida in 1996 after extensive reviews by relevant state and national authorities. The purpose of the release was to document the persistence of the molecular marker in a field population and to demonstrate that the transgenic population could be contained. All material associated with the release was removed at the end of the trial and monitoring gave no evidence for the transgenic predators escaping from the trial. As an added safety factor, this species, from the western USA, is unable to survive the hot and humid summers in Florida, thereby providing ecological containment of the GM strain.

This was just the first project to share the common purpose of beginning the process of assessing potential risks of releasing transgenic arthropods into the environment. Another project, the first to release a GM insect, assessed tethered, caged pink bollworms (*Gossypiella pectinophora*) modified to contain a green fluorescent protein gene. The research and the process of obtaining permission for these projects, together with the results of deliberations at other meetings since (e.g. in Rome[3] and Beijing[4]) have helped to clarify the potential risk issues to be resolved. These include whether:

- The inserted gene(s)/trait(s) is(are) stable.
- The traits (especially pesticide/antibiotic resistance) might be horizontally transferred to other populations/species.
- GM arthropods will perform as expected in terms of spread and distribution, host/prey specificity and other biological properties.
- They will have unanticipated environmental effects.
- (For short-term releases) they can be recovered from the field.

Risk assessments of fitness and host specificity can be conducted in the laboratory, even adapting protocols developed for testing 'conventional' biological control agents, but the potential risks of horizontal gene transfer and unintended effects on ecosystem function present more challenges.

It has become clear that GM arthropods raise new risk issues to add to those associated with GM plants.

- Even in the USA, where public acceptance of GM crops has been far greater than (for example) in Europe, there has been more unease about developing and releasing transgenic animals such as fish.
- Given their greater mobility, GM arthropods have greater potential than GM plants to escape from the laboratory or from field trials or release plots.
- Some projects require the GM arthropod to disperse and mate with wild populations (some GM mosquitoes, for example). In such cases, many GM individuals must be released into the field and establish on a permanent basis for the scheme to work. Other projects propose releasing 'drive elements' such as active transposable elements or microbial symbionts such as *Wolbachia* to drive desired genes into wild populations of arthropods.
- Particularly where the aim is to establish a permanent and self-disseminating population, there is an international dimension to the debate. GM arthropods could potentially disperse to other countries by any of the pathways by which pests move around the world.

One of the recommendations of the meeting in Rome[3] was that consultations should be made with countries into which the GM organism could spread before making a release and participants debated whether there could be a set of international risk guidelines for GM arthropods. However, the feeling was that no organization was prepared to take this on yet.

Research on GM arthropods has now reached the stage where it is possible to begin to consider their use in practical pest management programmes. (The actual timescale will depend on the system: a sterile [irradiated] arthropod with a marker gene and unable to establish in the wild is likely to be ready long before anything intended to establish permanently.) Arguments about whether they should be released cannot easily take place in the current policy vacuum.

As indicated above, a large number of questions have been identified that need to be answered when developing a genetic manipulation project, if it is to have any chance of leading to successful deployment of a GM natural enemy. It has become clear that prospective releases will need to be evaluated on a 'case by case' basis as there is no one set of issues for all GM arthropods. Over time this would build up a body of knowledge to inform subsequent decision-making, and could modify data requirements. However, although a good deal of effort has gone into identifying the questions to be answered, how they will need to be answered remains unclear. It is unclear which, if any, countries have explicit information as to what data would be required to allow a GM arthropod natural enemy to be released into the field with the aim of permanent establishment.

Both nationally and internationally, there has been a 'cart and horse' problem. Regulators have been hesitant to make elaborate regulatory provisions before a GM arthropod was ready to be released, and scientists have been concerned about investing time and funds on a GM project only to have it stalled while regulatory procedures were put in place. Other concerns include who will pay for the risk assessments because most scientists doing this research are in the public sector, not in commercial companies.

