FUTURE DIRECTIONS IN URBAN ENTOMOLOGY—PHEROMONES.

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Abstract—Pheromone usage in Urban and Stored Products Entomology has been confined predominantly to insect pest monitoring to date and only in a few cases have pheromones been used for direct population suppression. This paper reviews the advances that have been made over recent years in the use of pheromones for monitoring moths, beetles and cockroaches amongst others in the built environment. Some thought is also given to possible future developments which could come from the innovative use of pheromones in this branch of Entomology. Pheromones can also play an important role in suppressing urban and stored product insect pests through techniques such as mass trapping, mating disruption or 'lure and kill'. Mass trapping as a technique has been limited in its application mainly by the absence of suitable attractants and good trap design, whereas mating disruption has only been achieved to date with moth pests. Lure and Kill on the other hand provides the best opportunity for the application of pheromones where they can impact a fast changing insecticide industry which is increasingly trying to attract target insects to insecticides instead of propelling insecticides to insects. Successful exploitation of pheromones through this technique may however, require them to be mixed with other semiochemicals as well as visual or auditory cues.

INTRODUCTION

Since the characterisation of the first pheromone components over 30 years ago (Butenandt *et al.* 1959) much scientific and technical effort has been put into the development of products and techniques which make use of this potent group of semiochemicals. Commercial exploitation on the other hand has not received the same level of attention and resource allocation and pheromones have consequently not impacted significantly on urban and stored product insect pest management practices over the same period. During the late seventies and early eighties, however, pheromone-based products have gradually been introduced into the market and by the late eighties the value of pheromones in monitoring, and to a lesser extent in controlling, a number of key insect pests hasd been widely recognised by the more technically proficient practicioners of urban and stored product insect pest management.

Over five years have passed since the present author reviewed the commercial development of pheromone-based monitoring systems in Stored Product and Urban Entomology (Jones, 1987). During that time significant advances have been made, both technically and commercially, which have increased considerably the degree of sophistication and use level of pheromone-based products in these industrial sectors. It is the intention of this paper to review those advances, to comment on the current status of this technology and as the title of the paper suggests, to project future technical and commercial developments for pheromone based products in managing insect pests in the built environment.

THE USE OF PHEROMONES IN MONITORING INSECT PESTS IN THE BUILT ENVIRONMENT

Moths

Pheromone-based traps for the more important moth pests of stored products (*Plodia interpunctella* and *Ephestia* spp.) were probably the first to be adopted in any significant numbers by Pest Control Operatives (PCO's) in the food storage and processing industry. Their use has undoubtedly lead to improved pest detection (early warning before populations reach economic damage levels), improved location of infestations and have contributed significantly to a more rational use of insecticides in these sensitive food handling environments.

Advances have been made over the past five years in improving the lure system for these moths in terms of controlled release, length of life of the dispenser, stability of the pheromone and in our

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understanding of the role of the minor components in attracting the moth. Trap designs have also been developed which catch a greater number of moths attracted to the trap (Quartey & Coaker, 1992). Perhaps the most important advances, however, have been made in the development of methodologies for using these monitoring traps. Trap placement, data collection and interpretation have been advanced significantly but such advances are not often recorded in the scientific literature because the information is thought to be too applied, too elementary,too commercially oriented or proprietary. Such developments may by themselves not constitute a significant scientific or technical advance, but collectively it is clear that they have moved the field forward significantly.

Traditionally, not much thought has been given to placement of these traps. Recent collaborative developments between Agrisense BCS Ltd and Rentokil plc have shown that sources of *Ephestia* and *Plodia* infestations can be very accurately detected through using a combination of traps. The standard monitoring systems (delta or funnel traps), arranged in a grid pattern throughout the premises being monitored, is combined with and a series of 'mini' moth detectors, suitably baited for the environment in which they operate, and placed within food lines and machinery which are in the vicinity of the standard traps which have superseded pre-determined trap thresholds. By using this combination of standard moth trap which indicates that an infestation is developing and the mini moth detector, or locator, which accurately pin-points the source of the infestation, significant savings can be achieved in both time and labour. Such accurate infestation location means that only the production line which harbours the infestation need be closed down and treated, as opposed to closing down the whole production area in order to carry out a partial or complete fumigation.

