General News

A Dacoit Defoliator

The reasons behind the puzzling sudden yet devastating outbreaks of the teak defoliator (*Hyblaea puera*) in India's teak plantations are beginning to be unravelled – the result of 20 years' painstaking research at the Kerala Forest Research Institute (KFRI). These results, together with substantial progress in developing microbial control methods, are improving the prospects for the successful management of what is probably the best-known forestry pest in India.

Teak has been recognised for centuries as the finest hardwood in the world because of its strength, durability, pest and rot resistance, attractiveness and workability. These outstanding attributes led to its demand in a wide range of industries, from shipbuilding to fine carving. Teak's native range includes India, Myanmar, Thailand and Laos, but teak plantations are now found in many countries of tropical Asia, Africa, Latin America and the Caribbean. It is, for example, the most widely planted tropical hardwood in Africa. In India, natural teak forests are restricted to peninsular India south of latitude 24º North. Indian teak forests are remarkably diverse and the genetic diversity exhibited by Indian teak is unparalleled. Here, it grows in both moist and dry deciduous forests, in different tree associations and on a variety of soils.

In the early days of commercial exploitation, natural teak was harvested from forests by either selective or clear-cut felling. Elephants were used to bring the timber from remote forest to collecting points from where it could be transported on (by river, road or rail), and this practice continues even today in remote areas. In India, early reckless exploitation (largely to supply naval dockyards) of teak from the natural forests led to depletion of teak and eventually to worries about the sustainability of the supply. It was soon recognised that world demand for teak could not easily be met by harvesting timber from natural forests and therefore attempts were made to raise teak in plantations. After initial setbacks, success came in the 1840s when India's first teak plantation was established at Nilambur in Kerala. Further pioneering research conducted here led to the development of the stump-planting technique, which increased the ease with which plantations could be established. Now there are some 1.4 million ha of teak plantations in India, and nearly 9 million ha are established worldwide.

With the expansion of teak plantations, pest problems also arose. The most serious is the teak defoliator. It was first recognised in 1898 in Konni Forest Division in Kerala State, and since then outbreaks have been recorded every year across India in extensive areas of teak plantations. Major outbreaks occur suddenly and are often spectacular, with millions of caterpillars feeding in the teak canopy. Trees can be defoliated within days, and healthy new growth can be stripped from thousands of hectares of teak forest in as little as a fortnight. However, although the outbreaks are spectacular when they occur, they are sporadic, so whether or not the defoliator causes significant long-term damage was the subject of some argument, until the matter was settled unequivocally by KFRI scientists. They undertook a five-year study in four- to eight-year-old teak plantations at Nilambur, where there are now 10,000 ha of teak plantations. The results showed that exposure to defoliator infestations led to a 44% loss of potential volume increment of these young trees. Extrapolating from this, trees protected from infestation would be ready for harvest in 26 years, rather than the usual 60 years, provided that other necessary inputs are given. This gave a clear indication of the economic desirability of controlling the teak defoliator.

Early attempts to control the pest concentrated on the use of insect parasitoids. By the 1940s, a package of practices was developed for biological control that relied on augmentation of the natural enemies by manipulating the natural vegetation within the teak plantation and the surrounding areas to promote some species of plants useful for the survival of the parasitoids. These recommendations were pushed aggressively by the forest entomologists but success was hard to achieve. Recent work has shown that successive generations of the teak defoliator do not inhabit the same place, so parasitoids are unable to cope with outbreak populations of the pest. Dr K. S. S. Nair, Director of KFRI, says that in many ways the teak defoliator control problem resembles a dacoity (banditry) situation. Even if they have the guns ready, they cannot pull the trigger unless they know where the dacoit will strike. So at KFRI they have been developing and refining methods of control, while at the same time trying to develop a method to predict the onset of an outbreak, by elucidating the mechanisms of outbreak initiation.

Population Studies

Studies on population dynamics showed that, contrary to expectations, small populations of the teak defoliator were present in teak plantations and natural forest during the non-outbreak period when food (i.e. young foliage) was scarce. What allows these to develop into massive outbreaks? It was initially supposed that numbers build up over several generations, but then, in large plantation areas in Nilambur, it was found that small (0.5-1.5 ha) widely separated epicentres were the forerunners of a more widespread outbreak as populations built up and spread. The appearance of these isolated treetop infestations proved to be correlated with the arrival of pre-monsoon showers, and represented the transitional stage between very sparse endemic populations and high density outbreak populations.

However, the reasons for the appearance of the epicentres were still not clear: they were not constant over the years and they did not represent highly favourable local environments. Furthermore, the results indicated that moth populations originating from the epicentres alone could not account for all the subsequent outbreaks within Nilambur, and an influx of moths from elsewhere was indicated. To explain where these might originate, scientists considered also the observations of newly emerged moth aggregations, synchronized flight activity and orientated movements of moths. KFRI scientists compared their findings with published accounts of research into aerial displacement of the spruce budworm, and suggested one of two hypotheses (or a combination of them) to explain the outbreaks: monsoon-linked long-distance displacement of airborne moth populations, or wind-aided concentration of dispersed local populations of moths.

Control

Given the increased understanding of the outbreak mechanism, it was possible to consider control options. KFRI began by re-assessing the long-advocated biological-cum-silvicultural control strategy described above. At Nilambur, researchers recorded 15 of 40 parasitoid species known to occur in India, together with 79 species of pred-

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ator, ranging from insects and spiders to birds. However, studies on the spatial dynamics of outbreaks showed that successive generations of the defoliator do not inhabit the same place, but emerging moths disperse before laying eggs, thus evading the impact of local build-up of parasitoid populations. It was argued that a control strategy based on naturally occurring parasitoids was unlikely to be effective, because this spatial separation of host and natural enemies during outbreaks would prevent a numerical response by parasitoid populations to host density. Parasitoids are thus unlikely to have an impact on outbreak populations, although they may play a role in suppressing endemic populations.

There also appears to be little prospect at the moment for using tree resistance to combat the problem. Many isolated trees often remain unaffected in the midst of a defoliated area. However, marking studies showed that the apparent resistance was phenological rather than genetic, and a tree not attacked in one year may be attacked in another year. There is, however, one early-flushing variety from Karnataka State, 'Teli', which may be a useful genetic resource if the hypothesis of outbreak origin being linked to the onset of monsoon rains proves correct.

More promise currently is being shown by microbial agents. Some commercial preparations of *Bacillus thuringiensis (Bt)* have been shown to be effective in laboratory and field trials at Nilambur. However, a naturally occurring baculovirus has generated most interest. Natural infections of this pathogen usually account for large-scale mortality of later generation larvae, which leads to the collapse of the outbreak phase. The disease was characterized in a project funded by the Department of Biotechnology, Government of India as a nucleopolyhedrovirus (NPV). These viruses have a long history of safe and effective use in pest management worldwide and are highly specific to their target hosts. As the name implies, virus particles (the infectious units) are held within crystals of protein known as Polyhedral Inclusion Bodies (PIBs). Research demonstrated the defoliator NPV to have poor field persistence, which precludes inducing disease epizootics, but disease can be induced by spraying PIBs onto foliage. In field trials at Nilambur, 70-76% of foliage loss was prevented by a timely one-off spray of viral preparation during each outbreak. A collaborative programme with the UK Forest Research Agency (FR), led by Dr H. F. Evans, Head of Entomology, (funded by the UK Department for International Development, DFID) allowed protocols to be developed for field application of the virus. Use of a 'Control Window' concept developed by FR enabled rapid progress to be made on the essential parameters required to use the virus in the field. The 'Control Window' included rates and locations of larval feeding (target area), dosage-mortality relationships for all larvae (the dose), loss of virus from field factors such as ultra-violet light (attrition) and rates of coverage of foliage using selected sprayers and formulations (droplet density). These data were combined to determine precise field application rates for both virus concentration and droplet densities; preliminary field trials indicated that the parameters gave good predictions of expected target mortality rates. Further field trials have been conducted using the refined methods, and current work is focusing on developing mass production protocols and formulations for storage as well as field application, and determining optimum dosage and method of application to achieve maximum control of the infestation.

Preliminary trials in 1993 used a high volume sprayer and a rocker sprayer to reach the canopy of eight-year-old trees, and about one litre of spray fluid was required to cover each tree adequately. The recent collaborative work between KFRI and FR concentrated on ultra-low volume (ULV) sprayers. These have been standardized for delivery so that excellent coverage of foliage at the precise feeding sites of the teak defoliator larvae can be achieved, both with battery operated spinning disk atomisers and with motorized spinning cage atomisers. Spray parameters have also been calibrated to determine the optimum droplet sizes to deliver the desired dosage of PIBs per unit leaf. An oil-based emulsion was developed to prevent rapid evaporation under the very high temperature conditions typical in teak plantations.

After two decades of steady progress, the prospects for teak defoliator control appear to be very promising, but Dr Nair points out that much research is still needed. Testing the hypotheses of how outbreaks originate requires interdisciplinary efforts from the biological and physical sciences and coordinated data collection from the Asia-Pacific region. A critical mass of funds, expertise and technological inputs are necessary to address this problem, and KFRI hope to be able to catalyse such an effort. If it were established that outbreaks are indeed associated with northward progression of monsoon rains, forecasting methods can be developed to allow timely intervention, and the early flushing teak variety described above can be investigated further. On the other hand, recent studies have indicated that many of the late-season large outbreaks may be caused by moth populations originating from early epicentres. In a large teak area, such as Nilambur, it would therefore be useful to investigate whether rapid detection and destruction of early epicentres would prevent the late season widespread outbreaks.

Information: Nair, K.S.S. (1998) KFRI's tryst with the teak defoliator. *Evergreen, Newsletter of the Kerala Forest Research Institute* No. 40, pp. 1-7.

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Biocontrol Salsa!

Latin America and the Caribbean are producing a fascinating array of biocontrol solutions and practices to suit the diverse agro-ecosystems and the variety of problems and farmer needs in this region.