The last thing researchers involved in genetic modification of arthropods want to see is a repeat of the very public disagreements between scientists that marked the GM crop debate. In November 2004, an online conference on biosafety in relation to the use of genetic modification to manage animal populations focused on mammals and arthropods[5]. A wide range of stakeholders contributed, and messages that emerged reinforced calls for regulation, wide consultation and risk assessment. Unless such issues can be addressed in a way that involves all stakeholders, research on transgenic arthropods may founder. Whether any GM arthropod will be judged sufficiently safe to release remains to be seen, but without effective regulatory and risk assessment procedures, and the funding to develop the regulations and funding for the research on the potential risks of specific GM arthropods, it will not be possible to find out.

Further Information

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[4]Seventh International Symposium on the Biosafety of Genetically Modified Organisms, Beijing, China. 10–16 October 2002. See: www.edpsciences.org/articles/ebr/abs/2003/01/04/04.html

[5]Biosafety Considerations in the use of Genetically Modified Organisms for the Management of Animal Populations. Online conference hosted by the Biosafety Clearing-House of the Convention on Biological Diversity, 18 October – 15 November 2004. See: http://bch.biodiv.org/onlineconferences/gmoam.shtml

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IPM Systems

This section covers integrated pest management (IPM) including biological control, and techniques that are compatible with the use of biological control or minimize negative impact on natural enemies.

IPM in Honduran Subsistence Agriculture: a Multi-Focal Perspective

In many Central American countries, agrochemicals are commonly used in both subsistence and intensive agriculture. For resource-poor farmers, reliance on pesticides for pest management can engender significant costs, and can also instigate pest problems in their production systems. In an effort to discourage farmers from irrational pesticide use, various institutions have introduced them to the key principles of integrated pest management (IPM). Several IPM methods offer cheap and sustainable pest management options, considered attractive to resource-poor farmers. IPM technologies include conservation biological control which encourages the use of indigenous natural enemies for suppression or prevention of pest outbreaks. Since many natural enemies have ecological requirements beyond the field edge, the success of conservation biological control depends upon the wider landscape in which fields are embedded. In Central America, slash-and-burn agriculture, deforestation and inappropriate management of natural resources have affected this landscape considerably and can compromise IPM to varying extents. Quantifying the contribution of the agro-landscape will therefore help us explain farmers' degree of success in adopting IPM within their respective field settings.

The successful adoption of many IPM technologies depends on farmer knowledge and on enabling ecological conditions in their field settings. Where farmers' knowledge is deficient, adoption of such technologies can be increased through delivering essential information to farmers by means of IPM training workshops. This information can contain both technical and non-technical components. Connecting farmers' knowledge with the ecological conditions of their production systems can help explain farmers' actions, including their adoption of IPM. This understanding could also help identify needs for IPM extension and the limits of some IPM technologies like conservation biological control.

In our research we proposed to investigate the potential for conservation biological control in Honduran small-scale maize cropping systems. Influential factors for success of conservation biological control were identified relating in-field natural control to the specificities of the agro-landscape. Our work also set out to assess the importance of farmer knowledge in determining farmer pest management behaviour, specifically their exploitation of the available potential for biological control within their respective field settings. Farmer knowledge systems were validated by comparing them to ecological conditions as observed within the farming environment. Lastly, we quantified the effect of IPM training history on farmer knowledge and pest management behaviour.

Fieldwork was conducted during 2002/03 in rain-fed, hillside areas of southeastern Honduras, where local small-scale farmers cultivate maize as their primary staple crop. In the region, fall armyworm (FAW) (*Spodoptera frugiperda*) is a key pest of maize.

We took a threefold approach.

- Firstly, we quantified pest severity and dynamics within farmers' fields and related those to the abundance and diversity of natural enemies as observed.
- Secondly, we measured the contribution of the agro-landscape to in-field conservation biological control and the associated potential for sustainable pest management. Agro-landscape composition was assessed through combining aerial imagery analysis with *in-situ* vegetation classification.
- Lastly, adoption of IPM practices was evaluated through farmer surveys, conducted in communities that were typified by differences in training history and historical pest severity. Farmers' appreciation of key biological and ecological concepts was determined and related to their associated pest management behaviour. Linkages with the ecological characteristics of the farming environment were explored.

