URBAN PEST MANAGEMENT

An Environmental Perspective

Edited by Partho Dhang

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Urban Pest Management: An Environmental Perspective

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Partho Dhang
15 March 2011
Manila, Philippines

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Introduction

PARTHO DHANG

Summary

The resettlement of humans on earth has never taken place as rapidly as it is doing now. As little as 1% of the earth's total land mass is used as urban centres (cities) and these cities, astoundingly, carry 50% of the world's population. Urban centres are extremely well suited to a group of insects which have associated their lives with humans and their activities. These urban insects cause pain, annoyance, emotional distress, disability and damage as a result of bites, stings and physical reactions, in addition to a plethora of diseases and other damage. The purpose of this book is to highlight approaches to urban pest prevention and control by the judicious use of pesticides. The increasing use of pesticides requires that the adverse effects arising from their use do not outweigh the risks posed by pests. Long-term pesticide use has been documented to cause adverse health effects in humans, and particularly in children. The book discusses key strategies for minimizing pesticide use without compromising quality of pest control; foremost among these are strict adherence to the principles of integrated pest management (IPM), the adoption of novel technologies and enacting effective regulations.

Urban Entomology

The subject of urban entomology is a relatively lesser known subject. It only comes into focus when there are outbreaks of vector-borne diseases and, at times, through some spectacular occurrences of insect pests. It is not uncommon to read reports of unsuspected insects being found inside food packages, or with cleaned laundry. In fact, urban areas are extremely well suited for a group of insects which have associated their lives with humans and their activities. These urban insects cause pain, annoyance, disfigurement, emotional distress, disability and damage as a result of bites, stings, feeding on humans and physical reactions to these processes, in addition to a plethora of diseases and other damage. In spite of these negative effects on humans, urban entomology – and the related subject of urban pest management – hardly find a place in most university curricula or in federal statutes. Furthermore, at times, the various components of this subject are governed by different federal bodies which are independent of each other. This further hinders collective data collection, implementation of guidelines, coherent decision making and overall governance.

Recently, however, it has become common to find new insects encroaching into urban domain, with new groups of these being detected and remedies sought. It is now time for the subject of urban pest management to include all insects that invade, thrive in and regularly come into contact with humans in urban areas. It is appropriate, as well, that the subject of urban entomology, though relatively new, is now growing at a faster pace than before. This growth is to keep up with the pace of understanding of the importance of pests, which has taken a new significance. It is also timely as a result of the (relatively) recent shift of human focus towards urban living, as shown by the shifting of an increased majority of the world's population in both developed and developing countries to man-made environments such as cities (Povolný, 1971). Human population growth and resettlement in cities can be summed up by quoting Friedman (2009), who wrote 'in 1800, London was the world's largest city with 1 million people. By 1960, there were 111 cities with more than 1 million people. By 1995, there were 280 and today there are 300. The number of megacities with 10 million people has climbed from 5 in 1975 to 14 in 1995 and is expected to reach 26 by 2015'.

Cities too are growing to keep up with human migration into them. Rapid urbanization through a dramatic expansion of urban sprawl is growing into the natural habitats of pests (Bonnefoy *et al*., 2008). Although half of the world's population lives in cities, the total amount of land dedicated to urban use is only 1% of the total land surface (WHO, 1997). Additionally, urban centres whether concentrated in high-rise buildings or spread over large shanty-town or suburban areas, allow concentrations of people, and their activities and consumption produce greater levels of waste and pollution. These wastes add up to the countless man-made niches and microhabitats which, together, make urban areas susceptible to pest invasion and long-term harbourage.

Insects as Urban Pests

The history of human interaction with insects goes back to the beginning of civilization. Insects, at an estimated number of 10 quintillion, outnumber and outweigh every form of multicellular life form on earth (Berenbaum, 1997). Their confrontation with humans is inevitable as humans exploit the planet for food, shelter and resources. Moreover, encounters in places such as urban areas or cities are more serious, as many of the insects involved are known to injure or disable human lives and damage property, as well as sharing human resources. Thus, it is not uncommon for the majority of people to make efforts to minimize their interaction with the insect world. Homes are sealed, sprayed and kept clean; bodies are bathed, hair shampooed, clothing washed in order to distance humans from insects as much as possible (Berenbaum, 1997). Culturally, these activities have shaped human life so much that, in some societies, discussing insects in public has become a taboo.

From the perspective of urban living, the majority of people mistakenly consider insects to be merely a nuisance. It is also imperative to mention that insects have literally plagued humanity with death and destruction in the past. Ana Campos, in Chapter 2, has chosen Brazil, an emerging economy and a rapidly growing country, to emphasize how pests remain a socio-economic concern by causing disabilities and fatalities.

Pests associated with human blood

It is notable that representatives of about half a dozen orders of insects use humans as sources of food (Berenbaum, 1995). Direct blood feeders, such as mosquitoes and bed bugs, rank top in the group of insects causing intentional injury. Injuries caused by feeding could be considered insignificant when compared with the indirect effect of this feeding in transmitting fatal diseases. Of all the insects that transmit diseases, mosquitoes, by far, represent the greatest threat to humans, although, as Partho Dhang and Robert Kunst discuss in Chapter 3, there is irony behind the amount of attention being given to mosquitoes, the majority of which prefer not to feed on human blood. Most mosquito bites on humans are probably a consequence of the easy availability and abundance of humans, signifying possible anthropocentric reasons for mosquitoes having become a public pest.

Among the blood feeders, mosquitoes are commonest in the tropics, while bed bugs are common in both the tropics and in temperate areas. Bed bugs have been the most persistent pests of humans throughout recorded history. Their nocturnal, cryptic behaviour and habit of sheltering in places where humans find comfort have made them an important nuisance pest around the world. In addition, bed bugs are known to naturally carry 28 human pathogens, even though these have never been proven to be transmitted by bed bugs directly (CIEH, 2008). Apart from direct bites by bed bugs, common airborne allergens from these insects may produce bronchial asthma (CIEH, 2008). In Chapter 4, Changlu Wang and Richard Cooper examine the re-emergence of bed bugs in parts of developed countries, and discuss the need for methods of continuous surveillance and education in checking the spread of these pests.

Another group of insects that feed on human blood as ectoparasites are human lice, fleas and ticks, which are included in the list of blood feeders causing injuries and possible diseases. Ticks are known to transmit Lyme disease, tick-borne encephalitis and also tick paralysis (CIEH, 2008). Similarly, fleas are associated with plague, and lice are associated with typhus. Outbreaks of these diseases are not frequent, but their presence in natural reservoirs in certain parts of the world does make the human population in nearby cities vulnerable.

Pests inflicting injury

Envenomation by bees, ants and wasps is another source of injury to humans which, at times, can be fatal. Insect venom is considered to be a leading cause of human mortality through direct injury by arthropods, and the USA accounts for half of all venom-related deaths (Berenbaum, 1995). However, almost all of these encounters are the result of accidental infringement by humans on insect territory, and the use of venom by the insects is a self-defence reaction (Berenbaum, 1997).

Pests associated with allergens, contamination and phobias

A number of insects are less conspicuous in causing human fatalities, but cause indirect injuries by being a source of allergens, food contamination and entomophobic reactions. Although allergens and food contamination can be avoided easily, serious entomophobia in humans can elicit related avoidance behaviours, not only in regard to the insect itself but also to the areas, or objects, where the insect was spotted; these cases can need medical treatment. Cockroaches and dust mites are the major sources of house allergens for humans, and these allergens can trigger asthma in people who are allergic to insect body parts. In Chapter 6, Faith Oi describes cockroach allergens as a major pollutant for children in schools.

Pests of stored products

There is a relatively inconspicuous group of insects that humans encounter in stored products. Stored items such as food, clothing, furnishings, artefacts and books are continuously attacked by this group of insects, which can cause significant amounts of monetary – and at times emotional – damage. Even though these insects have relatively less impact on household goods, their significance is manifested strongly in commercial sectors.

Pests of buildings and structures

Insect pests of buildings and other structures are notable for using parts of human dwellings as food and shelter. Termites and powder post beetles exploit wood used in construction as well as furnishing as a potential food source. In tropical cities, damage by termites to property can be very serious. In the USA alone, termites are estimated to cause more than one billion US dollars of annual damage to properties, and the figure could be similar in other countries, particularly in the tropics and subtropics. As urban cities encroach into agricultural land and prime ecosystems, almost all of the structures built have a fair chance of being attacked by subterranean termites. Ants living in soil also have become a major structural pest in recent times. Urban homes with rich landscaping and sources of shelter have made them attractive to ants, which, while they do not cause significant damage, do cause annoyance. However, certain species of ants have been reported to cause damage to stored products, and even to computers and other electrical appliances – where the damage can result in short circuits and the choking of switching mechanisms.

Pest Control

The need for pest control in urban areas has come from a common realization that pests represent unhygienic conditions and can inflict damage. It also comes from the fact that pests can become vectors and carriers of a number of human diseases which are easily transmitted by the pests in the presence of a concentrated human population. The prevalence and migration of pests have further increased as a result of the pace of transportation of both humans and goods in today's world. The case of the German cockroach possibly illustrates this phenomenon. Once thought to have originated from Africa, this cockroach is now a cosmopolitan pest because of transportation and the availability of conducive indoor environments. Similarly, the Asian tiger mosquito (now a pest in many parts of the world) and the Formosan termite (a common pest in the southern USA) are believed to have spread from Asia.

The history of insect pest control goes back as early as recorded human civilization. Ancient societies used religion, magic and natural products to keep them free from insect pests. In contrast, the discovery of synthetic pesticides started the era of modern pest control. The journal *International Pest Control* (2009) reported that termite control, as the largest segment in the global pest control industry, is worth US$8000 million. This indicates the seriousness of pest control in modern world. However, the era of synthetic chemicals is challenged by the development of resistance in insects. Houseflies, mosquitoes and German cockroaches were the earliest known pests with resistance. Thus, reliance on pesticides became a failed strategy, and together with discovery of the harmful effects of pesticides, a need for new methods was felt.

Even though it is not yet established that household pesticides can pose a serious threat to urban occupants in general, their long-term effect on children and pregnant women are clearly evident. Partho Dhang, in Chapter 1, reviews the subject of insecticides and human health, and concludes that while acute poisoning from pesticide exposure can be treated symptomatically, the effects from long-term exposure remain a concern. As misuse and overuse of pesticides by homeowners and in commercial applications are becoming much too common, the exposure to humans to pesticides has become a grave concern. Faith Oi, in Chapter 6, integrates both the dimensions of pest occurrence and pesticide application to describe the challenges in developing a pest management system particularly for a vulnerable population – that of schoolchildren.

Integrated Pest Management

Integrated pest management (IPM) has been developed to provide the most acceptable solution to pest problems. IPM is defined as the selection, integration and implementation of pest control based on predicted economic, ecological and sociological consequences (Olkowski *et al*., 1991). Though the concept of IPM was developed for agriculture, it is very suitable for urban pest control as well. The practice of IPM is as dynamic as its definition, and the technique continues to incorporate new knowledge and technologies in the field of insect pest management. Successful outcome-driven IPM programmes emphasize management over eradication, and reduce the frequency of insecticide application by using other methods of intervention (Robinson, 1993).

IPM employs human judgement in pest management; it is a method in which inspection, monitoring, and physical and cultural methods play greater roles than chemical control. IPM also uses the methodology of testing human tolerance to design and implement programmes. Attempts were made in the USA to determine the perceived levels of infestation that were intolerable and which would therefore warrant treatment (Boase, 2009); this author uses various references to show that there is an acceptable level of tolerance for pests among residents, and that this differs between cities. Boase (2009) further quoted other observations that in Malaysia, 37% of homeowners would not take any action until ant numbers exceeded 50 at any one sighting, and that in California, an average of 7.7 bites per night was considered to be only a mild problem. A certain degree of pest tolerance allows a minimum acceptable level of control, which is useful in the practice of IPM.

A sustainable approach for future pest control is being realized through passive methods, such as improved designs in construction and in the sanitation of cities and housing. However, suitable conditions for pests will continue to exist, although through improvement in construction methods, their contact with humans can be minimized. In Chapter 5, Naresh Duggal provides a case study on the county of Santa Clara in California, which adopted an IPM ordinance with a primary focus on controlling pest populations by managing elements of the environment and overcoming psychological and institutional barriers through a targeted programme administered by digital governance. The chapter substantiates the advantages of digital management and strict governance of IPM which, in this case, eventually resulted in a 95% reduction in the total number of pesticides used, the number of applications using pesticides, the total pesticide volume and toxic exposure to pesticides. The 5 year performance data also recorded a steady decline in service-related complaints.

The termite management industry has undergone dramatic developments in recent times with the withdrawal of long-lasting soil insecticides from the market. This has forced a welcome shift from a strategy of intensive chemical application to an integrated method. In Chapter 8, Xing Ping Hu describes how newer termiticides with a unique mode of action are modifying the application methods used and helping termite management fit into an IPM programme. In Chapter 9, Brian Forschler discusses a successful demonstration of an integrated termite management (ITM) programme based on continuous inspection and intervention, which achieved 98% termite elimination in addition to a reduction in insecticide use. This programme significantly differed from all other methods in that the property owners had responsibilities related to termite management. The involvement of a customer or client in this way helps to mitigate the situation as regards a number of critical points, which eventually prevents pest infestation. This is a rational shift from the conventional methodology of pest control, and is sustainable and futuristic.

One critical area in which IPM is challenged is in multi-storied high-rise blocks, which are a common feature in urban landscapes. These blocks provide ideal conditions for pest outbreaks and are often difficult to treat owing to a multitude of problems. In Chapter 7, Sam Bryks mentions using an 'action threshold' or 'aesthetic injury level' as an early warning indicator and as a useful strategy in designing an IPM programme for multi-storied low-income structures. The chapter also points out that pest control services in low-income housing are often based on low-bid contracts. Moreover, pest control services in low-income housing are commonly managed either on complaint of severe infestation or by a reactive total building treatment, and this scenario prevents implementation of the very basic elements of an IPM programme. Furthermore, most cities in fast-developing countries have decided on the option of housing their public vertically to keep costs down – and although these structures are designed for the middle and upper classes as they are located in prime city spots, they face a commonality when it comes to pest control. The major hurdle in these settings is that not all areas are accessible to inspection, monitoring and the conducting of treatment, so pests are allowed to breed unchecked.

Adopting New Technologies

Incentives for using broad-spectrum toxic chemicals, especially those belonging to older generation pesticides, are high. They bring immediate kill, are persistent and are cheap to procure. So a conceptual change in attitudes to undertaking pest control as needed under IPM should be sufficiently supported by the availability of newer technologies. These must be designed rationally based on an understanding of the dynamics of pest behaviour, in addition to being precise and specific. A few relevant technologies are the development of growth regulators, baits, pheromones, natural products and encapsulated formulations. Each of these technologies is increasingly becoming popular as a pest control method.

Insect growth regulators (IGRs)

The concept of urban pest management has brought about the emergence of IGRs as a popular alternative to broad-spectrum conventional insecticides. This group of insecticides is relatively safe and is often used at very low concentrations, which still adversely affects target organisms. IGRs are most suitable for use in insect baits for a wide variety of insect pests. They can also be used as sprays – specifically during the growth stages of insects. From the manufacturing point of view, the preparation of IGRs allows direct synthesis based on knowledge of insect biochemistry and physiology. This approach offers considerable savings over following an empirical or random synthesis and screening approach to the discovery of new insecticides.

Bait

The discovery of various analogues and antagonists of IGRs, such as juvenile hormone (JH), ecdysone, chitin synthesis inhibitors and related compounds, has helped to develop bait formulation. Among these, chitin synthesis inhibitors have become more useful in developing bait formulations for urban pests. In Chapter 13, Partho Dhang reviews insect baits that are target specific and allow easy application, resulting in popularity as a safer alternative to conventional sprays. Consequently, baiting technology has gained global acceptance for use against a wide range of pests, such as cockroaches, flies, ants and termites. Baiting has significantly improved and has supported the implementation of IPM. In addition, it has been found useful for cutting down the use of insecticides in urban areas. Steven Broadbent, in Chapter 10, further illustrates the key reasons behind termite baiting systems in Australia, where this method has gained significance as a practical and environmentally responsible choice.

Microencapsulated formulations

Current difficulties in developing and registering new molecules have restricted the availability of products to a limited number for urban pest management. However, the focus has shifted to the discovery of newer formulations that use existing insecticides but have enhanced properties. One such direction is the development of insecticide formulations which can be more effective gram for gram but are safer to both operators and the environment. As the aromatic solvents that are commonly used in regular formulations are increasingly coming under scrutiny, the development of a capsule suspension (CS) has shown potential. A capsule suspension formulation is water based, uses less solvent, is robust, is cost effective to develop and is less toxic than emulsifiable concentrates (Perrin, 2000). A CS formulation can also be formulated as dry powders, which can be used for bait, and as dust or wettable powder.

A formulation containing microcapsules, depending on its design, can provide a number of improvements over a conventional formulation. These are improved residual activity, longer application intervals and reduction of application dosage. Janusz Swietoslawski *et al.*, in Chapter 11, describe the benefits of encapsulation technology and its use not only in developing newer formulations but also in improving older ones. The advantage of encapsulation is slowly being recognized worldwide by the pest control industry, and the number of patents granted for the microencapsulated insecticide products is becoming increasingly important as proof of the orderly progression of this technology.

Pheromones

Pheromones have been used increasingly for monitoring, mass trapping and the disruption of mating of pests. They are increasingly playing an important role in decision-making methods involved in designing IPM programmes. This novel technology has been significantly refined in both science and delivery and, with continued research, will no doubt be a major player in bio-rational pest control strategies for a large group of pests. In the urban pest control industry, pheromones have predominantly been used for the management of pests of stored foods, but their use in trapping cockroaches and bed bugs is becoming increasingly popular. In Chapter 12, Alain VanRyckeghem provides details of a number of areas where pheromones are useful, while also identifying the future use of alarm pheromones for pests.

Natural products

The search for natural products as future pesticides has always been an attractive proposition. Natural products of botanical origin such as nicotine, rotenone and azadirachtin are known to have excellent insecticidal properties, but have not been exploited commercially for various reasons. It is also recognized that plant defence chemistry has probably evolved more to discourage herbivory rather than to kill the herbivore concerned outright (Isman and Akhtar, 2007). This kind of finding could reduce the chances of discovering botanical products with bioactivity in line with synthetic products. A number of plant substances, mostly essential oils, have been considered for use as repellents, but apart from these, little commercial success has ensued for natural products, although it is strongly felt that these products will continue to provide newer templates for the synthesis of novel bioactive compounds.

The discovery of the soil actinomycete, *Saccharopolyspora spinosa*, and its insecticidal metabolite spinosad, is one notable exception. Spinosad is a naturally derived bio-rational insecticide which shows potency comparable to that of the chemical insecticide temephos against mosquitoes (Bond *et al.*, 2004). Spinosad and the bacterial insecticide *Bacillus thuringiensis* will probably remain the most dominant natural products in the market.

Regulation

The methods and tools available for urban pest management will not see any dramatic changes in the near future. However, the demand for pesticides will increase significantly to keep pace with pest outbreaks. Countries around the world have strengthened their regulatory statutes with regards to use of pesticides, but visible gaps remain. Kevin Sweeney, in Chapter 14, recognizes the need for rigorous registration and compliance programmes, and the requirement for expanding the use of IPM at an international level. The chapter discusses the future regulatory landscape for urban pest management as it will be mandated to include new policies and programmes to reduce exposure to pesticides, manage resistance, reduce environmental impacts and meet public demand for alternatives to conventional practices. Practitioners and professionals will be expected to provide more sophisticated services and embrace data management practices for the purpose of recording pesticide applications and pest management activities.

The implementation of guidelines and policies at an international level needs to be routed downwards to individual agencies at the national level. It is, therefore, important that there is an effective local regulatory presence to ensure an acceptable level of compliance of all pest control activity with regard to human health and the environment. The checking and monitoring of non-compliance and malpractices of practitioners are an integral part of effective regulation. In Chapter 15, Steven Dwinell identifies a number of key elements of effective regulation, including training, regularity of inspection and the power to take disciplinary action as foremost in safeguarding humans and the environment.

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1 Insecticides as Urban Pollutants

PARTHO DHANG

Summary

Increased urbanization has made pest infestation a common occurrence in cities around the world. This has increased the use of pesticides and consequently the chances of mass human exposure to these pesticides. Most pesticides are considered toxic to humans as they are known to produce a wide range of harmful effects on human health, such as nausea and vomiting, skin ailments, impaired immune functions, birth defects, neurotoxicity and cancer. Although acute poisoning from pesticide exposure can be treated symptomatically, the effects from long-term exposure remain a grave concern.

Introduction

Pesticides have dramatically changed human lives in helping increase food production and lower the risks of vector-borne diseases. These have mediated trade and commerce, and helped to build economies and human settlements in inhospitable regions of the world. However, awareness of the adverse effects of pesticides on the environment and on human health has turned public opinion against their indiscriminate use. This change in thinking followed the large-scale use of pesticides in agriculture nearly a decade after the Second World War. The book *Silent Spring* by Rachel Carson (1962) stirred public opinion on the subject, and since then the use of pesticides has been subjected to closer scrutiny.

Increased urbanization and occupation of natural habitats have made pest occurrence a common concern in cities around the world. This phenomenon eventually increased the use of pesticides. Consequently, the chances of mass human exposure to pesticides have also increased in recent years. Studies have demonstrated that the home environment throughout the USA is often

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contaminated with pesticides (Eskenazi *et al.*, 1999). According to a recent survey, 75% of households in the USA used at least one pesticide product indoors during the past year; the products used most often are insecticides and disinfectants (US EPA, 2001).The survey also suggested that 80% of exposure to pesticides occurs indoors and that measurable levels of up to a dozen pesticides have been found in the air inside homes in the USA (US EPA, 2006).

A careful interpretation is however needed, to determine the role of pesticides as urban or indoor pollutants. The detection of pesticides or their derivatives could be a result of pest control activity far from the area of evaluation. Most pesticides volatilize and are transformed by solar irradiation, the exceptions to which are persistent organochlorine compounds (Plimmer, 1998). Atmospheric transport and deposition of the compounds or their transformed derivatives to water and terrestrial surfaces far from the area of application are known to occur. In some cases, the transformed derivatives may be more toxic than the parent compounds (Plimmer and Johnson, 1991). These findings demonstrate the global nature of pesticide pollution arising from their large-scale use.

Urban pesticides can be divided into four main classes: insecticides, herbicides, rodenticides and fungicides. This chapter attempts to present a selective review on the role of insecticides as possible urban pollutants, because these are the most identifiable pesticide type associated with indoor application. The chapter also reviews available data on pesticide poisoning, their effects on health and their toxicity. In addition, the chapter presents possible pathways by which the unsuspecting urban population is exposed to insecticides, while addressing the need to reduce their use appropriately and safeguard human health.

Urban Pests

Urban household insect pests are common all over the world, irrespective of geography. They include cockroaches, flies, mosquitoes, bed bugs, ticks, fleas, ants and termites. These pests thrive in dark, warm and moist conditions in houses and other buildings, particularly in places where there is food, heat and poor sanitation. Moreover, a number of human activities and habits, such as living in homes with insufficient ventilation, creating clutter, poor lighting, poor temperature control, poor recycling of rubbish, improper composting methods, poor water storage and the use of wood in construction, attract pests. Community and public areas in cities, such as parks, recreation centres, wastelands, rivers, canals, sewerage canals, storm-water drains, dump sites, flea markets and recycling plants, often serve as breeding grounds and harbourage areas for pests too.

Urban pests are among the prime sources of many human illnesses and injuries: they are the leading causes of illnesses resulting from allergies, bites, food contamination and phobias. In addition, they harm humans by causing significant damage to properties and structures. Because of the human need to eliminate pests, the pest control industry has flourished and generates millions of dollars annually. The seriousness of this business has resulted in countries needing to create regulatory bodies to ensure the safe and appropriate use of pesticides.

Pesticides and Health

Data on the effects of pesticides on human health are mostly generated from occupational settings and dietary exposure. However, very limited data are available on the health effects of indoor exposure to various pest control activities. Seemingly, indoor application of pesticides – which themselves are regulated by a complex risk assessment before and after they are put on the market – does not pose a high level of risk if the application of the product and the management of the application take place according to proper and adequate procedures (Maroni *et al*., 2008). However, grave concerns remain over persistent and repeated exposure to chemicals over a lifetime, in particular over the risk to the paediatric population (Reigart, 1995).

Most pesticides are considered toxic to humans as they are known to cause a wide range of illnesses. Examples of these are nausea and vomiting, skin ailments, impaired immune function, birth defects, neurotoxicity and cancer (WHO, 1990). Although acute poisoning from pesticide exposure can be treated symptomatically, effects from long-term exposure remain a grave concern. Pesticides have been linked to adverse health effects in children (Davis *et al*., 1992) that include cancer, immunological disorders, reproductive anomalies (Muto *et al*., 1992), neurological disorders (Baum and Shannon, 1995; Zahm, 1999) and childhood leukaemia (Infante-Rivard *et al*., 1999). Children are at higher risk because their metabolic processes are not fully developed, making them less able to detoxify chemicals (Maroni *et al*., 2008). In fact, exposure to pesticides during pregnancy can have potential adverse effects on fetal growth and on neurodevelopment in children (Landrigan *et al*., 1999). Such exposure in fetal life can also contribute to the development of a number of diseases in adult life, including cancer (Birnbaum and Fenton, 2003).

Children can be exposed to pesticides *in utero* or during childhood through their parents' work, through domestic use, or from the general environment, such as via residues in food, water, air and soil. It is not clear which sources of pesticide exposure are most important for children. Some researchers have considered household pesticide exposure through usage as the major route of exposure (Grossman, 1995; Bradman and Whyatt, 2005). This agrees with the findings of studies conducted in the USA and the UK, which reported high rates of household use and storage of pesticides (Adgate *et al*., 2000; Grey *et al*., 2006); the incidents found in these two countries could be prevalent elsewhere as well, but this has yet to be reported in the literature.

Epidemiological evidence suggests a relationship between certain children's ailments and chemicals (Maroni *et al*., 2008). Data from a structured telephone questionnaire revealed that domestic use of insecticides (used at home on pets or garden crops), herbicides and fungicides during pregnancy strongly supported the etiology of childhood haematopoietic malignancies (Rudant *et al.*, 2005). A more conclusive review and meta-analysis revealed positive associations between exposure to residential pesticides in pregnancy and childhood leukaemia, with the strongest association observed for insecticides (Turner *et al.*, 2010); this study was based on a comprehensive search of MEDLINE and other electronic databases from 1950 to 2009.

The World Health Organization (WHO) has stated that over 30% of the global burden of disease in children could be attributed to environmental factors, including pesticides (WHO, 2006). Children are highly vulnerable to pesticides owing to their proximity to surfaces and the ground. Because of their play close to the ground, their hand-to-mouth behaviour and their unique dietary patterns, children absorb more pesticides from their environment than adults (Landrigan *et al.*, 1999). In addition, inner-city children spend most of their time indoors, which allows greater exposure to household pesticides (Landrigan *et al.*, 1999). Compounding this latter fact is the decreased ability of children to detoxify and excrete pesticides. Their rapid growth and development, which includes rapid differentiation of their organ systems, also makes them very vulnerable to pesticides (Landrigan *et al.*, 1999).

Insecticides and Toxicity

The quantity of insecticide usage in urban areas could serve as an indicator of severity of pesticide pollution. In the USA, an estimated 36 million kg of pesticide active ingredient is used for home and garden use, and insecticides form 18% of this (Lewis, 2007). In 1996, the domestic consumption of pesticide was estimated globally as a total of 10×10^8 aerosols, 290×10^8 coils, 0.8×10^8 vaporizers and 240×10^8 vaporizing mats which were used against household pests (Krieger *et al.*, 2003). The active ingredients that constitute household insecticide products are the same as those used in agriculture. These belong to categories such as organophosphates, carbamates, synthetic pyrethroids, neonicotinoids and a number of insect growth regulators (IGRs). Organophosphates possibly form the most used active ingredient of household chemicals in a global context, although these are slowly being replaced by pyrethroids and a new generation of active ingredients.

WHO's International Agency for Research on Cancer (IARC, 1991) has classified most of the common active ingredients used in urban pest control in Group 3 category of carcinogenic risk (agents not classifiable as carcinogenic to people). However, one of the organophosphates, namely dichlorvos, has been placed in Group 2B (an agent possibly carcinogenic to people). Though the toxicity of each insecticide may vary from that of another, its usage pattern can be a serious cause of concern. The method and area of usage could make products risky or safe as these determine the exposure. A review of some of the insecticides in common use in urban households follows.

Chlorpyrifos

In urban areas, chlorpyrifos is commonly applied around skirting boards (baseboards) and injected into cracks and crevices to control termites and cockroaches, as well as being used to control fleas on pets. In most Asian countries, this insecticide is commonly used for termite protection as a barrier chemical. Occasionally, it is applied directly on to wooden surfaces against wood borers and dry wood termites (Parthiban and David, 2007). It is estimated that organophosphates, including chlorpyrifos, account for up to 50% of all insecticides applied worldwide (Casida and Quistad, 2004). A national non-occupational pesticide exposure study found that chlorpyrifos is one of the pesticides most widely detected in American homes; in Jacksonville, Florida, chlorpyrifos residues were found in air samples in 83–97% of homes; and in Massachusetts, chlorpyrifos residues were found in 30–40% of homes (Whitmore *et al.*, 1994). In a recent survey of pest control operators in the Philippines, chlorpyrifos and dichlorvos remained the two most used insecticides for treating household pests, including termites (Dhang, 2008, unpublished). Neither compound is presently in use in neighbouring countries such as Singapore and Malaysia (Lee 2008, personal communication) but they are both in widespread use in India and the Middle East.