Classical and augmentative biocontrol strategies are well established in sugarcane production in Venezuela, one of the countries where beneficials production in the private sector is strongest. Augmentative releases of *Cotesia flavipes* against *Diatraea* spp. borers on 35,000 ha of sugarcane estates in western Venezuela started in 1988, to complement earlier introduction of tachinid flies in the 1950s. Infestation levels have dropped from around 14% to 2% with average cost:benefit ratios for the industry in the order of 1:28. The success of biocontrol in sugarcane is largely due to the good organization of the sector and a network of rearing laboratories across the country. In contrast, maize is predominantly a smallholder crop and implementation of biocontrol has proved far more difficult in this sector, for socioeconomic rather than technical factors. Fall armyworm, *Spodoptera frugiperda*, is the key pest in maize and current reliance on chemical control has led to massive production costs and increasing pest damage. Biocontrol agents available for *S. frugiperda* include *Bacillus thuringiensis* (*Bt*), the fungus *Nomuraea rileyi* and the exotic egg parasitoid *Telenomus remus*, introduced in 1979. In the last two decades private and public sector Venezuelan organizations have developed and refined rearing systems for mass production of *T. remus*, including artificial diets for the host. New stocks of *T. remus* were obtained from Trinidad in 1986, which enabled production efficiency to increase and field releases to become feasible. Semi-commercial releases were made in 1989 and commercial releases have expanded from 120 ha in 1990 to over 1000 ha in 1997, with 50% reduction in maize input costs due to savings on insecticides. The private sector is now collaborating with NGOs and farmers' cooperatives to promote the use of natural enemies by smallholder farmers and one project involves farm family rearing of *T. remus* for local use [see *BNI* **19(3)**, 76N].

In Cuba, biocontrol has been implemented on a national scale since the early 1990s, mainly in response to the withdrawal of aid, including agrochemicals, from the former Soviet Union. Cuba has established a unique system of state and public sector beneficials and microbials rearing units known as Reproduction Centres for Entomophages and Entomopathogens (CREEs). *Trichogramma* production is carried out on a manual, cottage-industry scale on state farms and cooperative CREEs, where a two- room *Sitotroga cerealella* production unit can produce 50-70 million wasps per month for local supply to around 1000 ha. There are currently over 250 CREEs throughout the island and these are supervised by national research institutes who supply cultures and implement the national quality control system. In 1995 *Trichogramma* production was 94 million, treating 1.6 million ha of crops including cassava, pasture, cabbage and watercress, maize, solanaceous crops, beans, sweetpotato and other vegetables. The main targets for *Trichogramma* are the cassava hornworm *Erinnys ello* (26% area treated), *Mocis* spp. borers in pasture and *Diaphania* spp. borers on squash and cucumber. The tachinid *Lixophaga diatraeae* is produced in 49 rearing centres for stemborer control over one million ha of the country's important sugarcane industry. Predator conservation and augmentation methods used traditionally by smallholders have been reclaimed and refined under the current biocontrol programme. Predatory ants *Tetramonium guinense* and *Pheidole megacephala* can successfully control banana weevil *Cosmopolites sordidus* and sweetpotato weevil *Cylas formicarius* through a combination of artificial refuges and nest relocation. In 1995 over 96, 000 ha were treated with *P. megacephala.* Lacewings are used to a limited extent in hydroponic cultivation and in cassava and roses, and predatory mite production is now underway for mite control in citrus and other crops. Cuban laboratory production of predators includes two mite species, six coccinellids, three lacewings and the two predatory ants.

These are just two examples from 'Nuevos Aportes del Control Biologico en la Agricultura Sostenible'*, a collection of state-of-the-art syntheses of biocontrol potential and practice in Latin America and the Caribbean presented at the 2nd International Seminar on 'Biological Control within Sustainable Agriculture', held in Lima, Peru in May 1998. The seminar was organized by the Peruvian NGO Action Network for Alternatives to Agrochemicals (RAAA) in collaboration with the Peruvian National Plant Protection Service (SENASA) and the Neotropical Regional Section of the International Organization for Biological Control (IOBC). Twenty-three papers on biocontrol practice and implementation in the continent are included in the proceedings, representing seven different countries (Colombia, Honduras, Venezuela, Peru, Cuba, Mexico and Argentina). The seminar aimed to focus on current field practice rather than research and to disseminate experiences and analyse impact where possible, and contributions range from overviews of predator, parasitoid and pathogen control agents to summaries of crop-specific methods, country reports, commercial production, training and extension and the new paradigm of biotechnology in relation to biocontrol.

*Lizárraga Travaglini, A.; Barreto Campodónico, U.; Hollands, J. (1998) Nuevos Aportes del Control Biologico en la Agricultura Sostenible. Lima, Peru; Red de Accíon en Alternativas al uso de Agroquímicos, 397 pp.

The proceedings can be obtained (in Spanish only) from: Action Network for Alternatives to Agrochemicals (RAAA), Apartado Postal 11-0581, Lima, Peru
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Host Specificity Testing of *Rodolia cardinalis*... One Hundred Years Late?

Serious damage to indigenous plant species of the Galápagos Islands by the cottony cushion scale, *Icerya purchasi*, has led the Galápagos National Park Service and the Charles Darwin Research Station to consider the use of biological control in the archipelago for the first time. The cottony cushion scale was first discovered in the Galápagos in 1982 and has since spread to ten islands. At least 48 plant species are damaged by this species. High infestations of this scale pest debilitate the plant sufficiently to cause mortality in some species. In response to this, an advisory committee was set up in 1996 to discuss the pros and cons of using *Rodolia cardinalis* to control this species. The committee was primarily concerned with the impact that *R. cardinalis* might have on the Galápagos fauna and that it might feed on endemic scale insects, most notably, an endemic margarodid. Although *R. cardinalis* has been used as a biological control agent of the cottony cushion scale for over 100 years and has been introduced into many countries, to our knowledge, the feeding range of *R. cardinalis* has not been studied and only a few anecdoctal observations exist regarding its feeding behaviour (please enlighten us, if information exists to the contrary!). After two years of deliberations it was decided to host test *R. cardinalis* in a newly constructed insect containment facility at the Charles Darwin Research Station, while concurrently conducting experimental trials to determine the impact of the scale on endemic plant species. CSIRO Entomology in Brisbane kindly donated beetles and provided training, and in April 1999, a colony was established and research initiated to develop a suitable host testing methodology. Forays into the field to find the endemic scale insects, some of which have not been collected since the Beebe expedition (1923), have been successful so far and feeding trials are now underway. If all the species can be found, we hope to test endemic and native representatives of Margarodidae, Ortheziidae, Pseudococcidae, Eriococcidae and Diaspididae, among others. Results of the trials are expected to be available by December 1999 and will be presented to the advisory committee and the Park Service for a decision to be made as to whether the liberation of *R. cardinalis* is feasible in the Galápagos Islands or not.

We are indebted to Veronica Brancatini and Richard Vickers at CSIRO Entomology, Brisbane, for their continual support and advice, and of course for the beetles. Many thanks to Dug Miller at SEL/USDA for the scale insect identifications. We would also like to thank the Embassy of the Netherlands and Fundación Galápagos Ecuador for making this research possible.

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Congratulations...

Congratulations to the Project Directorate of Biological Control (PDBC) at Bangalore in India and its Director, Dr S. P. Singh. The PDBC has been chosen for the ICAR Best Institution Award – 1998 by the Indian Council for Agricultural Research

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Biorational

Integrated pest management (IPM) involves the use of many techniques, including biological control, to provide effective control of crop pests with minimum harmful side-effects. Those techniques which are compatible with the use of biological control or have little impact on natural enemies have been described as 'biorational'.

Colombian Coffee IPM

Coffee berry borer (*Hypothenemus hampei)* was first identified in coffee some 130 years ago, and is now its most serious pest in many of the major coffee-producing areas of the world, including Latin America and India. A few coffee-producing countries (Costa Rica, Cuba, Panama) are still free of the pest, and for them stringent quarantine precautions are important, for transportation of seeds containing borers has been the vehicle for its worldwide spread. Crop losses can be severe, with 50-100% of berries attacked if no control measures are applied, leading to up to 50% crop losses and poor quality coffee which can be difficult to market.

A number of natural enemies, insects and pathogens, has been recorded from the borer. Two bethylids, *Cephalonomia stephanoderis* and *Prorops nasuta*, were introduced to many Latin American countries from Africa, particularly in the 1980s and 1990s, and seemed to establish easily. In addition, *Beauveria bassiana* is an important natural control agent in very wet regions including Colombia. However, these agents have not by themselves been able to control the borer and farmers worldwide still rely mostly on chemicals or hand picking to control the pest. Hence there is a need to develop IPM strategies to control this difficult pest, especially in Colombia, where the borer has become the country's most serious pest problem.

In Colombia the borer is widespread in over 650,000 ha of coffee. This report* summarizes activities carried out for a bilateral project on coffee IPM for Colombia during 1993-98, funded by DFID (the UK Department for International Development) and Cenicafé (Federación Nacional de Cafeteros de Colombia). The project encompassed both research and training, and focused solely on the coffee berry borer and its control. Activities included farmer studies (socio-economic and anthropological), basic research, the introduction of a new natural enemy, sampling, modelling and IPM-related research.

Studies of farmer adoption of control methods for the borer revealed that nearly all have adopted some form of regular picking in order to keep the borer under control. However, efficiency of picking depends on the age of the tree and the height of the branch above the ground; older trees and lower branches tend to carry berries with a disproportionately high level of borer infestation and are a serious source of re-infestation. Field experiments looking at the impact of berry removal found that removal of lower non-productive branches can be achieved without risk of infecting the tree with *Ceratocystus fimbriata*. However, although this reduces incidence of borer, there appeared to be no associated cost advantage. Importantly, farmers do not collect the large numbers of berries that fall to the ground before during and after harvest. These are an important reservoir of borer infestations, but they proved particularly difficult to remove and available mechanical methods were unsuccessful.

The coffee farmers in this project (85% of whom farmed less than 3 ha) tended to have small families, whose members were generally not involved in routine work on the farm. Instead, farmers hired labour, which they perceived as expensive. Although they had received extension training, safety aspects of insecticide use were poorly understood, as were technical terms used in extension work. Case studies revealed that farmers tend to apply higher-than-recommended doses of insecticide, while few have adopted sampling to determine the optimum time to control the borer. Most had tried spraying *Beauveria bassiana* to control the pest, but less than 10% had continued to use it, while most (two-thirds) used chemicals sprays, an average of three times a year. A study of a young coffee plot, in which there were 22 flowerings in 17 months, revealed that borer attack following these flowering episodes was not uniform. Even detailed sampling was unable to relate field damage to damage on the harvested crop. This suggests that it would be effectively impossible to develop a simple sampling method for farmers to be able to predict crop losses.