Data collection and interpretation is also becoming increasingly sophisticated. Computerisation of trapping data is now beginning to appear and trap catch records over many years for any particular site can now be called up at the touch of a button. Comparisons can then be made between sites over many years to spot long term trends in levels of infestation and control achieved. The scope for centralised data evaluation and interpretation also exists with pest management decisions being made both centrally and locally. These trends in the increasing use of information technology coupled to pheromone monitoring systems can only gather momentum over the coming years.

There is also an increasing tendency amongst PCO's to move away from the prophylactic use of insecticides to control stored product insect pests and to use them only when and where necessary. Pheromone-based monitoring systems which are accurate and reliable will help make this happen. A strategy of standard monitoring practices on a grid basis, followed by location of any infestation through the use of short range detectors, followed by intensive hygiene measures, sometimes referred to as 'smart cleaning' or 'clever cleaning' followed by further intensive monitoring for effectiveness of the hygiene measures, could lead to a pesticide-free pest management strategy in some PCO sectors.

Whereas the use of pheromones for *Ephestia* spp, *Plodia interpunctella* and *Sitotroga cerealella* is increasingly becoming well established, the pheromones of some other important Urban Entomology pests appear to have had little or no attention. Although not as important as the above named species in terms of the total damage they cause, moth pests such as *Tinea pellionella, Tineola bisselliella, Endrosis sarciterella, Hofmannophila pseudospretella* and *Trichophaga tapetzella* can all cause irreparable damage to the national heritage of many countries in museums, collections, etc, as well as to household materials. Given the sophistication and rate of discovery nowadays of pheromone technology, modest resourcing in this area would lead to the rapid development of useful tools in detection and monitoring of these important pests.

Beetle pests of bulk grain

Monitoring devices for these pests have been reviewed frequently during the last 5 to 10 years (Barak, *et al.*, 1991; Burkholder & Ma, 1985; Chambers, 1987; Cogan *et al.*,1991a). The devices used have fallen generally into two categories, probe or pitfall traps. The latter group generally tend to catch beetles which spend most of their time at or on the grain surface whereas the former group is better suited for insects which are generally found at greater depths. The development by Cogan et al. (1991b) of a new trap which can be used both at the surface of grain and at depth is probably one of the most significant advances for beetle pest monitoring in this sector. Although not essential for the successful use of these traps, pheromone lures or food based attractants have been shown to enhance their performance in practice (Cogan & Wakefield, 1987) and significant progress has been made in the isolation, synthesis and formulation of pheromone and food attractants for *Oryzaephilus surinamensis* (Pierce, *et al.* 1987), *Cryptolestes ferrugineus* (Loschiavo *et al.*, 1986; Oehlschlager, *et al.* 1988), *Sitophilus* spp. (Walgenbach *et al.*, 1987) and *Trogoderma* spp (Greenblatt, *et al.* 1977). Technically speaking, there is little doubt that these traps, whether baited or not, are significantly more sensitive in beetle detection than spear or vacuum sampling followed by visual inspection of samples (Cogan *et al.*, 1985). However, their introduction into the marketplace has not lead to their widespread use as was originally forecast. The main reason for this relates to the lack of perceived benefits from their use on the part of the end-user. The person whose responsibility it is to monitor for, and deal with, insect infestations would, in many cases, prefer not to know about the beetle populations infesting the grain being stored. In many countries, national legislation, directives, etc, actually encourage such a state of ignorant bliss. Until recently, to have shown the presence of beetles in bulk grain using these more sensitive traps would have downgraded the value of the grain concerned in a number of countries. Using conventional inspection systems, with their lower sensitivity, would not have detected the infestations and consequently, would have given the grain a higher value than it actually deserved. Inspection authorities are, however, changing their rules and regulations to allow for the use of monitoring traps without prejudicing in any way the position of the user. The prophylactic treatment of grain as it goes into storage is increasingly being discouraged and as strategic holding of grain becomes common practice in a global grain market, the need to use such traps will become essential. However, authorities are going to have to recognize that the technologies used for monitoring beetle pests currently are very sensitive and that indications of the presence of a few insects in the grain do not require immediate recourse to chemical treatments. They must instead be regarded as early warning systems which allow the operators to take grain pest management decisions at an early stage before the problem has become economically significant. This problem is not unique to grain pest management and has occurred and been successfully overcome in other industries where analytical techniques have improved to such an extent that action thresholds have had to be modified.