Persistent residues and deposits after an application of chlorpyrifos can remain on household objects such as rugs, furniture, stuffed toys and other absorbent surfaces. Experimental data suggest, for example, that chlorpyrifos may be a developmental neurotoxin and that exposure *in utero* may cause biochemical and functional aberrations in fetal neurons, as well as deficits in the number of neurons (Landrigan *et al.*, 1999). Other animal studies have revealed similar findings: long-term neurochemical and behavioural deficits in offspring (Chanda and Pope, 1996); neurotoxicity (Song *et al.*, 1997), cellular deficits in developing brain that contributed to behavioural abnormalities (Campbell *et al.*, 1997); inhibition of DNA synthesis in *in vitro* culture of fetal rat neurons; inhibition of cell replication and acceleration in neurotoxic apoptotosis (Slotkin, 1999). Concerns over its toxicity made the US Environmental Protection Agency (US EPA) cancel and phase out nearly all residential usage of chlorpyrifos in the year 2000.

Dichlorvos

Dichlorvos (DDVP) is extensively used in developing countries against household pests and is available in concentrates, strips and aerosols. Its usage has been restricted in most developed countries because of its high acute toxicity. The oral LD_{50} in rats is between 56 and 108 mg/kg. As already stated, IARC classifies dichlorvos in Group 2B (possibly carcinogenic to humans) based on what it considers to be sufficient evidence in animals, although it has inadequate evidence in the case of humans. The dermal toxicity of the insecticide is similar to its oral toxicity, and dermal exposure is a cause for concern. Most human poisonings have resulted from the splashing of concentrated formulations on to the skin. Prompt removal has resulted in symptoms of intoxication, but a full recovery is achieved after treatment.

Dichlorvos vaporizes quickly and a spray can possibly introduce a many times greater concentration of the insecticide in the air indoors. A concentration of 100 $\mu g/m^3$ or greater has been recorded in a room with diclorvos strips alone (Lewis and Lee, 1976). Cholinesterase inhibition has been reported from exposure by inhalation after the use of dichlorvos in non-ventilated and poorly ventilated areas (FAO/UNEP, 1992). A report of recurrent asthma triggered by a single exposure to dichlorvos gave rise to speculation that direct toxicity to the cells lining the airways was the cause (Leiss and Savitz, 1995).

Propoxur

Propoxur is a methyl carbamate insecticide that is commonly used as a household insecticide. It is sold both as a consumer product and a professional product. Propoxur is available as a concentrate and an aerosol for the control of cockroaches and flies. As it is a carbamate it could pose serious health risks if used indoors. In a study on infants born in an agricultural community in the Philippines, the prevalence of a common acute myelogenous leukaemia (AML) translocation in cord blood samples was found to be about twofold higher among those with detectable meconium levels of propoxur (Raimondi *et al.*, 1999; Lafiura *et al.*, 2007).

Pyrethroids

Pyrethroids have high insecticidal potency but low mammalian toxicity, and were found to be in widespread use after restrictions were imposed on the use of organophosphates and carbamates. Acute poisoning from pyrethroids is characterized by dizziness, headaches, nausea, muscular fasciculation, convulsive attacks and coma (Chen, 1991). Even though acute and chronic toxicity are considered low, reports have revealed neurological and respiratory reactivity to certain pyrethroids (Vijverberg and vanden Bercken, 1990; Cantalamessa, 1993). Pyrethroids may also have oestrogenic and anti-progestogenic activities (Garey and Wolff, 1998; Go *et al.*, 1999).

Elevated exposures of children to pyrethroids could be attributed to their use in homes. The use of pyrethroid insecticides in the household was found to be a significant predictor of urinary pyrethroid metabolite levels in children in a recent longitudinal study (Lu *et al.*, 2006). Earlier, a similar association was found between parent's self-reported use of pyrethroids in the residential environment and elevated pyrethroid metabolites found in their children's urine (Bravo, 2006).

Fipronil

Fipronil is a widely used insecticide for controlling urban pests, including cockroaches, ants, termites, and for flea and tick control in pets. It is formulated for application as baits, sprays, dusts and aerosols. The insecticide acts as a disruptor of the central nervous system in insects by interfering with the GABA (gamma-aminobutyric acid) regulated chloride channel. Of all the GABA receptor-binding pesticides in use, fipronil has the highest specificity for native insect receptors over native mammalian receptors, with 150–2000 fold selectivity (Hainzl *et al*., 1998).

Published data on the acute toxicity of fipronil to humans are scarce. Mohamed *et al*. (2004) reported that among the seven prospectively recorded patients with fipronil poisoning, two had significant central nervous system toxicity with seizures. This was associated with sweating, nausea, vomiting and agitation both in these two and in a few other patients. All patients were essentially asymptomatic within 12 h of fipronil ingestion and were discharged within 4 days of admission. In the same report, fipronil exposure was proven in the patients tested by its detection in the plasma. In rodents, acute fipronil toxicity is characterized by tremors, altered activity or gait, hunched posture, agitation, seizures and mortality at doses greater than 50 mg/kg (US EPA, 1996; WHO, 1997a). Deaths were generally observed within 2 days of dosing, while changes in nervous system function were noted principally 7 h following dosing. At lower dosages, only slight functional neurological changes were observed (US EPA, 1996; WHO, 1997a).

Fipronil is metabolized in mammals to a sulfone compound. Binding assays indicate that the sulfone binds to native human and mouse GABA receptors with around sixfold higher avidity than fipronil. The mouse LD_{50} for fipronil and its sulfone metabolite were found to be 41 and 50 mg/kg, respectively. This value is five times higher than the LD_{50} of α-endosulfan (Hainzl *et al*., 1998).

Imidacloprid

Imidacloprid is a neonicotinoid insecticide which produces neurotoxicity by fully or partially binding to specific areas of the nicotinic acetylcholine receptor. It is popularly used as soil termiticide and in baits for the control of ants, cockroaches and houseflies, as well as in pet products against fleas and ticks.

A dose of approximately 10 mg/kg BW (body weight) of imidacloprid ingested by a 4-year-old child did not show signs of adverse health effects (Maroni *et al*., 2008). However, two fatal imidacloprid-related cases have been reported in the literature (Proença *et al*., 2005).

Imidacloprid and its nitrosoimine metabolite (WAK 3839) have been well studied in rats, mice and dogs. One report noted that in mammals, the primary effects following acute high-dose oral exposure to imidacloprid are mortality, transient cholinergic effects (dizziness, apathy, locomotor effects, laboured breathing) and transient growth retardation (USDA Forest Service, 2005). The same study suggested that exposure to high doses may cause degenerative changes in the testes, thymus, bone marrow and pancreas. Cardiovascular and haematological effects have also been observed at higher doses. The primary effects of longer term, lower dose exposure to imidacloprid are on the liver, thyroid and body weight (a reduction). Low-to-mid dose oral exposures have been associated with reproductive toxicity, developmental retardation and neurobehavioural deficits in rats and rabbits. Imidacloprid is neither carcinogenic in laboratory animals nor mutagenic in standard laboratory assays (USDA Forest Service, 2005).

Method of Exposure

The general human population is exposed to insecticides either from a direct indoor application such as an indoor residual spray from extermination work, and usage from off-the-shelf consumer products such as insect repellents and vaporizers. In addition, applications outside the home for termite control, and the treatment of pets against fleas and ticks, can expose humans to insecticides. Each of these methods of application can contribute to an accumulative exposure to an unsuspecting indoor human population, and the risks of this exposure are not known. Maroni *et al.* (2008) concluded that by not considering multiple routes of exposure in evaluating risk, various regulatory bodies (such as the US EPA) provide a very serious underestimation of the total risk that a family faces from the use of pesticide products in and around the home.

Exposure by indoor application

There is a greater possibility of pesticide exposure to the general public in homes than outside them. A typical pesticide concentration in indoor air and house dust is 10–100 times higher than those found in outdoor air or soil surfaces (Lewis, 2007). House dust is the major reservoir of pesticide residues that may be easily accessible for human exposure in the home environment (Lewis *et al.*, 1994). Homes and buildings with periodic extermination activity can introduce significant concentrations of pesticides indoors. Insecticides sprayed on cracks and crevices, or sprayed around the skirting boards and wall voids leave insecticide residues on surfaces as well as in the air. However the presence of airborne insecticides after an application is dependent on the ventilation of the room during and after the application, and on the rate that the air in the room is changed (Fenske *et al.*, 1990). The leftover airborne chemical(s) may then diffuse into various items kept in the room and subsequently be re-emitted over a long time.

The structural application of insecticides for the control of dry wood termites, subterranean termites and powder post beetles is common in many regions of the world. This application of insecticides on indoor wood can be hazardous to the occupants, who are exposed for a long period. Chlorpyrifos (Parthiban and David, 2007) and pyrethroids such as deltamethrin and permethrin are the most common insecticides used to treat indoor wood in Asia. Semi-volatile insecticides such as chlorpyrifos are absorbed by carpets, stuffed animals and plush furniture, which release vapours into the air over time (Landrigan *et al*., 1999). Furthermore, one study showed that chlorpyrifos residues absorbed on to the surface of plastic toys peaked at a week after application (Gurunathan *et al*., 1998). While chlorpyrifos volatilizes from the treated surfaces, pyrethroids with a low vapour pressure are mostly found in house dust. This indicates that both aerial and dermal routes are means of human exposure to typical indoor pest control activity.

Exposure by outdoor application

The primary source of pests that affect humans and invade their buildings is usually the surrounding landscapes (Shetlar, 2002). Landscape features such as ponds, the presence of mulch, stone and brick works, wooden structures and lighting can all contribute to attracting pests. Even outdoor application of pesticides for controlling termites and other pests on garden plants, as well as for the treatment of turf, could be a principal cause of insecticide exposure indoors. Also, community fogging or ultra-low volume space treatment for mosquito control is another mode by which indoor space can become contaminated.

Insecticide application outdoors can move indoors via circulation of the outdoor air to the inside, through cracks or openings in the foundation walls, or through other points of entry. Air is an important route by which outdoor pesticides can reach indoors. For example, pesticides used in the garden may move indoors and accumulate as house dust. Weather can play a role in exposure as well. Hot weather may increase the volatilization of outdoor termiticides from the soil, resulting in higher concentrations that could move indoors.

Exposure from consumer pesticide products

Homeowners commonly protect themselves from nuisance pests – mostly mosquitoes – by using insecticides sold in consumer stores. In fact, of the pesticides used in homes, inhalation exposures overshadow those from the diet (Landrigan *et al*., 1999). These products contain only a small percentage of the active ingredient (below 1.0% wt/wt) and are sold directly to the public. The annual worldwide consumption of the four major types of residential insecticide products – aerosols, mosquito coils, liquid vaporizers and vaporizing mats – is in the billions of units (Krieger *et al*., 2003).

Mosquito coils

Mosquito coils are a crude and cheap form of repelling mosquitoes. These coils are burned indoors and outdoors in parts of Asia, and to a limited extent in other parts of the world, including the USA. In Indonesia alone, an estimated 7 billion coils are purchased annually (Krieger *et al*., 2003).

The coils are made of wood dust, starch, coconut-shell powder (charcoal), dyes, binders and burning regulators, in addition to a suitable insecticide (Parthiban and David, 2007). The most common active ingredients in coils are pyrethroids. Pyrethroid-based coils are effective against several genera of mosquitoes, including *Aedes*, *Anopheles* and *Mansonia* (Krieger *et al*., 2003). Some mosquito coils contain octachlorodipropyl ether (S-2) as a synergist and pyrethrin and *d*-allethrin as active ingredients (Krieger *et al*., 2003). The degradation of S-2 to bis(chloromethylethyl) ether (BCME) and congeners, including bis(chloromethylmethyl) ether (CMME), during the burning of mosquito coils is of particular health concern (WHO 1998). One of the degradation products, BCME, may be one of the most potent lung carcinogens known (ATSDR, 1989).

Plug-in vaporizers

Electric vaporizers used for mosquito control can cause consumers to be exposed to insecticide over a long period of time. Mosquito vaporizers generally use Type I synthetic pyrethroids as insecticide. These insecticides are heat stable and are used in the treatment of both mats and vaporizers. The insecticides popularly used are allethrin and bioallethrin, *d*-allethrin, *d*-transallethrin and (*S*)-bioallethrin (Sharma, 2001).

Vaporizers could pose risks to newborn babies and children exposed to pyrethroids for long periods. Occupational and experimental studies indicate that pyrethroids can cause clinical, biochemical and neurological changes, and that exposure to these insecticides during organogenesis and early developmental period is very harmful. The neurotoxicity caused by mosquito repellents has aroused concern from the public regarding their use (Sinha *et al*., 2003). In a survey, 11.8% of the people using various types of repellents complained of ill-health effects, and some had required medical treatment. Although symptoms disappeared shortly after withdrawal from exposure, those who do not suffer acute toxicity symptoms but continue to use these repellents for extended periods may suffer from the neurotoxic and immunotoxic effects (Sharma, 2001).

There are a number of research works that are available and show the risks involved in using these repellents in animals. The compound allethrin increased blood–brain barrier (BBB) permeability, suggesting a delayed maturity of the BBB and biochemical changes causing health risks, especially at an early age in life (Gupta *et al*., 1999). In a study on rat pups exposed to pyrethroid-based mosquito repellent (allethrin 3.6% w/v, 8 h/day, through inhalation) during various stages of development, the rats showed significant oxidative stress, increase in lipid peroxidation and decreased antioxidants, glutathione, superoxide dismutase and catalase in various brain areas, such as the cerebellum, corpus striatum, frontal cortex and hippocampus (Sinha *et al*., 2006). This study further reported that the hippocampus was the most affected region and exhibited altered cholinergic functioning in the form of a significant decrease in cholinergic (muscarinic) receptor binding and inhibition of acetylcholinesterase activity. Neurochemical changes were found to accompany a decrease in learning and memory performance in exposed rats – the function governed by the hippocampus. The result suggested that the inhalation of pyrethroid-based repellents during the early developmental period may have an adverse effect on the developing nervous system, causing cholinergic dysfunction leading to learning and memory deficit. Another compound, *d*-transallethrin, was reported to contribute to reproductive dysfunction, development impairment and cancer (Garey and Wolff, 1998).

Repellent lotions and gels

N,N-diethyl-3-methylbenzamide (DEET) and picaridin are the most common insect repellents used in lotions and gels against mosquitoes. For use as topical insect repellents, these two compounds have been evaluated many times for their human health risks. Most of the studies have found no toxicological risks from typical use of these repellents, in both adults and children.

DEET was developed by the US Army in 1946 and, later, in 1957, it was made available for the general public. Over 200 million people use DEET every year and over 8 billion doses have been applied over past years; it is thus believed to be safe. However, with the publication of a recent study on DEET by Corbel *et al*. (2009) a question was raised on its overall safety. Using toxicological, biochemical and electrophysiological techniques, these researchers showed that DEET is not simply a behaviour-modifying chemical, but also inhibits cholinesterase activity in both insect and mammalian neuronal preparations. DEET (if used in combination with other insecticides) has the capacity to strengthen the toxicity of carbamates, a class of insecticides known to block acetylcholinesterase (Corbel *et al*., 2009). This observation could initiate a re-evaluation of DEET for reasons of public safety.

Exposure from household pet treatment

Fleas and ticks are common household pests of pet dogs and cats. All pet products against fleas and ticks contain insecticides, and a large number of insecticides are used in pet products, many of which fall into the category of organophosphates (such as chlorpyrifos, dichlorvos, diazinon, malathion, phosmet and tetrachlorvinphos). The insecticides used include insecticides from other groups too, such as carbamates, pyrethrins, synthetic pyrethroids and, lately, IGRs and neonicotinoids. Pet products are usually available in the form of shampoos, sprays, dips, dusts, collars, spot-ons and pills, and these products can contain a combination of two or more insecticides.

The Centers for Disease Control and Prevention (CDC) in the USA had warned that flea-control shampoos, dips and other pet products containing insecticides may pose risks to consumers (Anon., 1999). On one of its web sites, the US EPA recognizes the importance of human exposure to pesticides through pet products. It declares that all pet pesticide products undergo a dermal assessment for adults and a dermal and oral exposure assessment for children based on conservative assumptions of pet contact and pesticide transfer to persons exposed to the products. The assessment of inhalation from pet pesticide treatments is considered on a case-by-case basis, and EPA scientists have estimated the amount of applied pesticide that can transfer from the animal to the child's skin from hugging or otherwise contacting a treated animal. Based on these estimates, the EPA ensures that children are protected from exposure to pesticide-treated pets. A report put forward by the US National Research Council (US NRC, 1991) similarly acknowledges the fact that each time an animal is treated with flea and tick dip, sublethal human exposure is likely to occur primarily by absorption through skin while handling that animal.

Insecticides in pet products stand a good chance of moving to humans. In their homes, people interact intensively with their dogs and cats through hugging and sharing living space. Most often, pets spend their time living on the floor, the carpet or sofa, where they can pick up insecticide residues and could transfer them to the owners. Particularly vulnerable are toddlers and pregnant women. The US EPA calculates that toddlers exposed to pets treated with certain organophosphate products in one day can exceed the safe exposure level by 500 times more than the limits that have been set (Wallinga and Greer, 2000). The Pesticide Control Program of the New Jersey Department of Environmental Protection conducted a health and safety survey among all licensed pet applicators in New Jersey. The survey concluded that approximately 36% of the respondents indicated that during the 1994 flea season, they experienced at least one of the 17 symptoms associated with insecticide application (Bukowski *et al.*, 1996).

In April 2009, the US EPA issued an advisory concerning spot-on pesticide products for flea and tick control in cats and dogs. The advisory mentioned that the EPA is intensifying its evaluation of these products owing to recent increases in the numbers of reported bad reactions. The reactions range from mild skin irritation to skin burns, seizures and, in some cases, death. In May 2009, the EPA met with registrants of spot-on pet pesticide products to discuss pet incident reports and the EPA's plans for enhanced evaluation of these products. The EPA's evaluation may result in actions such as additional label restrictions or the cancellation of registration to remove certain spot-on products from the market (US FDA, 2009). This advisory clearly implies the indirect risk of these products to human health.

Acute poisoning by accidental exposure

Acute poisoning by accidental exposure to pesticides is common in regions with a high rate of illiteracy. Such poisoning occurs when pesticides are carelessly stored in medicine or soft-drink bottles. Also, accidental exposure occurs because some pesticide bottles have a look that resembles bottles used for pharmaceuticals or food. A daily newspaper (*The Hindu*, 15 March, 2010) reported an incident in which 25 people were hospitalized in southern Vietnam after a shopkeeper accidentally sold a woman rat poison instead of 'curry' (spices) for a family feast. The shopkeeper apparently confused the rat poison with the curry spices because of the similarity in packaging. Both the shopkeeper and the buyer had been unable to read the packaging. As other examples, deltamethrin chalks sold to treat cockroach infestations have been produced and packaged in a similar manner to crayons used by children for colouring and drawing activities, and vaporizers for mosquito control have been designed to resemble toy items. This is another area in which regulatory guidelines for product packaging should be strictly implemented to prevent accidental exposure.

Pesticide Poisoning: How Reliable are the Data?

Thousands of man-made chemicals are commonly used throughout the world, and each year 1000–2000 new chemicals are introduced into the market, but assessing the contributions of toxic exposures to poisoning solely by pesticides in a global context is difficult (WHO, 1997b). However, it is accepted that exposure to pesticides is a major cause of poisoning. The US EPA estimates that 10,000–20,000 physician-diagnosed pesticide poisonings occur each year (Duggal and Siddiqi, 2008). Population-based studies in 17 countries have given an annual incidence rate of unintentional pesticide poisoning of 0.3–18.0 cases per 100,000 people (Jeyaratnam, 1990).

Pesticides are regulated as toxicants, and their chemical nature and patterns of use can result in significant exposure (Maroni *et al.*, 2008). However, it remains unknown how much impairment pesticides can cause to the human population. In a survey in the USA, 76% of the respondents were very concerned or somewhat concerned about using pesticides in and around their homes for the control of insects (Rust, 1999). Approximately 43.8% of these respondents thought that pesticides in general cause cancer. Though fear of the injudicious use of pesticides is grossly unfounded, it cannot be denied that, even if used correctly, pesticides still hold a risk for both humans and the environment. Therefore, a comprehensive technical risk–benefit analysis is required before such pesticides are marketed (Bonnefoy *et al.*, 2008).

To date, no study has compared the risk for human beings of acquiring disease from exposure to urban pests and the risk of pesticide exposure (Bonnefoy *et al.,* 2008). As such, no data exist to substantiate the level of exposure of humans to urban insecticides. Bonnefoy *et al.* (2008) concluded that more research on pesticide use in residential settings should be conducted to quantify the environmental concentration of pesticides in order to assist in the assessment of residual pesticide exposure and risk characterization. The difficulty in this assessment of exposure may lie in the multiplicity of exposure sources.

Conclusion

The urban use of insecticides has increased as a result of a number of non-related factors, such as a reduction in human tolerance to pests, increased awareness of pest-borne diseases, heightened living standards and growing affordability. These factors are in addition to a host of environmental factors, which include increased pest prevalence, frequent pest outbreaks, climate change and habitat destruction. Consequently, human exposure to insecticides has increased. Though it is not yet established that household insecticides can pose a serious threat to urban occupants in general, their long-term effects on children and pregnant women have been clearly evident.

Exposure to pesticides is inevitable, as residues from a pest control operation can be transported by air and water. In addition, pesticides have become part of many household products, such as paints, wall hangings, carpets, furniture and building materials, thereby adding to indoor pollution and unsuspected exposures. Environmental surveys have repeatedly detected pesticide residues both outdoors and indoors, even in the absence of pest control activity. So it is likely that the usage of household insecticides adds to this overall burden. This cumulative exposure, including dietary exposure, of humans could add up to more than all the estimated risks; this is an area not well understood or evaluated.

It is a recognized fact that homeowners and commercial applicators frequently misuse pesticides because of the need to get rid of pests causing human disease and discomfort (Lewis, 2007). In addition, the over-reliance of exterminators and pest control officers on pesticides as a means to combat pests is much too common. Such pesticide use can easily be minimized by training and education. It is recognized that public information and education are fundamental to efficient and successful pest management, with respect to both preventive and control measures (Maroni *et al.*, 2008). Thus, public information is not only a basic need, but is also an economically sound strategy, because it contributes considerably to preventing pest infestations through private action (Maroni *et al.*, 2008). The reduction of pests can invariably reduce the need for pesticide use, and, consequently, could minimize the exposure of the human population to pesticides.

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2 Emerging Urban Pests and Vector-borne Diseases in Brazil

Ana Eugênia de Carvalho Campos

Summary

Brazil is the fifth largest country by geographical area, occupying nearly half of South America. It has the Atlantic Ocean to the east and has a vast area of different biomes, which include the Amazon region and cerrado, pantanal, pampas, caatinga and rainforest. Brazil's biodiversity reserves are the greatest in the world, and its urban pests are similarly biodiverse. It is estimated that 85% of the inhabitants in the country live in urban areas, and urbanization processes have been chaotic in many regions. Less than 50% of these urban areas have adequate solid residue collections and few technically planned landfills exist. Vectors of tropical diseases are common and the transmission of diseases such as malaria, yellow fever, dengue, Chagas' disease and leishmaniasis are prevalent. Because of the large area and with diverse problems related to pests – which include mosquitoes, sandflies, ants, termites and rodents – scientists are challenged to find solutions for minimizing pest populations and protecting human health. This chapter describes important public programmes that are available for promoting urban pest management and implementing control methods for vectors of tropical diseases in Brazil.

Introduction

Brazil, located between the equator and Tropic of Capricorn, has a land area of 8.5 million km^2, and is influenced by variable conditions relating to altitude, temperature, rainfall, air currents and proximity to the vast expanse of the Atlantic Ocean. These variations mean that the country experiences a combination of tropical, temperate and equatorial climates. The climate in the north-eastern, south-eastern and mid-western regions of Brazil is mainly

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tropical, with an average temperature of above 20°C and high rainfall. The climate changes from humid in the summer and spring to dry in the winter and autumn. The equatorial climate includes much of Brazil's territory and comprises mainly the region of the Amazon rainforest. In these equatorial areas, the temperatures are high and range between 25°C and 27°C, with daily rainfall. The temperate climate is prevalent in the south of the country, where the temperature falls to below 18°C in the winter.

Brazil ranks as the fifth most populous country in the world. A census conducted in 2000 showed that the northern region was the least densely populated, with a population density of 3.4 inhabitants/km^2, while the south-eastern region was the most densely populated, with 78.2 inhabitants/km^2. The Brazilian population is predominantly urban and, in 2000, the urban population exceeded two-thirds of the total population, which reached 138 million.

The country has a number of important pests associated with humans and their structures. Since its colonization, the country has continuously had to deal with a number of vector-borne tropical diseases, and many of these still persist. This chapter describes some of the important pests associated with urban areas and the human population in them – pests that are increasing in economic significance. Also outlined in the chapter are the various public programmes in Brazil that are directed towards urban pest management and the prevention of disease transmission by pests.

Urban Pests

In view of the commitment made by Brazil to the United Nations (UN) Convention on Biological Diversity, principles and guidelines to develop a National Biodiversity Policy were established in 2002, by Decree No. 4339. Under this policy, studies of terrestrial invertebrates became important for understanding the dynamics of ecosystems and the environment. Thus, studies have been done to identify diverse groups of insects, and establish their presence, in both natural and urban environments, and various work is being conducted in Brazil – from the Amazon region to the south of the country – towards the creation of a national database. As in natural environments, household pest species are diverse in Brazil, a fact which is illustrated by a survey carried out in Brazilian hospitals, in which 23 species of ants were identified (Bueno and Fowler, 1994).

Mosquitoes, sandflies and reduviid bugs dominate the list of important public pests affecting both urban and rural communities in Brazil. Mosquitoes remain the dominant pest owing to the favourable climatic conditions for these insects, and they are responsible for a number of vector-borne diseases. Other pests, such as ants, termites, bed bugs and rodents are also important emerging pests.

Ants

Among all the listed household and urban pests in Brazil, ants hold the most significance because of their diversity and prevalence. Of the nearly 2000 known ant species in the country, almost 50 species are classified as tramp ants (Bueno and Campos-Farinha, 1999). Many species have the ability to displace others, and eventually to become the dominant species in the habitat concerned. Some species of ants cause severe injuries to humans, and cases of anaphylaxis have been reported. The ant group includes ants of the genus *Solenopsis* (fire ants), which occur with high diversity and abundance in tropical and subtropical areas worldwide (Bueno and Campos-Farinha, 1999). Approximately 185 species of *Solenopsis* are known globally, and around 20 species from the Americas are known to build large colonies and are highly aggressive during foraging and in colony defence. Four species are native to North America, and the rest are native to the neotropics (Trager, 1991). Fire ants from the *Solenopsis saevissima* species group (Pitts *et al*., 2005) cause most injuries in Brazil, especially *Solenopsis invicta* and *Solenopsis saevissima* (Bueno and Campos-Farinha, 1999).

Species of ants belonging to the genera *Odontomachus*, *Pachydondyla* and *Paraponera* are next on the list of ant pests causing injuries as they are known to sting both humans and pet animals. Both *Odontomachus* and *Pachycondyla* spp. are found in all regions of Brazil, but *Paraponera* spp. are found only in the states in northern and mid-western Brazil. Another species, *Wasmannia auropunctata*, known as the little fire ant is distributed throughout Brazil and has been reported to reach severe infestation levels (Bueno and Campos-Farinha, 1999). In cocoa plantations in Ilheus, Bahia, in north-eastern Brazil, this species has inflicted severe stings on the workers. In another report from Rio Grande do Norte, more than 80% of 250 ornamental palm trees were infested by nests of *W. auropunctata*. People bitten by little fire ants suffer from severe cases of allergy, including anaphylactic shock. Several native ants, species of *Brachymyrmex*, *Camponotus*, *Crematogaster*, *Linepithema*, *Nylanderia* and *Pheidole*, have invaded structures and cause severe nuisance, especially *Nylanderia fulva*, *Camponotus atriceps*, *Camponotus crassus* and *Camponotus rufipes*. Also common are exotic ant species such as *Paratrechina longicornis*, *Monomorium pharaonis*, *Monomorium floricola*, *Pheidole megacephala* and *Tapinoma melanocephalum*.

Leaf-cutting ants are also important pests to humans when they occur in urban areas. *Atta* and *Acromyrmex* spp. are distributed over the country and defoliate ornamental plants in gardens, parks and squares. Campos-Farinha and Zorzenon (2008) reported more than 40 ornamental plant species (most of them exotic plants) damaged by leaf-cutting ants in urban areas. A total of nine *Atta* spp. and 21 *Acromyrmex* spp. have been reported in Brazil. The most common species in urban areas are *Atta sexdens rubropilosa*, *Atta laevigata*, *Atta bisphaerica* and *Atta capiguara*. Colonies may have thousands to millions of workers, brood and sexual individuals, and are mostly active in the wet and warm seasons (Mariconi, 1970; Della Lucia and Moreira, 1993; Campos-Farinha *et al*., 2008).