Pest Severity and Natural Control

FAW infestation levels were low during both years, and remained below the action threshold (30% plants infested) in most farm plots. FAW infestation appeared influenced by abiotic conditions (altitude, weather) and natural enemies. Levels of FAW parasitism and disease incidence were low, while the arthropod predator complex was extremely diverse and abundant. Infestation patterns indicated that earwigs, carabid beetles and spiders significantly impacted FAW population establishment and growth. Fire ants (*Solenopsis* spp.), a key predator in many maize-growing systems, seem to be of lesser importance in hillside agriculture.

Agro-Landscape Contribution

In-field natural control was linked to features of the broader agro-landscape. Abundance levels of several natural enemies were related to the composition of the surrounding landscape mosaic. Some natural enemies, such as earwigs and fire ants, were associated with early successional habitats (grasslands, shrublands, etc.). Others however, including spiders and carabid beetles, reached high abundance levels in fields located within later successional environments (broadleaved/pine forest). Although the composition of the agro-landscape affected natural enemy abundance and diversity, it generally did not compromise the suppressive potential of the in-field natural enemy.

Farmers' Actions and the Farming Environment

Although farmers had a limited understanding of pest biology and ecology, they correctly assessed pest severity in their farm plots. Most farmers considered FAW to be of low or sporadic importance and few farmers felt a need to adopt curative pest management techniques. Farmers' agroecological understanding was surprisingly broad. Natural enemies most commonly enumerated included vertebrate and invertebrate predators. Evidence was weak for farmers' appreciation of the role of parasitoids and entomopathogens. Conspicuous and culturally important insects were more often mentioned, thereby confirming earlier findings in the same region. (In 1993, Jeffery Bentley an anthropologist then at the Panamerican School of Agriculture (Zamorano) noted that farmers have an extensive knowledge of various phenomena. He determined that folk knowledge was largely built on the principles of cultural importance and ease of observation.) Farmers' understanding of biological control was consequently related to the ecological specificities of their farming environment. Farmers' appreciation of natural enemies was related to their respective in-field abundance. It was found that abundant, conspicuous natural enemies were better known than species that were less common. IPM training significantly influenced farmer knowledge. Trained farmers had more extensive agroecological knowledge and were likely to try out new technologies. Training had the additional impact as key agroecological concepts were spread through the community through friendship, work or family ties. Since both trained and untrained farmers perceived no acute need for pest management intervention in maize, they responded in a rational manner and did not apply pesticides.

Conclusions

Our research found that subsistence production systems are characterized by high abundance and diversity of natural enemies, which adequately affect pest population dynamics. In-field natural enemy abundance is directly related to the extra-field environment. Even though alterations in agro-landscape composition and management lead to shifts in the natural enemy community, its suppressive potential was rarely compromised. Such findings could facilitate the design of multi-functional landscapes and the promotion of more drastic measures for environmental mitigation. Landscapes can ultimately be designed where natural resources (soil, water, etc.) are conserved while resilience of the maize cropping system is maintained. Landscape management could thereby modify the extra-field environment without negative impacts on pest abundance in this subsistence cropping system.

We also discovered that farmer knowledge is adapted to the agroecological conditions of the farming environment. Ecological processes occurring at a field level are being observed by farmers, and individual experiences are consequently propelled through the community. When introduced to new concepts and theories (through IPM workshops), farmers tend to cross-check acquired information by using their field settings as a touchstone environment. In the case of Honduran small-scale maize cropping, many of the key agroecological processes were easily observable and farmer knowledge reflected in-field conditions. In cases however where inconspicuous ecological processes (parasitism, insect disease) determine pest dynamics, IPM extension would need to supplement existing farmer knowledge systems with key agroecological concepts. Our work highlighted the linkages between farmer knowledge, within-field ecology and the larger agro-landscape and how those elements operate together in determining farmer practices and facilitating IPM adoption. Ultimately, our research showed that, by introducing farmers to IPM and key agroecological concepts, irrational use of pesticides could be prevented.

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Organic Cotton in Peru: a Retrospective and Future Look

Efforts have been underway over the past few years to produce organic cotton in Peru. This has not been an easy venture and a more detailed analysis of the Peruvian socioeconomic and agroecological context is required for future development, particularly concerning pest management systems.