Studies of the borer life cycle indicated that the reproductive rate depends on the age of the berry. Borer growth and survival were best on cherries infested when they were more than 180 days old (i.e. more than 180 days after flowering), while mortality was high and few borers survived to become adults in berries attacked at less than 120 days old. Borers could complete their life cycle before harvest in berries attacked at 120-180 days old, and up to three second generation adults emerge per infested berry before harvest. Some third of emerging borers manage to re-infest berries in the same plot. However, emergence of borers was found to be fastest and greatest where felled material was left in the field following stumping to promote re-growth, and this causes substantial re-infestation of surrounding plots. The recommendation that farmers leave 'trap' trees in cleared fields would seem not to be effective.

Extensive field releases of *C. stephanoderis* indicated that the parasitoid could control borer populations over a period of a year, but cost projections from mass-rearing suggested that it could never be produced sufficiently cheaply to make commercial releases economically viable. The principal action of the parasitoid was found to be predatory, and parasitism rates remained stubbornly low (at less than 10%), even at release rates of 100 wasps per infested berry. Laboratory studies contributed the information that the parasitoid developed too slowly and required too many immature stages of the borer for it to be an efficient control agent.

The eulophid *Phymastichus coffea* was introduced into Colombia, and has been established in the field. A rearing technique was successfully developed for it, although it had previously been considered difficult to rear, and by early 1998 up to one million wasps per month were being produced. First field results suggest it is more promising than *C. stephanoderis* or *P. nasuta,* with up to 67% parasitism recorded.

Ironically, results with *Beauveria bassiana* proved to be disappointing, despite the widespread and highly visible naturally occurring infestations in the field. It was most effective on borers attacking young berries, but its action was slow compared to insecticides. Although mortality at very high spore concentrations could get to 80%, this took some 30 days to develop fully. Extensive formulation work failed to improve its efficacy and reliability in the field, and analysis of Cenicafé work suggests that it is currently uneconomic to use and should not be recommended until technical problems have been overcome.

Entomopathogenic nematodes were found to be able to penetrate and infect borers inside berries, and a new *Steinernema* sp. was discovered.

A computer model of the borer and its effects on coffee was developed, including control activities, harvesting, etc., based on data collected during this project, and suggestions for borer research and management in Colombia are discussed.

The report concludes that IPM of coffee berry borer in Colombia is potentially complex, but that on the basis of what has been learned it is possible to rule out a number of potential elements: the bethylid parasitoids previously introduced, *B. bassiana*, numerical sampling and trap trees all play only a minor role in helping to control the pest. In the short term, this leaves cultural controls, insecticides, possibly *P. coffea* and modelling as the blocks from which to build an IPM strategy, and it is suggested that the logical way to do this may be to move away from sampling-based farmer decisions to model-based extension advice. The importance of thinking strategically about coffee berry borer in the longer term is stressed. It is suggested that cultural control might be promoted in young coffee (up to two years old) before serious infestations develop and while the procedures are relatively easy to carry out. Further research and modelling of the role of *P. coffea* is proposed. Importance is also attached to enhancing the transfer of coffee berry borer control technology to farmers, and the differing needs of large- and small-scale growers are considered.

*Baker, P. (1999) The coffee berry borer in Colombia. Final report of the DFID–Cenicafé–CABI Bioscience IPM for coffee project (CNTR 93/1536A). Chinchiná, Colombia; DFID–Cenicafé, 144 pp.

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Pheromone Pot-pourri[1]

The past decade has seen many refinements in the use of pheromones worldwide for detecting and monitoring pests and for control of pest populations. Pheromones are chemicals produced by insects that elicit strong behavioural reactions in the same species at minute amounts. They are usually produced by females to attract males of the same species for mating. Since the first insect pheromone product was registered for commercial use in 1991, considerable effort has been put into making the theoretical possibility of pheromone use in pest management an economic reality.

Recently, research into the effects of pest kairomones and plant semiochemicals on parasitoid behaviour has suggested new avenues to be explored. Pest kairomones, used for host location, may be used to monitor parasitoid activity and population size. There may also be a role for pest kairomones and plant semiochemicals in enhancing parasitoid activity and populations, but this work is still at an early stage.

Sniffing Them Out

Pheromones are used for monitoring pest populations to collect data for optimizing decision making. Probably the earliest example of an area-wide monitoring system was established by Clive Wall in the UK for pea moth, and this system is still in widespread use in Europe. Pheromone monitoring is now a cornerstone of pest management systems worldwide. Pheromone traps are used in most crop systems, and traps are available for all economically important species. For example, there are probably not many commercial fruit orchards in Europe and North America without a pheromone trap.

Unlike crop pests, many forest pests are cyclical, erupting into outbreaks at intervals of several years separated by long periods of vanishingly low densities. Effective monitoring is key to keeping tabs on such species. One well-established system has used pheromone traps for the last ten years deployed at more than 700 sites throughout North America to monitor the spruce budworm (*Choristoneura fumiferana*), which fluctuates on a long cycle of 35-40 years. Before the advent of pheromone traps, pre-outbreak population build-ups generally went undetected until trees became visibly defoliated. Now, the use of pheromone-based systems to monitor populations of defoliating forest pests and to optimize treatment timings is widespread.

The Douglas-fir tussock moth (*Orgyia pseudotsuga*) is a native defoliator of western North American forests. Outbreaks occur in British Columbia about every seven to 13 years, and these cause extensive tree mortality among the primary host, the interior Douglas fir, *Pseudotsuga menziesii* ssp. *glauca*: in 1993 over 25,000 ha were defoliated, and similar damage was only narrowly avoided in succeeding years. Since then the Canadian Forest Service, in cooperation with the British Columbia Ministry of Forests and the USDA Forest Service has developed a management strategy. Areas vulnerable to future attack are identified on the basis of forest types and biogeoclimatic zones of previously defoliated stands. Pheromone traps are used to monitor populations in these areas. If a threshold number of males is reached for three consecutive years, an outbreak is predicted as likely to occur in the next few years. Intensive sequential surveying for egg masses is then conducted to assess whether an outbreak is developing and the level of defoliation to be expected, and these predictions are confirmed by larval sampling.

When an outbreak and unacceptable levels of defoliation are judged to be imminent, control measures are implemented. A mating disruption method (mating disruption is dealt with in more detail below) has been used, the first successful use of this technique against a forest pest in Canada. Aerial or ground sprays, using standard equipment, of a synthetic sex pheromone enclosed in polyvinyl chloride beads of 250-400 μm in diameter (from Consep Membranes, Bend, OR, USA) at doses of 18 g/ha resulted in 100% mating disruption. Aerial or ground sprays of a naturally occurring nucleopolyhedrovirus (NPV) have also been successful. The NPV builds up naturally during outbreaks, and eventually puts an end to them. But precise spray timing is crucial as the virus needs to be applied soon after egg hatch for its optimum spread through the population. The value of pheromone monitoring is that it allows widespread monitoring and gives valuable forewarning of annual population build up. The spray is triggered before defoliation is visible from the air, and the NPV starts to build up in the population earlier in the outbreak than it would naturally, and thus the severity of the infestation can be effectively limited. Combining these treatments could be synergistic, and logistical or biological drawbacks of either method may be offset by the other. NPV treatment could keep populations to a level where mating disruption is most effective, while adult moths developing from uninfected larvae would be subjected to mating disruption.

Information: Managing Douglas-fir tussock moth outbreaks. Victoria, B.C., Canada; Pacific Forestry Centre, Canadian Forest Service, Information Forestry, April 1999, p.3.

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[1]Terminology: Whether a chemical message is a pheromone, semiochemical or kairomone depends on who is getting the message. A pheromone is a compound produced by a member of one species that has a behavioural effect on another member of *the same species*. If a (or the same!) compound produces an effect in *another species* it is a semiochemical, but if that effect is to the detriment of the producer (e.g. is a cue for host-finding by parasitoids) it is a kairomone.

Fewer Shot-holes

Pheromone monitoring is also used in a management programme for black army cutworm, *Actebia fennica*, developed by the Canadian Forestry Service in British Columbia. There is no effective control strategy for this pest, so the accent is on outbreak prevention. Pheromone monitoring is used to determine whether to plant seedlings or not.

The black army cutworm is widely distributed throughout the north temperate and subarctic regions of the world, and occurs throughout most of Canada and the northern USA. Caterpillars are polyphagous, and have been reported as pests of conifer seedlings and blueberries and occasionally forage crops in North America. First visual evidence of damage, resembling shot-holes in the vegetation, is often observed for the first time by planting crews, at which time it is difficult and costly to alter planting programmes. It is therefore crucial to identify vulnerable sites during the planning stage.

A natural or prescribed fire is the triggering mechanism for an outbreak – so fire-clearance of sites for planting is playing with fire in more ways than one. Moths fly throughout July-September, and congregate on sites burned earlier that spring or the previous autumn. The eggs they lay during the summer hatch after some two months and overwinter as early-instar larvae in the soil. In spring, caterpillars remain buried in the top layers of the soil by day, emerging to feed at night. They are therefore extremely difficult to locate by visual survey, but finding new infestations early is crucial. Larval feeding is usually complete within six weeks of spring emergence, and most damage is caused by these first-season outbreaks, with often little damage in subsequent years. Although infestations are generally fairly localized, entire blocks of trees are occasionally defoliated, and damage to seedlings can have long-term effects on growth.

With a sporadic occurrence of outbreaks combined with rapid onset of feeding damage, knowing where and when it is safe to plant is important, but appropriate management involving careful monitoring and planning can minimize the damage. The importance of pheromone monitoring in this system is that it can detect potentially damaging insect populations long before visual monitoring of pests or damage would be effective.

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Sent Packing

The Chemical Ecology Unit at Simon Fraser University in British Columbia has carried out basic research on the identification of bark and ambrosia beetle pheromones and their application in forest and industrial settings. The results from work by John Borden and John McLean have been developed commercially by Phero Tech Inc., and this includes bark and ambrosia beetle management programmes.

Aggregation pheromones are used to lure the insects to traps so populations can be sampled. This monitoring information is combined with other observations to improve control programmes through better targeting and timing: a threshold is established, and catches above this number indicate a control programme should be initiated. In some instances it has been possible to show a good correlation between trap catches and potential insect damage.

Generally, mass trapping using large numbers of traps is not an effective control strategy, and should be approached with caution. However, it is sometimes a useful tool in combination with other techniques. This is demonstrated by ambrosia beetle control in British Columbia, which has used mass trapping for the last 15 years. Ambrosia beetle populations in sawmills, log sorting areas and around log boom storage areas are surveyed with pheromone-baited traps, and areas of high risk are mass-trapped using funnel traps.