Urban ant control is mostly dependent upon using baits. The most common are baits using active ingredients such as hydramethylnon, boric acid and sulfluramide. For leaf-cutting ants, baits carrying sulfluramid and fipronil have been found most effective. A number of physical methods are also used against ants, particularly in protecting plants and landscape trees. For the very large nests of *Atta*, especially when they are located in public areas, fogging or misting is recommended. Brazil has not registered any insect growth regulator (IGR)-based baits for ant control.

Termites

From a list of over 2900 species of termites described in the world, the termite fauna from the Neotropical region is the second largest in the world in species number, with more than 500 species reported (Potenza and Zorzenon, 2006). Very little is known about termites in Brazil, and very few researchers have worked on this group of insects. Most research on Brazilian termites is from the Amazon, southern and south-eastern regions and Distrito Federal.

Reports of termite infestation, particularly concerning urban areas, are becoming increasingly common. *Coptotermes gestroi* is one of the most important species, with colony sizes which can reach up to a million individuals (Costa-Leonardo, 2002). *C. gestroi* is distributed in north-eastern, south-eastern and southern Brazil, but may also be present in other regions where, as yet, it remains unreported (Costa-Leonardo, 2007; Costa-Leonardo *et al.*, 2007). The species was probably introduced into Brazil in the 20th century, and is the most important termite species in the south-east. *C. gestroi* has been extensively studied in the last few years, and surveys have indicated the species has expanded its area of distribution. It is also believed that owing to the anthropogenic introduction of the species, records of its occurrence are in areas far from each other, so that its distribution is discontinuous. Infestation in urban areas could be due to swarming from established sites or from infested urban trees (Milano and Fontes, 2002). Brazil also faces severe termite infestations in trees grown in urban areas, such as landscaped areas. The most common species found are *C. gestroi*, *Cryptotermes* sp., *Incisitermes* sp., *Heterotermes* sp. and *Nasutitermes* sp. (Potenza and Zorzenon, 2008).

The drywood termite, *Cryptotermes brevis*, is the second most important termite pest in Brazil and is distributed along the coast in the state of Rio Grande do Sul. It also occurs in the interior of the state of São Paulo, in Belo Horizonte, Minas Gerais and in João Pessoa, Paraíba. In established urban centres such as São Paulo and Rio de Janeiro, *C. brevis* ranks second to *C. gestroi* in the level of infestation and damage caused (Potenza and Zorzenon, 2006). *Coptotermes dudleyi* and *Cryptotermes havilandi* have also been recorded in urban areas, mostly attacking structural wood (Mariconi *et al.*, 1980; Mill, 1991; Constantino and Cancello, 1992; Milano and Fontes, 2002).

Bed bugs

Bed bug-related incidents have been reported recently from the urban population of Brazil, particularly from people with higher per capita income (Nascimento, 2010). Public institutions have also reported bed bug-related complaints regularly, and these are being addressed by the government departments responsible for providing guidance on pest control through environmental management and sanitation. *Cimex lectularius* and *Cimex hemipterus* are the common bed bug species in Brazil, with *C. lectularius* being more abundant in the south-eastern region of the country.

Rodents

Several Brazilian cities have been suffering from rodent infestation for decades. To address these issues, the government has launched a public information, environmental management and control programme 'Operation Rat Outside' (*Operação Rato Fora*) in the city of São Paulo, where major infestation is notable. The objective of the programme is to reduce the conditions that facilitate the reproduction and permanence of these rodents at critical points of the city and thereby reduce the incidence of diseases such as leptospirosis. The programme aims to reduce the rodent population through systematic plans and the optimization of various control methods, and to implement it, agents trained in zoonosis control are used to facilitate the management of households and the general environment. Parallel to a number of technical activities, the emphasis is also on education, which is directed to encourage the public to adopt practices that discourage the proliferation of rodents, such as reducing the supply of food, water and shelter available to the pests.

Mosquitoes

Mosquitoes (Culicidae) remain a major public pest in Brazil. The country faces a number of mosquito-borne tropical diseases, such as malaria, dengue and yellow fever. The occurrence of these diseases is common as a result of the favourable climatic conditions available for vectors to inhabit and breed in. Failure of solid waste management, the increase in urban agriculture, poor water management, poor water storage methods, high human population density, lack of education and the potentially synanthropic characteristics of the mosquito favour its breeding.

Several species of Culicidae are found in urban areas of Brazil. These include *Aedes aegypti* and *Ae. albopictus*, *Ae. fluviatilis*, *Culex bidens*, *Cu. quinquefasciatus*, *Cu. chidesteri*, *Cu. coronator*, *Cu. dolosus*, *Limatus durhamii* and *Mansonia titillans*. While most of the species do not have any public health importance, the exotic species *Cu. quinquefasciatus*, *Ae. aegypti* and *Ae. albopictus* have called for the attention of public health authorities and control programmes.

Mosquito control in Brazil is usually based on direct control with chemical insecticides and biolarvicides, especially bacteria. In the late 1960s and early 1970s, a great deal of optimism was placed on the use of the sterile insect technique (SIT) as an alternative strategy for controlling mosquito vectors. However, SIT has been used against only a few species of mosquitoes to date, mostly because of certain fundamental problems inherent to the system (Milby *et al.*, 1983; Alphey, 2002), such as mechanical sexing of the specimens (Ansari *et al.*, 1977).

Vector-borne Diseases and their Management

A number of insect vector-borne diseases are common in Brazil. Each of these has economic significance, making its management a priority for the government.

Dengue

Ae. aegypti, the vector of dengue, was considered to have been eradicated in 1956, but by the end of the 1960s, it had re-emerged. In the 1970s, the species was found to be widely distributed in the country; so in the 1980s, dengue was considered an epidemic disease, which then became endemic in the 1990s. Today, the spread of dengue is a major challenge for the health authorities. The ability of *Ae. aegypti* to spread by flying and the adaptation of its eggs to desiccation, both favour its dispersal to new areas.

As Brazil has such favourable conditions for *Ae. aegypti*, control of this vector is a priority in the country. The Ministry of Health, in cooperation with the National Council of Secretaries of Health and CONASEMS (National Council of Municipal Health), has developed national guidelines for the prevention and control of dengue epidemics through mosquito management. This aims to provide managers with various contingency plans at the state, regional and metropolitan levels. These guidelines are communicated nationwide with the aim of including all managers and professionals involved in health care, vector control and other community related work.

A Monitoring System and Population Control system (named SMCP-*Aedes*) for *Ae.* a*egypti* has been developed by Brazilian researchers to provide an entomological surveillance framework as a basis for the epidemiological surveillance of dengue. SMCP-*Aedes* is supported by intensive use of the Web and free software for collecting, storing, analysing and disseminating information on the spatio-temporal distribution of the estimated density and population of *Ae.* a*egypti*. These data are systematically collected based on information from ovitraps (Regis *et al.*, 2009).The system was implemented in two municipalities of Pernambuco as a pilot project, using more than 10,000 ovitraps that collected more than 300,000 mosquito eggs. It proved to be viable at the municipal level, as it indicated accuracy in monitoring the presence of the mosquito and variations in its population density. This information, through the maps it generates, is key to detecting critical sites and locations which have a greater risk of dengue transmission. Furthermore, it was noticed that the use of ovitraps reduced the *Ae. aegypti* population each month (Regis *et al*., 2009).

Malaria

Malaria is still a serious public health problem in Brazil, especially in the Amazon region. This region alone records approximately 99.5% of the total infections in Brazil. A high incidence of malaria is prevalent in the states of Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, Tocantins, Mato Grosso and Maranhão. Detection of malaria in urban and suburban areas is now noticeable as a result of the intensification of agriculture in urban and peri-urban areas. Specifically, the rearing of fish in tanks has favoured the multiplication of the main malaria vector, the mosquito *Anopheles darling*. The disease (and its long-term consequences) has reduced the productive capability of the population and, ultimately, the economic growth of the region.

National projects designed for malaria control often encounter difficulties in controlling the breeding of malaria vectors inside the Amazon rainforest. However, it is possible to implement control measures, especially in the peripheral zones of the rainforest, and most efforts are presently directed towards this. Indigenous and migrant populations living in and near the forest are the focal group for all malaria surveillance and control programmes.

Yellow fever

There are two major mosquito vectors for yellow fever in Brazil, namely *Haemagogus janthinomys* and *H. leucocelaenus*. The first is the main vector of yellow fever in endemic areas, and particularly in the state of São Paulo (Dégallier *et al*., 1992). *H. janthinomys* is a mosquito with a strict host specificity for wild animals, indicating that virus transmission occurs within or near forested areas. In contrast, *H. leucocelaenus* has a more broad host range; it sometimes leaves the forest and can be found at ground level in areas surrounding woods or forested groves, which are common in southern Brazil. Historically, epizootic outbreaks of the disease have been reported in Brazil from time to time. These outbreaks vary from region to region and occur periodically, as they are dependent on the non-human and primate population, which is essential for viral amplification. This situation, combined with favourable vector breeding conditions, increases the chances of disease transmission (Vasconcelos, 2010).

Filariasis

Lymphatic filariasis is caused by the parasitic filarial nematode *Wuchereria bancrofti*, which is transmitted by a known vector, *Cu. quinquefasciatus*. This disease is present in cities of the north and north-east of the country, where control programmes are being implemented. *Cu. quinquefasciatus* is a nuisance in most Brazilian cities and persists even where it is controlled, owing to the availability of breeding grounds.

Chagas' disease

A total of about 140 species of insects have been or are currently known to transmit Chagas' disease. Of these, 69 have been identified as present in Brazil. The spatial distribution of Chagas' disease is limited primarily to the American continent, so it is also called American trypanosomiasis. Brazil currently dominates the chronic cases of Chagas' disease transmitted by triatomines (Triatominae, a subfamily of the Reduviidae), with cases of over 3 million infected individuals. The occurrence of acute Chagas' disease has been observed in a number of states, particularly in the region of the Amazon. The endemic area at risk of vector transmission of Chagas' disease includes 18 states with more than 2200 municipalities.

The major vector transmission of the disease takes place by blood-sucking bugs of the family Reduviidae, namely, *Triatoma infestans*, *T. brasiliensis*, *T. pseudomaculata*, *T. sordida* and *Panstrongylus megistus.* In addition species, such as *T. rubrovaria* in Rio Grande do Sul and *Rhodnius neglectus* in Goiás, have been recorded in households. *T. vitticeps* (in Rio de Janeiro and Espírito Santo) and *P. lutzi* (in Ceará and Pernambuco) deserve attention because of their high rates of natural infection. *R. nasutus* is often captured outside households in north-eastern Brazil (Ceará and Rio Grande do Norte). In the Amazon, the species most often found are *R. pictipes, R. robustus, P. geniculatus, P. lignarius* and *T. maculata.* Species of the genus *Rhodnius* are primarily associated with palm trees, while species of the genera *Triatoma* and *Panstrongylus* live preferably with terrestrial hosts. A few species have adapted to shelter in houses and structures such as henhouses and piggeries.

The usual forms of transmission of Chagas' disease to humans are through vectors, blood transfusion, transfer across the placenta and, more recently, through oral transmission by the ingestion of food contaminated with the flagellate protozoan *Trypanosoma cruzi*. Less common mechanisms of transmission involve laboratory accidents, the handling of infected animals, organ transplants and breast milk. Systematized actions focused on the chemical control of *T. infestans* were introduced in 1975, and have been followed regularly since then. A significant reduction has been recorded in the infestation by *T. infestans* of households and, simultaneously, in the transmission of *T. cruzi* to humans. Associated with these systematized actions are various methods of environmental management, and a better understanding of disease transmission dynamics, which have helped to control the disease.

Chagas' disease is treated under a mandatory notification system. Hence, all cases have to be immediately reported to the Information System for Notifiable Diseases.

Visceral leishmaniasis

Cases of visceral leishmaniasis and its transmission have been reported in various Brazilian municipalities in both large and medium cities for the past 30 years. However, since the 1980s, serious outbreaks of human visceral leishmaniasis, also called kala-azar, have been reported in many cities and city municipalities (Silva *et al.*, 1997; Bevilacqua *et al.*, 2001, Ministério da Saúde, 2004; Maia-Elkhoury *et al.*, 2008).

The major vector of this disease is the sandfly *Lutzomiya longipalpis*. Despite well-defined guidelines for the control of visceral leishmaniasis and the investments that have been made in organizing services and developing the proposed activities, regular monitoring of vectors and disease reservoirs in urban areas poses the greatest challenge for all control programmes. Often, the results of vector control are limited by lack of understanding of the vector's behaviour in the urban setting, by operational difficulties in performing vector control work activities, and by the high cost of implementation of the proposed measures. It is also necessary to identify the environmental factors that actually have an impact on the control of *L. longipalpis*. The species has a high capability of recolonizing the urban environment, and identifying its breeding sites is usually a hard task. Use of information such as the presence or absence of the vector, its abundance and infestation are still limited. These parameters are necessary for estimating the risk of transmission of the disease.

With the urbanization of visceral leishmaniasis from 1980 to 2005, some 59,129 new cases of the disease were recorded in Brazil, with an annual average of 2274 new cases. Of all the cases, 82.5% occurred in the north-eastern region. The disease gradually spread to the central, west, north and south-east, where the cases increased from 15% of all cases in 1998 to 44% in 2005. Currently 20 (74%) of the states of Brazil are regularly recording indigenous cases of this disease (Maia-Elkhoury *et al.*, 2008). The mean incidence of visceral leishmaniasis in the last 12 years was two cases/100,000 inhabitants and the case fatality rate was 5.5%; compared with the case fatality rate in 1994 (3.2%), this included an increase of 117% in 2005 (6.9%).

American cutaneous leishmaniasis

In Brazil, American cutaneous leishmaniasis (ACL) is one of the dermatoses that deserves attention because of its frequency of occurrence and the risk of deformities that it can cause in humans. The disease has a wide distribution, with recorded cases in all regions. Currently in the Americas, 11 species of dermotropic *Leishmania* causing human disease and eight species causing disease in animals have been reported. In Brazil, however, seven species have been noted, six of the subgenus *Viannia* and one of the subgenus *Leishmania*. The main species involved in the transmission of ACL in the country are the sandflies *Lutzomyia flaviscutellata*, *L. whitmani*, *L. umbratilis*, *L. intermedia*, *L. wellcome* and *L. migonei*. The role of each of these species as a vector depends on the species of *Leishmania* present in the intestine of the fly (Ministério da Saúde, 2007).

Since the 1980s, an increase has been reported in the number of cases, from 3000 in 1980 to 35,748 in 1995. Transmission peaks are observed every 5 years. The increase in the total number of cases since 1985 was observed when health surveillance for leishmaniasis and control measures for the disease were implemented in the country. From 1985 to 2005, an average of 28,568 indigenous cases was reported, with an average detection rate of 18.5 cases/100,000 inhabitants.

The entomological surveillance of vectors is critical in managing disease transmission and prevention. Prevention can only be achieved by continuous observation and evaluation of information derived from the bio-ecological characteristics of the vector, including observations of the levels of interactions with human and animal reservoirs (Gomes, 2002).

Public Programmes on Urban Pests in Brazil

One of the major reasons for the resurgence of urban and public pests around the world is a lack of state-level resources for training and awareness. In Brazil, the Paulista State University and the Instituto Biológico of the Secretary of Agriculture for the State of São Paulo are promoting a course in urban entomology. The course, which lasts one and a half years, is in its fifth year and trains and educates 20 specialists in each batch of students. It has had a very positive effect on the urban pest industry in Brazil. Trained experts from the course occupy managerial positions in pest control companies in manufacturing and in public health departments and institutions. They also act as trainers in their respective companies and places of work, helping to spread professionalism in the industry. Both educational institutions mentioned also offer postgraduate courses on disciplines focused on urban pests.

Brazil also has a number of national and state-level training activities on pest control. Conferences and seminars are directed to train and educate both practitioners and public officers on pest control developments. One such event, called 'Expoprag', is held every 2 years. This is considered to be the largest event on urban pests in Latin America. It is organized by a Pest Control Operator Association in São Paulo. The congress brings together experts in pest control from various parts of Brazil and the world in a 3 day event, at which basic biology, control, application technology, legislation and subjects involving the industry are discussed. The associated fair is known to receive around 4000 visitors.

Another event, called 'Ecoprag', also held every 2 years, brings the pest control industry together in Rio de Janeiro. This event started in the year 2005. It is a technical meeting which discusses technical, motivational and management issues through lectures, workshops and tutorials, with specific emphasis on discussions, debates and innovations. It brings together pest control operators, manufacturers, distributors, academics, consultants, researchers and regulators in the sector of professional control of vectors and pests. During this event, manufacturers also exhibit their products and equipment and launch new products.

Conclusion

The Neotropical region, with its vast biodiversity, and including its urban areas, needs to be studied in greater depth. This need arises from the fact that some of the species found might come into close proximity with humans and be categorized as pests. It is also noticeable that various control technologies used in other countries are not always efficient under local conditions. Thus, training of qualified personnel both for basic and applied research is very important, and should form part of national government policy.

Brazil is slowly becoming aware of urban pests and their importance. This is evident in the increasing interest of students on various courses about urban pests. Also noticeable is the increasing attention and interest from the various scientific congresses and training courses organized in the country. Eventually, all these will go a long way to help protect urban life and human health.

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3 Mosquitoes: a Consequential Pest

PARTHO DHANG AND ROBERT KUNST

Summary

Disproportionate attention has been given to mosquitoes, the majority of which would prefer not to feed on human blood. Most mosquito bites on humans are purely a consequence of the easy availability and abundance of human blood. The growth and distribution of the human population has made human blood much easier to locate and feed upon. This one-sided association also makes mosquitoes an ideal vector for parasites. The mosquito possesses blood feeding plasticity as a key survival trait, which explains further the emergence of many zoonotic mosquito-transmitted diseases in humans. This, in turn, has made mosquitoes an insect responsible for millions of deaths and disabilities over the course of history. However, mosquito management is challenged by factors such as changes in land usage patterns, climate, invasion and passive transportation. Each of these has contributed significantly in recent times to the huge scale of mosquito-related problems across the globe. Therefore, it is important that all mosquito control strategies in the future should not be limited to mere pest control, but to be elevated to vector control.

Introduction

Humans evolved in a world already stocked with blood-sucking insects (Lehane, 2005). Around 14,000 species of insects belonging to five orders feed on blood (Adams, 1999), but fewer than 400 species are encountered by humans, and mosquitoes (the family Culicidae) possibly form the largest group that is attracted to man. The majority of mosquito species are found in the tropics and subtropics, but they are also widespread in parts of Europe and North America. About 100 species of mosquitoes are recorded in Europe and over 160 in Canada and the USA (CIEH, 2008).

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To start with, people tended to consider mosquitoes merely as a source of nuisance, although this perception has changed over the past century or more as a number of diseases began to be linked with the pest (Table 3.1). Diseases such as malaria, yellow fever, and dengue were among the first diseases that mosquitoes were linked to as a vector. This became more significant when territories such as Europe and North America, which had been free from tropical mosquito-borne diseases, started recording them. The introduction of mosquito-borne diseases into new territories is the result of increased travel and trade which has allowed the accidental introduction of both infected hosts and vector species. Today, the mosquito is symbolically associated with many diseases, viz. malaria, yellow fever, dengue, lymphatic filariasis (LF), encephalitis, West Nile virus fever and Chikungunya fever. However, only a handful of mosquito species are associated with diseases which, unfortunately, has led to a disproportionate amount of attention being focused on them.

Among the various mosquito-borne diseases, malaria is the most important that is associated with substantial morbidity and mortality. Malaria is not confined to any country or continent. In 2008, there were an estimated 243 million cases of malaria worldwide. The majority of these were in the African region (85%), followed by the South-east Asian region (10%) and the Eastern Mediterranean region (4%). Malaria accounted for an estimated 863,000 deaths in 2008, of which 89% were in the African region, followed by the Eastern Mediterranean (6%) and South-east Asian (5%) regions. The majority (85%) of deaths were in children under 5 years of age (WHO, 1997a).The other noticeable mosquito-vectored disease is dengue, which used to be largely restricted in its occurrence, but has recently spread to newer territories, having moved further north (into the northern hemisphere) owing to the warmer temperatures that have been occurring, and aided by the introduction of the vector *Aedes albopictus.*

Mosquito Feeding Behaviour

Mosquitoes are generally perceived as having humans as their main source of food, although they in fact exploit a variety of mammals, birds, reptiles and amphibians as sources of their blood meals. For example, the species *Culex salinarius* uses hosts such as birds, equines and canines, and a typical meal of

Table 3.1. History of discoveries related to mosquitoes and human diseases (modified from Lehane, 2005).

Year	Discoveries of mosquito-vectored diseases
1879	Development of *Wuchereria bancrofti* (the causative organism of lymphatic filariasis) in the mosquito *Culex pipiens quinquefasciatus*
1897	Malarial parasites seen to develop in mosquitoes
1899	*Anopheles sp.* identified as the vector of human malaria
1900	Transmission of yellow fever by the mosquito *Aedes aegypti* confirmed
1902	Transmission of dengue by mosquitoes confirmed

this mosquito consists of a mixture of blood from different hosts (Cupp and Stokes, 1976). Similarly, in nature, species of both *Aedes* and the anopheline mosquitoes (subfamily Anophelinae) are known to have a wide range of host choice – extending from man to other animals and birds.

Host choice in mosquitoes is determined by a number of factors. These include behavioural, physiological, morphological, ecological, geographical, temporal and genetic factors, either working independently or in combination (Lehane, 2005). A bite on a human subject by a mosquito is possibly linked to host availability, distance to the host and defensive behaviour of the host, all working in favour of the mosquito. Over time, natural selection must have led a few species of mosquitoes to select and eventually specialize in feeding from humans, which could be the easiest available host. Feeding on humans is an evolutionary choice which could maximize overall fitness of the mosquito species.

The significance of host defensive behaviour in choice of blood meal is common in nature. The anti-mosquito behaviour displayed by many birds at roost urges mosquitoes to select a host that performs the least defensive behaviour (Webber and Edman, 1972). This is evident in the classic case of the mosquito *Culieta melanura,* which feeds exclusively on passerine birds when its own population is low. However, with an increase in the mosquito population, an increased defensive action is noticed in the birds, forcing the mosquito to expand its host range to other birds and mammals, including horses and humans (Lehane, 2005). Interestingly, this period coincides with the reporting of eastern equine encephalitis in the human population in the USA, thus illustrating an expansion of host range in mosquito.

Ecological factors also play a critical role in influencing host choice in mosquitoes. The best example to explain this is an analysis of the feeding patterns of anopheline mosquitoes in Europe in the early part of 20th century. The presence of both anopheline mosquitoes and malaria carriers failed to show any disease transmission in Europe during this period. It was later concluded that the reason was the improvement in living standards of humans, such as larger and brighter living places, decrease in birth rates, less of the population involved in agriculture and the increase in animal husbandry. Mosquitoes restricted their feeding to animals, which are easily available hosts, thus reducing the biting frequency on humans and, consequently, disease transmission (Harrison, 1978).

Species of mosquitoes occupying similar habitats may choose to feed on different hosts to avoid competition. This is prevalent in natural conditions and is evident in species belonging to the genus *Aedes*. *Ae. triseriatus* and *Ae. hendersoni* living in eastern and mid-western woodlands in the USA show characteristic host choice patterns even though both of the species live in the same habitat. *Ae. triseriatus* was found to feed mainly at ground level on animals such as deer and chipmunks, in contrast to *Ae. hendersoni*, which feeds on canopy animals such as tree squirrels (Nasci, 1982). In another study on the genus *Anopheles*, *An. gambiae* and *An. arabiensis* were shown in a carefully controlled experiment to have statistically similar levels of biting activity on humans and cattle (Diatta *et al*., 1998). This contradicted the previously held notion that *An. arabiensis* is more zoophilic than *An. gambiae.* Such observations lead towards the conclusion that inter-species competition, host abundance and host proximity may ultimately determine host choice of mosquitoes in many instances (Lehane, 2005).

Notwithstanding, host availability or abundance does not dictate the host choice of a mosquito simply. There needs to be an additional temporal overlap between mosquito feeding activity and host resting period. At rest, a host will show minimal or no defensive activity, which will benefit feeding. This explains why most anthropophilic mosquitoes prefer to feed during the night when humans are at rest. In addition, the night provides a lesser risk of desiccation, fewer predators and less atmospheric turbulence, and hence more continuous odour plumes for easy host location (Gibson and Torr, 1999).

Locating a Host

Unlike permanent ectoparasites, which live on their preferred host, mosquitoes face an arduous task to locate their host. To do this, they use a complex mixture of sensory stimuli unique to their preferred host. Information on how a mosquito detects its human host is sketchy, and consequently, a number of theories have been put forth. The subject is further complicated by the fact that all blood-feeding mosquito species are differently attracted to humans. It is possible that adaptation over time plays a significant role in determining how a species reacts to human presence. *An. quadriannulatus*, which has a broad host range, responds strongly to carbon dioxide (Dekker and Takken, 1998), while *An. gambiae* responds only weakly to carbon dioxide but strongly to human foot odours (Dekker *et al.*, 2001), which are generated by the action of coryneform skin bacteria thriving on human sebaceous secretions (Braks *et al.*, 1999). Such a unique species-specific response is an evolved strategy that assists in the easy location of hosts. People even differ in their individual attractiveness to mosquitoes. For example, pregnant women are more attractive to *An. gambiae* than non-pregnant women under similar conditions of exposure (Ansell *et al.*, 2002).

Behavioural studies have identified several lures as mosquito attractants. These include both visual and chemical cues. A large number of chemicals, mostly serving as kairomones, have been identified and listed (Barnard *et al.*, 2000). The primary odour cues are a mixture of different compounds, such as lactic acid, ammonia and other sweat compounds. However, the precise role of carbon dioxide in mosquito attraction is confusing, as studies have shown that pure plumes of carbon dioxide (rather than mixtures with body odour) attracted fewer mosquitoes (Mukabana *et al.*, 2004). In another study, it was observed that when combined with carbon dioxide, used socks become attractive to mosquitoes (Barnard *et al.*, 2000). Carbon dioxide appeared likely to be an important constituent in the odour blend, helping insect orientation as an attractant, repellent or a neutral substance in various studies. Among the odours, those produced by skin microflora, and that are similar to the volatiles of Limburger cheese, have been identified as a good attractant for mosquitoes

(Knols *et al.*, 1997). Skin microflora on the host body produce a characteristic odour caused by breakdown of triglycerides on the skin to form short and long chain fatty acids; this serves as a chemical signature which attracts the mosquitoes (Keswani and Bellare, 2006).

A number of synthetic host odours, such as carboxylic acids and enols, have been shown to stimulate mosquito sensory receptors (van den Broek and den Otter, 1999). For example, the compound 1-octen-3-ol has been identified as stimulating high responses in mosquitoes. Ammonia emitted from human skin as a microbial breakdown product and excreted in the human sweat was found to be attractive to mosquitoes (Meijerink and van Loon, 2001). Also, moisture is shown to influence mosquito behaviour, and specific receptors in *Ae. aegypti* have been shown to respond to the presence of water vapour (Keswani and Bellare, 2006); this was proven in a study in which *An. gambiae* was caught in traps with only clean humidified air (Dekker *et al.*, 2001).

Research has helped to shortlist several compounds as mosquito attractants, but none have shown positive results for all the species, which signifies the presence of species-specific kairomones. This subject is considered a key area in mosquito management as it would provide direction in the identification of suitable attractants. Attractants can help to provide an opportunity to interrupt and disrupt mosquito–host interaction, eventually reducing biting rates and the chance of disease transmission.

Blood as a Preferred Meal

The majority of the mosquito species in the world do not feed on human blood, instead they concentrate feeding on other vertebrate species. Consuming blood poses some nutritional challenges, but few other body fluids are as abundant and readily available as blood. In contrary to its ready availability, blood contains approximately 20% protein, mostly in the form of haemoglobin, which is hard to digest. In addition, blood tends to be low in vitamins, which mosquitoes compensate for by feeding on plant nectar. The result is that only a few species of mosquito depend on human blood. It is noteworthy, though, that only the females of the species need the blood meal, so that they can develop and lay viable eggs (Clements, 1999); the males of these species are not equipped to feed on blood.

Adult female mosquitoes of certain species have an affinity for feeding on human blood and a tendency to forego feeding on other diets. This is very evident in *Aedes* spp., which makes them a dangerous disease vector for humans. *Aedes* females live in close association with humans and meet their energy and reproductive needs by feeding frequently on human blood. In an experiment (Harrington *et al.*, 2001), it was shown that when female *Ae. aegypti* fed on human blood and water, it had greater age-specific survival (lx), reproductive output (mx) and cumulative net replacement (R0) than cohorts that fed on human blood plus sugar or isoleucine-rich mouse blood with or without access to sugar. The unique isoleucine concentration of human blood is associated with the unusual propensity of *Ae. aegypti* for feeding preferentially and frequently on humans, a behaviour that increases its overall fitness (Harrington *et al.*, 2001).