Socioeconomic Context

In Peru, the organic cotton processing plants, which export to the USA, Europe and Japan, provide incentives for organic cotton production, paying an organic certification based on international standards. At a national level, a future Law for the Support and Promotion of Organic and Ecological Agriculture is under discussion, and enterprises which process and export organic cotton are working with farmers and some NGOs, with the following main objectives:

- Maintain and develop sustainable agricultural systems, reducing damage to the environment and human health caused by agrochemicals, by efficient pest management.
- Improve the economic conditions of the small producers, generating ecosystem diversity and taking advantage of market opportunities.

The NGOs are involved in developing and promoting agricultural research, particularly in the area of pest management, and in some cases support the strengthening of farmers' organizations.

On a general level, the effect of fluctuations in the world market can be marked, generating a certain amount of instability in the production system for organic cotton in Peru. Also, the small-scale farmers are disadvantaged by their economic conditions and the characteristics of existing interrelationships. However, the organic cotton system continues to be dynamic, as demonstrated by the new proposed projects in Pucallpa and Chincha.

Agroecological Context

Cotton is grown in two distinct areas of Peru: the desert coast and the tropical rainforest. Along the coast, organic cotton is grown mainly in the Cañete Valley, but has also been produced in Arequipa, and is now recently being promoted in the Chincha Valley.

Tangüis cotton (*Gossypium barbadense*), a long-staple variety with white fibre, is cultivated in these areas, south of Lima. Pest management is based on the principles of integrated pest management (IPM), although clearly in these cases synthetic chemical pesticides are excluded. Pest management continues to be one of the bottlenecks and is one of the topics receiving most attention within agroecological research.

According to Vreeland (1999), on the northern coast, despite its prohibition by state law between 1930 and 1990, small producers continue to grow native coloured cotton (brown and green), using a traditional cropping system with perennial and associated crops, certified but in small quantities. Since prehispanic times, a specific plant whose scientific name is *Lippia alba* (according to Ceroni [2002]), has been sown and burnt, and the smoke repels the cotton stainer *Dysdercus peruvianus*.

In the rainforest, some farmers grow a native cotton, Áspero (*Gossypium barbadense*), a short-staple variety with white and light brown fibre. The farmers in the area surrounding Tarapoto grow cotton in a traditional cropping system with maize, beans and bananas as associated crops, and without the use of agrochemicals. Due to the resistance of the native variety and the biodiversity of the area, the few pests which do exist are at a manageable level. New projects for organic white cotton are projected for Pucallpa, in this case as an alternative to the illicit production of coca.

Cotton Pests in Peru

Tangüis cotton has a variety of pests. According to González (2000) the main pests are earthworms, a stem borer weevil (*Eutinobothrus gossypii*), the cotton aphid (*Aphis gossypii*), and Lepidoptera such as *Anomis texana, Alabama argillacea*, *Heliothis virescens*, *Pococera atramentalis*, *Bucculatrix thurberiella* and *Pectinophora gossypiella*. Additional pests are the Peruvian boll weevil *Anthonomus vestitus*) and the cotton stainer (*Dysdercus peruvianus*), *Mescinia peruella* (Lepidoptera) and to a lesser extent some thrips, mealybugs, mites and a leafhopper (*Empoasca kraemeri*).

In organic cotton, these pests are controlled by cultural methods (elimination of secondary hosts, sowing in moist soils, suitable irrigation management, destruction of damaged organs, periods of fallow, crop rotation); legal measures (sowing and harvesting dates, elimination of crop residues, compliance with quarantine requirements); biological control (mainly facilitating the development of beneficial fauna under natural conditions); and the use of sex pheromones for the control of the pink bollworm. The overall aim is to implement a system of prevention rather than control (Morán *et al.*, 1999).

One of the comparative advantages for the development and management of organic cotton in Peru is the absence of the cotton boll weevil *Anthonomus grandis*, the Colombian pink bollworm *Sacadodes pyralis*, and the Ecuadorian worm *Catarata lepisma*. SENASA (Servicio Nacional de Sanidad Agraria) considers the cotton boll weevil an exotic pest of quarantine importance, and its introduction and establishment in cotton-producing areas would cause considerable losses to Peruvian agriculture, decreasing yields and returns, which would result in an increase in cotton imports to satisfy the national industry. The new methodologies of 'knowledge transfer' are also beneficial. Some technicians have run farmer field schools, emphasizing knowledge of the life cycles of pests, methods for conserving biological control agents, etc. (CABI Bioscience, 2000).