Beetle pests of processed commodities

Five years ago, commercial sex pheromone based traps for *Lasioderma serricorne* were already well established within the tobacco processing industry and their uptake and use have increased significantly since that time. This industrial sector is dominated world-wide by a relatively small number of large companies, within which persons with sole responsibility for pest management can be established. These people, in turn, are technically very competent and can adopt and implement best practice principles very quickly and efficiently because of their key positions. As a result, *Lasioderma* monitoring with traps has been widely implemented in the tobacco industry. Unfortunately, this can not be said about some of the other monitoring systems for beetle pests of processed commodities such as *Tribolium* spp, *Stegobium* spp, or *Trogoderma* spp. It is probably correct to say that the two main reasons for this have centred around the technical performance of the systems concerned, and again, the lack of perceived benefits from their use. The early trapping systems for *Tribolium* spp and *Stegobium* spp have suffered technical problems in the synthesis of chirally pure pheromones and from inadequate design input into the traps to make them both effective and user friendly. This in turn has increased fears in the end user of getting a False Negative, ie, catching no insects even though there is an infestation. The false negative is clearly a potentially very damaging situation in that the operator is lead into a false sense of security; no control measures are initiated based on the low or zero catches, and the emerging infestation develops quickly to a level of economic loss. Significant effort has gone into improving both the synthetic routes to the pheromone active ingredients and the designs of traps and in the near future substantially more reliable traps will come onto the market to allay fears such as those described above. It is also hoped that reliable pheromone monitoring systems will soon be available for important species such as the wood worm beetle (*Anobium punctatum*), mealworms (*Tenebrio* spp), and the dried fruit beetle (*Carpophilus hemipterus*). Any new traps coming onto the market will be used by the same end users as those currently employing moth traps; provided these new traps are totally reliable in their performance, their introduction should be easier, their uptake faster, and their use level greater, as a qonsequence.

Cockroaches

Although sticky traps for cockroaches were introduced into the retail market for household use as far back as the mid seventies, their use by PCO's has not become commonplace until comparatively recently. Detectors or 'zone monitors' are now almost standard components of a PCO's operating procedure in many countries world-wide. Their use allows the PCO to gauge the species concerned, the severity of the problem, the main foci of infestation and seek out the most undetectable of cockroach harbourages without recourse to night inspections, flushing agents or undue disruption to the client's day-to-day activities. The development of newer, more powerful attractants (Schal, 1993) and improved trap designs will secure a place for these traps in all PCO cockroach control activities. Several lines of research currently under way will make these apparently simple devices even more sophisticated. It is likely that PCO's will be able to measure the cockroaches' susceptibility to different insecticides by carrying out a simple bioassay on the cockroaches caught (Moss *et al.*, 1993). Detailed observations of possible wing deformities, etc, on the cockroaches caught in traps will also tell the PCO if an Insect Growth Regulator (IGR) application is having an effect on the population before actual numbers begin to decrease. Correlations may also be established between the number of insects caught and the need for, and the quantity of insecticide product to be applied as has been shown in metropolitan housing projects in Canada (Bryks, 1993). It was demonstrated that a good correlation can be established between the number of cockroaches caught in sticky traps and the number of hydromethynon bait stations needed per location to achieve control.