The single amino acid isoleucine has been shown to influence the overall utilization of protein during oogenesis in *Aedes* spp. (Briegel, 1985). However, the concentration of isoleucine in vertebrate blood is higher than that in human blood. Thus *Aedes* spp., have adapted to live indoors in close proximity to humans to sustain a higher fitness. They feed frequently to compensate for the deficiency of isoleucine in human blood. Other anthropophilic mosquitoes feed by flying into populated areas where the availability of human blood is abundant and also during times when humans are at rest. According to Chaves *et al.* (2010), mosquito species in a given community may rely primarily on host availability in a given landscape, and contact with a specific host is influenced more by the presence or absence of the host than by innate mosquito choices. This observation stresses the importance of blood feeding plasticity in mosquitoes as a key trait. Furthermore, the blood feeding plasticity explains the emergence of many zoonotic mosquito-transmitted diseases in humans (Chaves *et al.*, 2010).

Mosquitoes as a Pest

A few species of mosquitoes have, ideally, chosen humans as their major source of food. Some of these anthropophilic species have to live and breed in urban areas. Others frequent urban dwellings for easy blood meals. The increase in the human population and spread of human habitation has made human blood easily available. Historically, human settlements were located in the vicinity of water, which is an essential factor in mosquito breeding. Modern cities may not be located near permanent water bodies but use large amounts of transported water. The water used for drinking, cleaning, washing and irrigating is often exploited by mosquito species for breeding. Among the various species, *Aedes* has become a truly urban mosquito as it has adapted so well to breeding in urban environments, particularly in artificial containers of freshwater.

Mosquitoes are widespread in their habitats and distribution, surviving and breeding under a broad range of geographical and atmospheric conditions. Some species live at altitudes of over 3600 m. The larvae, which are aquatic, can be found in salt, fresh or contaminated water bodies as small as the screw cap of a soda bottle. Water held by bromeliads, broken bamboos or tree holes are common and important breeding sites. Mosquito larvae live in water, but they must either surface for air or obtain it from the underwater portions of plants. Most species move about actively in the water and come to the surface frequently to breathe. Larvae go through four instars, usually in a period of 4 to 10 days, to form pupae. The pupae live in water and, like the larvae, are quite active. The pupal head and thorax are greatly enlarged and enclosed in a sheath, and a pair of respiratory tubes project from the sheath surface. The pupal stage lasts from a day to as long as a few weeks. When ready to hatch, the pupa rises to the surface, and the pupal skin breaks. Males usually emerge first and wait near the hatching point to mate with the females, which usually takes place within 24 to 48 h.

Mosquitoes can also change their behaviour and adapt to new breeding habits, which include slurry pits, liquid manure pits and rainwater pools (CIEH, 2008). In a survey carried out after the tsunami in 2004, the Vector Control Research Centre (VCRC) in Pondicherry, South India, found a breeding population of *An. stephensi* in the tsunami water inundated habitats. This had not been previously recorded. Other vector species of mosquito such as *Culex quinquefasciatus* and *Cu. tritaeniorhynchus* were also recorded in tidal water with measurable salinity between 2541 to 17,468 ppm. Also, low-lying paddy fields and fallow lands with salinity ranging from 3000 to 42,505 ppm were found to support high breeding populations of *An. sundaicus* and *An. subpictus* in the Andaman Islands (VCRC, 2005).

Mosquitoes are highly responsive to changes in climate. Increased temperature is associated with increased abundance, assuming that there are sufficient numbers of water-filled sites as habitats. Species belonging to the genus *Aedes* are known to have egg dormancy, but favourable weather can terminate this dormancy and make the species become abundant. Conversely, the species can also overcome unfavourable weather by riding over it using egg dormancy as a survival adaptation, so that it could become a dominant species in certain areas. This is evident from the behaviour of the Asian tiger mosquito, *Ae. albopictus*, which has outcompeted the local population of *Ae. aegypti* in the USA. *Ae. albopictus* is adapted to breed in large numbers in nutrient-depleted water and shows tolerance to higher temperature, which has helped it in displacing *Ae. aegypti* (Juliano, 1998). A combination of various habits, such as anthropophily, zoophily, endophagy, exophagy and exophily, based on geography, location and seasons, makes mosquitoes a complex and difficult group of pests to manage.

Mosquitoes as an Ideal Vector

Mosquitoes are excellent vectors owing to multiple factors, but one recent observation points to the evolutionary idea that the parasite that causes malaria might manipulate mosquito behaviour to enhance its transmission. This chance of manipulation by the parasites has made the mosquito an ideal vector and transmitter. It happens when the malarial parasites have completed their development within the mosquito and developed into the transmittable sporozoite stage. This stage increases the biting response of the mosquito and forces it to seek human hosts (Koella *et al.*, 1998). In contrast, in an earlier developmental non-transmissible stage, the parasite reduces the biting rate by decreasing the biting motivation of the mosquito (Koella *et al.*, 2002).

In addition, Day and Edman (1983) found that malaria-infected mice were more susceptible to mosquito attack at the time when gametocytes circulated in the rodents' bloodstream. Thus, it was felt that infection by the parasite can change the host's odour profile by changing the composition of skin microbes through its immunological and endocrine systems. This makes an infected host more attractive to mosquitoes, which leads to an increased rate of transmission. A study by Lacroix *et al.* (2005) provided further evidence for this theory by showing that the mosquito *An. gambiae* is more attracted to humans infected by the transmissible gametocyte stage of the malaria parasite than to uninfected individuals or individuals infected with the asexual non-transmissible stages. The study demonstrated that the gametocyte can manipulate the biting behaviour of mosquitoes to enhance transmission to humans. Further, it was noted that the attractiveness of the host is not the result of an intrinsic attractiveness of the gametocyte, but is a response towards the infection status of the host. This is achieved by changing the infected individual's breath and body odour, thereby making that individual more attractive to the vector (Lacroix *et al.*, 2005).

Meanwhile the status of *Aedes* as an ideal vector comes from its unique adaptation to live in close association with humans, deriving food, mates and substrates for laying eggs within human habitation. This makes *Aedes* a less frequent flier. In this situation, most of the dispersal of dengue fever occurs via movement of infected human hosts rather than movement of the vector. This feature makes *Aedes* an efficient vector, and renders transmission possible even when the mosquito population is very low (Kuno, 1995).

Challenges in Mosquito Management

Many attempts to control mosquitoes have been tried over the centuries. One of the oldest recorded attempts was the draining of marshlands by the Romans, which proved to be highly successful. The huge size and range of habitat in which mosquitoes can successfully breed and establish large populations requires specific and detailed planning for any management principle to work. Moreover, mosquito management is challenged by factors such as changes in land-use patterns and climate, and mosquito invasion and passive transportation. Each of these has contributed significantly in recent times to the enormity of mosquito-related problems across the globe. Unfortunately, in many instances, mosquito management has been equated with disease control, which has resulted in availability of federal funds and strategies only when there are reports of diseases and outbreaks. Consequently, most urban cities lack long-term mosquito prevention and control plans. A few major cities in India, for example, were free of filariasis until the early 1960s, but the sewage and sanitation facilities ceased to keep pace with the rapid expansion of the population, resulting in invasion by *Cu. quinquefasciatus* and the introduction of filariasis (WHO, 1997b).

Ecological factors contributing to mosquito breeding are also gaining ground in negating mosquito management programmes. These factors are related to climatic and habitat modification. Soil salinization resulting from agricultural clearing activities has recently been shown as a potential pathway for significantly increasing the burden of mosquito-borne diseases (Fearnley *et al.*, 2010). The replacement of deep-rooted perennial vegetation by shallow-rooted annual crops and pastures can cause water tables to rise. This may result in easy waterlogging where salt has been deposited, thereby resulting in severe salinity problems. Soil salinization results in an increased abundance and distribution of mosquitoes through a number of mechanisms (Jardine *et al.*, 2008); a good example of this is provided in western Australia, where the development of dryland salinity appears to have favoured the inland spread of *Ae. camptorhynchus*, a vector of the Ross River virus.

Increased travel and transport of goods in a globalized society has significantly increased the chances of dispersal of the mosquito population. Added to this is the increase in the number of geographical areas around the world that are receptive to mosquito breeding. This is happening with changing temperature, rainfall patterns and urbanization. Mosquito species with desiccation-resistant eggs, which enhance survival in inhospitable environments, have taken the advantage of dispersing and invading newer territories. Similarly, the capacity to breed in small man-made containers and the ability to occupy human-dominated habitats are some factors that enable mosquitoes to successfully invade human dwellings.

The basic strategy for controlling and managing the mosquito population has depended on a number of methods. Source reduction and personal protection can provide long-term solutions, especially in urban areas that allow easier detection of breeding grounds that can be easily eliminated. Also, buildings can be designed to prevent mosquito entry. In addition, a number of personal actions, if carefully undertaken, can prevent mosquito bites. Personal protection methods are gaining acceptance among the public with the development and availability of new technologies; repellents, protective clothing, and the use of bed nets and screens are notable tools for preventing mosquito bites.

Suburban and rural areas face a different situation. The presence of numerous breeding grounds for mosquitoes makes control measures less effective and often a failure. One notable mosquito control tool in combating mosquitoes is the use of long-lasting insecticide-treated nets. This method is used both in bed nets and screens. It has been shown that sleeping continuously under these nets reduces mosquito lifespan, lengthens the feeding cycle and discourages human biting by diverting bites on to non-human hosts (Le Menach *et al.*, 2007).

Insecticide-treated bed nets have also played a critical role in reducing the number of malaria infections in villages, where the level of transmission of malaria is low or moderate. In some villages, where the level of transmission is high, the use of insecticide-impregnated bed nets has reduced the parasitic load of infected people and, as a consequence, morbidity has been reduced by 50% and mortality by 20% (Kampen and Schaffner, 2008). These results confirmed those from an earlier trial against *An. dirus* in Hainan province, China, in which the use of bed nets demonstrated a progressive decline in parasite rates and the disappearance of *Plasmodium falciparum* (Curtis *et al.*, 1991). Another report by Killeen *et al.* (2007) calculated a coverage threshold in the use of insecticide-treated nets to safeguard humans against malaria. This report claimed that where alternative hosts for vector mosquitoes are absent, 35% of the human population must sleep under regular insecticide-treated nets to achieve an equivalence of personal and communal protection, resulting in major community-wide suppression of exposure. The same target was achieved at 55% coverage where alternative hosts such as cattle are present.

It is believed that continuous defensive behaviour displayed by humans, such as the use of repellents and sleeping under nets, would force mosquitoes to choose an easier host available in the vicinity. However, this strategy is only significant in reducing vector-borne diseases, but not reducing the mosquito population. Mosquito control can only be successfully achieved by educating the public on how to prevent the unintentional provision of breeding sites in the neighbourhood (CIEH, 2008).

Conclusion

As our climate and environment changes, mosquitoes will spread unnoticed to new areas. The availability of human blood in abundance can also make many mosquito species shift their host choice from zoophilic to anthropophilic. Thus, their interaction with humans is inevitable. Consequently, the chances of humans contacting newer and existing vector-borne diseases transmitted by mosquitoes will increase. It is strongly felt that mosquito-control strategies should be elevated from being mere pest control to the level of vector control. The dynamics of a vector control programme are more comprehensive, as it would eventually reach to a community level, thus making the urban environment more hospitable.

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4 Environmentally Sound Bed Bug Management Solutions

Changlu Wang and Richard Cooper

Summary

Bed bugs have become a serious pest in urban communities throughout the world. They are proving to be one of the most challenging urban pests facing pest management professionals, largely owing to the lack of effective pesticides and a lack of public awareness that has enabled bed bugs to spread at alarming rates. Non-chemical techniques and tools, and integrated pest management strategies are gaining popularity as they impose less environmental impact than pesticide driven programmes. This chapter discusses the use of 'low-impact' tools and methods. Also, a community-wide programme for effective bed bug management in society is explained.

Introduction

History of bed bug infestation and control

The bed bug, *Cimex lectularius* L., has been recorded in association with humans for thousands of years (Usinger, 1966). It was a common pest in temperate regions of the world through much of the 20th century. However, the advent of DDT in the 1940s dramatically reduced bed bug infestations. Leary *et al*. (1946) claimed that 'DDT is the most valuable weapon found against bed bugs'. Further the US Department of Agriculture called DDT 'the perfect answer' to the bed bug problem (Leary *et al*., 1946). A 5% spray or 10% DDT powder were used applied directly on to beds, bed frames, walls, skirting board (baseboard) cracks, behind loose wallpaper and to any other hiding places. Eradication was achieved in as little as 48 h. Control could last more than 6 months after only one treatment with DDT. Eventually, bed bugs

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became widely resistant to DDT and a switch to organophosphates, such as malathion, became necessary to eliminate DDT-resistant populations. The use of DDT and other highly effective insecticides minimized the bed bug population in many industrialized countries (Snetsinger, 1997).

Since 2000, bed bug infestations have become increasingly common in the USA (Cooper and Harlan, 2004; Gangloff-Kaufmann *et al*., 2006; Potter, 2008), Canada (Hwang *et al*., 2005), Australia (Doggett *et al*., 2004) and in Europe (Kilpinen *et al*., 2008). An increase in the tropical bed bug, *C. hemipterus* F., was also reported along with *C. lectularius* in Australia (Doggett *et al*., 2004). Incomplete data from the New York City Department of Housing Preservation and Development showed that bed bug complaints increased from 537 in 2004 to 12,768 in 2010. A survey of management staff from 16 apartment complexes occupied by low-income people in New Jersey found that 5% of all of the housing units experienced bed bug infestations; further, five out of eight complexes reported increases in bed bug infestations from 2008 to 2009 (Wang, unpublished data). The cause of the resurgence of bed bugs remains unclear. One of the more widely accepted theories is that insecticide resistance is one of the factors that led to increased global bed bug activity. Other factors that are likely to have contributed to the resurgence are increased international travel, lack of effective insecticides, more restricted use of insecticides in homes owing to health concerns, and a general lack of awareness in society in many parts of the world where bed bugs were rarely encountered for nearly five decades.

The exclusion of chlorinated insecticides from use inside homes and the restricted use of available insecticides as a result of health concerns could be the reasons for the recent resurgence of bed bugs. Added to these is the fact that bed bug detection is often challenging and, when combined with several non-chemical tools, requires multiple visits to eradicate an infestation (Wang *et al*., 2009a). This makes the process labour intensive and expensive. The cost for professional control in a single home can range from several hundred to thousands of US dollars.

As a countermeasure, researchers, government agencies and the pest management industry are responding to the bed bug resurgence and the difficulties in their control. A book dedicated to bed bug management has been published (Pinto *et al*., 2007). Numerous non-refereed articles and web sites about bed bugs have also appeared in recent years and many bed bug management tools are being developed. In spite of this increased focus on bed bugs, infestations continue to increase and spread. Added to this are concerns about the safe use of pesticides in the interior environment. This chapter reviews the existing bed bug management methods and discusses how to combine them into environmentally sound and practical bed bug management programmes. The chapter is not meant to provide detailed descriptions about individual control methods; rather, it focuses on the utility of the techniques, new research findings on bed bug management and sustainable integrated bed bug control solutions.

Inspection and Monitoring

Detecting the presence of bed bugs is very important in a bed bug management programme. In fact, early detection of bed bugs is perhaps the single most important factor in eradicating them in an efficient and cost-effective manner. Residential infestations that are detected early on (within the first month of introduction) tend to be localized and can be eliminated with relative ease. In contrast, the longer an infestation remains undetected, the more widely dispersed the bugs become within the infested structure. Failure to detect early allows bed bugs to start infesting various items in that structure, away from regular sleeping and resting areas. This also makes elimination work longer and more costly. The failure to detect bed bugs early on also provides the opportunity for bugs to spread to other units in multi-occupancy settings (i.e. hotels, apartments, dormitories, hospitals, etc.). The bed bugs can be transferred to residences, places of work, schools and other public and retail locations within the community via belongings such as backpacks, computer bags and handbags.

Methods of monitoring bed bugs fall into the following categories: visual inspection, client interview, the placing of monitors and the use of specially trained detection dogs. A combination of several methods generally provides better detection than relying on a single method.

Visual inspection

A thorough inspection by an experienced professional is valuable in determining the presence and distribution of bed bugs, and in designing treatment strategies. The inspection should be performed before conducting the initial treatment. The reliability of a visual inspection is limited by experience of the inspector, the time spent, accessibility, the complexity of the environment and the cooperation of the client. The cryptic and secretive behaviour of bed bugs renders visual inspections unreliable when only a few bugs or eggs are present. Many hiding places are difficult, impractical or inaccessible to inspect, especially when clutter obscures potential harbourages. Some examples include areas beneath floorboards, under skirting boards, behind radiators, inside wall voids or inside mattresses. Visual inspections should include looking for live bed bugs (including eggs), faecal spots and shed skins. Any signs of bed bug activity in previously uninfested environments are clear indicators of new infestation. The limitations of visual inspections were demonstrated by Wang *et al*. (2009a): biweekly visual inspections in eight apartments found 39 ± 22 bed bugs, whereas an intercepting device placed under furniture legs caught 219 ± 35 bed bugs in the same period.

Client interview

Feedback from clients can be helpful in determining when and how bed bugs may have been introduced, where the location of the infestation is, and how effective the treatment is. Like visual inspection, client interviews are not a reliable method for determining the presence or absence of bed bugs. Interview accuracy is influenced by the client's knowledge, motivation, sensitivity to bed bug bites and even visual acuity. For example, 50% of the residents interviewed in a low-income community were unaware that their apartments were infested (Wang *et al*., 2010). In another study, 30% of 474 individuals living in bed bug-infested homes indicated that they were not experiencing any bite symptoms (Potter *et al*., 2010a). In one instance, Wang *et al*. (2010) examined an elderly man who had an estimated 10,000 bed bugs present in his apartment. No red welts or scars were found on his arms or neck. In another instance, it was noted that individuals who are aware of infestations will not provide truthful information out of embarrassment, fear of social stigma or concerns that they may be held financially responsible for the infestation. Thus, while client interviews/surveys are strongly recommended, one should not rely solely on the resident's observations to evaluate a site and the success of a treatment.

Using monitors

Monitors designed for bed bugs may be classified as passive or active. Passive monitors do not contain lures for attracting bed bugs, whereas active monitors contain lures intended to draw bed bugs into the monitor or trap.

Passive monitors

Several passive monitors have been developed to help detect bed bugs. To date, the ClimbUp® Insect Interceptor (Susan McKnight, Inc, Memphis, Tennessee), which the first author helped to develop, is the only passive monitor that the authors have found to be both economical and effective for detecting low levels of infestations. It is used directly under beds or furniture legs. Despite the fact that the device by itself is passive, the presence of the human host provides this device with the most effective natural lure available. Because they kill bed bugs (by confining them), these interceptors can also help to reduce the number of bed bugs present (Wang *et al*., 2009a,c) as well as providing a degree of relief by reducing the feeding activity of bed bugs that are intercepted en route to acquire a blood meal (Pinto *et al*., 2007).

ClimbUp® interceptors cannot be placed under the legs of all beds. Some bed frames have legs that are too large for the interceptors. Likewise, platform-style bed frames preclude the use of interception devices under bed legs. Despite the fact that ClimbUp® interceptors cannot always be placed under the legs of beds or sofas, interceptors not placed directly under the legs of bed frames and other furniture can still be helpful in the detection of bed bugs. Two interceptors placed beside bed legs in six occupied one-bedroom apartments for 2 weeks collected a median number of seven bed bugs per apartment, compared with a median number of 16 bed bugs per apartment when 4–12 interceptors were placed under the legs of beds and sofas (Wang, unpublished data). Similarly, Cooper used ClimbUp® interceptors to monitor a 360 unit apartment complex for the elderly and was able to identify infestations by placing ClimbUp® interceptors adjacent to sleeping areas in units where bed frames were absent (Cooper, unpublished data). The tendency for bed bugs to climb up vertical surfaces (Aboul-Nasr and Erakey, 1968) appeared to be a factor in the effectiveness of this monitor. However, ClimbUp® interceptors need to be serviced regularly (e.g. every 2 weeks) by wiping off settled dust and reapplying talcum powder to keep the interior surfaces slippery. Although effective, ClimbUp® interceptors are also likely to be aesthetically unacceptable to some customers – such as hotel managers. The development of interception devices and barriers is currently an area of great interest and new devices are becoming commercially available on a regular basis. Some of the newer devices include the Bed Moat (Canada), Bedbug Barrier (Australia) and BB Secure Ring (Australia). However, efficacy data are lacking for all of these devices, which prevents further interpretation.

Sticky traps (Trapper® Insect Monitor, Bell Laboratories, Inc., Madison, Wisconsin), designed for catching crawling insects have not proved effective in detecting bed bugs in our field observations. Several other passive monitors consisting of layered or corrugated cardboard are commercially available. These offer alternative harbourages to bed bugs looking for hiding places, and are placed on or near beds or sofas. Infestations are identified by the presence of bed bugs or their faeces and cast skins. Passive monitors rely on the harbourage-seeking behaviour of bed bugs. Preliminary field results showed that Catchmaster BDS™ (AP & G Co., Inc., New York) and BB Alert Passive® (Midmos Solutions Ltd, UK) were much less effective than ClimbUp® interceptors.

Active monitors

Bed bugs can be attracted and trapped by baited pitfall traps (Anderson *et al.*, 2009; Wang *et al.*, 2009b). The bait can be carbon dioxide (CO_2), heat, a chemical lure or a combination of these above elements. Because baited traps contain attractants, they can be used both in occupied and vacant rooms, and results can often be obtained overnight. CO_2 was the most important lure when compared with heat and chemical attractants, and is believed to be the key attractant in an effective active monitor (Wang *et al.*, 2009b). The CO_2 release rate and release time of four active monitors are listed in Table 4.1.

Comparative studies in apartments of the CDC3000™ (Cimex Science LLC., Portland, Oregon), NightWatch™ (BioSensory Inc, Putnam, Connecticut) and a home-made dry ice trap showed that all monitors can detect low levels of bed bug infestations. The dry ice trap was the most effective and NightWatch was the least effective monitor over a 24 h monitoring period. Continuous monitoring over several consecutive days with NightWatch improved detection (Wang *et al.*, 2011). The CDC3000 and NightWatch utilized CO_2 (emitted from pressured CO_2 cylinders), heat (generated from an electric-powered

Table 4.1. Comparison of CO_2 release rates and release periods of four bed bug monitors.

Monitor	CO_2 release rate (ml/min)	Release period (h)
CDC 3000™	42	≈10
NightWatch™	150–200	8
Dry ice trap	737–801	10–12
Bedbug Beacon™	2–11[a]	48[b]

[a] Maximum CO_2 release rate measured 2 h after activation.
[b] After 48 h, CO_2 release rate was below 2 ml/min.

component) and chemical attractants to attract bed bugs. The homemade dry ice trap only utilized CO_2 (with dry ice as source) to attract bed bugs. The dry ice trap is much more affordable than both the CDC3000 and the NightWatch. However, dry ice is not often readily available and cannot be stored for more than a few days. It also needs to be secured in containers to prevent children and pets from accidental exposure or ingestion.

The Bedbug Beacon™ (Packtite/Nuvenco, Laporte, Colorado) is a new product using a similar principle to the dry ice trap. It utilizes ready-to-mix dry materials to generate CO_2, a concept similar to that explored in mosquito trapping (Kline *et al.*, 2006; Xue *et al.*, 2008). This source of CO_2 is more convenient than dry ice and does not require expensive hardware to regulate the release of CO_2. Laboratory experiments in 55.5 × 43.5 cm (L × W) arenas indicated that the device can attract approximately 80% of released bed bugs overnight. The authors tested the utility of the monitor in seven severely infested units (based on visual inspections). One Bedbug Beacon™ was placed beside the infested bed in each apartment. Four ClimbUp® interceptors were placed under the bed legs or beside the bed legs in each apartment. The results of these experiment showed that the Bedbug Beacon™ was not effective in detecting bed bugs (Table 4.2), while the ClimbUp® interceptors caught an average 16 bed bugs. Most of the bed bugs found in the interceptors were from the outer well of the interceptors, indicating that large numbers of bed bugs were present in the rooms and not in the beds. The inconsistency between laboratory and field results from the Bedbug Beacon™ highlighted the need for conducting field experiments when evaluating bed bug monitoring devices.

Detection dogs

Dogs specially trained to detect bed bugs are used by some pest control companies in the USA and elsewhere. However, the only peer-reviewed publication indicating detection dogs as an effective tool to detect the presence of bed bugs was by Pfiester *et al.* (2008). To date, there are no field data confirming the accuracy of detection dogs in occupied rooms where dead bed bugs and old bed bug faeces are present. From our interactions with pest control companies and clients, results from different trained dogs varied

Table 4.2. Relative effectiveness of the ClimbUp® Insect Interceptor and Bedbug Beacon™ for detecting bed bugs in occupied apartments.

Apartment	Bed bug infestation level	Number of days of placement	Bed bug count: Bedbug Beacon™	Bed bug count: ClimbUp® Insect Interceptor
1	Heavy	1	0	11
2	Very heavy	1	1	30
3	Medium	2	2	7
4	Heavy	2	0	36
5	Medium	5	0	9
6	Medium	5	0	13[a]
7	Medium	5	0	6[a]

[a] Interceptors were placed beside bed legs.

significantly. Both environmental and human factors affect the accuracy. In addition, dogs may fail to detect bed bugs if the scent is unavailable to them during the inspection owing to the location of the bug(s) and the airflow in the room. Thus, human assistance is needed to allow dogs to sniff inaccessible areas. The cost may not be affordable for individual residents (around US$300/hour in the USA). Conversely, canine scent inspections are the most efficient and economically practical method for large-scale inspections such as entire office buildings, theatres, hotels, dormitories, etc. However, because of the great degree of variability in the effectiveness of canine scent-detection inspections, it is strongly recommended that bed bug activity is verified in areas where dogs have indicated their presence. In the event that bed bug activity cannot be confirmed, the area in question may be treated by non-chemical measures (i.e. vacuum cleaners, heat/steam, etc.) and monitored for several weeks. Pesticides should not be applied unless activity is confirmed by physical evidence. Thus, more studies are needed to evaluate the reliability of detection dogs.

Prevention

New bed bug infestations often result from visiting infested rooms, bringing home infested furniture or receiving visitors with bed bugs in their clothing or personal belongings. In addition, bed bugs migrate from one unit to another in multi-occupancy settings (Doggett and Russell, 2008; Wang *et al.*, 2010). The ease in which bed bugs can be introduced into a previously uninfested environment makes prevention difficult and sometimes impossible. The most important step in the prevention of bed bugs is education and public awareness. Misinformation, misconceptions and a general lack of awareness have been the greatest allies of bed bugs and have enabled them to spread in a virtually unrestricted fashion.

There are a number of active steps that can be taken to avoid transferring bed bugs from infested environments to previously uninfested locations. The extent to which individuals will go to avoid introducing bed bugs will vary greatly depending on the amount of exposure that they have had to locations where bed bugs are likely to be present and their degree of concern. The following are essential actions which could help to prevent infestation and protect individuals from bites.

- People not presently experiencing a bed bug infestation should consider the following preventive measures: (i) become educated about the life history of bed bugs, how to avoid them, how to inspect for them and how to recognize the signs and symptoms of an infestation; (ii) exercise caution during travel that involves overnight stays and inspect sleeping quarters; (iii) avoid sitting on furniture or placing personal items near beds and upholstered furniture when visiting places where bed bugs are known to exist, and limit personal items (handbags, backpacks, etc.) when visiting areas that are known to have bed bug activity; (iv) immediately hot launder or run through a dryer all suitable items upon returning from areas where bed bugs are likely, or known, to be present; and (v) place items that cannot be laundered or dried into a freezer for at least 4 days when returning from locations that have bed bugs.
- Property owners/managers of facilities should consider: (i) educating building occupants about identification, prevention and control of bed bug infestations; (ii) periodically inspecting/monitoring high-risk areas of the facility; and (iii) developing a policy and procedure for dealing with reported or suspected bed bug activity. A suggested policy and procedure for the hospitality industry is available at www.bedbug.org.au, and procedure checklists are also available in the *Bed bug Handbook* (Pinto *et al*., 2007).
- People currently experiencing bed bug infestation in their homes should consider the following steps to prevent the further spread of bed bugs: (i) not discarding infested items without first eliminating as many bugs as possible and then completely wrapping or bagging the ítems and marking them as bed bug infested; (ii) not relocating items from infested dwellings unless they have been hot laundered, steamed, heat treated, fumigated or otherwise disinfected; (iii) storing personal items such as handbags, backpacks, computer bags, etc. away from sleeping and resting areas in an airtight storage container to prevent infestation of items that will be taken out of the home on a regular basis; (iv) periodically hot laundering and/or drying clothing and storing it in bags or an airtight container to prevent clothing that is being worn from becoming infested; and (v) reduce clutter throughout the home, especially in areas close to beds, upholstered furniture and closets.
- Repellents available commercially can be used against bed bug bites. Diethyltoluamide (DEET) is a commonly used insect repellent. Kumar *et al*. (1995) demonstrated the repellent effect of DEET and of *N,N*-diethylphenylacetamide (DEPA) to *C. hemipterus* over 8 h under

laboratory conditions. Laboratory studies also have demonstrated that filter paper treated with 10% DEET at a rate of 1.26 nmol/cm^2 remained repellent to *C. lectularius* for at least 8 h (Rutgers University, unpublished data). Also, spraying shoes, trousers, luggage and other vulnerable surfaces with repellent containing at least 10% DEET may prove effective in reducing the risk of contracting bed bugs. However, more research is necessary to verify whether this is an effective measure outside the laboratory setting. Rest Easy™ Bed Bug & Insect Control (0.5% permethrin; J T Eaton, Twinsburg, Ohio) and Cutter® Advanced™ insect repellent (7% picaridin; Spectrum/United Industries Corp., St Louis, Missouri) were not effective in repelling bed bugs in laboratory studies (Wang *et al.*, unpublished data).