These are important aspects to consider for generating greater synergies and promoting organic cotton in Peru, without losing sight of three important aspects: the need for coherent policies, the sustainable management of natural resources and promotion of the production and consumption of sustainable products; all these in relation to the strategies for sustainable development within the European Union (Van Houtte, 2004).

Further Reading

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Announcements

Are you producing a newsletter, holding a meeting, running an organization or rearing a natural enemy that you want other biocontrol workers to know about? Send us the details and we will announce it in BNI.

Fresh Ideas from IOBC

Biological control researchers and practitioners are recommended to take a look at the new website of IOBC (International Organization for Biological Control of Noxious Animals and Plants):

www.iobc-global.org

In its 50th anniversary year, IOBC aims to stimulate regional sections and working group activities and boost an already growing membership. Amongst new initiatives it is planning:

- The *IOBC Internet Book of Biological Control* to build up a body of free, accessible information on the success of biological control around the world. The book is aimed not just at the biological control sector, but at policy makers, the press and the public. A printed version may follow but the priority is to make it available free on the Internet. Much of the information is thought to be 'grey' literature and biocontrol workers are encouraged to contact IOBC with details of these hidden successes, or with offers to write country or regional reports.

- Writing partnerships to help starting-up scientists from developing countries where English is not the first language, by providing them with a partner to help prepare a research paper. (If interested in helping or needing help, contact IOBC.)

The site also has pages for global working groups and the regional sections and their working groups, with links to their and other biocontrol-related websites. The new membership fee system is explained and the IOBC newsletters can be downloaded. The December 2004 issue (*IOBC Newsletter* No. 76) includes a succinct summary by IOBC President Joop van Lenteren of six major initiatives regarding regulation of the import and release of exotic natural enemies.

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IOBC-NRS and Canada Biocontrol Network Meeting

A joint scientific meeting of the International Organization for Biological Control of Noxious Animals and Plants – Nearctic Regional Section (IOBC-NRS) and the Biocontrol Network of Canada will be held in Magog, Quebec, Canada on 8–11 May 2005.

Covering all aspects of biological control, the meeting will include a symposium on 'Trophic and guild interactions in biological control' featuring invited keynote speakers. They will discuss modern concepts of direct and indirect interactions among natural enemies in natural and agricultural ecosystems – a field that has become a hot topic in ecology and biological control. A book of papers from the proceedings is to be published by Springer. A special session is also scheduled to celebrate the IOBC Global 50th anniversary.

The conference will be followed by a summer school intended for graduate students and postdoctoral fellows who share an interest in biological control (11–13 May). The school will include lectures and informal discussion groups.

Conference information: www.biocontrol.ca

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Berkeley Biocontrol Website

The aims and activities of the Center for Biological Control (co-directors: Kent Daane and Nick Mills) at the University of California, Berkeley are described on its new website:

http://nature.berkeley.edu/biocon/

The Center for Biological Control facilitates the implementation of biological control through research, training and extension programmes, provides and supports forums for intellectual discussion, and provides a structure for the development of interagency cooperation within California and the western USA. The activities of the centre include promotion of the benefits of biological control and sustainable development, which will greatly improve public understanding of the importance of this pest management tool and facilitate cooperation at all levels. Specific goals include increasing capacity-building through funds for graduate student training in biological control within the University of California system and coordinating and sponsoring biological control conferences, working groups and lecture series.

The website keeps visitors up to date with biocontrol news, a diary and links to biocontrol journals. A 'showcase' section features a biological control project. It also provides a virtual home for 'W1185', the Western Regional Biological Control committee 'Biological Control in Pest Management Systems of Plants', including research conducted by members of the committee.