Bark beetle aggregation pheromones are used in a rather different, to concentrate beetle populations in an area about to be logged. Removal of the infested timber by clear cutting or selective logging removes brood-containing trees and reduces field populations, which continue to be monitored with pheromone-baited funnel traps.

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Grounding the Gypsy Moth

The gypsy moth, *Lymantria dispar*, is one of North America's most devastating forest pests. The European strain was introduced to Massachusetts in the 1860s and was quickly recognised to be a serious problem. The first and ultimately unsuccessful attempt to eradicate it began in 1890. It feeds on the foliage of hundreds of species, and its most common hosts are oaks and aspen. During heavy infestations trees may be completely defoliated. Males are strong fliers, although the females are flightless, and its range has increased inexorably. Even so, it still occupies only about 25% of the total area predicted to be susceptible to infestation. Until now, control of its spread was effected by monitoring for isolated populations occurring beyond its contiguous range, and then attempting their eradication by a combination of methods including mating disruption, sterile-male release and biological pesticide treatments. However, it continues to spread, and an additional threat persists in western North America in the shape of the Asian strain of the species, whose female is winged.

The gypsy moth mating pheromone, disparlure, was identified and synthesized in 1970, and many attempts have been made since then to manage low-level populations by mating disruption. Insects use sex pheromones to communicate for mating. Pheromones elicit strong behavioural reactions at minute amounts, they are species-specific and non-toxic. By permeating the atmosphere with synthetic pheromones, olfactory communication and mate finding can be prevented. Mating disruption works best when applied on an area-wide basis, so forest pests are good candidates. The European gypsy moth possesses characteristics both suited and ill-suited to this technique. Its high fecundity, highly polygamous males and clumped/aggregated distribution of females are far from ideal, but its flightless females, poor mating success at low densities and limited dispersal of males and single generation per year are more compatible with mating disruption. The USDA Forest Service mating disruption programme for gypsy moth recommends that the technique should only be used to manage isolated or area-wide low-density populations of the European strain of the moth.

The programme illustrates well some of the problems encountered with pheromone-based management, including the importance of adequate dispenser systems. Numerous formulations containing disparlure were evaluated during the early years, including hollow plastic fibres, gelatin microcapsules, and plastic laminated flakes. Although these seemed fine in the laboratory, in the field deposition and penetration were uneven, disparlure was inefficiently released, and there were major problems with the available aircraft release systems. Initial results were inconsistent and discouraging. However, a plastic laminate flake formulation (Disrupt II from Hercon) was registered with the US Environmental Protection Agency (EPA), which is still in use today. Disrupt II releases disparlure at a constant but slow rate. This is operationally too low during the male flight period in the first year and the high dose needed to rectify this is expensive. More seriously, although progress has been made with release systems and overall performance has been considerably improved, application problems persist and equipment performs erratically. An open-pore polymeric flowable bead formulation diameter was developed (Decoy GM from AgriSense, Fresno, CA – now ThermoTrilogy) that could be applied using conventional boom and nozzle systems. Initial trials demonstrated that the beads (range 50-1000 µm diameter, median 275 µm) released the pheromone too erratically and too fast (on average, flakes release 30-40% of their pheromone by day 42 after release, beads 50% by day 20) and further work is needed on additives to optimize suspension and adhesion of the bead formulation. The fast release rate can be compensated for by double applications, but with a concomitant increase in costs. AgriSense has a petition to the EPA to register the bead formulation, and 3M Canada also has a microencapsulated formulation that is being evaluated for gypsy moth control.

The USDA Forest Service is also looking at the use of countrywide monitoring to improve containment of the spread of European gypsy moth. The national Slow the Spread (STS) Project began in 1999, following a pilot study which demonstrated that application of the latest survey and management practices could slow the rate of spread of the European gypsy moth by 60%. The project is being implemented across a 2000-km frontier from North Carolina through to Michigan. The project goal is to use novel IPM strategies in order to slow the moth's spread westwards into uninfested areas. The project is based on the use of pheromone traps for intensive monitoring of low moth populations in the transition zone between areas generally considered infested and those considered uninfested, coupled with timely control of growing isolated populations. When males are trapped for several years in the same location, this is evidence of a breeding population, and suppression with mating disruption and/or sprays of *Bacillus thuringiensis* (*Bt*) or a formulation of a naturally occurring nucleopolyhedrovirus (Gypchek) is implemented.

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De-Worming the Apple

The sex pheromone of codling moth (*Cydia pomonella*), codlemone, was identified some 20 years ago, and in the USA the first commercial dispenser became available in 1991. The technique sounds simple: dispensers tied to branches release artificial sex pheromone, which confuses male moths looking for mates. Males normally follow a plume of natural pheromone emanating from a female moth and fly upwind to find her, but these plumes are 'lost' in a fog of artificial sex pheromone. Codling moth is a key pest of apple and pear (pome) orchards, and because consumers are squeamish about biting into the occasional worm, stringent control is crucial to the pome industry. In the absence of control measures it can damage up to 50% of the crop and can make it impossible to store as infested apples start to rot.

Initially there was low and slow grower uptake of the mating disruption technology because of its perceived high cost/low efficiency. Studies in the Pacific Northwest showed that growers needed to reduce insecticide applications by four or more per season for pheromone use to be economically viable; spraying machinery and time were still needed for fertilizer and fungicide applications, and insecticides were necessary for some secondary pests. In addition, mating disruption proved less effective than insecticides under high codling moth pressure, and there were significant failures of control at the 'edges' of pheromone-baited areas. Costs were also elevated because of the expense of the pheromone and the absence of an efficient applicator. However, interest was maintained because of public and farmer concern over high insecticide use, the development of insecticide resistance and, more recently, the moves to ban some widely used insecticides.

This year, a five-year large-scale areawide IPM programme for the management of codling moth in the Pacific Northwest region of the USA (which began in 1995) entered its final phase. The aim of this programme had been to take management practices used on a limited scale by a few growers and apply them in contiguous orchards owned and managed by several growers. The programme has been coordinated by the US Department of Agriculture – Agricultural Research Service (USDA-ARS) Yakima Agricultural Research Laboratory in Washington State, together with Washington and Oregon State Universities and the University of California at Berkeley. The management system uses not only mating disruption, but also *Bt* sprays and ichneumonid parasitoid (*Mastrus ridibundus* and *Liotryphon caudatus*) and sterile male codling moth releases. The goal was to get all orchards in a large area to function as a complex sustainable ecosystem, a process which it was envisaged would need several years to attain.

It is difficult to draw any definite conclusions because codling moth pressure varies between years, but certainly some of the aims of this ambitious programme are coming to fruition. There has been a large increase in farmer uptake and enthusiasm, and good results are being achieved at low codling moth pressure. Three years into the project, some farmers were reporting that they had halved use of insecticides and were looking forward to eliminating them altogether. Codling moth numbers have declined every year since the large treated areas were set up. By the end of 1998 seasonal catches in some locations were reduced from 1000/trap six years ago to single figures, while there was almost no (less than 0.2%) codling moth infestation at harvest. Even where pressure is high, growers found that a combination of half-rates of pheromone dispensers and spraying was successful in bringing moth numbers down to reasonable levels.

The picture is not entirely rosy, as there have been persistent problems with leafrollers, and an increasing incidence of (stink) bug problems. However, orchards that have been sprayed with insecticides for decades are not the ideal places to work in. Many of the secondary pests now pose a problem probably because their natural enemies have been knocked out, and the pest populations have bounced back while the natural enemies take longer to build up again. It is also important to remember that codling moth is the key pest for the industry, and does serious damage, while many of the secondary pests cause lesser, often only cosmetic, damage. Codling moth cannot be controlled by other biological methods alone (the larvae bore into the fruit and are protected) while the secondary pests tend to be surface or leaf feeders, and are more susceptible to, for example, *Bt* sprays, parasites and predators, and may eventually be kept under comparatively good control by the naturally occurring arthropod fauna.

One final note, the rate of expansion of pheromone use has decreased this year, owing to poor returns to growers for their apples. A timely reminder that making ends meet is the bottom line for farmers.

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Cans of Worms

Another, and spectacular, example of mating disruption success comes from South Africa. Stonefruit (peach, nectarine, plum and apricot) orchards cover some 20,000 ha, and the key pest, especially on canning peaches, is the Oriental fruit moth, *Grapholita molesta.* Introduced in the late 1980s, this species has four to six generations per year in South Africa, and spread rapidly through the stonefruit-growing areas. By 1991 and despite intensive chemical control measures involving up to 13 organophosphate treatments per season, it was causing shoot damage and crop losses in canning peach orchards of up to 80% in the worst-affected cases. In the face of the collapse of the industry as growers began to uproot susceptible orchards, a mating disruption programme was trialled. Isomate-M (Pacific Biocontrol) was deployed in a contiguous 1200 ha of peach and nectarine orchards in 1991-92. The success of the strategy was phenomenal. In the entire area, only 69 adults were trapped by the end of the season, there was only isolated shoot damage, and no infested fruit was recorded.

Key to the success of this project was the involvement of the fruit industry, research and extension back-up, support by the product distributor and participation by all growers. However, the cost of the programme far-outweighed the cost of an insecticide programme because the pheromone components had to be imported, and this was identified as the reason that mating disruption of Oriental fruit moth has not been widely used since.

Mating disruption of codling moth on pome fruit (a high-value export crop) is much more widely practised in South Africa. Resistance to both azinphos-methyl and pyrethroids was increasing and, by the early 1990s, 30% fruit damage was recorded in some orchards even after 12 sprays. A project began in 1992 to assess the efficacy of mating disruption using rope-style dispensers Isomate-C and Isomate-C Plus (Pacific Biocontrol) together with supplementary insecticide sprays. By 1996 insecticide applications had been reduced an average of 32% and fruit infestation limited to about 0.3%. This combination of improved codling moth control and reduced insecticide usage was particularly noteworthy given the development of insecticide resistance and the high reproductive potential of the pest in South Africa, and the situation has improved further since. In the past season some apple orchards which received no sprays had 0% fruit damage, even with dispensers reduced from 1000 to 500-800/ha.