Non-chemical Control Methods

Reduction of harbourages

Bed bugs are thigmotactic and prefer to hide in cracks and crevices, and along edges and folds. Also, textured surfaces (e.g. wood, fabric) are preferred to smooth metal, plastic or tiled surfaces. Replacing wooden bed frames with plastic or metal frames, encasing mattresses and box springs, sealing holes and cracks on walls and the floor, removing items from around beds and sofas, replacing carpets with solid flooring and removing skirting are useful measures for reducing the number of harbourages. Specially designed encasements are available that are bite proof, escape proof and entry proof. Encasing mattresses and box springs with bed bug-proof encasements will trap existing bed bugs inside where they will starve and die. In addition, encasements prevent additional bed bugs from getting inside mattresses and box springs (Cooper, 2007). Also, the smooth exterior of the encasement makes bed bug inspection much easier. In the event that infested beds are discarded, encasements can be used to protect replacement beds from becoming infested by bed bugs still present in other parts of the dwelling.

While the majority of bed bugs are associated with the bed complex (mattress, box springs and bed frame) and upholstered furniture, they can also infest many other items away from sleeping areas. The closer the item is to the sleeping and resting areas (i.e. beds and sofas), the more likely it is to become infested. Storing items under, on, or next to beds will promote the infestation of personal items that may be difficult to rid of bed bugs.

Sealing holes and harbourages on walls should always be considered as part of an active measure and may help to reduce the probability of bed bugs spreading through the common walls of neighbouring units; however, the actual effectiveness is unknown. Tapes placed over electric outlets caught bed bugs that were trying to enter the room. However, complete protection from dispersing bed bugs is difficult as they can also spread through doors and hallways (Wang *et al.* 2010).

Physical removal

Several studies have shown that the majority of bed bugs hide on beds, sofas and other furniture that the occupants spend extensive time on or near each day (Wang *et al.*, 2007, 2009a; Potter *et al.*, 2008). Disposing of infested furniture is the fastest way to remove large numbers of bed bugs from an infested room. Before disposal, furniture should be wrapped in plastic to avoid bed bugs crawling to the handlers or spreading to non-infested areas. The disposal of furniture should only be recommended if: (i) the cost of eliminating the bugs is expected to exceed the cost of replacement; (ii) the furniture cannot be properly treated using methods such as heat or steam treatment, fumigation or chemical applications, or encasement; or (iii) the owner of the furniture wishes to have it discarded rather than trying to salvage it. Disposal of infested furniture alone is rarely a solution. If infested furniture is being discarded, other control procedures must be carried out at the same time to tackle bed bugs in other parts of the dwelling. Replacing discarded furniture with new furniture before complete elimination of the infestation is likely to result in the replacement furniture becoming infested.

Hand picking the bed bugs found during careful inspection provides immediate relief to inhabitants if only a few of them are present, but when the numbers are large, hand picking becomes impractical and the effect is less significant. Vacuuming with crack and crevice attachments in heavily infested rooms is useful for quickly removing both live and dead bugs, as well as shed skins and debris. In areas where large numbers of bed bugs are present, this method can be very efficient, but it does have limitations. Bed bugs that are protected within cracks or crevices are not easily removed and will often escape vacuuming efforts. Moreover, eggs are not easily dislodged from the substrates upon which they have been cemented. The vacuumed areas still need to be treated with other non-chemical or chemical tools, such as steam or residual insecticides. In addition, care must be taken to avoid the potential spread of bed bugs to different rooms via infested vacuum cleaners and vacuum bags. Vacuum bags should be removed, sealed in an airtight bag and discarded in an outdoor trash receptacle, and the interior vacuum housing carefully inspected for bed bugs.

Barriers

The aforementioned ClimbUp® Insect Interceptor serves both as a monitor and barrier. After installing these interceptors under the furniture legs and moving the furniture away from the walls, the inhabitants can avoid being bitten by bed bugs in the furniture from the room. However, those bed bugs already in the furniture can still bite people. It is necessary to get rid of the bed bugs on the bed first to minimize the likelihood of being bitten. A number of other physical barriers are being developed and will be available in addition to ClimbUp® interceptors. A bed bug caster barrier and screw-in barrier developed by an

Australian company have been effective in preventing bed bugs accessing the furniture in the authors' laboratory studies.

Double-sided tape, smooth plastic tape, and a Vaseline/oil mixture can also serve as effective barriers for preventing bed bug movement between furniture and the floor. Unlike the ClimbUp® interceptors, these barriers cannot trap bed bugs, and ClimbUp® interceptors should only be used for preventing bed bugs from passing the barriers.

Laundering and drying

Frequent washing or cleaning is an effective and safe method for eradicating bed bugs that are hiding on clothing, bed sheets, pillows, blankets and other washable fabric materials. Standard hot washing or drying cycles alone or in combination are effective in killing bed bug eggs and mobile stages (Potter *et al.*, 2007). Naylor and Boase (2010) found that washing at 60°C and tumble drying on a hot cycle > 40°C for at least 30 min killed all stages. Moreover, clothing should be placed in disposable plastic bags before washing to avoid bed bug spread. Alternatively, dissolvable laundry bags (e.g. Green Clean™ Dissolvable Laundry Bags, Bed Bug Central, Lawrenceville, New Jersey) can be used to place infested items in, before washing them in the washing machine in order to reduce the chance of spreading bugs when transferring items to be laundered. Dry cleaning with perchloroethylene is also effective against all stages of bed bugs. However, this method should be used with caution because bed bugs may spread before they are killed.

Soaking infested fabric materials in water is lethal to bed bugs, but requires extended periods of time. A Chinese government study conducted in 1981 in Hangzhou, Zhejiang Province tested the effectiveness of 10, 20, 30 and 40 h soaking. Only the 40 h treatment killed all bed bugs (unpublished report). Very recently, Naylor and Boase (2010) found that soaking in water for 24 h killed the active stages of bed bugs but had no effect on the eggs.

Heat

Heat has long been used in bed bug control – well before the advent of the modern insecticides (Fox, 1925). Boiling water, petrol torches and steam were used to treat mattresses, box springs, bed frames and other harbourages. However, the first two methods are not convenient or safe because they can damage the furniture or cause fire. The US Army used heated air for treating barracks and was able to eradicate bed bugs. Steam radiators can heat up rooms to > 60°C. A minimum of 52°C–54°C was sufficient to kill bed bug mobile stages and eggs, and a 6 h exposure time was recommended. Laboratory tests show that nearly all bed bugs can be killed after a 1 h exposure at 48°C (Benoit, 2009).

A growing number of professionals, as well as property maintenance staff, are using steam machines as a safe and affordable method of bed bug control:

hot steam can instantly kill all stages of bed bugs. Users need to adjust the steam flow rate so that bed bugs are not blown away before being killed. Steam machines with larger attachments and multiple jet heads reduce the risk of blowing bed bugs away without killing them. The moving speed of the steamer attachment should have the treated surface reaching > 80°C (Kells, 2006). Treating upholstered furniture requires a slower speed in order to achieve the lethal temperatures needed to kill bugs that are hiding in folds and pleats. Containerized heat treatment can be performed inside rooms by building custom-made heat chambers using foam boards, oil heaters and fans (Pereira and Koehler, 2009). Portable heating units (PackTite™) are available for treating a small amount of materials. According to the manufacturer, the temperature inside the unit can reach at least 45°C when connected to electricity. Four hours is recommended to ensure that the centre of infested items reaches the minimum lethal temperature.

For homes with a large amount of furniture and other items, heat treatment of the whole house, or custom-made heat chambers are used to control bed bugs. Achieving the minimum threshold temperature (50°C) in all areas, including piles of clothing and deep inside furniture, is essential (Kells, unpublished data). Although highly effective, heat is only as effective as its ability to penetrate. Total elimination is less likely under cluttered conditions (especially with densely packed clothing) or in structures where concrete construction may serve as a heat sink. This makes it difficult to achieve lethal temperatures throughout the entire structure. Even under conditions where elimination is not achieved, structural heat treatments can dramatically reduce severe infestations, leaving only a small number of bugs to be eradicated through follow-up services using conventional tools such as vacuum cleaners, steam and insecticides.

Putting infested mattresses or clothing out in the sun or in a parked car in summer can kill some bed bugs. While this method can be helpful, temperatures may not always be sufficient to penetrate the items, resulting in survivorship of some bugs or eggs and providing a false sense of security to people trusting in the method. Doggett *et al*. (2006) found that temperatures were insufficient to cause complete mortality in an experiment with wrapped mattresses, and professionals should not recommend this method as a means of eradicating bed bugs from infested items.

Freezing

Freezing infested items to kill the bed bugs in them is effective. Bed bugs die within hours at a temperature of –15°C (Kemper, 1936). One hour's exposure to –16°C was lethal to adult females (Benoit, 2009). Jones and Wang (unpublished data) tested the effect of cold treatment on bed bugs using household freezers (–14°C to –15°C). The bed bugs were placed in 4 cm diameter Petri dishes along with pieces of paper. Each dish was wrapped with a cotton sock. Two out of the 15 nymphs recovered after 72 h of freezing. The recovered bed bugs were able to bite but were not successful in drawing blood and subsequently died. None of the bed bugs (30 eggs, 15 nymphs and 15 adults) recovered after 96 h of freezing. Based on these findings, freezing items in a household freezer for 4 days should be sufficient to kill bed bugs. Putting items outside in the winter months should not be recommended owing to fluctuations in the temperature when infested items absorb solar radiation; infested items must be held continuously for more than 5 days at –5°C or below to kill bed bugs (Kells, 2006).

Cryonite® technology uses liquid CO_2 to kill bed bugs. Liquid CO_2 coming out from a storage tank forms a 'snow' that immediately lowers the surface temperature well below 0°C in a very short time. There is no field research on the effectiveness of this technology alone. A limited laboratory study in a small aquarium (Insect Investigations Ltd, unpublished data) showed that four bursts of CO_2 killed eggs, nymphs and most adults. However, under field conditions, bed bugs can be blown away by the high pressure of the CO_2 during application. For this reason, this technology is not recommended in the Australian bed bug code of practice (Doggett, 2010).

Chemicals

Insecticides are an important bed bug management tool. Some insecticides not only kill bed bugs on contact, but also provide residual protection afterwards. Two key factors limit the efficacy and use of insecticides for bed bugs: toxicity and method of application. Chlorinated hydrocarbon insecticides such as DDT and many organophosphates and carbamates are no longer available for bed bug control in many countries. Commonly used liquid insecticides are not very effective when applied alone (Moore and Miller, 2008). Even if new and much more effective chemicals are discovered or registered for bed bug control in the future, these may not be effective against bed bug infestations. This was realized with DDT and other early synthetic insecticides, which required more restricted application methods in developed countries where a resurgence of bed bugs occurred.

Throughout history, bed bugs have demonstrated the ability to quickly develop resistance to pesticides. DDT resistance was found after only about 3 years of use in a military facility (Johnson and Hill, 1948). Lilly *et al*. (2009a,b) demonstrated the ineffectiveness of pesticides belonging to different chemical classes. In fact, resistance to pyrethroids has been well documented. The majority of the current bed bug populations collected in the field were resistant to deltamethrin, a common chemical in the pyrethroid class (Zhu *et al*., 2010). In addition, the resistance ratio of four bed bug colonies was > 12,765 (Romero *et al*., 2007). These findings confirmed that the effectiveness of insecticides will continue to be undermined by the ability of the bed bug to develop resistance mechanisms. Owing to these limitations and concerns about pesticide exposure, incorporating non-chemical methods into bed bug control programmes is necessary to obtain satisfactory results.

Organic insecticides

Several products in the organophosphate and carbamate groups are used to control bed bugs in Australia and Asia. However, the majority of the current residual insecticides registered for bed bugs in Australia (Doggett and Russell, 2008), Europe and the USA are pyrethroids. While organophosphates and carbamates have been shown to be more effective than pyrethroids (Lilly *et al*., 2009a), they are not registered for bed bug control in the USA because the US Environmental Protection Agency has determined that exposure to these pesticide groups poses potential risks to human health and the environment.

Studies have successfully demonstrated the effect of combining insecticides against bed bugs. A combination of Suspend® SC (0.06% deltamethrin) and Drione® (1% pyrethrin, 10% piperonyl butoxide, 40% silica gel) or DeltaDust® (0.05% deltamethrin) eliminated bed bugs from ten of 13 apartments after two to five treatments (Potter *et al*., 2006). Later, Wang *et al*. (2007) evaluated the effectiveness of deltamethrin spray and cyfluthrin dust treatment and found out that bed bugs were eliminated in six of eight infested apartments after 8 weeks; an average of two treatments was applied to each apartment. In an experiment involving 15 apartments, chlorfenapyr spray only eliminated bed bugs from one, four and five apartments at 4, 8 and 12 weeks, respectively (Potter *et al*., 2008). These studies demonstrated that thorough insecticide treatments can lead to satisfactory results, but that complete bed bug elimination is difficult. Also, the lack of resident cooperation is a contributing factor in the elimination failure (Wang *et al*., 2007).

Meanwhile, pyrethroid sprays were shown to be effective when applied directly on to bed bugs, but dry residues were much less effective or ineffective (More and Miller 2006; Potter *et al*., 2007). Dust formulations have been found to be superior to spray formulations (Romero *et al*., 2009). It appears advantageous to use dust formulations to control resistant populations. The effectiveness of various dust insecticides varied significantly (Doggett, personal communication). Continuous exposure to Tempo 1% dust (1% cyfluthrin, Bayer Environmental Science, Raleigh, North Carolina) killed 100% of pyrethroid-resistant bed bugs after 24 h. Wang (unpublished data) conducted an experiment in two heavily infested apartments where more than 500 bed bugs were found by visual inspection. One thorough application of Tempo 1% dust eradicated the infestations. In both apartments, the mattresses and box springs were wrapped in plastic, which might have contributed to the success of the eradication. Pyrethroid dusts can be very irritating to the applicator and proper personal protective equipment is required during application. After application, the excess dust should be vacuumed to minimize human exposure to the dust.

Less toxic chemicals have been researched and used in bed bug management. Hydroprene, a juvenile hormone mimic, is used in combination with pyrethroid sprays by professionals (Potter, 2008), but its effectiveness is unknown. Its mode of action is to prevent females from producing viable eggs, but laboratory experiments have shown that 0.07% hydroprene does not completely stop treated females from producing viable eggs, although fecundity is reduced by 75% (Miller, unpublished data).

There are no indications that organic insecticides made of plant-derived materials are effective against bed bugs as residual treatments. In our evaluations, alcohol sprays (70% or 91%) caused some mortality to bed bugs, especially in the nymphal stages. However, alcohol sprays do not have a residual effect and can be a fire hazard if used excessively near pilot lights or other flammable sources.

Inorganic insecticides

Among the inorganic insecticide dusts that have been evaluated – such as diatomaceous earth (DE), boric acid and limestone, only DE has demonstrated acceptable efficacy against bed bugs (Romero *et al.*, 2009). DE has the advantage over pyrethroid dust of having low mammalian toxicity, no known resistance in bed bug populations and long residual activity in a dry environment. Doggett and Russell (2008) achieved 100% mortality of adults within 9–15 days of treatment with doses of 1–8 g DE/m^2. At a dose of 4 g/m^2, 33% of the adults died within 2 days. Also, first instars were found to be significantly more susceptible to DE than adults, with 99% mortality observed 2 days after treatment using the same DE dose of 4 g/m^2. Similarly, experiments by Romero *et al.* (2009) showed that DE caused > 90% bed bug mortality in both nymphs and adults in 10 days.

Fumigants

In some cases, when other options are not practical, it is necessary to fumigate infested materials. Vikane® gas (active ingredient sulfuryl fluoride; Dow AgroSciences, Indianapolis, Indiana) is registered for the treatment of bed bugs and is effective against all stages, including eggs. Fumigation is the only method that, when applied correctly, will result in 100% elimination of all bed bug stages from infested structures and/or infested items. The fumigation process requires several days, is often difficult and can be cost prohibitive for large structures (e.g. apartment buildings, hotels, etc.). Finally, care must also be taken not to disperse bed bugs to new locations during the temporary relocation of the occupants of the structure that is being fumigated.

Resin strips impregnated with dichlorvos (DDVP; AMVAC, Los Angeles, California) are useful for treating small items such as clothing, shoes and books. Based on laboratory tests, placing a dichlorvos strip in a large rubbish bag with the infested items for 1–2 weeks killed all stages of bed bugs (AMVAC, unpublished data). Also, Potter *et al.* (2010b) demonstrated that 7–14 days of exposure to the DDVP vapours was required to achieve 100% mortality of bugs and eggs in items such as artwork, clocks and suitcases, while other items, such as shoes and books, still had live bugs or eggs even after 14 days of continuous exposure. These results suggest that the use of DDVP resin strips can be a very useful tool but is not completely reliable method in all situations.

Bed bugs are susceptible to high concentrations of CO_2. In laboratory trials (Wang, unpublished data), 100% CO_2 killed all active stages after 7 h and killed all eggs after 10 h at room temperature (around 24°C–26°C). To fumigate infested clothing, 1400 g dry ice (as source of CO_2) was placed in each of 158 l garbage bag filled with clothes (80% full) and the sealed bags for 24 h. The dry ice was placed at the bottom and in the centre of the clothes piles. Thirty bed bugs (adults, nymphs and eggs) were placed at the bottom, centre and top of the clothes pile. Five bags were tested. All bed bug life stages were killed after 24 h. The use of this technique in a ventilated room has little environmental risk and can be easily carried out by both professionals and residents. Meanwhile, CO_2 fumigation is a potentially safe and affordable method to treat non-washable items such as books, CDs, electronics, shoes, clothing, etc. When large amounts of materials need to be fumigated, a fumigation bubble or custom-made fumigation chamber is necessary, and liquid CO_2 may be needed for fumigating these chambers.

Integrated Bed Bug Management

As discussed in the previous sections, each method or tool has its limitations in bed bug control, which calls for an integrated pest management (IPM) approach involving multiple methods. This is necessary to minimize the risk of new infestations, discover infestations at an early stage, effective eradication existing bed bug infestations and to maintain sustainable control. Education and awareness is absolutely critical, and is the foundation upon which successful control is achieved.

The use of IPM to manage bed bugs was recently tested in low-income households (Wang *et al.*, 2009a). The methods included education, installation of mattress encasements and application of steam followed by chemicals. The apartments were monitored biweekly and retreated when necessary. The cost per one-bedroom apartment over a 10 week period was estimated as US$463–482. Bed bugs were only 50% eliminated in the test apartments after 10 weeks. This was because some residents had piles of unwashed clothing on the floor and large amount of clutter; these conditions contributed to the eradiation failure.

We propose the following elements of a sustainable bed bug IPM programme for apartment buildings: (i) establish a management policy which includes educating property management staff and residents, and maintaining an ongoing bed bug monitoring and reporting programme to all units in a building; (ii) maximize the use of non-chemical tools and use chemicals sparingly; (iii) encourage the cooperation of residents; and (iv) repeat services on a biweekly basis (or more frequently) until eradication is achieved.

Resident knowledge and cooperation directly affect treatment results. In a survey of management staff from 16 housing authorities in New Jersey, 11 of them cited lack of resident cooperation as the main obstacle to bed bug control efforts. Some residents did not seem to care that bed bugs were in their homes, or they were incapable of or unwilling to follow recommendations such as reporting infestations, cleaning, decluttering and installing mattress encasements. Poor cooperation allows bed bugs to remain untreated until they become widespread and established. Lack of awareness by the public also leads to continuing unintentional spread of bed bugs in occupied units.

Some control methods are more expensive than others. The determination of the control method to use is often limited by the financial capability of the clients. This means that coordination is needed to implement the most cost-effective strategies. Our survey of public housing authorities in New Jersey in 2010 found that the median control cost for each infestation was US$363. Follow-up inspection and treatment of infested units was necessary for the eradication of bed bugs. Only 6.1% of the surveyed pest control companies claimed that a one-time treatment could eliminate bed bug infestations (Gangloff-Koffmann *et al*., 2006). These data highlight the need for better cooperation among involved parties and the adoption of IPM programmes.

Community-based Bed Bug Management

Currently, bed bug management efforts are focused at the individual level. However, bed bugs are often not an individual pest problem but a community-wide pest problem. Wang *et al*. (2010) documented that bed bug infestations expanded from one to 101 units within 41 months in a 223 unit apartment building. This shows that lack of community-based efforts favours the rapid dispersal of bed bugs within society. Less than 10 years ago, bed bugs were rarely encountered in New York City. However, it is now common for them to be found in apartment buildings, as well as in office buildings and in public and commercial retail locations. There are several factors that promote the successful spread of bed bugs in cities like New York City. These include: (i) a general lack of awareness and failure to detect infestations quickly; (ii) failure of people whose homes are infested to take steps to prevent taking bugs with them when they leave their homes; (iii) lack of affordable professional bed bug management services; and (iv) lack of effective 'self-help' tools and techniques. These factors must be corrected or bed bug problems will continue to spread throughout the community.

Implementing community-based bed bug management is more than an entomological challenge. It is also a social and political challenge which requires the mobilization of communities and various parties. Establishing laws and regulations governing the management of bed bugs will be extremely helpful. Public education, research, and the demonstration of effective bed bug prevention and control strategies are needed to reduce bed bug infestations in society.

Conclusion

Methods for better bed bug prevention and control are being actively sought to tackle this emerging public health pest. Effective and safe bed bug eradication hinges upon community-wide IPM action. This incorporates education, multiple tools and the cooperation of all involved parties. Programmes are lacking in multi-unit dwellings, where bed bug infestations tend to be chronic and badly infested apartments become reservoirs of new infestations.

Bed bug control is both expensive and difficult. Repeated application of insecticides can result in unnecessary exposure of inhabitants to pesticides. The cost and risks associated with bed bug control can be greatly reduced with education, prevention, early detection and the selective use of existing non-chemical and chemical tools. Customized IPM programmes need to be designed and implemented with consideration of resident demographics, income level, building type and history of pest infestation. Finally, more affordable control measures must be identified and safe and effective 'self-help' methods developed to provide solutions for those that cannot afford the expensive control options that are primarily used today.

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5 Digital Governance in Urban Entomology: an Innovative Approach

Naresh Duggal

Summary

Site-specific inspections and accurate problem identification are critical steps before pest control measures are applied, and this knowledge is important for the success of an integrated pest management (IPM) programme. Besides knowledge of pest biology, structural IPM professionals must understand how to develop a site survey and IPM measures with a minimal amount of effort. In 2008, the IPM programme in Santa Clara County, California, in collaboration with the structural IPM service provider, implemented a trial using PDA (personal digital assistant)-based software, bar-code scanners, and Web-based applications to conduct structural IPM inspections. The successful trial was followed by a full-scale adoption in 2009. Adoption of this technology is a move from primarily paper-based methods of pest traceability to consolidated digital methods that are more immediate and accessible for temporal and spatial pest data. In practice, the Internet-PDA-based inspection tool collects field observations on a unique hand-held PDA platform. It synchronizes those data to an Internet-based server, then allows a data modelling tool to track trends, predict and counter potential problems before they become serious. The data and reports are then made available to Department IPM coordinators/ facility managers through desktop applications for analysis of pest trends and spatial distribution, and rapid response and mitigation efforts. These prioritize habitat modification through improvement in structural and landscape designs, sanitation, housekeeping and maintenance. Data analysis using digital governance tools developed under this public–private IPM partnership provides a picture in which improvements can be made to developing and promoting better pest management services at reduced risks. The development of this important management tool (as well as best practices and outreach components) has provided a foundation for continued success and improved employee and stakeholder participation. This has set an example for other government and

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non-government agencies and industry. Overall, digital governance has helped to monitor pest populations and then assisted customers in habitat modifications to solve pest problems with no or minimum use of reduced-risk pesticides.

Introduction

Pest control is a common activity of public agencies associated with public health, natural resource management, and the maintenance of open spaces, turf and landscape, rights of way – including roads, and airports, parks and facilities, public works and other structures. Samples of these structures include office complexes, libraries, correctional facilities, hospitals, schools, yards and animal shelters. Generally, all pest control services include the use of pesticides. Consumers have diverse views and preferences about pesticide use; in the past two decades, the public have become increasingly concerned about the impact of pesticides on human health and the local ecosystem. While the public generally believe that insects, diseases and other pests need to be controlled, they also believe that control of pest insects should be done using alternatives to pesticides. This has important implications for public policy, marketing and risk communication. The health of building occupants and the health of the local ecosystem is directly affected by the use of chemical pesticides. The US Environmental Protection Agency (EPA) states that 'economic benefits from pesticides use are not achieved without potential risks to human health and the environment due to the toxicity of pesticide chemicals' (Aspelin and Grube, 1999). Pesticides may also pollute the indoor air quality, both via exterior application proximate to air intakes and by the use of chemicals for indoor pest control.

Regulatory agencies are also highly concerned about non-point source pollution (NPS) resulting from the use of pesticides, and its effect on air, land and water resources. NPS, unlike direct pollution from industrial and sewage-treatment plants, comes from many diffuse sources. Water pollution resulting from NPS is caused by rainfall or snowmelt moving over and through the ground; as the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters and underground sources of drinking water. Pesticides from agricultural lands and residential areas are one of the major sources pollutants that cause water quality impairment in rivers and streams in the USA (US EPA, 2010). To reduce NPS contamination from pesticides, people can use integrated pest management (IPM) techniques. IPM helps to limit pesticide use and manages the necessary pesticides so that application minimizes their movement from the target area.

Frequent pesticide use in highly populated urban municipalities increases the risk and probability of pesticide exposure in urban communities. Local governments have a particularly difficult job in keeping a balance between pest management and pesticide use. In addition, complying with stricter environmental regulations is often made harder because of the size and complexity of the areas that they maintain. Increasingly managers are challenged to develop pest management plans for many different ecosystems (some of which have already been listed at the beginning of this section). These range from unincorporated open spaces and parks to rights of way (including roads), and airports and trails; and from urban landscapes to the interiors of office complexes, libraries, hospitals, correctional facilities and other public buildings.

Resolving pest problems in these urban environments also faces infrastructural complexities and public relations issues that rely on the coordinated activities of many individuals. These individuals have direct or indirect yet critical roles in the success of a pest management programme. Furthermore, in addition to evaluating and improving pest management activity, document and data maintenance has also become very important in order to be responsive to the public, who have gradually become aware of and informed about pests.

Santa Clara County, the largest county in the San Francisco bay area of California, provides an example of the challenge of accomplishing the complex planning and execution of an IPM programme. The County of Santa Clara, a government organization with its administrative site in the city of San José, includes 15 cities and provides essential services to a population of 1.7 million. It has a Board of Supervisors that governs and manages a workforce of more than 16,000 employees, and functions as an extension to the California State government to manage California's social, health and safety programmes. In May 2002, the County Board of Supervisors passed an ordinance on IPM and a pesticide use reduction ordinance, both aimed at reducing human and environmental exposure to the physical and chemical hazards associated with pest management products and services. The ordinances stated that the provision of these environmental services must focus on pest prevention through non-chemical strategies.

As defined in the National Roadmap for IPM (National Information System for Regional IPM Centers, 2004):

> Integrated Pest Management, or IPM, is a long-standing, science-based, decision-making process that identifies and reduces risks from pests and pest management related strategies. It coordinates the use of pest biology, environmental information, and available technology to prevent unacceptable levels of pest damage by the most economical means, while posing the least possible risks to people, property, resources, and the environment. IPM provides an effective strategy for managing pests in all arenas from developed residential and public areas to wild lands. IPM serves as an umbrella to provide an effective, all encompassing, low-risk approach to protect resources and people from pests.

Limitations of the Conventional Method

The IPM ordinance radically changed Santa Clara County's pest management approach to a primary focus on controlling pest populations by managing elements of the environment. This includes structural sanitation, housekeeping and maintenance, and landscape design and maintenance practices. Another focus of this approach is overcoming psychological and institutional barriers through targeted outreach. This non-chemical approach encourages planning, designing and maintaining facilities and surrounding landscapes, controlling the flow of goods and services, and improving the personal habits of the occupants of buildings. Together, these strategies are believed to eliminate or reduce sources of food, water and harbourage that are available to pests, and limit pest access into and throughout buildings, thereby promoting a healthy environment while minimizing pest problems.