Other Pests

Although pheromone components have been described for natural fibre pests such as *Anthrenus* spp(Burkholder *et al.*, 1974; Fukui *et al.*, 1974; Kuwahara & Nakamura, 1985), *Attagenus* spp (Silverstein *et al.* 1967; Fukui et al., 1977) and *Dermestes maculatus* (Levinson *et al.* 1978), widespread adoption of monitoring systems based on these compounds has not been realised due again to doubtful technical performance and the fear of the false negative. Important pest species such as *Ptinus tectus*, Psocids and flour mites have still not had their pheromone systems described, if they exist. Whereas commercial companies can impact greatly on the development of *Anthrenus* and *Attagenus* monitoring systems, progress on the others will only come through public sector finance of the discovery-type research which will be required to isolate and identify the chemical components involved.

THE USE OF PHEROMONES IN SUPPRESSION OF INSECT PESTS IN THE BUILT ENVIRONMENT

Pheromones will probably have a role in suppressing urban and stored product insect pests in three main ways, namely, mass trapping, mating disruption and lure and kill.

Mass Trapping

In concept, this method of controlling insects is relatively simple; catch as many of the problem insects as possible in some sort of trap so as to suppress populations. In practice, however, to achieve it is often difficult. The main reasons for this relate to the inadequacy of the lures and the trap designs used. In many cases, for instance, sex pheromones are produced by the female to attract males, as in the case of the stored product moths described earlier. Consequently, only the males are attracted to the traps. Any attempt to use sex pheromone-baited traps for pest suppression can only succeed if sufficient males are captured to leave the females unmated. A very high proportion of males would therefore have to be caught and the trap to female ratio might have to be as high as 5:1 (Roelofs *et al.*, 1970). For such a high proportion of males to be caught, both the attractant lure and the trap design have to be highly effective. Recent studies of trap designs and their effect on capture of *Ephestia cautella* (Quartey and Coaker, 1992) have shown that although the number of male moths attracted to the trap can be very high, the actual number caught of those attracted to the trap can be quite low. However, the same authors have shown that modifications to the trap design and the inclusion of visual stimuli can improve significantly the number of insects caught. Only by improving the trapping system in this way can any significant advances be made in the use of mass trapping as a technique to control insect pests where only the male insect is attracted. Despite inadequacies of the currently available traps, several reports of the successful use of sex pheromone baited traps to control stored product moths have appeared in the literature (Levinson & Levinson, 1979; Trematerra & Battaini, 1987; Trematerra, 1991). With improved lures and trap design this trend may accelerate significantly.

Aggregation pheromones on the other hand offer much more promise in this area since they usually attract both sexes and in many cases, the immature stages as well. Experience with bark beetles in Canadian and European forests has shown that traps baited with aggregation pheromones can suppress beetle populations significantly when used at the correct density. Aggregation pheromones have been characterised for species such as *Rhyzopertha dominica* (Williams *et al.*,1981), *Tribolium* spp (Suzuki & Sugawara, 1979) and *Prostephanus truncatus* (Hodges *et al.*, 1984) but there are no records in the literature of attempts to suppress these beetle pests by mass trapping. Aggregation pheromones are known to exist in a number of cockroach species but their chemical identity has still to be unravelled in most cases. As the chemistry of these and other aggregation pheromones is eventually resolved, many opportunities will open up for mass trapping as a technique to suppress insect pests in the built environment.

The possibility also exists of combining pheromones which attract one of the two sexes only with food attractants for the other sex. This possibility has been exploited in the agricultural sector as in the case of the tephritid fruit flies *Bactrocera oleae* and *Ceratitis capitata.* In the case of the common housefly (*Musca domestica*) the old sticky fly paper has been making somewhat of a come-back in the retail sector and is perceived by the end user as being reasonably effective. It must be one of the earliest forms of mass trapping in urban Entomology but was thought unsightly and fell from favour as fast knock-down insecticides were developed. However, widespread unease about the use of insecticides in the home is making consumers turn once again to sticky papers as a form of control for *M. domestica*. The launch of traps of novel design based on the use of non drying adhesives coupled with powerful attractants for this species cannot be far away.