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On the Grapevine

The grape berry moth (GBM), *Endopiza viteana*, is the most important insect pest of grapes in eastern North America. Mating disruption has proven a highly effective for managing this pest. Decoy GBM (Agri-Sense, Fresno, CA), a polymer-matrix-gel pheromone dispenser, was registered for use in Canada in 1992. These dispensers were commercially available from 1992 to 1995 but were never used on more than 4% of the 5400 ha of commercial vineyards in Ontario. The low rate of adoption was due to the relatively greater cost of pheromone compared with insecticide treatment, and the labour required to apply the dispensers at the recommended rate of 1000/ha. It was also suggested that the marketing strategy was at fault. Promoting mating disruption purely on the grounds that it was environmentally friendly did not cut much ice with growers, and an approach that focused on the benefits of using it as part of a proactive resistance management programme would have probably had more impact.

Sprayable pheromone is being developed for controlling the GBM. This will permit growers to apply pheromone with conventional pesticide application technology, and in some cases in combination with other vineyard pest control products.

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On the Scent

The IOBC-WPRS (International Organization for Biological Control – West Palaearctic Regional Section) Working Group on the Use of Pheromones and Other Semiochemicals in Integrated Control is coordinated by Peter Witzgall at the Swedish University of Agricultural Sciences at Alnarp. The group has traditionally taken the role of liaising between basic research and practical application, and regularly runs workshops and symposia [see Announcements, this issue]. Their Internet site hosts Pheronet [see Internet Round-up, this issue], based on the book 'List of Sex Pheromones of Lepidoptera and Related Attractants' by Heinrich Arn, Miklós Tóth and Ernst Priesner.

Amongst a variety of useful publications are the proceedings of a meeting held in Montpellier, France in 1996 on technology transfer in mating disruption. Detection and monitoring with pheromones is covered, including programmes for spruce budworm and the European cornborer, *Ostrinia nubilalis*. There is a wealth of information on mating disruption programmes in orchards and vineyards (including some of the codling moth, Oriental fruit moth and grape berry moth examples described above). Research on insect behaviour in relation to mating disruption includes the role of antagonist chemicals. Mass trapping, attract-and-kill techniques and the integration of pheromone techniques with microbial control are also included. Other key areas dealt with are methodology (novel methods for release) and technological and commercial aspects. The proceedings are on the Working Group website at:

Internet: http://216.172.92.219/iobc/index.html
A printed version is available from:
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Cheaper Scent?

The costs of both development of pheromones and their use have tended to confine this technology to high-value crops. Effectively, they are only used by smallholder farmers in cash crops such as cotton (for example, see 'Making Use of the Good Bugs in Cotton', Training News, and 'Organic Cotton', New Books, both this issue). In addition, mating disruption works best on larger areas and as a consequence is difficult to apply on areas farmed by smallholders unless they are willing to work collaboratively.

IPM programmes using pheromones to control pink bollworm (*Pectinophora gossypiella*) and *Helicoverpa* bollworms are in use in India and Pakistan, but the biggest area under pheromone treatment, some 40,000 ha, has been in Egypt. Until recently, the Egyptian cotton industry was regulated by the government, and they introduced a centrally managed programme of IPM with pheromone monitoring as a core element in 1980. Mating disruption is used particularly against pink bollworm, and this was so effective that the Ministry of Agriculture produced an illustrated pamphlet for farmers to explain the methods. Amongst products used is Frustrate-PBW (AgriSense-BCS, UK), formulated as small polymer strips incorporating the *P. gossypiella* sex pheromone and applied to young plants by placing them over the terminals at the first appearance of moths. In the growing organic sector, pheromone trapping is used to reduce cotton leaf worm (*Spodoptera littoralis*) populations, but pheromones have been less effective against a new pest, spiny bollworm (*Earias insulana)*. Knowing how to use pheromone technology effectively is a common problem for farmers. Following the withdrawal of central control and support, the Egyptian German Cotton Sector Promotion Program is focusing on farmer learning groups, in which farmers are getting together with extensionists to discuss problems, improve observation in the field and learn how they can improve decision making.

Information: El-Araby, A; Merckens, K (1999) Egypt. *In*: Myers, D.; Stolton, S. (*eds*) Organic cotton. From field to final product, pp. 164-175.
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NRI (the Natural Resources Institute, UK) have investigated the potential of mating disruption to control yellow rice stemborer (*Scirpophaga incertulas*) in India, a project which aimed to improve the productivity and sustainability of smallholder-based high potential rice production systems. They have been able to demonstrate season-long control of the stemborers by using the natural ratio of artificially produced sex pheromone in a Selibate release system (AgriSense-BCS) in trials at three locations in Andhra Pradesh. Selibate was developed for the control of striped stemborer (*Chilo suppressalis*). In this project, it was formulated as strings which were tied to or forced into the split ends of attachment sticks, and these were placed on sticks or bamboo canes some 1 m high. Assessed by pheromone trap catches, it was found that pheromone-mediated communication in two of the trial areas was reduced at least 94% for up to three months after pheromone deployment, and rice damage was reduced 40-83% in comparison to damage in conventional farmers' practice plots.

The work done by NRI in India has clearly demonstrated the effectiveness of the mating disruption system. The main barriers to entry of this technology are its comparatively high costs, which are further compounded by import taxes in India and the natural resistance of farmers to a technology where it is very difficult to see visible evidence of the effect of the product (no dead insects). A survey of farmers revealed that 92-100% of the farmers applied insecticides once against stemborers (the number varying between areas) and 60% in one area treated their plots twice. Even so, this represented only some 5% of rice production costs, and it remains to be seen whether they will, or can, pay for the more expensive pheromone technology.

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Commercial Sense

The messages coming from these initiatives are similar. If they are to play an effective role in pest management, pheromones need to be economically competitive with chemical treatments, application technology needs to be simplified (and ideally it should be possible to combine pheromone deployment with other treatment applications), field persistence has to be improved, together with efficacy at high pest densities.

A key player in the cost stakes has been Shin-Etsu (Japan), whose development of acetylene derivatives paved the way for relatively low-cost mass production, and they now produce a wide variety of pheromone products. Application technology has also advanced. Deployment of hand dispensers may be semi-automated with clip-on ties that can be attached by long-handled devices, so growers no longer have to climb each tree with a ladder to tie on dispensers by hand. However, even with rope-style dispensers it has been estimated that less than 20% of pheromone is released into the air, the remainder being lost to photodegradation, isomerization and polymerization.

Working with codling moth and other orchard pests at the University of California at Riverside, a team led by the late Professor Harry Shorey was developing a pheromone dispensing system based on remote control mechanical timers that periodically dispense puffs of product from aerosol cans (or 'puffers'). Field trials conducted over a number of years in California demonstrated that these devices could be more widely spaced than conventional dispensers that operate by passive diffusion, and the pheromones within the cans are better protected from environmental and chemical degradation. The cans can be filled with selected amounts of a number of chemicals, and thus used to control more than one species (for example, codling moth and leafrollers). The timed release system means that the pheromone release rate remains constant over time and is also not affected by weather conditions, At the time of Professor Shorey's death in August 1998, this system was at the point of commercialization following several years of extended field trials in California.

Lingering Scent

Sprayable microencapsulated formulations are also a promising development, but as described for the gypsy moth programme above, they have the big drawback of fast release, and therefore low persistence, in the field. Sprayable products are now available for a number of crop pests (including pink bollworm) and tree fruit pests (including Oriental fruit moth).

The production process involves mixing the pheromone with a polymer and forming microcapsules with diameters for pheromone products of generally around 20 µm (half the diameter of human hair). The pheromones diffuse through pores in the capsule wall, which also protects the pheromone from the effects of oxidation and ultra-violet light. However, the small capsules, with their high surface area:volume ratio, release all their pheromone too quickly; current lifetimes are around 2-4 weeks. An investment by 3M Canada and the Canadian Government will allow a team led by Harald Stover at McMaster University to conduct research on the structure of polymers, particularly those used in pheromone microencapsulation, and it is hoped that this will lead to effective pest control over a longer time period.

Mixed Messages

Natural pheromones contain a number of components, but synthetic (commercially available) pheromone blends used in pest control are usually much simpler. For example, mating disruption of codling moth still relies largely on a single compound, codlemone, identified in 1971. The difference between natural and synthetic products is suggested to be one reason for the failure of mating disruption, especially at high pest densities.

Deployment of artificial sex pheromone stimulates search flights of codling moths in the tree canopy. Visual cues and the female pheromone signal, containing behaviorally active components other than codlemone, guide the males to calling females at close range. The increased male flight activity observed under codlemone treatment will thus lead to matings, especially at high population densities. Vulnerable areas include orchard edges and treetops where the concentrations of synthetic pheromone are lowest.

An interdisciplinary programme of MISTRA, the Swedish Foundation for Strategic Environmental Research is conducting research on pheromones and kairomones. Its overall goal is to develop biological control methods for some important insect pests in Europe, including codling moth and other pests in pome fruit orchards, stored-product pests in mills and bakeries (flour moths, flour beetles), and aphids, and the use of antifeedants for protection of conifer seedlings against pine weevils. The objective of the codling moth project is to identify behavioural synergists and antagonists, and to see whether the activity of the main pheromone compound can be amplified by blending it with these compounds.

A group of scientists in Sweden, Italy and France, coordinated by Peter Witzgall of the Swedish University of Agricultural Sciences, has looked at the effectiveness of sex pheromone/antagonist blends for disrupting mating in codling moth. Antagonists are usually pheromone compounds from closely related species which play a role in reproductive isolation. They disrupt the ability of male moths to respond to sex pheromones and may be very potent repellents. They have been shown to be effective mating disruptants on their own, but are most efficient and give the best communication disruption when blended with sex pheromone.

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Early Breakfast

Natural enemies use a variety of chemical cues to locate their hosts. Female aphid parasitoids, belonging to seven species so far investigated, are attracted to aphid sex pheromones, which are potential cues for host location. So is it possible to use these pheromones to manipulate aphid parasitoid populations in the field? Robert Glinwood and Wilf Powell at the Institute of Arable Crops Research (IACR), Rothamsted (funded through the MAFF-LINK scheme by the UK Ministry of Agriculture Fisheries and Food, the Horticultural Development Council, the Home-grown Cereals Authority and the Processors and Growers Research Organization) have looked at the potential for pheromones to improve early season control of pest aphid populations on cereal crops.