In 2002, during the implementation phase of the countywide IPM programme, it was evident that a need existed within the 36 county departments (housed in 188 plus facilities) for more than just information on pests and use of pesticides to control them. This need brought about a new initiative and led to the development of a new programme based on IPM principles that could be governed digitally. In the beginning, the facility maintenance groups and pest control service providers were faced with limited information on pests from manual paper-based data logs and no data logic to provide a birds-eye view of real problems. It was observed that pest control activity was often of more of a reactive nature to solving day-to-day pest activities, and without any long-term strategy to prevent recurrence. This exposed the limitation of a paper-based system that can only be organized in a single way. Data could not be easily searched, modified, accessed remotely, conveniently cross-referenced, maintained, updated and protected. Moreover it was impossible to expand data without considerable effort. Apart from these considerations, there were issues related to psychological resistance to change, loss of authority, resistance to learning new technologies, and general fear of the failure of an IPM programme. The fears were that IPM might restrict use and access to pesticides, and that it might be more expensive than traditional pest control.

It was difficult to quickly collate hundreds of paper documents or data containing previous information and a history of the sites that could give the primary reasons for pest activity. The lack of aggregate data also prevented analysis for the efficient control of pests and the prevention of recurrence without using pesticides. The pest control actions were more reactive than preventive. It was also very difficult and time-consuming to determine caller locations and pest issues that spread across over 180 buildings that were equivalent to an area of 10.64 million ft^2 and situated over more than a 50 mile radius throughout the county. So, using the manual system limited the creation of strategies to deal with pest issues in the long term – an essential requirement for the success of an IPM programme. Because of this, a complete data management system was essential to address the following:

1. Understanding the complex pest management issues that go beyond pests and pesticide use.
2. Creating or modifying and making available life-cycle cost budgets to address pest management issues through improvements in sanitation, housekeeping and maintenance of structures and landscapes.
3. Educating policy makers, budget managers, facility management groups and 16,000 plus staff, and making them aware of complex pest management

issues in order to seek their assistance in overcoming psychological and institutional barriers.

4. Improving response time and incident handling.
5. Accommodating IPM programmes on a daily business basis.

Application of Digital Governance Technologies

The solution to overcoming the limitations of conventional (paper) methods was the use of digital governance (DG) technologies, and the county began to develop tools for a digitally governed IPM programme. The use of digital governance technology in complex programme/project management increases communication between both individuals and institutions (see Fig. 5.1).

Some of the operational/management benefits of digital governance are:

- Information is acquired, analysed and used strategically for programme purposes.
- Well-informed decision making is informed by this timely information.

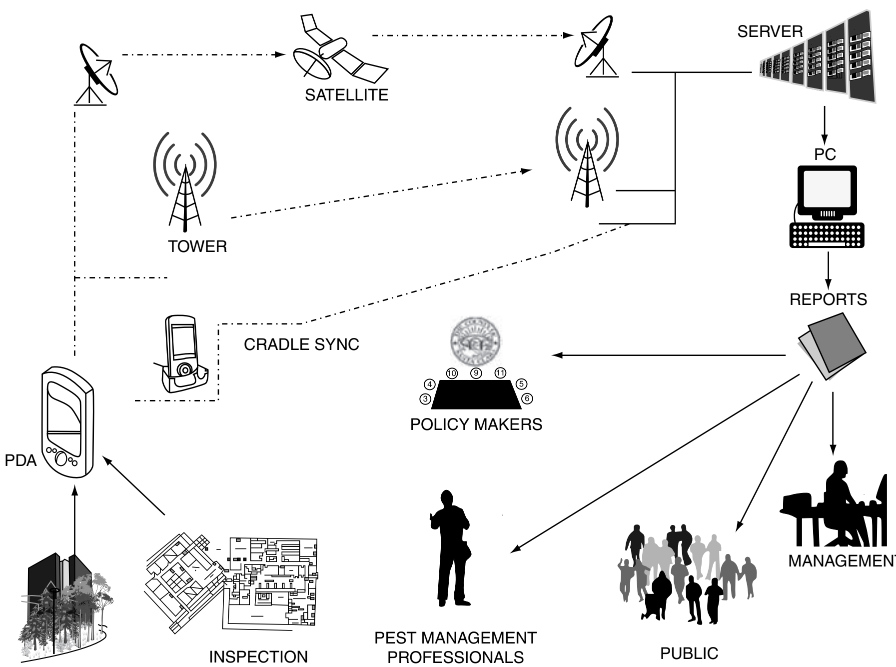


Fig. 5.1. PDA-based pest control inspections and data flow.

- Automation of repetitive tasks simplifies and streamlines complex multi-jurisdictional projects, and improves efficiency, consistency, performance, productivity and reporting by reducing the time and risk of clerical errors, decreasing the cost of governance processes and reducing the time and energy required to maintain data and documents.
- Existing efforts and processes are complemented to improve governance.
- New mechanisms are initiated resulting in improved service delivery.
- User groups are made more responsive to everyone's needs.
- Paper usage in data maintenance is reduced.

The digital governance tools that have already been developed or are under development consist of:

1. An informative web site.
2. Relational databases that include: (i) a service index facility; (ii) a monitoring device layout map facility; (iii) PDA (personal digital assistant)-based field inspection software; (iv) an IPM pesticide use reporting database (IPM-PUR); and (v) the integration of GIS/GPS (geographical information system, global positioning system) into PDA-based field inspection software and IPM-PUR (under consideration).
3. A virtual IPM training platform (design under development).

An informative web site

The informative web site provides essential information and facilities that include:

1. Provision of a cheaper and more flexible resource than print media which serves as an information clearing house and is flexible enough to update or include additional data sets when they become available.
2. Convenience of research on subject matter that breaks through geographical barriers and reaches a wider audience in real time.
3. Facilitation of the distribution of a vast array of information through hyperlinks.

The County of Santa Clara IPM web site (http://IPM.sccgov.org) is designed to meet all the above objectives. The web architecture is designed in such a manner as to make it easy to navigate, learn, find and incorporate a huge body of data or information into useful and meaningful segments. The web site is organized into several sections; its structure is outlined in Table 5.1.

Table 5.1. The structure of the Santa Clara County (SCC) California integrated pest management (IPM) web site.

Primary channels	Sub-channels 1	Sub-channels 2
Background	Purpose	
	Benefits of IPM	
	Strategy	
	Technical Advisory Group	
	Target audience	
Resources	Reasons for IPM	Pesticide use
		Risk and public perception
	Legislative policy framework	Pesticide and pest management regulatory agencies
		Pesticide and pest management laws, act and regulations
		General material and local government IPM ordinances, by-laws, policies, guidelines and reports
	Best practices	IPM in general
		IPM for invasive pests
		Pesticide safety education and pest management
		IPM for public health pests
		IVM for rights-of-way
		Structural IPM
		Sustainable urban landscape, plant health care (PHC) and IPM
		IPM guidance manual for facility managers and building occupants
		Santa Clara County's IPM administrative guidelines and procedures
		Outreach tools
Connect with experts	Information sharing tools	
	Connect with experts	
What's new		
Feedback		

Relational databases

Site-specific inspection and accurate problem identification are the critical first steps before any pest control application is made. This knowledge is important in the success of the IPM programme. Besides pest biology, structural IPM professionals and facility management groups must also know how to develop a site survey and IPM plan, monitor pest populations and assist the customer in habitat modifications by improving structural and landscape designs, sanitation, housekeeping and maintenance. Relational databases were developed to accomplish these tasks. The databases include several facilities: a site service index facility; a monitoring device layout map facility; PDA-based field inspection software, bar-code scanners and Web-based applications for the conduct of structural IPM inspections; a Web-based IPM activities and pesticide use reporting system (IPM-PUR); and GIS–GPS applications. Adoption of this database set-up is a move from primarily paper-based methods of pest traceability to consolidated digital methods that provide greater immediacy and accessibility of temporal and spatial pest data. The five main components are described separately below.

The service index facility

The service index is a tailored guide that dissects an entire site (building or number of buildings and its various segments) and allows the technician to focus service frequencies/resources on likely areas of pest activity. This helps to use the time efficiently while on service and makes the pest management programme successful and competitive.

Not all of the area of a building requires detailed inspection on each service visit. Some areas need more frequent attention than others. For example, food service areas receiving storage may require weekly inspection whereas the roofs of offices may only require monthly or quarterly inspections.

Pest management professionals who know the behaviours of their target pest species are more efficient and effective in controlling those pests than those who do not. Knowing common travel routes and typical breeding, hiding and feeding places helps the professional conduct a focused inspection. Instead of wasting time looking where the pest probably is not, he/she can spend the time looking where the pest is most likely to be. Once these areas are located, controlling the pest is also more effective when treatments are targeted where the pest spends time the most. Furthermore, this enables the professional to explain better to the customer both the cause of infestation and the reasons for the control measures prescribed.

A service index is commonly written for a large facility, normally by the technical officer in consultation with a technical group. This is written before the start of a new service, and is reviewed and revised periodically during quality assurance audits of the site.

The monitoring device layout map facility

A floor plan facilitates both the performance of pest control services by the service group and easy reporting of those services. Floor plans are primarily used to indicate the location of pest control traps and devices; knowledge of this layout assists service personnel in conducting systematic inspection and reporting.

When a report contains numerous service-related (sanitation, housekeeping, maintenance or treatment) observations, it is better to use floor plans that highlight the areas of concern. These areas can then be synchronized with the narrative report and help the technician and the customer to make the necessary follow ups without getting lost in the script.

The PDA-based field inspection software

The following are the benefits and advantages of using PDA-based digital governance technology in the performance of structural IPM:

- Accountability for work done, time spent on site and observations made.
- Transparency of service, giving the IPM professional the control to effectively monitor and track exactly what is being done on site in real time.
- Transition of all information from the PDA to tables and graphs, which allows the system operator and the client to monitor infestation levels.
- Time stamps of each station inspected, which can be monitored whenever the IPM professional scans the bar code attached to that station.
- Data analysis and trend identification.
- More efficient implementation of a systematic way of inspecting and monitoring, as designed under the general IPM plan/service index in the PDA.
- The setting of pest parameters for instant alerts when pest thresholds are breached.
- Information to use in examining and deciding which pesticides (if these are used at all) account most for any pest increase, and the underlying causes of this increase – factors that are important for identifying emerging pest management challenges and focusing attention on strategies for their resolution.
- The development of a service index which is versatile and can be modified to cater for the requirements and specifications of various sites.
- Provision of data capture in real time, and presentation in a manner that illustrates conditions conducive to pests – the primary and the most important element of any pest control service.
- Provision of information to clients (facility management groups) in real time and in a snapshot on conditions conducive to pests in order to assist pest control operators in solving pest problems and preventing their recurrence.
- Management by pest control operators of multiple sites, including monitoring stations, defining the job, scheduling and executing tasks, and generating reports and follow up.
- A facility for the Department IPM Coordinator to monitor and educate building occupants, budget managers and policy makers concerning their roles in pest management and related environmental issues.

In 2008, the Santa Clara County IPM programme, in collaboration with the structural IPM contractor, implemented a trial using PDA-based software, bar-code scanners and Web-based applications to conduct structural IPM inspections. This successful trial was followed by a full-scale adoption of the GG method in 2009. As already noted, the adoption of this technology is a move from primarily paper-based methods of pest traceability to consolidated digital methods that provide greater immediacy and accessibility of temporal and spatial pest data. In practice, the Internet-PDA-based inspection tool collects field observations on a unique hand-held PDA platform synchronizing those data to an Internet-based server, then allowing a data modelling tool to track trends, and predict and counter potential problems before they can become serious. The data and reports are now made available to Department IPM coordinators/facility managers through desktop application for the analysis of pest trends and spatial distribution, and for rapid response and mitigation efforts for sanitation, housekeeping and maintenance. The structural pest management system has become a 'living document' that can be modified as gains are made in experience, new information and/or technology.

The IPM pesticide use reporting database

The IPM and pesticide use reporting system (IPM-PUR) is a Web-based relational database that provides a framework and user data entry process. This can provide analytical tools for IPM decision making processes, including cost-economics, worker safety information, environmental data, compliance with signage posting, and regulatory reports and data for structural and non-agricultural pest management.

The need for the IPM-PUR database was felt as all sustainable pest management requires an integrated approach. Pesticides are among many tools used in IPM. The main focus of non-agricultural and structural pest management is on pesticide applications for rights of way, turf and landscape, rangelands and indoor areas. Understanding the initial distribution of pesticides in the environment at the landscape scale requires information on pesticide use practices. Timely data, such as the identity of pesticide, amount used, target pest and site can be enormously useful in the protection of both human and environmental health. Accurate information can help to provide better risk assessments and illuminate pest management practices that are particularly problematic so they can be targeted for the development of alternatives. In situations where more toxic chemicals must be used, the data will help managers to employ training and technologies specifically designed to protect applicators, workers and the environment. It is also useful in making short- and long-term policy and budgeting decisions related to IPM and best management practices.

The Santa Clara County's IPM Program, in collaboration with the County's Information Services Department, developed the IPM-PUR database, which can be described as a central data bank of pest management activities and (non-production agricultural and structural) pesticide use information that includes most of the data mentioned earlier. This will facilitate analytical reporting by applicators and departments focusing on pesticide use reduction, as well meeting all legal and administrative reporting requirements.

The IPM-PUR system offers a range of useful features that have minimized (after initial set-up of the site/location file) the amount of time and efforts necessary to prepare a pest management activity report. These features include:

- Password protection and encryption.
- Auto search engines for name of operator, applicators, pesticide products by name and EPA number, pest, pest control categories and site by name or street address.

- Ability to create customized lists of inventory by each user group.
- Ability to use previously created applications as a template for a new entry, to edit/view work orders and report features and to review/approval/rejection/notes/email communication features.
- Ability to sort and search previous applications by reference numbers, user group, operator name, site address and application date.
- Ability to calculate pesticide rate of application, quantity, dilution rate, area, cost, alternatives, labour, etc.
- Ability to review label and material safety data sheet (MSDS), site road map, GIS/GPS map.
- Ability to capture and report information, including pest control recommendations, site information (descriptions of location and sub-location), target pest, pest management operator and pesticide applicator information, chemical and non-chemical materials used, application method, worker safety information, environmental safety information and cost analysis (labour and materials).

Other requested fields (not mandatory) available in the reporting system include information on weather conditions, neighbouring locations, protective equipment used, nearby wells, sensitive areas (water, wetlands, schools) and water application. The system also has the capability of generating a variety of reports, such as pest control recommendation (PCR), notice of intent to apply restricted materials, pesticide use reports (PURs), monthly summary pesticide use reports (state reports) and business reports (periodic – pesticide applications by pest, pesticide, category, location; county departments, etc.).

The system is designed with everyday users in mind. It is Web based, so one does not need software installation. It is easy to use, and enables departments and contractors to enter data at their work stations, seek approval on pest management activities needed and monitor pest management activities. Moreover, pesticide use by each application, site, location, purpose and associated cost can also be entered. All of these facets allow an analytical and strategic shift from chemical to non-chemical pest management.

Integration of the GIS/GPS into PDA-based inspection software and the IPM-PUR database

Still under consideration is the full integration of the SCC IPM-PURs with a GIS so that pest monitoring and control activities, including pesticide use, can be visually displayed on maps. Some of the benefits of this integration would be as follows:

- Staff could review any area/location/site on the map simultaneously without having to trade paper maps.
- Staff could make any changes to maps, additions/deletions of monitoring locations could be made in minutes and the digital map would be immediately current, as opposed to using a paper map with dated information.

- Digital maps are electronic and can be printed at any time if paper copies are lost, soiled, or torn.
- Pest activity or breeding sites could be displayed on the interactive map and all data associated with the sites could be reviewed by all participating/concerned individuals or groups.
- Areas of concern could be updated and kept current through daily routines.
- Spatial relationships could be derived concerning pest breeding sites, and promptly addressed. Staff could easily locate all needed data layers, when responding to a pest management issue, and the resulting work order could be created and verified in a single step.
- An integrated system would also address public safety issues, as the spread of pests could be more accurately predicted and controlled. Spatial relationships concerning breeding sites could be expanded to include notification and preventive treatment. Pest breeding sites beyond facilities could also be identified: what are those breeding sites like; what control needs to be used; who needs to be notified; whose cooperation from the neighbourhood is needed; who needs to notify in the case of pesticide applications.
- An integrated system would also allow information on pest activities to be collected, stored, manipulated and analysed.
- Staff would have more time to spend on conducting field investigation and less time redoing paperwork.
- All this would be reflected in financial saving, as control methods could be used more wisely and efficiently.

A virtual IPM training platform

Also still to be developed is the facility to provide online training which offers ‘anytime, anyplace, and any pace’ instructions. This could be organized and delivered in a consistent format, and produce measurable results. Training could be updated regularly to reflect industry standards, thus helping pest control professionals to build content mastery and troubleshooting skills. Above all, online training is cheaper, faster and easier to deliver than conventional training.

This E-learning platform would:

- Provide users’ with the necessary training materials and interactive learning opportunities, and help them to understand complex pest management issues and make environmentally friendly decisions.
- Help pest control professionals prepare for certification to meet continuing trade-related education requirements.
- Track trainee progress online.
- Create a repository of quizzes, discussion forums, chats, profiles, etc.

Results

The successful outcome of implementing the Santa Clara County IPM digital governance programme not only allowed the maintenance of pest-free status but also resulted in significant achievements in reducing pesticide use in all structural IPM projects. The total number of pesticides, number of applications using pesticides, total pesticide volume and toxic exposure to pesticides has been reduced to 95% (Duggal, 2009). This can be called a 'minuscule use (statistically insignificant) of reduced risk pesticides' (see Figs 5.2, 5.3 and 5.4). The 5 year performance data also recorded a steady decline in service-related complaints, which made up only 7% over the total of the 180 buildings; these complaints were identified as from a court complex, hospital complex and correctional facilities, all areas receiving a high influx of people and goods (Duggal and Siddiqi, 2008).

The programme has also significantly increased dependence on non-chemical alternatives for pest control. Regular site inspections, followed by education of building occupants, sanitation, housekeeping and maintenance improvements, have helped to alter many pest situations which would have otherwise resulted in pesticide applications. Figure 5.5 provides some examples of this.

Another outcome of the application of digital governance technology has been to give the IPM service provider more accountability for work done, time spent on site and observations made. It has also provided an unparalleled transparency of service, giving the IPM professional the control both to effectively monitor and to track exactly what is being done on site in real time. In addition all information from the PDA can be translated to tables and graphs for easy comparison. The PDA allows the system operator and the client to monitor the infestation levels through time-stamps from each station inspected, which can be monitored whenever the IPM professional scans the bar code attached to that station. The data collected can be analysed, and trending carried more quickly and efficiently.

Digital governance trains the IPM professional to follow a systematic way of inspecting and monitoring as designed under the general IPM plan/service index in the PDA. Uniform data collection and data input allow easy diagnosis. Digital governance also allows for the setting of pest parameters and instant alerts when these pest thresholds are breached. It provides information for examining which pesticides (if any) accounted for most of the increase, and the underlying causes of this increase. These factors are important in identifying emerging pest management challenges and focusing attention on strategies for their resolution. This mode of running an IPM programme was found to be both versatile and flexible because it can be modified to cater to the requirements and specifications of various industries.

In summary, the application of PDA-based digital governance technology in structural IPM has facilitated Santa Clara County's IPM Program by providing the following:

Pesticide Quantity lbs					
	2005	2006	2007	2008	2009
Eco-Exempt G					6.5
Sluggo Snail and Slub Bait					3
Mother Earth Granular Ant Bait	0.00			3.90	
Talstar Granular	0.50				
PT 565	0.16				
P.I		2.25			
Advance Ant Bait			6.94		0.69
EcoPco Acu	0.00	0.25	0.00	2.00	
Victor Wasp-Hornet Killer	0.42	6.75	5.75	2.50	
Perma-Dust Boric Acid	4.54	0.08	1.67	34.28	
Niban FG Orthoboric Acid	17.45	48.88	64.64	610.09	13.34
Maxforce Roach Bait Stations	0.27	0.34	1.28	1.11	0.02
Maxforce Roach Bait Gel	1.80	0.52	0.43	0.38	
Maxforce Ant Bait Gel	0.79	1.08	3.73	2.13	
Maxforce Ant Bait Stations	0.86	0.47	0.87	6.74	
Eco Exempt-D	4.44	5.94	0.66	0.00	
Drax Liquid Ant Bait	3.39	0.03	2.04	9.62	0.19
Contrac Blox	38.31	43.88	51.21	31.37	0.06
Borid	0.41	0.00	1.76	16.42	
Avert Dry Flowable Ant Bait	0.07	0.00	0.88	0.55	0.07

Fig. 5.2. Structural integrated pest management (IPM) for general pests in Santa Clara County IPM Program, 2002–2009. Pesticide use as dry formulations.

- Accountability for work done, time spent on site and observations made.
- Transparency of service, giving the IPM professional the control to effectively monitor and track exactly what is being done on site at a particular time.
- Transition of all information from the PDA to tables and graphs, which allows the system operator and the client to monitor infestation levels.
- Time stamps of each station inspected, which can be monitored whenever the IPM professional scans the bar code attached to that station.
- Data analysis and trend identification.
- More efficient implementation of a systematic way of inspecting and monitoring, as designed under the general IPM plan/service index in the PDA.
- The setting of pest parameters for instant alerts when pest thresholds are breached.
- Information to use in examining and deciding which pesticides (if these are used at all) account for most of any pest increase, and the underlying causes of this increase – factors that are important in identifying emerging

	Pesticide Quantity gal				
	2005	2006	2007	2008	2009
M-Pede					0.12
Pyronyl UL-100					0.02
Terro Ant Bait			0.00	2.46	6.75
Precor Concentrate			0.16		
Gourmet Ant Bait			2.02		
Sterifab			0.02		
OE-30 CONCENTRATE			8.00	12.00	
OE-30 FOAM	0.22		1.33	9.08	
Gentrol IGR	0.06	0.02	0.00	0.00	0.00
Eco Exempt 1-C	0.00	28.50	126.52	8.21	

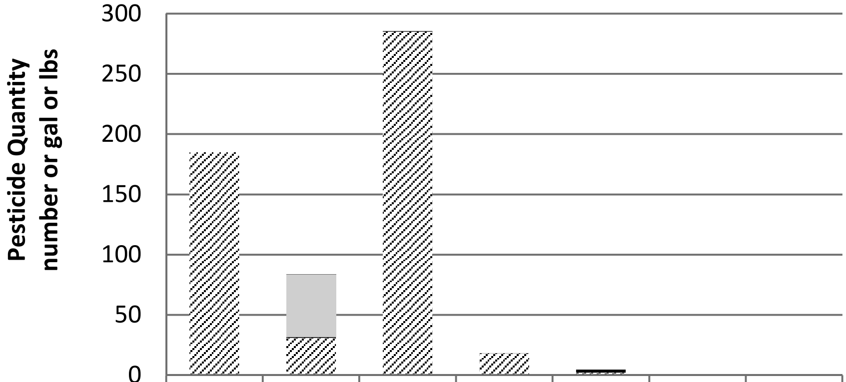
Fig. 5.3. Structural integrated pest management (IPM) for general pests in Santa Clara County IPM Program, 2002–2009. Pesticide use as liquid formulations.

pest management challenges and focusing attention on strategies for their resolution.

- The development of a service index which is versatile and can be modified to cater for the requirements and specifications of various sites.
- Provision of data capture in real time and presentation in a manner that illustrates conditions conducive to pests – the primary and most important element of any pest control service.
- Provision of information to clients (facility management groups) in real time and in a snapshot on conditions conducive to pests in order to assist pest control operators in solving pest problems and preventing their recurrence.
- Management by pest control operators of multiple sites, including monitoring stations, defining the job, scheduling and executing tasks, and generating reports and follow up.
- A facility for the Department IPM Coordinator to monitor and educate building occupants, budget managers and policy makers concerning their roles in pest management and related environmental issues.

Conclusion

Digital governance using a comprehensive relational data management system and informative web site is essential to implement an effective IPM programme, whether it is for a multi-jurisdictional, multi-project, area-wide pest management programme or for a pest control company. This type of governance can maintain accurate information on pest management activities, and accurate data help to prevent distortion of pest management practices, including pesticide use. Overestimates of risks and margins of safety can be replaced to



	2003	2005	2006	2007	2008	2009	2010
Termidor (gal)		0.07				0	0
Termicon Monitors (#)		52				0	0
Premise (gal)		0.68	0.62	0.11	2.49	0	0
Vikane (lb)	185	30.9	285	18	2	0	0

Fig. 5.4. Structural integrated pest management (IPM) for termites in Santa Clara County IPM Program, 2002–2009. Pesticide use as dry and wet formulations (or number of monitors).

avoid unnecessary cancellations or restrictions on pest control products and services. In addition, pest management professionals have the advantage of using the data to identify and reduce the costs of pesticide use, determine pesticide effectiveness, implement more efficient pest control practices and identify promising pesticide reduction practices.

Collected data on all pest control activities help researchers estimate human exposure to pesticides, which will give them a better and more thorough understanding of the risks associated with pesticide use. Moreover, regulatory agencies can use the data to compare facilities or geographical areas and identify areas of concern in order to evaluate the effectiveness of existing agricultural and environmental pest management programmes. Also, agencies can set regulatory priorities more efficiently, and track progress in pollution control and reduction. Finally, both the public and policy makers can use this information to identify potential concerns and gain a more realistic understanding of pesticide use and its potential risks, thereby reducing pesticide risks appropriately while providing a pest-free environment.

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Fig. 5.5. Examples of non-chemical and reduced-risk control measures: (a) controlling ants by precision baiting; (b) vacuuming to control ground-nesting wasps (yellow jackets); (c) use of enzymes to control small flies by cleaning drains; (d) use of steam to control wasps/bees; (e) rodent exclusion; (f) bird exclusion;

(g)

(h)

(i)

(j)

(k)

(l)

(g) use of cold temperature (refrigerator) to control cockroaches in returned electronic surveillance units; (h) midge exclusion by fixing HVAC (heating, ventilation or air conditioning) filters; (i) use of heat and dehumidifier to control psocids (booklice); (j) improving food storage practices in offices; (k) drywood termite control using heat and borates; and (l) improving landscaping practices to eliminate pest harbourage around office complexes.

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6 Community Integrated Pest Management with Special Reference to School Environments

Faith M. Oi

Summary

The area of pest management in schools began in the early to mid 1990s in the USA. The state of Florida was one of the first to initiate an integrated pest management (IPM) training programme focused on schools. Changes in people's perceptions of pesticides and modifications in the school facility use pattern – from traditional to multiple use – have necessitated changes in pest management practices. Several models for starting an IPM programme in schools exist, although the sustainability of these programmes remains problematic. Part of the challenge of developing a model for IPM in schools depends upon regional and local differences in pest pressure and acceptable pest management practices. Additionally, a sustainable IPM programme requires inter-agency cooperation which can be more challenging from one locality to another, although children's environmental health is said to be a priority in every state. Direct broadcast applications of pesticides do still occur in and around schools, and the exposure of children to pesticides has been implicated in childhood diseases such as asthma. While it is difficult to prove the link between chronic pesticide exposure and disease symptoms, it is prudent to minimize the risk of unnecessary pesticide exposure and the risk caused by pests through an IPM approach.

Introduction

The United Nations Children's Fund (UNICEF) reported that of over 2.2 billion children in the world, over a billion children live in poverty (Bellamy, 2005). A consistent goal for children worldwide has been access to education in safe learning environments. To attain this, child-friendly schools have to be built where children can access quality education, and this aim is listed in the

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'Convention of the Rights of the Child', Articles 28 and 29 (Bellamy, 2005; UNICEF, 2010). Still, over 100 million children worldwide do not have access to schools or education, but for those who do, schools are often promoted as 'zones of peace' and learning. In war-torn areas, pest control in schools is understandably not a priority, in contrast to some other areas, where pests are an important issue.

The need to have pest control in schools stems from the fact that children are often part of an 'at risk' population that is affected by pests and pesticides. A population at risk can be defined as 'a group of people who share a characteristic that causes each member to be susceptible to a particular event' (Mosby's Medical Dictionary, 2009). The lessons learned from pest control in schools can be a model for decreasing the risk of unnecessary pesticide exposure for other areas where at-risk populations are found in our communities. Children spend 30–40% of their day in the school environment for formal learning and after-school activities, so schools can be viewed as a place where large numbers of an 'at risk' population gather on an almost daily basis for a significant amount of time. Thus, in many communities, protecting children's health against the risk of pests and unnecessary pesticide use is a critical need. If pests are left unchecked or pest control methods are inappropriately applied, this population could be endangered. The solution to reducing the risk of pests and pesticides lies in the implementation of a verifiable integrated pest management (IPM) programme.

Verifiable IPM

Many hours and manuscript pages have been dedicated to defining IPM in both the agricultural and community settings. Suffice it to say that most would agree that the basis of a successful IPM programme is communication between the pest management professional (PMP) and the occupants. An IPM programme entails monitoring, identifying the pest, devising a control or management strategy based on the monitoring data and pest identification, followed by implementation and evaluation of the strategy. It also does not mean calendar spraying (applying pesticide on a fixed schedule as a prophylactic treatment) or treat without a reason. IPM does not mean that pest control products cannot be used (i.e. a non-chemical approach). Within the pest control industry, it is practiced on a continuum; at a minimum, one can verify whether IPM is being used if monitors are present, there is an absence of pest infestations (not just the occasional pest) and occupants know where to report a pest before it becomes a problem (communication).