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Asian Plants in the USA

A new publication from the US Department of Agriculture - Forest Service summarizes existing information on 40 plant species found in Asia that were introduced either purposefully or accidentally into the USA, and have established and in many cases become invasive. Natural enemies are listed for each species in its native range. The book is particularly valuable because it provides a synthesis in English of information about these plant species that was previously either unpublished or relatively inaccessible and scattered through the Chinese literature. The book contains background information on the biology of each plant species, an image to help with identification, a map of its distribution in China, indexes of scientific and common names for plant species and a bibliography of over 200 references. Also included are maps of US distribution for all plant species. This book is intended to serve as a resource for regulatory and plant protection agencies worldwide.

Zheng, H., Wu, Y., Ding, J., Binion, D., Fu, W. and Reardon, R. (2004) Invasive plants of Asian origin established in the United States and their natural enemies, Vol. 1. USDA Forest Service, FHTET, Morgantown, WV, USA. 147 pp.

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Conference Report

Have you held or attended a meeting that you want other biocontrol workers to know about? Send us a report and we will include it in BNI.

Neobiota

The 3rd International Conference on Biological Invasions, 'Neobiota – From Ecology to Control' was held on 30 September and 1 October 2004 at the Zoological Institute, University of Bern, Switzerland.

Neobiota, a working group concerned with biological invasions, was founded by 25 German ecologists during an initial meeting in Berlin in 1999. The group aims to collect data on non-native species in Europe, to enhance communication and collaboration between scientists working in various relevant research fields and to coordinate theoretical and applied aspects of this research. The 2-day meeting in Bern was attended by around 200 delegates from most parts of Europe, and also from Canada, Iran and Japan, reflecting the growing European awareness of the threat posed by non-native species to the indigenous fauna and flora. The meeting had a very full programme addressing the ecology of invasive species, covering many taxonomic groups, and impact and risk assessment as well as prevention and control with 40 oral and 84 poster contributions.

Although the main emphasis of this meeting was (as in previous Neobiota meetings) on the ecology of invasive species, new themes were also addressed, including aspects of biological control of invasive species and associated questions concerning risk assessments and legislation. For example, Dirk Babendreier (Agroscope FAL Reckenholz, Zurich) gave an excellent presentation on 'Risk assessment of natural enemies used in inundative biological control' outlining a general framework of a risk assessment methodology for biological control agents developed during the EU Project ERBIC (Evaluating Environmental Risks of Biological Control Introductions into Europe).

The Neobiota meetings series now provides a European forum on invasive alien species and has clearly gained in importance in terms of both number of participants and (European and non-European) countries represented. It has become a key venue to learn about research undertaken in different parts of Europe concerning non-native species, and to establish links with European scientists and practitioners.

Web: www.tu-berlin.de/~neobiota or www.neobiota.unibe.ch/

Proceedings

Developing Quarantine Facilities in India

Classical biological control, by its very nature, involves the introduction of biological control agents (BCAs) into areas outside their native range. The process of introduction includes a number of key safety issues, principally host specificity, contaminants and potential hazards to human health. Another key issue is the quality of the introduced material and how good genetic stock can be maintained.

It was to address these issues that the Indian Council for Agricultural Research (ICAR) provided funds through the National Agricultural Technology Project (NATP) for a workshop on quarantine procedures and facilities for BCAs, followed by a consultancy (conducted by CABI Bioscience) to finalize the specifications and infrastructure required for new quarantine facilities. The outputs have been collated in a publication*, which will also be a useful resource for other countries considering such a facility.

Quarantine techniques for BCAs were developed during the workshop and through recommendations arising from a visit to the proposed site and discussions. Papers in the proceedings include an overview of protocols and regulations worldwide, and how these apply to the principles and operation of quarantine facilities, followed by a summary of previous classical biological control attempts in India. A series of papers provides a synthesis of a variety of topics (guidelines, protocols, procedures, techniques, containment facilities) relating to the assessment in quarantine of various types of BCA (fungal, arthropod parasitoids and predators, pathogens of arthropods and nematodes, entomopathogenic nematodes, arthropods for weed control, weed pathogens, genetically modified organisms). Case studies on the classical biological control of *Mikania micrantha* and *Cryptostegia grandiflora* using rust pathogens make special reference to quarantine issues. This section ends with the recommendations of the workshop.