Parasitoids can play a vital role in the regulation of aphid populations, but only if they are active in the crop during the initial period of aphid population increase. Glinwood and Powell demonstrated that parasitoid behaviour can be manipulated in the field, and they suggest that this provides the opportunity to develop an aphid control strategy based on the use of aphid sex pheromones. They showed that the major braconid parasitoids of cereal aphids are attracted to aphid sex pheromones and will attack aphids present around pheromone lures. For potted cereal plants artificially infested with *Sitobion avenae* and exposed in the field for three days, parasitization levels on plants baited with sex pheromone lures were significantly higher than on unbaited plants. Only asexual aphids (virginoparae), which do not produce sex pheromone, were present on the plants, yet these were attacked by the parasitoids, indicating that parasitoids attracted/arrested by the lure will attack aphid morphs other than the sexual females (oviparae) that naturally produce the pheromone. Parasitism was enhanced in aphids on plants 20 cm from the lure for the generalist aphid parasitoid *Praon volucre*, and up to 1 m away for the cereal aphid specialist *Aphidius rhopalosiphi*; parasitism rates on plants at greater (15 m) distances were apparently not affected by the lures. Since *A. rhopalosiphi* is usually the dominant parasitoid species attacking aphids in cereal crops, it could be an important target species for a parasitoid manipulation strategy.

Further work showed that parasitization levels were higher and increased earlier in pheromone-baited field plots of winter wheat than in unbaited plots, and Powell and Glinwood argued that this indicates that the aphid sex pheromones encouraged parasitoid activity during the initial period of aphid population increase, the stage at which parasitoids can have their greatest impact as control agents.

When arable crops are harvested, aphid parasitoids must disperse into other habitats to find alternative prey populations. In temperate regions, the parasitoids overwinter in these habitats, and spend time foraging there the next spring, before dispersing back into the cereal fields. The key to early-season enhancement, then, is to encourage parasitoids to make this move early. A strategy is being developed at Rothamsted to concentrate over-wintering parasitoids into vegetation strips along field margins (designed and managed to provide aphid hosts and winter shelter) by using aphid sex pheromones as lures to attract the parasitoids when they disperse from cereal fields at the end of the summer. This, it is hoped, should ensure a more rapid recolonization of the fields the following spring.

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Plant Tricks

In an analogous situation, research and trials in East Africa looked at whether cropping regimes may be able to exploit the different reactions of pests and parasitoids to plant semiochemicals [see *BNI* **18**, 27N]. A team of scientists from IACR-Rothamsted in the UK, and ICIPE (the International Centre for Insect Physiology and Ecology, based in Kenya) and KARI (the Kenya Agricultural Research Institute) showed that while undamaged plants of some species, such as Sudan grass (*Sorghum sudanensis*) and Napier grass (*Pennisetum purpureum*), repelled stemborer pests (*Busseola fusca* and *Chilo partellus*), others repelled the pests but attracted their parasitoids. Intercropping maize with molasses grass (*Melinis minutiflora*) significantly decreased populations of stemborers in the maize crop and increased larval parasitism by *Cotesia sesamiae*. They further demonstrated that a volatile component produced by undamaged molasses grass attracted the parasitoid but repelled gravid *C. partellus*. They suggested that intact plants with the ability to release such compounds could be used in 'push-pull' crop protection strategies to entice pests out of the crop and natural enemies in.

There is also evidence that some plants produce distinct semiochemicals in response to damage by different pests, and that these plant emissions can transmit herbivore-specific information that is detectable by parasitoids. De Moraes and co-workers showed using chemical and behavioural assays that tobacco, cotton and maize plants produced different volatile blends of chemicals with different pests. They also found that in field trials the specialist braconid parasitoid *Cardiochiles nigriceps* exploited these differences to distinguish infestation by its host, *Heliothis virescens*, from that by *Helicoverpa zea*.

Jennifer Thaler has now shown that manipulating the biochemical pathways implicated in defence systems against herbivores increased parasitism of lepidopteran pests in tomatoes. She sprayed plants with jasmonic acid to induce the octadeconoid pathway, which contributes to plant resistance both by directly killing herbivores and by enhancing the action of natural enemies. Although parasitoid performance was shown to be reduced on hosts reared on induced plants compared with control plants, parasitism of *Spodoptera exigua* by *Hyposoter exiguae* on treated plants was increased two-fold in an agricultural field. Thaler found that the expression of the octadeconoid pathway was associated with an increased attractiveness and/or retention of parasitoids to the plants. She notes that the abundance of three guilds insects (leaf-, phloem-, and cell content-feeders) was reduced following treatment of the host plants with jasmonic acid, and suggests that elicitors of plant resistance could be investigated as tools in pest management.

Information: Khan, Z.R. *et al.* (1997) Intercropping increases parasitism of pests. *Nature* **388**, 631-632.
De Moraes, C.M.; Lewis, W.J.; Pare, P.W.; Alborn, H.T.; Tumlinson, J.H.; (1998) Herbivore-infested plants selectively attract parasitoids. *Nature* **393**, 570-573.
Thaler, J.S. (1999) Jasmonate-inducible plant defences cause increased parasitism of herbivores. *Nature* **399**, 686-688.

Parasitoid Monitoring

Biocontrollers are beginning to exploit pest kairomones as a tool for sampling natural enemy populations. In New Zealand, Landcare Research are using pheromone traps for monitoring populations of *Cydia succedana*, a seed feeder introduced for control of gorse. They have also been using traps to monitor the presence or absence of the braconid parasitoid *Ascogaster* in orchards.

Information: Suckling, D.M.; Hill, R.L.; Gourlay, A.H.; Witzgall, P. (1999) Sex attractant-based monitoring of a biological control agent for gorse. *Biocontrol Science and Technology* **9**, 99-104.

Lure-and-Infect

We have reported on research aimed at recruiting natural enemies as dispersal agents for pathogens in recent issues. The 'contamination device' for *Glossina pallidipes* and *Glossina longipennis* described in by Nguya Maniania and David Nadel in 'Tsetse's Lethal Path' [*BNI* 20(1), 7N-8N] used a trap baited with cow urine to lure tsetse flies into a trap that contaminates them with the entomopathogenic fungus *Metarhizium anisopliae.* Judith Pell and Michael Furlong at IACR-Rothamsted have been developing 'lure and infect' strategies for management of the diamondback moth, *Plutella xylostella* in collaboration with scientists in Asia and, more recently, Africa (DFID Project No. R6615). The entomopathogenic fungus *Zoophthora radicans* is a widespread and important member of the natural enemy complex attacking the diamondback moth. Epizootics, which contribute to the suppression of larval populations, are common but often occur too late in the season to retain crop damage below the economic threshold. By combining *Z. radicans* with synthetic female sex pheromone Pell and Furlong hypothesize that epizootics can be encouraged earlier when pest populations are small. Male moths are lured, in response to sex pheromone, into inoculum stations where they become contaminated with the fungus. On leaving the inoculum station they return to the crop disseminating infection amongst the susceptible population with the potential to establish early season epizootics. Simple and effective inoculum stations have been designed and evaluated in laboratory and field studies. Future work will include more extensive field testing in different geographic regions.

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Sweet Smell of Success?

The key to the future of pheromones in pest management is threefold: efficacy of product, ease of deployment and effective use, and this will involve research, industry and farmers in equal measure. Research has the role of improving the efficacy of synthetic pheromones by identifying key behavioural compounds, and industry needs to take on the commercial development of these highly specific (and therefore in many cases small-market) products. Industry is taking the lead in improving ways of dispensing pheromones, sometimes developing ideas from researchers elsewhere. The final step is training for the end-users, the farmers and growers. Growers' associations are ideally placed but do not exist in all sectors and/or regions, and finding ways of providing users with technical back-up will be crucial to ensuring adoption of pheromone systems. Pheromone-based control is a more complex technology than chemical control, and growers will need clear instructions and strict guidelines to follow.

The use of pheromones to control insect pests is still in its early stages, although a number of outstanding successes have enhanced the profile of the technique and stimulated a high level of interest, especially against a background of disillusionment with chemical control. The enormous wealth and diversity of chemical communication within the animal kingdom may offer a lot for specifically designed pest control techniques. If the next decade experiences a similar varied use of pheromones to the past one, and advances in formulations and synthesis continue at the present rate, then great strides can be achieved in pest management and control of both forest and agricultural pests. It would be, to paraphrase Heinrich Arn, an elegant way of doing it.

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Training News

In this section we welcome all your experiences in working directly with the end-users of arthropod and microbial biocontrol agents or in educational activities on natural enemies aimed at students, farmers, extension staff or policymakers.

Making Use of the Good Bugs in Cotton

In Peru, organic cotton production started in 1993 in the Cañete Valley, and the Peruvian Action Network on Alternatives to Agrochemicals (RAAA) has been working for three years on organic cotton promotion and training. In 1997 some 700 tonnes of organic cotton were produced in Peru, but this constituted less than 2% of national tonnage.

The international seminar on Alternative Production and Marketing Systems for Organic Cotton in Latin America held on 5-8 April 1999 in the Cañete Valley (organized by RAAA and the North American and Latin American Pesticide Action Networks) provided participants with the opportunity of exchanging experiences, and for seeing how some farmers put these into practice. They visited the farm of Mr Jorge Bustamante, RAAA activist and key member of the Cañete Cottongrowers' Association, who has established a sophisticated system of conservation and augmentation of natural enemies. Mr Bustamante owns 40 ha in NE Cañete on which he rotates around 25 ha of organic cotton with asparagus and maize, and the remainder is under grazing and citrus. He has been growing organic cotton since 1996 as part of an eco-technological renovation of his farm. Under RAAA's IPM programme, he had successfully reduced insecticide applications to one per season before converting to organic production. He places equal importance on improving soil organic matter, as fertility is the main constraint on his land.

In the first year of conversion, he had foci of early season aphid (*Aphis gossypii*) attacks (these can delay plant development) but was confident in the power of natural enemies to deal with these. Mr Bustamante had noticed ladybird beetles feeding on aphids on nutsedge weed (*Cyperus* sp.) and after checking with local entomologists that the aphids were not cotton-feeding species, he collected weed infested with ladybird egg masses or larvae and transferred these to his cotton aphid 'hotspots'. When trying to make larger collections of ladybirds, he observed larval cannibalism and now instructs his staff to make sure prey is included in collection jars. Mr Bustamante is convinced that natural enemy numbers must be augmented for effective aphid control in cases when ladybird beetles are not sufficient. He has also found that irrigation can help water-stressed plants tolerate aphid attack.