The timing of the use of a pesticide is often the topic of debate. Some believe that pesticides should be used only as a last resort, while others believe that it is acceptable to concurrently use targeted applications where there is historically a problem, in combination with other interventions, such as sanitation, particularly with new chemistries. The concept of risk is often debated in terms of product selection. Risk due to a pesticide is best reduced by minimizing if not preventing exposure, regardless of the active ingredient involved. Thus, a targeted bait application holds far less risk than a broadcast spray application, even if the broadcast product is considered ‘green’.

IPM is intended to produce sustainable pest management. Its success is dependent on the cooperation of pest control operators and customers, which requires changes in people’s behaviour. IPM is sometimes referred to as ‘integrated people management’. Interestingly, in this context, many customers are willing to ‘go green’ without a clear definition of ‘green’; the word itself makes people feel good so they not only want to pay for the service, but also want to engage in it. Customer engagement is exactly what is needed for successful IPM programmes.

Verifiable IPM programmes are especially important for school facilities. There is growing evidence that green school buildings and efforts to improve indoor air quality in schools can have a significant impact on class attendance, learning and teacher retention (Schneider, 2002; Moglia, 2006). The need for IPM programmes in school facilities and in other areas where at-risk populations reside is based on two concerns: (i) the health effects of allowing pests to infest schools (or other areas); and (ii) the possible unintended effects of the pest management tactics used to control pests. The goals of IPM programmes for at-risk populations should be to balance the risks resulting from pests and pesticides.

Communication and education

A number of different health issues are involved with pest presence in buildings, and in schools in particular. Several common pests in schools are known to transmit pathogens in a structural setting. These include cockroaches, rodents, bats and birds (Hedges, 2004). Biting and stinging pests cause additional concerns, especially for children with allergic sensitivities to toxin proteins (Portnoy *et al*., 1999). Venomous arthropods, such as scorpions, spiders, wasps and bees, are commonly associated with schools across the country. In addition, certain arthropods, such as cockroaches, have been associated with allergens that can affect children, especially those with asthma (Rosenstreich *et al*., 1997; Arbes *et al*., 2005).

Many misconceptions on what IPM entails can discourage its potential adoption. Pest control is commonly viewed as a trivial but burdensome duty until there is a pest outbreak. There is a misguided belief that IPM costs significantly more money than other pest control methods and that adopting an IPM programme means that no chemicals are used. While it is true that an IPM service may initially cost more, the result is that the pest problem is solved because of the system of monitoring, treatment and communicating with the customer (Williams *et al*., 2005). Non-IPM services often consist of broadcast spraying on a routine basis without regard to pest presence and communication with the customer. The question that must be asked is: ‘Is it really saving money if a facility is paying for a non-IPM service that is believed to be less expensive but pests are not eliminated?’.

Sustainable pest control is preventing pest problems from occurring. The foundation of a successful IPM programme is education, and communication between the pest control technician and customer, so that both parties understand what behaviours contribute in preventing and causing pest problems. One way of opening lines of communication and education for IPM implementation is to let the school staff know that IPM is a simple process of 'doing what they are doing now, just think pests' (Lame, 2005). For example, the staff are responsible for security of the students. In order to carry out this responsibility, people are assigned to monitor property for any unauthorized personnel. If they monitor school property for people who do not belong on site, they can be asked to expand their monitoring to pests that do not belong on site. Spotting one cockroach and taking action is pest prevention; not knowing the cockroach has invaded and allowing the pest population to build over time is a pest problem. Another example involves energy conservation. Many schools are tasked with sealing buildings as part of energy conservation efforts. If buildings are properly sealed, pests also will be excluded and prevented from access. Building maintenance is an important and often overlooked component of pest management.

Another approach to IPM is by presenting it not as an extra duty, but as something that is already being done. This shift in attitude reduces resistance to implementation. However, there are instances when this rationale is not enough to motivate people. At times, clients in an IPM programme are resistant to decluttering and doing the sanitation necessary for sustainable pest control. Likewise, pest control technicians are not authorized to reorganize or throw away customer property. In such cases, sanitation as a principle component of the IPM programme is greatly compromised. A discussion of the details that may help to highlight the importance of sanitation and pest biology follows.

Emphasis on sanitation

Sanitation is pest management. Clutter helps to create a conducive condition for pest harbourage that allows pests to eat, rest and reproduce. It has been shown that light can penetrate the ootheca of an American cockroach and significantly reduce the weight of the subsequently emerging nymphs. Reduced fitness reduces survival and keeps the population in check. In 1976, Sandler and Solomon published a study in which newly dropped American cockroach ootheca were placed in a transparent vial and subjected to three light regimes. Environmental chambers were set to have light:dark (L:D) cycles (in hours) of 24L:0D; 12L:12D and 0L:24D. The results showed that translucent oothecae subject to light for 24 h resulted in nymphal weight of 2.83 mg compared with a more robust 3.87 mg when oothecae were held in complete darkness for 24 h. However, the L:D cycle did not significantly affect other factors, such as incubation time to emergence, number of nymphs produced and viability of the ootheca. Comparable observations were made by Solomon *et al.* (1977), who studied the nymphal development, maturation rate and longevity of the American cockroach when subjected to similar light cycles.

The results showed that cockroaches under 24 h of light died sooner. Thus, by eliminating clutter and increasing light, a decrease in the cockroach population can be achieved.

In addition to the above results, adult female German cockroaches were found to live for almost 13 days, even without food or water. However, if food and water are present, their longevity increased to 85 days. Moreover, the female American cockroach can live for almost 42 days without food and water, while the male can survive for about 28 days. The longevity of the American cockroaches increases to 190 days for females and 97 days for males in the presence of food and water. The longevity of other species of starved cockroaches is also detailed in Willis and Lewis (1957).

These facts provide plenty of reasons to hold sanitation as a key reason in cockroach management. In addition, sanitation further leads to success in implementing key IPM components such as:

- Making critical areas accessible and improving targeted treatments.
- Increasing the effectiveness of monitoring.
- Eliminating alternative food sources which directly compete with baits.

Significance of Cockroach Allergens

It is estimated that 26% of the general population in the USA reacts negatively to allergens of the German cockroach – the most common indoor cockroach (Arbes *et al*., 2005). Rosenstreich *et al* (1997) reported that 37% of children with asthma living in the inner city were sensitive to cockroach allergens; sensitization led to asthma and lost school days, lost days at work for caregivers and loss of sleep for both children and caregivers. It is worth noting that 12.8 million school days are lost per year owing to asthma alone (American Lung Association, 2010).

It was previously believed that cockroach allergens are very ‘stable’ materials, remaining on surfaces for many years in the absence of proper cleaning, so that pest control alone would not alleviate asthma symptoms. However, this thinking has changed lately. Recent evidence indicates that cockroach control alone can significantly reduce allergen levels, even below asthma trigger levels (Sever *et al*., 2007; Nalyanya *et al*., 2009).

The healthy human body is a wonderful fortress of defences. When these defences are invaded by antigens (allergens), antibodies are produced to fight the invaders. A cascade of events occurs via specialized cells that eventually unload histamines into our bodies, and these produce the symptoms of allergy (running nose, itching, etc.). That is why antihistamines work to quell allergy symptoms. Allergens from German and American cockroaches have been recognized in the World Health Organization/International Union of Immunological Societies nomenclatural system. This means that there is a specific nomenclature or official naming and numbering system for these allergens and their variants, so that scientists have a reference point.

The allergen often associated with the German cockroach in allergy studies is 'Blattella germanica allergen 1' or 'Bla g 1'. The antibody produced by our bodies after exposure to Bla g 1 is 'immunoglobulin E' ('IgE'), which is the antibody associated with allergic reactions (there are other immunoglobulins that contribute to our immune system as well). Anywhere from 30–70% of people who have been exposed to Bla g 1 have detectable IgE antibody levels in skin allergy tests. In fact, there are seven Bla gs associated with the German cockroach, some producing stronger allergic reactions than others. Bla g 1 is associated with part of the cockroach midgut (Gore and Schal, 2007). An increase in cockroach feeding results in an increased excretion of Bla g 1, and females tend to excrete more Bla g 1 than males, except during gestation, when feeding decreases. The Bla g 1 output of one female German cockroach is estimated as (Schal, 2008):

- 1 faecal pellet = ~1 mg
- 1 mg faeces = 500 units Bla g 1
- 1 female produces about 3 mg faeces a day
- Therefore, in 1 day, a female can produce ~1500 units of Bla g 1.

Moreover, the human sensitization threshold is estimated to be about 2 units of Bla g 1 and the threshold for illness is about 8 units of Bla g 1. Thus, there is a need to reduce cockroach infestation and, consequently, allergens from indoor environments.

Case study

The theory that pest control can help to reduce indoor allergens by reducing the cockroach population has been reviewed by various researchers (Sever *et al.*, 2007; Nalyanya *et al.*, 2009; Schal, 2009). To test this theory, researchers selected 60 homes from a pool of 150, with German cockroach populations ranging from 50 to 1000, based on trap counts (Sever *et al.*, 2007). Allergen loads were measured after 0, 6 and 12 months via vacuum dust samples taken by a trained technician from the floors of the kitchen, living room and bedroom, and by a bed, from all 60 of the houses. The study divided homes into three treatment groups. None of the occupants were instructed to clean their homes or were given additional education on cockroach pest management.

The first treatment group consisted of 20 homes, which were monitored and treated by university entomologists using sticky traps and gel baits. Treatments were done at 0, 1, 3, 6 and 9 months in areas of infestation as indicated by trap counts. The second group consisted of 20 homes and was treated by commercial pest control companies that were screened for the job. None of the companies were informed that the work was part of a study so as not to bias their usual pest control practices. The companies followed their own policy for treating homes. All of them used hydramethylnon-based gel baits, but not as a stand-alone treatment. Three companies used an insect growth regulator, three companies used synergized pyrethrins and two companies used pyrethroid sprays. The annual contract of two companies included 12 visits, one company included seven visits and one company included four visits. Educational material that a company would usually provide to residents was allowed, but there were no further instructions from the study staff. The third treatment group consisted of 20 homes and these remained untreated and served as the control. The houses were all monitored regularly, and each received a complete treatment by the university entomologists at the end of the study.

Results

The results from the study showed that the houses treated by university entomologists resulted in the most complete control, with a 99.9% reduction in cockroach populations by 6 months. Control was sustained over a 12 month period. In comparison, cockroach populations treated by pest control companies had decreased by 83.5% at the end of the 12 month study period, while untreated control homes experienced a 30% reduction in their cockroach populations. In homes treated by the university entomologists, the reduction in cockroach populations also resulted in a significant decrease in allergen loads of Bla g 1. Allergens decreased by 90% in the kitchen area treated by university entomologists compared with a 35% reduction in the kitchen area treated by the pest control companies. Homes treated by the pest control companies in this study did not have significantly reduced allergen loads from the untreated control homes.

Based on the results obtained, the researchers believed that the reasons behind the differences in cockroach populations and allergen reductions had to do with cockroach monitoring. None of the pest control companies used monitors, while the university entomologists used a layout map of the home so that they knew where the problem areas were and where to target treatments. Treatments by the university entomologists also relied purely on bait application while, in contrast, the pest control companies used calendar-based methods, including less bait, monthly spraying and dusts applied to skirting boards (baseboards) and in cracks and crevices.

Cost and time for treatment

The total cost for cockroach control done by the university entomologists was US$281, compared with a median cost of US$475 for a 12 month contract with a pest control company. The breakdown of cost for the pest control done by the university entomologists was as follows:

- US$80 for bait placement
- US$201 for cockroach traps, labour for placing the traps, retrieving the traps and counting the trapped cockroaches.

It took university entomologists 1.5 h to do the initial treatment, including mapping and monitor placement, while the follow-up visits ranged from 15 to 30 min per house. So in this study, the university entomologists, using the principles of IPM, provided a significantly greater reduction in cockroach populations (99.9%) than the pest control companies, who were following standard business practices and provided an 83.5% reduction in cockroach populations.

The Impact of Pesticides

While the effects of pests (cockroaches and others) are clearly defined, the effects of pesticide use and misuse are poorly understood. Pesticide poisoning can be attributed to 'acute' and 'chronic' toxicity. Acute toxicity can be seen a few minutes to hours after exposure, while chronic toxicity may take years to become evident. As such, the link between children's health issues and pesticides is difficult to prove, although pesticides have been implicated in a number of such issues, including asthma and other respiratory symptoms (Salameh *et al.*, 2003; Salam *et al.*, 2004,), endocrine disruption and cognitive impairment (Guillette *et al.*, 1998), and other possible developmental impacts (Whyatt *et al.*, 2004). Also, the effects of acute poisoning in schools have been surveyed (US GAO, 1999; Alarcon *et al.*, 2005).

Understanding pesticide risk entails grasping the concept of 'acceptable risk', which has been defined by the US Environmental Agency (EPA) as the 'level of risk judged to be outweighed by corresponding benefits or one that is of such a degree, that it is considered to pose minimal potential for adverse effects'. Acceptable risk describes the likelihood of an event causing harm to be so small that its benefit outweighs the potential negative impact. This makes society willing to take the risk. A common example is pesticide use. What is the common level of acceptable risk? Many regulatory agencies use 'a million to one' lifetime risks as a level to determine acceptable risk.

Survey on exposure of children to pesticides

Alarcon *et al*. (2005) caused a stir for the pest control industry in the USA. The news reports based on their 2005 publication indicated that there were 7.4 cases of acute pesticide illness per million children and 27.3 cases per million school employees. These figures far exceeded the one in a million acceptable risk levels already noted. Fortunately, the authors presented the data in such a way that the numbers could be examined. In summary, from 1998 to 2002, some 2593 people suffered 'acute pesticide-related illnesses associated with exposure at schools'. These data came from three separate databases: the Toxic Exposure Surveillance System (TESS), the California Department of Pesticide Regulation (CDPR) and the Sentinel Event Notification System for Occupational Risks (SENSOR). The TESS database collected information from 67 poison control centres that covered every state except Hawaii, but also included the District of Columbia. The SENSOR data were collected from California, Washington, Texas, Florida, Louisiana, New York, Oregon and Michigan, while the CDPR data were from California. Only 13% of the cases in the TESS database were called in by physicians diagnosing pesticide exposure as the probable cause of illness. The rest (87%) came from patients or their relatives. Furthermore, cases reported to TESS were primarily non-work related cases.

Incidents reported to the SENSOR and CDPR databases were primarily work-related cases. The significance of these data lies in the fact that the incidents were separated into those related to pesticides applied on school grounds versus those related to pesticide drift from surrounding agricultural lands. A state surveillance professional (SENSOR, CDPR) or poison control centre specialist (TESS) determined whether symptoms were consistent with the known toxicological effects of the pesticide after exposure. This assumed that the pesticide product was known. The person collecting the information from these agencies could not determine whether the symptoms being described were from the flu or whether they resulted from pesticide exposure in school or from an application done at home. A summary and re-evaluation of the data were revealing, and showed:

- 895 cases (35%) were from insecticides
- 830 (30%) were from disinfectants
- 335 (13%) were from repellents (moth balls, DEET)
- 279 (11%) were from herbicides
- 102 (3.9%) were from fungicides
- 93 (3.6%) were from rodenticides
- 10 (0.4%) were from fumigants
- 49 (1.9%) were from other products.

Disinfectants and repellents are not products that the pest control industry typically uses. By assuming that the 2593 people reported as suffering from 'acute pesticide-related illnesses associated with exposure at schools' are valid cases of illness, and subtracting those illnesses due to disinfectants and repellents, about 43% of the cases were eliminated. This resulted in 1428 cases that can be considered as 'pesticide-related' exposures from all three databases.

The TESS database cannot be considered in determining the pesticide exposures of children allegedly due to applications at schools because the data came in from 67 poison control centres across the USA. Clearly, it sported the largest contribution of data, with 2187 cases, but the TESS data were not separated by acute-illness due to 'on-site' applications at schools versus illness potentially resulting from agricultural drift, while the SENSOR and CDPR data sets were so separated. The drawback in eliminating the TESS data set is that it leaves only 406 reported cases; this is still not trivial, but it is much smaller. So the 406 SENSOR and CDPR cases were used to determine the subject (student or staff member) being exposed and the reason (agricultural drift or school application). Of these cases, 281 cases were reported after an application of pesticide on the school grounds, and were not due to drift or other reasons. In fact, 31% of the cases in these databases were due to drift. The analysis using the 406 cases indicated the following:

- 156 (55.5%) of cases were from insecticides
- 99 (35.2%) of cases were from disinfectants
- 20 (7.1%) of cases were from herbicides
- 0 (0%) of cases were from fumigants
- 3 (1.1%) of cases were from repellents
- 3 (1.1%) of cases were from other products.

By subtracting the number of cases due to disinfectants and repellents, 179 (281 – 99 – 3 = 179) cases were attributed to application of pesticides on school grounds. This is a much smaller number than the 2593 cases reported in the article.

In conclusion, the acute illness incidence rate reported as 7.4 in 1 million children included pesticide drift, disinfectants, repellents and other products not usually associated with structural pest control applications. To arrive at 7.4 in one million, Alarcon *et al.* (2005) used the 1972 children reported as ill, and divided it by 265,738,476 total contacts from 1998–2002. However, the present analysis led us to 179 confirmed cases (adults and children) without cases of drift, disinfectants and repellents. Thus, 179 cases divided by 265,738,476 contacts = 0.67 cases per million. This number is within the range of acceptable risk.

While reported illnesses due to pesticide exposure in children are low, precautions and reducing unnecessary exposure are advisable. In this respect, a new series of studies are beginning to emerge with information on the potential biological effects of pesticides on newborn infants. The case study below is one of a series of articles that is building the case against older chemistries.

Potential impacts of pesticides on newborn babies

A study by Whyatt *et al.* (2004) attempted to link chlorpyrifos and diazinon exposure to decreased fetal growth. Whenever researchers do a study on human health, it is very important to understand the population that forms part of the study. Behavioural, cultural and environmental factors have an impact on the research outcome. The population in the study by Whyatt *et al.* (2004) was composed of 314 mother and baby pairs from Washington Heights or Harlem (New York), and were either African American or Dominican. The mothers volunteered to commit to a 45 min interview during their third trimester of pregnancy. They were excluded if they smoked or used other tobacco products, used illicit drugs, had diabetes, hypertension or HIV, or had had their first prenatal visit after 20 weeks of pregnancy. In other words, the mothers were eliminated if they participated in behaviours or had conditions that were known to also contribute to decreased birth weight, length and head circumference.

As part of the survey, the mothers were questioned on the physical condition of the apartments, pest problems and their pest control practices. All the babies were delivered in the years 1998 and 2002. Data were separated based on interviews done before and after 2001, the effective date separating the period when chlorpyrifos was being used, and when the US EPA phased out the residential use of chlorpyrifos. The researchers measured pesticide exposure using several measures by taking 'personal ambient air' samples, blood samples from mothers and umbilical cord blood from the babies at or very close to birth.

The findings of the study showed that before 2001, 85.6% of mothers reported using some form of pest control. Of the mothers reporting the use of some form of pest control, 56.5% reported using more than one highly toxic pest control method. A highly toxic pest control method was defined by the researchers as either using can sprays or pest bombs, and having sprays by pest exterminators. After 2001, 84.0% of mothers reported using some form of pest control with 54.5% using a highly toxic pest control method. Pesticide use patterns were not statistically different between the subjects.

After the data analysis, the researchers concluded that the association between the birth outcomes (weight, length or head circumference) and the organophosphate levels in maternal personal air samples was not statistically significant. Neither were significant associations revealed between the birth outcomes and maternal self-reported use of pest control methods during the pregnancy. In other words, pesticides in their living environment did not contribute to decreased birth weight or length.

However, the researchers then grouped the amounts of chlorpyrifos found in the umbilical cord plasma of the babies and formed four groups, as follows:

- Group 1 (31% of babies), pesticides were below the limits of detection. For the rest of the babies that had detectable limits of pesticides:
- Group 2 had the lowest amounts of pesticides
- Group 3 had middle amounts of pesticides
- Group 4 had the highest amounts of pesticides.

Analysis of these groups, led to the conclusion that there was a 'significant inverse association between birth weight and length in levels of the organophosphate in umbilical cord plasma' for babies born before 2001. In other words, the more pesticide detected in the umbilical cord plasma, the lower the birth weight and shorter the length of the baby. Specifically, babies with the highest amount of chlorpyrifos alone recovered from their umbilical cord blood (Group 4) weighed 150.1 g less and measured 0.75 cm less than babies with no pesticides detected in their umbilical cord plasma (Group 1). Babies with the highest amount of both chlorpyrifos and diazinon recovered from their umbilical cord plasma weighed 186.3 g less and measured 0.80 cm less than babies with no pesticides detected in their umbilical cord plasma. To put these data in context, the average weight of a baby born in the USA is around 3400 g.

This study showed that there are multiple factors that can contribute to why the pesticides chlorpyrifos and diazinon showed up in umbilical cord blood and maternal blood, including exposure, because these were applied in the home. A single factor, such as an indoor application, may not have been significant, but confounded with other factors, pesticide exposure can have a negative outcome in infants. In this particular study, self-reported pesticide use and maternal air samples did not significantly contribute to decreased birth weight and length of the babies. However, pesticides were recovered from maternal and umbilical cord blood, which means that babies were exposed to pesticides somehow.

Conclusion

Pest infestations and allergic reactions to pest exposures are common in schools and other facilities that children frequent. While it is difficult to definitively prove the link between chronic pesticide exposure and the presentation of disease symptoms, it is prudent to minimize the risk of unnecessary pesticide exposure as well as minimizing the risk caused by pests by using an IPM approach. The risk due to pesticide exposure can be minimized by the selection of application methods that target treatments, versus selecting a method that applies product in a broadcast fashion. The lessons learned from pest control in schools can be a model for decreasing the risk of unnecessary pesticide exposure in other areas where at-risk populations reside in our communities. Unfortunately, the overall progress towards complete adoption of IPM tactics and strategies has been slow (Lame, 2005). None the less, increasing adoption of IPM needs the help and full cooperation of pest control operators, who must provide their clients with information on pest biology and control in the context of an IPM strategy in order to gain customer compliance.

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7 Providing Integrated Pest Management to Multi-dwelling Low-income Housing

SAM BRYKS

Summary

Pest control in low-income housing, whether in private or publicly managed multi-dwelling structures has traditionally been at the low end of pest control service work in North America. Owing to the complexity of pest ecosystems in housing, this has resulted in chronic infestations of cockroaches, mice and, more recently, bed bugs. Control of cockroaches, notably the German cockroach (*Blatella germanicus*), by residual sprays on a repetitive basis was the mainstream treatment in the past – before the advent of the widespread use of baits. This resulted in the contamination of indoor environments. The health of children growing up in these settings was impaired, especially as a result of allergy and asthma from exposure to cockroach allergens, as well as potential exposure to insecticide residues. Starting in the 1980s, the control of the German cockroach was improved by the use of baits, but the development of resistance to baits, especially behavioural resistance (bait aversion) resulted in a reversion to spraying in this environment. More recently, low-income housing sites have become bed bug reservoirs because of failure of control as a consequence of poorly managed programmes contracted to the lowest bidder. The deployment of integrated pest management (IPM), with its sound knowledge-based foundation, offers a real prospect of sustainable elimination of common pests in the low-income housing setting and a significant reduction in pesticide use. This approach necessitates strong support from management and involvement of many stakeholders. As an innovation, IPM can be difficult to implement owing to resistance to change and the pressure of costs. Achieving the benefits of IPM requires the education of stakeholders, the support and leadership of managers at all levels, and the enrolment of staff and tenants in a cooperative effort.

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Introduction

A wide variety of dwellings provide housing for mixed populations of low-income citizens. These include low- and high-rise apartments, row and town houses as well as detached and semi-detached single family dwellings, some of which are converted into rooming houses. The majority of low-income housing is multi-dwelling, as this is cheaper to construct and easier to sustain. Multi-dwelling structures pose greater problems in pest management than single or semi-detached dwellings because of inherent variations in lifestyle, housekeeping and sanitary practices, as well as multi-occupancy. Further, the risk of imported pest infestation is greater. Cockroaches are commonly brought into the home in boxes from grocery shopping. This may represent a relatively rare occurrence in a single family dwelling, with a risk factor of once in 20 years, but at a site with 100 units, the risk factor increases by 100, representing five new infestations a year (Bryks, 2000).

In the past, the treatment of cockroaches and other insect pests by residual sprays on a repetitive basis was the mainstream treatment method that resulted in contaminated indoor environments. This had a negative effect on health of children, not only as a result of allergy and asthma from exposure to cockroach allergens, but also from exposure to insecticide residues (Kitch *et al*., 2000; Carter-Pokras *et al*., 2007). Starting in the 1980s, control of the German cockroach (*Blatella germanicus*), the major pest encountered, was improved by the use of baits. However, owing to the development of behavioural resistance and the slow action of this method (Wang *et al*., 2004), this improvement was temporary, and eventually led to a reversion to spraying in moderate-to-heavy infestations.

This chapter describes key issues in the management of pests in multi-dwelling housing environments, mainly with reference to North America, and includes the difficulties of achieving sustainable control by conventional approaches. The details and benefits of the successful implementation of integrated pest management (IPM) in housing through a cooperative approach are outlined.

Pests in Multi-dwelling Housing

The multi-dwelling housing environment is an urban ecosystem that provides a fertile habitat for a variety of pest species. While there is diversity in pest types depending on geography and location (urban or rural), the most common pests (cockroaches, mice, bed bugs and others) are found in human dwellings across the globe. The multi-dwelling setting is ideal for pest species as it provides them with the necessary requirements for success. These are harbourage, ambient climate, a source of moisture and an abundance of food resources. Preventive and control measures that are ineffective, for a wide range of reasons, aid pests in their survival and reproduction. These include failure to address environmental, structural and general maintenance issues. The lack of adequate pest control services adds to the potential for success of the pests

(Bashir, 2002; Chew *et al.*, 2006; Wang *et al.*, 2008). The most common of all pests in housing, notwithstanding the current focus on bed bugs, are cockroaches – the cockroach has been the subject of many articles in pest control trade magazines and books in North America and Europe.

Cockroaches, mice and ants were the most common pests treated by the Metropolitan Toronto Housing Authority (MTHA) in Ontario from 1987 to 2000, as determined from service data records. Bed bug infestations were fewer than ten per year, on average (Bryks, 2008, historical service data records 1989–2000 from the MTHA). The annual frequency of service work orders for the most common pests from a number of non-profit buildings in Ontario in 2008 showed that the frequency of cockroach service requests remained the highest, while bed bug requests increased from less than 0.05 to 10% (Bryks, 2008, data from MHTA service records in various buildings prepared for a presentation).

Use of Integrated Pest Management (IPM) in Pest Control

The management of pests in multi-dwelling structures is often challenging. The more complex the structure in terms of number of units, the more difficult it is to eliminate the pest. Complexity of structure in terms of the number of individual units relates directly to the human population and their activities, which can contribute to the success of pests. This is evident when a unit becomes vacant or is kept empty for months, in which case it has been observed that even the most severe German cockroach infestation will eventually die out owing to lack of food and water.

The use of the term ‘action threshold’ represents a degree of infestation at which action is taken. This is often used in pest management to initiate treatment. The ‘economic injury level’ is also used to indicate a point at which pest control actions yield economic benefits as an investment (Higley and Pedigo, 1997). Some practitioners have characterized the term ‘action threshold’ also as ‘aesthetic injury level’ (AIL) in urban pest management. The action threshold and the AIL for common pests in a home is generally anything more than one, i.e. the detection of one pest – for example one cockroach or one mouse – is considered to reach the action threshold or AIL that can trigger an action. A study by Zungoli and Robinson (1984) showed that in the face of a history of severe infestations, people tend to tolerate some degree of infestation. It is, however, correct and advisable that the action threshold/AIL in homes be kept at one for pests that are capable of reproducing indoors and having an impact on human well-being. Occasional or seasonal harmless insect intruders are excluded from this because they cannot reproduce indoors. Action may be triggered as a result of revulsion for an occasional intruder such as the European earwig, but this should be a preventive approach, not using pesticides indoors.

IPM should be a mandatory conceptual approach for pest management. Without the methodology and conceptual soundness of IPM, sustainable control is practically impossible in multi-dwelling scenarios as a cost-effective programme.

Sustainable control implies a lot of effort in early detection and treatment, as well as a wide range of preventive measures, including sanitation, maintenance and best practices (Miller and Meek, 2004). One of the major goals of IPM, therefore, is sustainable control resulting in total elimination in the individual home without the need for excessive use of pesticides as a ‘quick fix’ for runaway infestations. IPM using action threshold or AIL as an early warning indicator is a useful strategy for structures, and the IPM model used in schools in North America remains an excellent example of how IPM can also be implemented in the housing sector. The activities of the IPM programmes of the US National Centre for Healthy Housing (NCHH) are reflective of common elements. The IPM school model also addresses key issues, such as resistance to innovation, that need to be overcome in order to enable IPM to succeed in the housing sector.