Details of the quarantine facilities for BCAs were developed during the subsequent consultancy. This section begins with an outline of the facilities' purpose, followed by detailed recommendations for their construction, equipping and operation, together with plans, showing how they were modified to meet requirements. The final plans for the quarantine building at the Project Directorate of Biological Control, Bangalore are appended. Portions of the Government of India legislation relevant to the import and release of BCAs are also included.

*Ramani, S., Bhumannavar, B.S. & Rabindra, R.J. (2004) Quarantine procedures and facilities for biological control agents. Proceedings of the ICAR–

CABI Workshop and Consultancy on Development of Quarantine Techniques for Biological Control Agents. Technical Document No. 54, Project Directorate of Biological Control, ICAR, Bangalore, India, 149 pp.

Biopesticide Registration in Kenya

The proceedings have been published of a workshop*, held in Kenya in November 2003, to discuss ways of formulating protocols that would facilitate amendment of the relevant legislation and thus enable fast registration of biopesticides, as a key step towards facilitating widespread use of this pest control alternative.

The workshop was held in response to challenges presented to the horticultural industry by changes in European Union (EU) legislation regarding pesticide residues, which affects many ACP (African, Caribbean and Pacific) and other countries. Harmonization of maximum residue levels (MRLs) permitted in agricultural produce imported into EU countries has led, in the absence of data, to MRLs for most of the conventional older pesticides being set at the limit of detection. As detection techniques have improved this functionally means a zero level in many cases, and severely restricts or even prohibits the use of these products on crops intended for export to the EU. However, strict sanitary and phytosanitary standards prohibit the presence of many pests and acceptable crop damage is also severely limited. In Kenya as in many countries, IPM is seen as the key to overcoming the paradox of export horticultural crops needing to be both pesticide residue free and pest free for the EU market. Papers in the proceedings are organized under four themes:

• *Demand from the horticultural industry*: This section begins with overviews of the flower and the vegetable and fruit industries in Kenya, outlining threats from the legislative changes and what is needed from biopesticide registration. These are followed by an introduction to commercial opportunities for biopesticides. The section ends with papers on implementing IPM and the role of regulatory authorities in facilitating it, and how neem-based pesticides demonstrate the need for appropriate biopesticide registration requirements.

• *Contribution of research in Africa*. The first paper provides an overview of types of biological control agents and their use. Next is a detailed discussion of baculoviruses and bacteria and their usefulness in biological control (including some already registered in Kenya), together with registration requirements and suggestions for increasing their use. The final paper considers 'Green Muscle' in a case study on the development, registration and commercialization of a biopesticide.

• *Registration in Africa*: The first paper summarizes the properties of pyrethrum, and makes proposals about registration requirements for botanical pesticides. In the next paper *Trichogramma* is used as a case study on regulating quality in mass-produced macrobials, with detailed recommendations on regulatory guidelines for Kenya. This is followed by papers outlining the Kenyan regulations on the importation of biological control agents, the registration procedures for pesticides in Kenya, and the proposed guidelines for registration of biopesticides in Kenya. The section ends with a report on the Pan-Africa Workshop on Biopesticide Registration, and includes the harmonized guidelines it developed.

• *Registration in the rest of the world*: This section contains contributions about development and registration of biopesticides in India and Thailand, Europe and OECD (Organisation for Economic Co-operation and Development) countries, and Cuba. These countries have considerable, but differing, experience with biopesticides. The Cuba paper includes annexes listing the information that must be supplied at various stages in biopesticide development, registration, importing, exporting and manufacturing.

Annexes to the publication contain current Kenyan application forms for registration of microbial, macrobial and biochemical pest control products.

The EurepGAP (Global Partnership for Safe and Sustainable Agriculture) standards came into force in January 2005, making the publication of these proceedings timely, and of interest to those in the horticultural sectors of many countries besides Kenya.

*Wabule, M.N., Ngaruiya, P.N., Kimmins, F.K. & Silverside, P.J. (2004) Registration for biocontrol agents in Kenya. Proceedings, Pest Control Products Board/Kenya Agricultural Research Institute/ Department for International Development Crop Protection Programme Workshop, Nakuru, Kenya. 14–16 May 2003. KARI/PCPB, Nairobi, Kenya and Natural Resources International Ltd, Aylesford, UK. 230 pp. ISBN 0 9546452 2 7