Mating Disruption

Mating disruption has only been achieved to date using the sex pheromones of Lepidoptera. This technique is becoming well established in the agricultural sector, where the moth pest in question is the key pest, is not dispersive or migratory, and is difficult to control by conventional means. The only opportunity of any commercial significance in the built environment is that of stored product moths (*Ephestia* spp and *Plodia interpunctella*). There is evidence that mating disruption can be achieved in these species using the main component of their sex pheromone (Prevett *et al.*, 1989) but to date no commercial product has been launched. The technology to produce a commercial product exists already; pheromone synthesis, controlled release formulations and application techniques. The reluctance to commercialize the technology however, has more to do with the enormous educational component of such a development, customer acceptance and registration requirements than any technical problem. Such a product would, under the legislation existing currently in most developed countries, require some degree of registration and this could be an issue which could delay the development of such technology unless an enlightened attitude is taken by registration authorities. This has been the case with the agricultural applications of this technique in the USA and a number of European countries (Ridgway, *et al.*, 1992).

Lure and Kill

Of all the roles for pheromones in future pest control practice in the built environment, their role in Lure and Kill must be the most promising. Several convergent trends are moving in their favour: insecticides which work predominantly in the vapour phase are becoming increasingly less acceptable; total surface coverage with residual insecticides is becoming unacceptable; there is a trend towards decreasing the total amount of insecticides being used for urban pest control. All these factors are leading the insecticide manufacturers to change their strategy from one of propelling the insecticide to the insect to one of bringing the insect to the insecticide. In this way, the insecticide need not be volatile, it need only be used in a restricted area and it need only be used in small amounts. Several options exist for the role of pheromones in this context:

(a) As tank-mixers.
Pheromones can be formulated in sprayable controlled release micro-capsules or micro-beads. These in turn can be tank-mixed with contact insecticides and the mixture then sprayed onto limited surface areas. If the pheromone attracts the insect in sufficient numbers to the insecticide-sprayed surface then the level of control should be at least equal to a total insecticide cover-spray. A number of sprayable housefly insecticides currently sold in the animal rearing house market contain Z-9-tricosene, the sex pheromone of *Musca domestica,* and it has given a good measure of improved kill to the insecticide with which it is mixed.

(a) As attractants in insecticide granules.
In this option the insecticide is mixed with the pheromone and formulated in the form of a granule. With the insecticide thus confined to the granule, and reliance upon the attractant to bring the insect to the insecticide, all the advantages described earlier are derived. The scatter baits used for housefly control in animal rearing houses again reflect the successful use of the housefly sex pheromone in a lure and kill granule option.

(c) As attractants in bait stations and target devices.
In this option the insecticide is formulated with an attractant and the mixture is placed either in a device which allows only the target insect to get to the insecticide, eg cockroach bait stations, or incorporated into a visual landing site for flying insect pests, eg target devices for houseflies which contain a contact insecticide plus visual and olfactory attractants. As was stated earlier, the aggregation pheromones for cockroaches have still to be characterised in most cases and therefore the attractants used to date have been mostly volatile substances associated with their preferred foods. A bait station product for *Periplaneta americana* based on a combination of the insecticide Propoxur and the sex pheromone of that species, periplanone-B, was launched in the early eighties (Bell, *et al.*, 1986) but it did not achieve widescale use since the pheromone attracted the males only. As the aggregation pheromones of cockroaches are characterized, the scope for developing many more lure and kill products will increase significantly. Similarly, target devices for *Musca domestica* which consist of cardboard surfaces treated with a mixture of a contact insecticide and the sex pheromone of *M. domestica* have been launched on the retail markets in continental Europe but it is too early to say yet whether they will find widescale acceptance. Preliminary evidence would suggest that they will require even more attractive powers than they currently have if they are to be successfully developed.

The success of lure and kill as a strategy for insect pest control in the built environment will depend largely on the power and the reliability of the attractant systems employed. Pheromones will undoubtedly play a role in such developments but other semiochemicals such as food odours, oviposition attractants together with visual and auditory cues may also have to be incorporated in order to arrive at the degree of attraction efficiency required for successful insect control.

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