To improve aphid control further, he collected parasitized aphid mummies from other crops for distribution in his cotton. At first, the mummies dehydrated under full sun and adult *Aphytis* wasp emergence was low so he now uses shade covers. To increase numbers, he started on-farm rearing-out of parasites and their reproduction in simple emergence and exposure cages made of wood, gauze and plastic sweet containers. He deployed the emergence cages at one per hectare for adult wasp release but found that aphid numbers did not decrease as expected. After consultation with the university, he realized that his rearing unit contained a large proportion of hyperparasites of *Aphytis* spp. He now uses smaller recuperation cages and checks regularly to identify emerging adults. He has tried Rotebiol (rotenone) for aphid control but found that underleaf coverage is very important and that the product can kill other natural enemies.

For bollweevil (*Anthonomus grandis* and *Anthonomus vestitus*) control, he collects damaged squares on a regular basis and plans to rear out possible parasitoids. For *Heliothis virescens* bollworm, he plants cheap fodder maize every four rows and every 4 m, using a lemonade bottle attached to the seeding plough to deliver the maize seed to avoid extra labour costs. Mr Bustamante has observed that maize generates a large number of predatory bugs and beetles due to its rapid growth and these have built up to good levels by the time the cotton is at boll stage. He stakes and marks *Heliothis* egg masses to check progress but on many occasions the eggs disappear after a day or so, indicating high predation levels. This monitoring has enabled him to save on the expense of *Trichogramma* releases, which are recommended at an action threshold of 6-10 bolls with eggs. When *Trichogramma* releases are unavoidable, he prefers to make small releases every three or four days rather than one mass release.

If the cotton-associated maize is left to form cobs, *Pocosera* spp. caterpillars can become problematic in the cotton. He prefers to take out the maize at this stage and use it directly for fodder. Neighbouring maize fields may also encourage *Pocosera* infestation at the boll stage so regular monitoring is needed. For pink bollworm, *Pectinophora gossypiella*, Mr Bustamante uses pheromone traps for monitoring and collection but still gets around 8% boll attack. Whilst conventional farmers resort to pesticides to reduce this level of pink bollworm damage, he has observed that the cotton plant's natural defence mechanism often seals the larva in one lobe of the boll and thus eventual yield loss is only a quarter of the percentage boll damage. Incorporating cotton stalks into soil post-harvest can cause pink bollworm carry-over so he makes sure all boll remains and semi-open bolls are removed from plants and burnt before crop residues are ploughed in.

Mr Bustamante has adapted the use of black strip lights with winged trap plates to collect both pest and beneficial insects. The insects hit the plates and fall through a sieve, which separates them by size. The traps are inspected early each morning and the beneficials redistributed to plots with low natural enemy numbers. Pest species are killed and used as compost or fed to chickens. One record night's catch was 7 litres of *Heliothis* moths. He uses 16 one-metre length light traps over a 7-ha area. He also uses them in sweetpotato to catch potato weevils. Other biocontrol practices on his farm are planting mandarin and strips of late-sown weedy maize as natural enemy refuges and control of nutsedge by enclosing geese in $2 \times 2 \times 1$ m cages over weedy patches where they uproot and feed on the rhizomes. Mr Bustamante's current sophisticated and time-consuming biocontrol practices cost around four times as much in labour as insecticide application inputs, thus the organic premium is essential to be competitive. His organic cotton plot gives yields of 1260-3150 kg/ha with an average of 2700 kg. 'Break-even' point is 2250 kg.

Mr Bustamante has also experimented with a bean-cotton rotation but found that sucking pests are worse and *Rhizoctonia* fungal disease can be serious in cotton planted on land previously sown to beans. He is therefore only using beans as an associated crop rather than in rotation. He is currently experimenting with different rates and combinations of manure and *guano* (seabird droppings) for fertilization and he uses copper sulphate for seed disinfectant. In the *El Niño*-induced whitefly outbreaks in 1998, he recorded massive infestations (over 800 nymphs/cm^2) in conventional farmers' sweetpotato fields where pesticides were applied. He also reported fungal epizootics causing 90-100% mortality of whitefly in heavily-infested sweetpotato and beans in late 1998. This fungus was identified as *Paecilomyces farinosus* by the National Plant Protection Service, SENASA, and continued epizootics have controlled whitefly in 1999 in many parts of the Cañete Valley.

Mr Bustamante is an example of the medium-scale farmer who has become convinced of the merits of biocontrol through his own observations and who is actively experimenting with organic systems with support from research colleagues and with organic expertise from RAAA. He also works with smallholders to train them in natural enemy recognition. Peru has a long history in the use of classical biological control, however, it is only in recent years that farmers and their associations have been actively involved in conserving and augmenting natural enemies. A multi-institutional National Biological Control Programme was set up in 1995, under the supervision of the National Plant Protection Service, which administers a network of 109 biocontrol laboratories run by private and public sector agencies including growers' associations and non-governmental organizations. Currently the network produces 14 species of parasitoids and predators and five species of fungal and viral microbial control agents. For cotton lepidopteran pests, five species of trichogrammatids are reared commercially while two encyrtids and one braconid species are regularly collected from the field and redistributed for aphid and scale control. Some farmers are now starting to try out *Beauveria bassiana* mycopesticides for the increasing whitefly problem.

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Internet Round-up

By: Tony Little, Technical Support Group to the Global IPM Facility, CABI Bioscience.

My task this quarter would be much harder were it not for the 'Pheromone pages & research groups' and the 'chemical ecology' sections of the Internet Jump List at

http://www.pheromone.ekol.lu.se/links.html

It provides links to sites dealing with particular areas of research, for example gypsy moth and tick pheromone research, and commercial pheromone companies. The list is managed by the pheromone research group at the University of Lund, Sweden and details of their work can be found at

http://www.pheromone.ekol.lu.se/HomePage.html

The group also has close links with the chemical ecology group at the Swedish University of Agricultural Sciences at Alnarp at

http://www.vsv.slu.se/cec/h.htm

which is worth a look at.

'Pheronet' at

http://www.phero.net

is the virtual home of the International Organization of Biological Control's Working Group (IOBC WG) on the Use of Pheromones and Other Semiochemicals in Integrated Control. This gives details of meetings, past and forthcoming, and a list of WG publications. Pheronet also plays host to the pherolist, a database of chemical components identified from female Lepidoptera, and other chemicals attractive to male moths.

There are a number of sites dealing with the use of pheromone traps for the use of monitoring, for example: the University of Maine's work on maize pests at

http://130.111.117.45/swetcorn/pheromon.htm

also the role of pheromone monitoring in the USDA Boll Weevil eradication programme in the USA at

http://www.aphis.usda.gov/ppq/weevil.html

and a nice little summary for major pests of different crops in the state of Colorado at

http://www.colostate.edu/Depts/IPM/pdf/05562.pdf

Brief summaries of several NRI projects involving the use of pheromones in IPM can be accessed from

http://www.nri.org/Projects/theme15.htm

Some of the commercial company sites are quite interesting. IPM Technologies, for instance, at

http://www.ipmtech.com/home_old.html

who are collaborating with Agricultural Research Service, the US Department of Agriculture's chief scientific research agency, on a project to control a range of pests by developing attract-and-kill traps, details of which are posted at

http://www.ars.usda.gov/is/pr/1999/990111.htm

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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.

ICE Hots Up

The organization of the International Congress of Entomology (ICE) is well underway, and the Congress organizers are now calling for papers. Abstracts must be received by 31 December 1999, and the rules for submission are explained fully on the ICE website at:
http://www.embrapa.br/ice/
Email: ice@sercomtel.com.br
Also note their new fax number:
+55 41 3721415

Participants hoping to do some collecting during their visit are also asked to familiarize themselves with Brazil's rules on exploration for insects and other biocontrol agents, and to make necessary arrangements for permits well in advance. The regulations and procedures for obtaining permits are described on the website under 'Collecting insects', and participants are also invited to contact the Quarantine Laboratory.

Since 1991, the EMBRAPA National Quarantine Laboratory (Laboratório de Quarentena "Costa Lima"), located in Jaguariúna, State of Sao Paulo, has interacted with researchers from different institutions to cooperate with their projects and promote biocontrol activities. Nearly 90 biocontrol agent introductions, involving predators, parasitoids and pathogens, have been processed in this time. It is one of the mandates of the Quarantine Laboratory to interact with foreign institutions for exportation of biocontrol agents under a previous cooperative agreement. The Quarantine Laboratory intends to be an overseas laboratory to foreign research institutions around the world in order to promote biological control programmes. Any participant of the XXI International Congress of Entomology is invited to contact them for information on and assistance with complying with the requirements of Brazilian law.

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Smallholder Organic Banana Workshop

Many small-scale banana farmers are facing increasing difficulty in competing directly with large-scale producers in a free market economy, and production and diversification alternatives for such growers have become clear needs. The growing interest in, and market for, organic produce by consumers in importing countries offers one possible solution. In response to this demand, CAB International, INIBAP, CTA and other collaborators are organizing a workshop in the Dominican Republic on 1-4 November 1999 to address the issues, challenges and opportunities facing smallholder producers of organic bananas.

The workshop will have a specific focus on production and marketing requirements and constraints for organic bananas produced by small-scale farmers in the Caribbean/Latin American region. It is planned that key stakeholders in the entire chain, from the field to the table (producers, research/extension services, members of banana boards, NGOs, certifiers, exporters/importers, brokers, traders and retailers) will be represented. The meeting will aim to provide an impartial forum to catalyse discussion between these main stakeholders in order to create a common understanding of the key issues involved in an organic production initiative and to determine how these might best be jointly addressed and moved forward.

The workshop will consist mainly of discussion and planning sessions, although some presentations will be given by keynote speakers and a field trip to visit organic banana production areas in the Dominican Republic will also be included. The workshop organizers also offer the possibility of a post-workshop field trip to Cuba, to view the organic production of improved *Musa* hybrids with resistance to major diseases. Production of these new varieties, which hold great promise for wider-scale organic production, is particularly well advanced in Cuba.

Expressions of interest in attending the Workshop are invited. It should be noted that, in order to ensure an effective dialogue, the number of participants will be restricted. Efforts will be made to ensure a balanced representation from each of the main categories of stakeholders.

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Pheromone Meetings

For readers whose interest has been (re)kindled by the articles in this issue on pheromones, the 25th Anniversary Jubilee Reunion of the IOBC-WPRS Working Group ‘Use of Pheromones and Other Semiochemicals in Integrated Control’ is to be held in Samos, Greece on 25-29 September 2000. Here, new developments will be presented by researchers for researchers interested in practical solutions.

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There is a meeting of the Working Group before then, but the deadline for registration is 15 September. The meeting is at Hohenheim, Germany on 10-12 November 1999, and will focus on the practical use of pheromones in orchards and vineyards. But look out for the proceedings which will appear on the Working Group website.

Fewer and fewer insecticides are available for use against codling moth in Europe, and elsewhere, as resistance and bans take their tolls. In Germany, the official fruit growers’ journal (*Obstau*) says, “legal fruit production will not be possible in the future”. More and more growers are beginning to think about other methods, but have no obvious place to go for advice unless they have access, as in the USA for example, to large growers’ associations. The Hohenheim meeting is intended to bridge this gap and bring together scientists and pest control advisers.

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Transgenic Global Working Group Newsletter

The International Organization of Biological Control (IOBC) Global Working Group on ‘Transgenic Organisms in Integrated Management and Biological Control’ have produced their first newsletter. It contains notes on the scope and objectives of the working group and a membership directory. There is a section giving the summaries of presentations given at the symposium, Transgenic Plants in Agriculture: Agroecological Implications held during the annual meeting of the Entomological Society of America at Las Vegas on 8-12 November 1998. There are articles on GM crops in Brazil and China. There are also sections giving relevant websites, recent publications and forthcoming meetings.

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Chromolaena Workshop

The Fifth International Workshop on Biological Control and Management of *Chromolaena odorata* will be held in Durban, South Africa, from 23-25 October 2000. The purpose of this workshop is to facilitate the dissemination of information on the management and control of *Chromolaena*, to identify areas in which new research is needed, and to foster global co-operation on managing and controlling this plant.

For more information visit the *Chromolaena* biocontrol web page: http://www.ctpm.uq.edu.au/chromolaena/siamhome.html

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New Books

Enhancing Biological Control

This book*, edited by Charles Pickett and Robert Bugg, was a second brilliant major review on the subject of conservation biological control to appear in 1998 (the first was edited by Barbosa**). The theme is habitat management to enhance biological control, which the editors, in their introductory chapter define as “the provision of resources to natural enemies to improve their effectiveness at controlling pests”. They also stress the important point that habitat management could be used in conjunction with classical biological control or augmentative biological control to enhance the establishment and/or impact of introduced or repeated releases of natural enemies. Like Barbosa's book, this book contains chapters on a wide range of important subjects authored by an international group of scientists: there are 15 contributions including ones from the United States, Finland, Germany, Great Britain, New Zealand, the People’s Republic of China, and Switzerland.

Understandably, the ‘core’ of the book, again like Barbosa’s, is about effects of vegetational diversity, scale and mosaics on natural enemy diversity and activity and the identification of those resources (e.g. food sources and refuges) that are necessary to enhance the responses of natural enemies to their prey populations. Pickett & Bugg draw attention to the point that, despite the debates about diversity *vs* stability, most studies show that fewer crop pests are found as the diversity of an agro-ecosystem increases; and this has clearly been a stimulation behind much research underpinning habitat modification for biological control even though “to date, no comprehensive theory has been proposed to predict under what conditions and to what extent vegetational diversity may increase the effectiveness of natural enemies”.

There are, however, important differences between this book and Barbosa's which, this reviewer believes, make them complementary. In Pickett & Bugg there is nothing on microbials, or the effects of pesticides or genetically modified (GM) crops on natural enemies. There is also less on ecological theory (but an adequate amount) but much on practical science and experimental design, which is very useful given the subject area. There is also a lot on important predatory groups such as spiders.

Chapters 1 and 6 (counting numerically from the introductory chapter – the chapters are not numbered) provide good reviews on the background and theory relevant to the subject and highlight some of the major issues: the inadequacies of simple host-predator models and the concept of stability for agro-ecosystems, the importance of polyphagous, highly mobile predators, and the dangers of applying simplistic thinking when trying to interpret the importance of vegetational diversity for natural enemy enhancement. Chapter 2 is theoretical and considers the effects and availability of vegetational strips in crops on the response of natural enemies with different dispersal capabilities. One of the model predictions is that when natural enemies are present in interplantings at crop germination, natural enemies are enhanced, even if strips provide more resources than the crop. Thus a key characteristic of vegetation management systems is whether natural enemies can overwinter in the interplantings. Some practical examples are provided for carabid beetles in wheat fields in chapter 15.

The resources necessary or likely for the enhancement of insect predators, parasitoids and spiders are covered in a number of the other chapters. Chapter 5 considers parasitoids and concludes that, contrary to theory, generalist and specialist parasitoids are equally enhanced by an increase in plant diversity. However, effects are variable and thus rather than seeking to increase crop diversity *per se*, agro-ecosystems should be designed to provide natural enemies with specific resources that will augment their efficiency. Chapters 6 and 4 discuss insect predators and chapters 8 and 13 spiders, and these conclude the same. There is an important discussion of the usefulness of artificial overwintering shelters for predators in chapter 9. The problems of providing resources for the natural enemies of one pest and creating another are illustrated in chapter 3; here various plants used to attract predators of lettuce aphids in California also resulted in population increases in the agromyzid leafminer *Liriomyza huidobrensis*. This illustrates the point that if pest diversity is high, relatively more may be gained by enhancing generalist predators than by enhancing or introducing a specific enemy against just one pest species. This in turn raises the question of considering agro-ecosystems as whole entities rather than trying to develop a suite of management packages for components such as individual pest species. There are two interesting chapters on this important subject. Chapter 14 discusses ‘farmscaping’ in California while chapter 7 provides an overview of more ambitious integrated farming systems in Switzerland and how this can provide a model for other countries.

Agricultural practices are rapidly changing in many parts of the world. For example, in EEC countries, more farming land is becoming available for ‘set-aside’ because of over-production of cereals. This important book provides guidance to researchers, agriculturalists and policy makers in why and how to design land-use systems that conserve natural enemies of agricultural pests.

*Pickett, C.H.; Bugg, R.L. (eds) (1998) Enhancing Biological Control. Berkeley, CA, USA; University of California Press, 422pp. Hbk. ISBN 0 520 21362 9.

[**Barbosa, P. (ed) (1998) Conservation Biological Control. San Diego, CA, USA; Academic Press, 396 pp. For a review of this title see *BNI* **19(4)** 114N-115N.]

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Organic Cotton

Cotton is one of the world’s leading crops, and represents almost half the world’s fibre market with cotton fibre production in 1997-98 estimated at 18,888,000 tonnes worldwide. It is grown on all the continents, in tropical, subtropical and warm temperate environments, from the monsoon tropics through Mediterranean climates to arid, near-desert conditions, by all sizes of producers from giant commercial concerns to smallholders. So it is almost inevitable that it should have acquired a vast array of pest and disease problems. For example, although most losses are caused by six species of bollworm, cotton is attacked by close to 50 different insect pests. Thus conventional cotton growing is heavily dependent on chemical inputs (nearly a quarter of insecticides used around the world each year is applied in cotton).

Concern about the environmental effects of cotton production and the welfare of cotton farmers and farmworkers has led to the promotion of a number of organic programmes in cotton, along with a growing niche market for pesticide-free and ‘ecological cotton’. Some programmes are highly sophisticated in terms of crop management and marketing, while many are organic more by default, where smallholders can no longer afford agrochemicals and cultivate their cotton in low-input mixed cropping systems.

Commercial organic cotton production is a new sector, barely ten years old, and in 1997 still had less than 0.05% of the world market. The independent development of alternative solutions to problems of cotton growing in a diversity of agro-ecological situations has led to a wide range of options being researched, developed and tested. This book* provides a good summary of the experiences of organic cotton production so far, which will help to remedy the dearth of publications in this field. Case study material is given prominence, and is drawn from both well-established and experimental projects to present an overview of developments to date with detailed examples from the USA, Peru, India, Turkey, Egypt and six subSaharan African countries.

The book draws together experience from a diversity of sources, including most of the current organic cotton projects worldwide, to provide the first comprehensive overview of organic cotton production. Chapters are arranged according to the stages in the cotton ‘chain’, from farmer to consumer. The problems of the dominant cotton production systems, debate on the use of genetically-modified cotton varieties and the current state of organic production, processing and use are summarized, with a special emphasis on small-scale farming systems in developing countries. Technical aspects of organic cotton growing, including pest, weed and disease management are covered, as are marketing and project support requirements. Problems at the processing level, and approaches that are more environmentally responsible are discussed. Economic and marketing aspects and developments in regulatory systems are examined, including cost and yield comparisons of conventional and organic cotton, certification, price premiums, labelling and consumer demand. Perspectives on current problems and future developments are reviewed and the book contains a comprehensive list of 100 contacts and sources of support in producer and consumer countries.

Alternative cultural and biological practices to chemical control are outlined for major cotton pests such as boll weevil, bollworms, aphids, bugs and whitefly, within the context of a holistic approach with equal emphasis on soil health, water management and good crop husbandry. Augmentation of natural enemies is carried out by organic farmers in the USA, and some in India, Peru and, occasionally, Egypt and Turkey. In India organic farmers may release *Trichogramma* wasps and lacewings and use bacterial or viral products or collect viral-diseased larvae to prepare a crude biopesticide. In subSaharan Africa, biocontrol is currently limited to conservation of natural enemies. Many organic farmers in developing countries will also combat pests by sowing repellent plants such as marigold, trapcropping and intercropping, applying home-made botanical preparations and using yellow sticky and pheromone traps.

In Egypt there are now 150 biodynamic farms cultivating over 2000 ha. Biodynamic cotton seed is treated with *Trichoderma harzanium* and *Bacillus subtilis* for fungal disease control and sown with biodynamic preparations before covering with quartz sand. The warm sand helps to prevent cutworm (*Agrotis ypsilon*) attack. Whitefly, aphids, jassids and thrips are countered in early season by the use of yellow sticky traps at 30/ha. Dilute potassium soap solution or neem extract may also be applied. Irrigation timing is carefully regulated to prevent disease attack. Cotton leaf worm, *Spodoptera littoralis*, is controlled by collection and burning of egg masses and pheromone traps to disrupt mating. *Bt* sprays may be used if leafworm damage is evident. Delta traps are used for mating disruption of pink (*Pectinophora gossypiella*) and *Helicoverpa* bollworms. As a result of pesticide elimination, 64 species of predators, including vertebrates, are now observed in biodynamic fields, with *Orius* spp. the most common, followed by spiders, ladybirds and lacewings.

*Myers, D.; Stolton, S. (*eds*) (1999) Organic cotton. From field to final product. London; Intermediate Technology Publications Ltd., 267 pp. Pbk. ISBN 1 85339 464 5
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