In North America, there has been a long-standing concern about the use of pesticides both in homes and in the urban environment. A literature review by The College of Family Physicians in Ontario (Sanborn *et al*., 2004) emphasized the potential risks of pesticides in the interior home environment. More recently, studies have shown the effects on children as a result of the exposure of mothers to pesticides during pregnancy (Barr *et al*., 2010). These findings make it very clear that housing providers and government regulatory agencies, as well as the pest management industry, must approach the use of pesticides in the interior environment more carefully. It is also clear that the historical primary reliance on spraying must be replaced by IPM practices. This has been the focus of the US Environment Protection Agency (EPA), and there is now pressure to implement IPM as a standard practice in public housing by the US Department of Housing and Urban Development (HUD). Some states have launched a lawsuit against the HUD to recover medical costs resulting from cases of asthma and to ensure that IPM is being executed in housing organizations supported by the HUD.

The National Pest Management Association (NPMA) in the USA, which is the largest professional pest control association, endorses IPM through the IPM Institute, although great difficulty remains in the practice of IPM in a real world situation. At times, IPM continues to exist in the simplistic form of inspection, identification and treatment (Baumann, 2010). A review report entitled ‘*Role of Pest Management in Environmental Health: A Guidance Document for Local Authorities*’ (Battersby *et al*., 2003), whose production was undertaken by the UK Chartered Institute of Environmental Health in the UK, identified practices and types of service delivery in more than 270 local housing authorities. The report concluded that there was a need for more education and consistency in standards and quality in service delivery, and placed a very strong emphasis on IPM as the only approach for safe, sustainable and long-term pest management.

Competitive Pest Control Services in Low-income Housing

Before the resurgence of bed bugs, the German cockroach had more attention as a worldwide pest in multi-dwelling housing. The common practices used for control of this cockroach set a low standard of approach, especially in low-income housing. Treatment was largely focused on spray application of insecticides in a 'soak the place' model. Dusting in voids, and fogging or ultra-low volume (ULV) application was common. The principle was to apply sufficient insecticide to kill most active stages and to depend on the residual effects to kill any emergent stages. Success was dependent on the extensive surface coverage. One of the most respected pest control firms in the USA using this kind of treatment, "Bugs" Burger Bug Killers, was known for offering exceptional guarantees of control in the hospitality and restaurant sector (Hart, 1988). The firm was also famous for 'firing' clients who did not cooperate according to its specific recommendations.

The 'soak the place' technique of treatment was superseded as best practice by the development of crack and crevice application methods (Gooch, 2004). Whitmire, the company that developed this treatment method, emphasized education of the applicators and use of detailed 3-D maps of critical treatment points. Many pest control firms continue to rely on the classic spray application methods to keep costs low as proper crack and crevice application requires much more time and meticulous attention to detail. The advent of cockroach baits, initially in bait stations in the 1980s, and some years later applied as gel bait in cracks and crevices, or as a spot treatment, gradually changed the approach to cockroach control. The acceptance of this approach however, was initially slow for low-income housing owing to the much higher costs compared with those of spray treatment. The fact that baits did not provide an instantaneous knock-down made their use unpopular, and spraying remains a traditional treatment for cockroach control to the present (Miller and Meek, 2004).

Some have suggested that pest threshold levels in low-income housing should be higher than in other type of housing, which implies that low-income tenants should accept chronic infestations. It has also been suggested that tenants be provided with low-toxicity products that are not classified as pesticides. Some of these products, such as cedar oil, kill bed bugs by direct contact but have not been subjected to usual efficacy testing. Further, the notion of tenants doing their own pesticide application increases risk dramatically and suggests that little skill is needed to provide pest control treatment. While tenants can do a great deal to help, the application of pesticides by tenants carries the risks of misapplication and over-application, and is not a sound recommendation.

Fundamental to all of this is the common knowledge that pest control services in low-income housing are often based on low-bid contracts. Pest control services in low-income housing are commonly managed either on complaints of severe infestation or by a reactive total building treatment that is sometimes included as part of the agreement. This scenario prevents implementation of the very basic elements of an IPM programme. Service work is often carried out as rushed jobs by technicians in order to meet job completion schedules related to production/performance demands. The pressure of low prices that do not provide adequate time or materials to inspect and treat units thus creates a no-win situation for pest control technicians, tenants and property management. This vicious cycle forces a total building treatment as a simplistic approach that lacks sustainability.

Model IPM Programme in Multi-dwelling Low-income Housing

One of the first IPM programmes in housing in North America was implemented by the MTHA in 1987. This was the result of a consultative process comprising the City of Toronto Public Health Department, pest control industry representatives, the Ministry of Housing, Ministry of Environment (provincial pesticide regulators) and the management of the MTHA. The need arose from concerns about difficulties and failure in managing cockroaches in the largest housing authority in Canada. The MTHA had previously hired contract pest control technicians but, owing to the intense workload, the MHTA faced frequent turnover of these staff and needed to rely mostly on low-bid contractors. Professor Gordon Surgeoner of Guelph University, was consulted, and prepared a recommendation and initial specification for a new programme. This included the hiring of a supervisor and four licensed structural exterminators working with MTHA property management staff to facilitate implementation of the IPM programme. Ensuring quality and adherence to service requirements was undertaken through random inspection of treated units as well as investigation of every received complaint. Contractors were involved in a consultative process on the treatment methods.

The first demand of the new programme was a request by the staff of a 121 unit high-rise building for a full building treatment for cockroaches. The number of tenants was small (less than five), but the perception was that the only way to control cockroaches was by treatment of all the units. The supervisor (the author) refused to consider treating the entire site by spraying without a knowledge-based assessment. Insect glue traps were placed in kitchens at specific locations and were retrieved within 48 h. The number of units with detected infestation was found to be less than five. The monitoring time with glue traps was subsequently extended to one week to ensure that even low-level infestation cases could be detected. If tenants were present, they were asked if they were aware of any infestations. Surprisingly, only a very small number of units showed infestation. Based on these findings, only the units with actual trap capture or those with reported sightings were treated. The rest of the units were treated with baits in stations. This was a striking example of the value of monitoring before undertaking a widespread treatment. 'Decision rules' for treatment were established based on the levels of infestation found on glue traps. Using this 'decision rule system', any exceptions, such as tenants reporting infestation in the absence of findings on glue traps, or confounding results (such as visible infestations in spite of low numbers on traps) were handled as a moderate infestation. This enabled reduction in the use of spray treatment by using bait stations. More emphasis was placed on the use of vacuuming to remove visible pockets of infestation, especially in severe cases, where spraying could not be performed owing to the risk of contamination. Treatment preparation protocols were developed to advise tenants of this new approach in which spraying was not offered as an optional choice, but was abandoned in all but exceptional cases.

The approach that had been developed was reported at the first Urban Pest Management Conference held in Maryland in 1990 (Bryks, 1990). The use of this type of approach – an IPM approach, and especially the use of decision rules in pest management in housing, had not been reported previously. Later, building-wide monitoring with glue traps was abandoned as a standard approach when spraying was no longer a standard control option, and was replaced by the use of tenant surveys as an evaluation of the status of infestation level. The option of visual monitoring for severe infestation cases was based on tenant survey findings, and also on the use of glue traps as an investigative tool in cases of unresolved infestations only. The programme succeeded in reducing both pesticide use and infestations dramatically.

Wang and Bennet (2010) in their chapter 'Least toxic strategies for managing German cockroaches' in the book *Pesticides in Household, Structural and Residential Pest Management*, outlined the available methods and reviewed studies on IPM compared with conventional methods. Their conclusion reflected this author's views and stated that 'Although the above experimental IPM programmes showed various advantages over the chemical-only method, voluntary IPM adoption is very limited. The initial high cost and the need for involvement of multiple parties in education, coordination, and record keeping make it less appealing to property management staff. When selecting a pest control contractor, property managers are compelled to select the lowest bid. Pest management companies often offer low bids in order to obtain a contract, and the low bid practice often does not provide effective pest reduction and long-term control'.

The evidence-based decision rule process

Decision rules can be very straightforward undertakings. Humans often live by decision rules in their daily activities. A well-known decision rule is obeying traffic lights. An example of an IPM decision rule is this: one cockroach is sufficient to require a pest control treatment in a home, but when does one treat an entire building for cockroaches?

These are both IPM decision rules based on evidence. In pest management, most decision rules of treatment for household pests are based on tenant requests or staff sightings. The rules can vary considerably depending on circumstances and are often related to costs, but the goal is to have a reasonable decision rule that will address the issue and enable an action that will eliminate and limit spread of infestation. As in the example noted earlier, treatment of an entire building of 121 units on the basis of three or four low-level infestations is not an appropriate cost-effective response. Inspection of all adjacent units to the infested units with appropriate actions is considered a more rational decision. Decision rules can also determine the type of treatment needed in individual units, or whether further investigations are needed.

In the case of bed bug infestations, would a full block monitoring be a cost-effective approach? A strategy of inspecting only units adjacent to the units to be treated would be most recommended. Monitoring after the treatment with appropriate detection approaches would yield information about the success of the treatment. This kind of approach takes into account both costs and practicalities. The use of bed bug detection dogs is a decision rule predicated upon noting that infestations have become widespread in a site across many floors based on the tracking of service requests, surveys, annual inspections and inspections of adjacent units. When a widespread infestation has been determined by these means, then the decision rule notes that bed bug detection dogs become the most cost-effective means of monitoring multiple units. Scent-detection dogs trained for bed bug detection are highly accurate in finding infestations (Pfiester *et al.*, 2008), but their use must be applied appropriately because of the cost of this method.

Education of stakeholders

The education of stakeholders is absolutely critical in implementing IPM programmes. Notwithstanding the historical difficulty of controlling cockroach infestations in low-income housing, the control of bed bugs is immensely more difficult, as the insects can be anywhere in a home once an infestation has become well established or has been disturbed. In contrast, German cockroach infestations do tend to follow set patterns, albeit with variation in the specific setting, but starting and spreading from the kitchen in a predictable way depending on the conditions. Although sanitation does not have an impact on the initiation of bed bug infestations as the food source is people, deteriorated housekeeping can render control practically impossible.

Education in IPM practice, therefore, must reach a wide audience of so-called stakeholders (those affected by infestations), including social workers, caregivers, property management and building staff, tenants and relatives. In the past, many of these staff/people considered pest control to be out of their sphere of responsibility. Housing Services Inc. (HSI), the maintenance division of the Toronto Community Housing Corporation, developed the concept of the IPM Chain of Accountability Programme (IPM-CAP) (Bryks, 2007). This emphasizes the roles of various stakeholders and the necessity that they are educated in their roles. Educating key staff and tenants in the importance of a cooperative effort, and emphasizing their accountability, are critical. For example, a caregiver needs to be aware of bed bugs and to know how to deal with an infestation both for self-protection and to advise appropriate contacts – such as families or supervisors – of the discovery of bed bugs or other pests. This awareness and early reporting is a key element in early treatment. The education of tenants about pest control services and the basic elements of IPM that they need to know, for example preparation details and preventive measures, are also critical. This approach has been facilitated in the Boston Housing Authority as described by the NCHH, by the training of IPM Educators or Facilitators to assist tenants (Condon *et al.*, 2007).

Condition and treatment reporting and follow-up monitoring

As noted earlier, there was a tendency in the housing sector to either mount an all-inclusive treatment of a multi-dwelling structure annually or to wait for requests for treatment, rather than rely on a carefully managed programme. An ideal IPM programme includes review and surveillance using such models as Deming's 'in process' checkpoints (Deming, 1982) or the Hazard Analysis Critical Control Points (HACCP) (CFIA, 2010) approach in the food industry. These are helpful tools enabling the early correction of deficiencies in the process to stop an ongoing failure in quality before it becomes a common outcome. An example of an HACCP or Deming approach in IPM would be the identification of high-risk locations for the introduction of pests into a structure, such as garbage areas, or identifying units in which the tenants need support, such as in cases of hoarding. A property manager may not be inclined to get involved in these scenarios, but management leadership is essential in ensuring that cleaning processes are defined and deficiencies reported by a pest management technician, ensuring that there is a process to make certain that tenants needing support are connected with support workers. These may not seem to be the roles of property management, but the fact is that non-profit or low-income housing serves people with special needs, and so building property management staff and administrators must be involved in handling these issues as part of an IPM model.

A well-managed IPM programme also involves addressing issues through a follow-up monitoring system. The term monitoring is suggestive of actual physical monitoring in a unit, using either a visual inspection or a detection device. Monitoring can also be implemented by calling a tenant at an appropriate time or sending a survey response form to tenants and encouraging them to report problems early and without fear. Contacting tenants in advance of treatment to confirm preparation requirements, or after treatment to ask if the problem has improved, is very beneficial. The use of trained tenants or staff as IPM educators or facilitators is another excellent approach first developed formally by the Boston Housing Authority. Reporting by contractors of key elements at the time of treatment is another form of monitoring as it determines key factors that can contribute to the failure or success of a treatment. This enables early action in a variety of ways; for example, in marshalling resources to address hoarding and/or clutter cases or ensuring that a senior citizen gets appropriate assistance to prepare for treatment. When this kind of practice is commonplace, it reduces fear and encourages tenants to report problems earlier, and also has an overall benefit in reducing the costs of treatment.

Key elements for standard reporting

While there are many levels of reporting in services, the process of IPM reporting of key factors of pest management services in housing has been fairly rare. Reporting processes have reached very sophisticated levels in the food and other commercial industries, where use is made of modern hand-held computer technology, including using bar-code scanners for documenting actual service activities. In contrast, this sort of reporting has not been used to any significant extent in low-income housing in the past. An electronic system using Palm PDA hand-held units has been used by contractors working for HSI, and the advent of more easily accessible wireless networks has made this much easier to accomplish ‘live’. This approach enables action through IPM decision rules. For example, reports can be generated from the pest control technician that identify and give details of all units with heavy infestations or poor housekeeping so that housing staff can address these issues.

Accessibility

Difficulties of accessibility are costly to contractors, and certainly degrade the quality of services as less time is available for treatment. Documentation of accessibility is therefore a most important element to track in order to ensure that poor accessibility does not impede the IPM programme, thereby wasting time. Some contractors do not actually send sufficient staff to treat all service requests as they expect cancellations owing to lack of access, which often result from a lack of preparedness of units for treatment. If the rate of cancellation is lower, then this can mean less time for treatment of units. Property management can reduce cancellations by a standard reminder processes, such as a phone call or a note a day or two before the service date. Management of cancellations should be taken seriously as this affects the quality of service, even though it may not seem to do so. It is better practice to ensure that the contractor provides sufficient staff on the presumption that all units will be treated, and to remind tenants of the forthcoming treatments and preparation requirements. If there are issues of access or lack of preparedness, then the contractor should be reimbursed for actual time at cancellation, and tenants can be charged appropriately.

Preparedness for treatment

Good preparation for treatment is critical in IPM. For example, cockroach control with baits is more difficult if sanitation is poor as any food spillages act as competition to the bait. Good preparation is a focus of IPM education, but it needs to be carefully documented to enable appropriate corrective actions. A process of reminding the tenant of the steps needed to prepare a unit supports the programme and is key to success. The Boston Housing Authority IPM Educator programme improved control success through ensuring that preparation for treatment was improved (Condon, 2007).

Housekeeping and sanitary conditions

Conditions of sanitation or housekeeping are critical to an IPM approach. When these factors are reported accurately, the report serves as a trigger to processes for corrective actions. In terms of managing pests in a multi-dwelling structure this is similar to an HACCP type of approach, as a unit that could harbour major infestations is a critical control point in enabling IPM success.

Degree of infestation

A simple system of reporting the degree of infestation indicates whether additional treatments are needed beyond the number planned. It also highlights special cases that need attention, such as hoarding. Handling one extreme case as a major pest reservoir, whether cockroaches or bed bugs, has significant impact in reducing the spread throughout a building. Pest population pressure in these extreme cases will guarantee spread. In addition, analysis of service requests offers an overview of infestation and enables treatment decisions on the basis of the distribution of infestation on floors, and the adjacency of infested units. Many units will not require any treatment, so there is a significant saving, while also targeting treatment in order to achieve elimination.

Details of treatment

The details of treatment is a legal requirement in many jurisdictions in terms of the type and quantity of pesticide that is used. The use of an integrated approach should include such details as vacuuming, steam treatment and sealing when these are part of the service. It is also important to consider the amount of bait stations or gel used for cockroach control. Often, low-bid contracts can result in minimizing product usage. This can be evaluated by gathering information on costs to treat a unit for common pests in terms of material costs as well as service time and administrative (overhead) costs.

Time in and time out

It is a common practice among many service providers in various trades to note the time at the start and completion of a service call. A time signature should be mandatory in pest management as it is a clear statement of the job done. This has the effect of highlighting when a technician is 'shorting' the service process, either because of an excessive number of calls, or because of the desire to finish early. Some technicians may be more proficient in completing their work but, in some cases, the short time spent is not enough for a proper job to be done. This is why low bids without reasonable evaluation can result in pressuring technicians to the extent that they are on a tightrope between unscrupulous employers and site staff expecting proper services.

Ongoing monitoring process

Monitoring processes may change depending on the pest type and the circumstances. Service treatment data can also be used to calculate the percentage of reported service requests as a projected action threshold level (ATL). A simple ATL for a building would be the percentage of units treated for a given pest during a calendar year. For example, if the ATL for cockroach infestations is set at no more than 20%, then a projection of more than 20% of units treated per calendar year being reached by mid-year should result in an ATL review to determine what kind of actions are needed to reduce the infestation. A simple formula for this kind of ATL would be:

$$\text{ATL} = (\text{SR}/\text{TU}) \times 100$$

where ATL is given as a percentage, SR = service requests for cockroach infestations and TU = total units. The projected ATL (also as a percentage) would then be given by:

Projected ATL = (ATL/M) × 12

where M = months of service. A fair projection can be determined from 6 months of service activity.

On reaching the ATL, an appropriate action can be initiated. Different monitoring schemes can be developed that fit a particular circumstance, but basic tenant survey monitoring is a very good and inexpensive approach as first-level monitoring. A review of the tenant survey enables IPM decisions on the kind of appropriate action to take, or on whether other monitoring (field inspections, detection dogs) is needed.

Service Contracts in Multi-dwelling Housing

Low-bid tenders

The most common type of pest control contract is based on a tendering process that specifies certain expectations of service delivery under a price structure and with details of treatment. A request for proposals for services under a generalized guideline is another common approach. In many cases, housing organizations do not have the in-house expertise to reasonably evaluate the proposals. In both of the scenarios outlined above, pricing is generally the most critical factor as organizations are restricted by fixed budgets and limited resources. As pest control services to low-income housing organizations have traditionally been the low end of service, these types of agreements tend to set very low prices with poorly managed quality control that is usually based on complaints and often involves blame. Some firms offer an annual fixed price based on a promise to treat all units for cockroaches (the most common pest), if necessary. This seems appealing from a budgetary perspective but once it has been accomplished, additional costs may be incurred for further services. The negative pressure on all stakeholders in these low-bid agreements does not enable a successful IPM Best Practices programme. Housing organizations should ensure that contract specification details are reviewed or written by qualified IPM consultant specialists or university extension urban entomologists.

Other contract options

Performance-based contract agreements

Some years ago, the US Department of Defense promoted Performance-Based Contracting (PBC) agreements as a form of contracting services. These were subsequently renamed as Performance-Based Acquisition (PBA) agreements (US GSA, 2010a). This approach was based on the development of Performance Work Outcome (PWO) or Statement of Objectives (SOO) as an expectation, but the general details of achieving it are left to the contractor, much as in a request for proposal. The US General Services Administration (GSA) has developed a seven-step process for progressing PBA. However, few pest control firms have established details of programme delivery and this form of agreement has rarely been used for pest control. All the same, the concept remains an important principle that could be utilized in IPM programmes in the terms of contractor performance, as managing performance is the last key step. At this time though, the PBA as the main frame of an IPM programme is simply impractical in the low-income housing setting.

Fixed-cost contracts

Another type of contract that is appealing in terms of control of budgets and enabling better outcomes is the fixed-cost contract, or as renamed the fixed acquisition contract or agreement (US GSA, 2010b). The basis of this contract is to establish a baseline of service requirements from the service frequencies of previous years and set the frequency of services for different pests for quotation purposes. The idea of a fixed cost contract is that a well-managed IPM programme delivered by a highly qualified firm could result in a reduction of services needed as a result of improved programme management. As a request, the contractor would benefit from this because of the reduced costs from the lower number of service calls. This kind of programme can fail if the contractor is not committed to the IPM approach in managing services through proactive actions and quality assurance measures. For example, if a technician is providing an inferior quality of service, then the frequency of service requests could increase rather than decrease. This approach was used by the MTHA, but the advent of bait gels for cockroaches and the fact that these products were essentially odourless resulted in a spike of service requests that was unexpected. Some contractors were still able to realize profits under these conditions but others found the obligations onerous.

The bed bug resurgence has rendered fixed-cost contracts as an unattractive option that has been discontinued. This type of contract did, however, provide insights into the relevance of contractor commitment to programme oversight and management that was totally lacking during the implementation of the IPM approach. A contractor must be involved in the details of unit service reporting as an IPM requirement. For a large housing organization, this is a key element of an IPM programme in terms of addressing specific unit issues as well as in making decisions about treatment and monitoring strategies highlighted by field data analysis. Traditional fixed-cost agreements designed to provide an attractive price to budget-minded management can result in very poor services without the context of performance management, and dependence on contractors to manage performance without proper client contract administration is a formula for failure.

Levelling request for quotation

In view of the difficulties of low bid tenders, and the ‘all or nothing’ outcomes in which only one or perhaps two contractors are awarded contracts based on low bids in various property management units of a large housing organization, another approach was developed by HSI. Rather than relying on low bids as the standard, this method would call for bids involving a Request for Quotation that included all the required elements of IPM but was based on a pricing schedule broken down into material costs and service time costs. This was determined by a combination of field experience and data from professional surveys of actual time spent in services for bed bugs – as representing the most time-consuming treatment (Gangloff-Kaufmann *et al.*, 2006). After receiving the quotes for service for common pests, as well as hourly rates provided by firms for services, a standard price was established for all successful proponents that could be accepted or rejected. This resulted in a number of service firms willing to provide services, and work was assigned on the basis of firm capacity. The benefit of this type of agreement is that it neither rewards low bids nor excludes high bids, but offers all firms an opportunity to provide services on a levelled price structure that is based on real-time minimum expectations, as well as on exceptions in which more time is needed as a result of reported contributory factors, such as degree of infestation. This approach also establishes an arena of competition for proponents to maximize profits through performance and efficiency.

The bottom line

The key to a successful a IPM programme contract is a fair price for services in the framework of common goals and accountabilities. Well-documented and affirmed contractor services create confidence in the work. This establishes a climate of getting needed work done at a fair price and raises expectations of staff, tenants and contractor technicians. Warranties are offered in a context of contributing factors, so that a fair warranty will be honoured under conditions (e.g. proper preparation, and confirmation that adjacent units are not infested).

Contracts are guidelines to prevent misunderstandings and define the work and expectations. Contract administration by housing providers is intended to confirm that work is being performed properly, but the bottom line remains the cooperative process and accountability, as illustrated by the IPM synergy model, which demonstrates the synergy between the various facets of treatment, prevention and cooperation in IPM. The use of process diagrams and graphic representations of the details, relationships, responsibilities and accountabilities of stakeholders in the programme are essential. This eliminates the tendency of some to say ‘it’s not my job’, which is a common reaction when facing the unpleasantness of dealing with pest problems that are sometimes extreme, and with the fears associated with some pests.

Conclusion

IPM in the multi-dwelling housing sector is clearly a societal responsibility involving many stakeholders beyond tenants, landlords and pest control firms. The key elements of this knowledge-based concept are often overlooked or ignored in traditional reactive treatment approaches. Cost factors and ignorance have inhibited development of good IPM programmes. The key to a successful IPM programme in terms of contracts is a fair price for services in the framework of common goals and accountabilities. Well-documented and affirmed contractor services create confidence in the work. This establishes a climate of getting the needed work done at a fair price and raises the expectations of staff, tenants and contractor technicians.

The development of IPM in schools in the USA is a useful model for implementation in the low-income housing sector. The Monroe Model of IPM in Schools in ten school districts in seven states in the USA resulted in a reduction of pesticide use of 71% and a reduction in pest complaints by 78% (Gouge, 2006). Lame (2005) who is one of the leaders in implementing IPM in schools, describes this as follows: 'The Monroe IPM Model is a 22 step process reliant on intensive communication and partnership and based on sound pest management as practiced by national experts. Adjusting and enhancing the IPM management processes will allow increase diffusion and program success'. Diffusion in this context means acceptance of the IPM programme by other school districts through association.

IPM promises sustainable control that is the clear hallmark of a successful pest management programme in multi-dwelling low-income settings. It is clear that without regulatory components setting standards, urban IPM will only happen in isolation. The IPM Model in Schools in the USA occurred through legislative requirements, and sets a high standard for similar implementation in the multi-dwelling, low-income housing environment. The impact of common pests and excess use of pesticides in housing on human health and well-being is well recognized, but society has been slow to correct these issues. The current bed bug resurgence crisis has brought this to the forefront. In the face of the contradictions between the use of pesticides potentially harmful to people and the eradication of pests (Berg, 2010), change has been slow. IPM is clearly the approach that is needed (Bryks, 2010; CDC/US EPA, 2010).

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8 Liquid Termiticides: their Role in Subterranean Termite Management

Xing Ping Hu

Summary

The majority of termite management practices rely upon the use of termiticides, and these are likely to remain an important approach in termite management programmes in the future. However, the termiticides on the market and their application methods have undergone vast changes since the discovery of the harmful effects associated with organochlorine insecticides. Newer reduced-risk chemicals have become available and application methods are improving, leading towards more environmentally safe and effective termite management. The currently available products are primarily divided into two categories: repellents that are fast acting at lethal doses; and non-repellents that are slow acting at lower concentrations. This chapter describes the characteristics of both types using examples from trials to explain their toxicity, uptake, transfer and control efficiency. Specific case studies are included on a new termiticide application strategy used in long-term termite management programmes. The chapter concludes with some guidelines for pest control operators in choosing the right termiticide.

Introduction

Insecticides registered for use in termite control are referred to as termiticides. Termiticides have been the cornerstone in termite management. This is largely owing to the cryptic life of termites, the high value of structural property, and the zero tolerance action threshold of termite infestation in residential structures. Termiticides are likely to remain an imperative component in termite integrated pest management (IPM) programmes in the future because newer reduced-risk chemicals have become available. Also, termiticide application methods are improving in the direction of a more environmentally benign and

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effective management that involves knowledge of the ecology and the behaviour of termites.

Termites are eusocial insects living in organized colonies characterized by division of labour among colony members. A typical colony is composed of workers, soldiers, nymphs, larvae (1st and 2nd instars) and reproductives. Unlike ant workers, which are sterile females, termite workers are sexually immature males and females that retain the capacity to transform into secondary reproductives and produce the next generation of offspring. Termites live cryptically in large populations in interconnecting tunnels which are both underground and above ground. This behaviour necessitates the need for an effective termite management programme to be built upon the concept of continuous population suppression and elimination.

The objective of termite management is to protect wood used in structures, non-structures, trees and other plants from termite attack. For over six decades, soil treatment with liquid insecticide has been the most widely used technique for controlling subterranean termites (hereafter referred to as termites). Although baiting has become a popular method since the mid 1990s, conventional soil application of liquid insecticide has remained the most common practice (Curl, 2004; Hu, 2010, unpublished data). However, the chemistry of termiticides and their methods of application have undergone a vast improvement since the discovery of the harmful effects on the environment and on human health that are associated with organochlorine insecticides. Currently available commercial products are primarily divided into two categories: fast-acting repellents and slow-acting non-repellents. These are differentiated by how they affect termite behaviour and death when applied at the recommended rates.

This chapter summarizes the historical development of soil-applied termiticides for termite management. It also describes in detail the characteristics of many popular termiticides and discusses the concept of termite control and the efficiency of these products using examples from trials. Specific case studies are included on a new termiticide application strategy used in long-term termite management programmes. The chapter concludes with tips and considerations for pest control operators in their choice for the right termiticide.

A Historical Perspective on Soil-applied Termiticides

Many types of insecticides have been used for controlling termites, including organochlorines, organophosphates, carbamates, pyrethroids, neonicotinoids, phenylpyrazoles and others. In the USA, before a termiticide is registered by the Environmental Protection Agency (US EPA), it must undergo intensive laboratory screening and at least 5 years of semi-field concrete-slab and ground-board tests by the US Department of Agriculture Forest Service (USDA FS). This is followed by evaluations done on actual termite-infested houses under a nationwide Experimental Use Program (EUP) which involves cooperating pest control professionals, state regulators and university researchers (Wagner, 2003).

The first class of insecticides registered for termite control – in 1952 – was the organochlorine cyclodienes (chlordane and heptachlor). These were used as soil-barrier treatments and were considered to be inexpensive, effective and persistent. They remained dominant in the market until 1987, when their use was banned in the USA, and soon after also in other countries, because of the negative effects they had on human health and the natural environment (US EPA, 1987; Ahmed and Frech, 2008).

The organophosphates and pyrethroids were the next two groups of chemicals used in termiticide barrier treatments (Mix, 1988). Organophosphates such as chlorpyrifos can kill termites quickly upon contact, but have short soil longevity. Fast killing leads to a large number of termite corpses in the treatment site, thereby preventing extended foraging by unexposed termites in the treatment area (Smith and Rust, 1990). Organophosphates were phased out for use in termite control by the EPA in 2000, like the organochlorine cyclodienes because of the side effects that they had on wildlife and public health. In contrast, pyrethroid-based termiticides act as repellents, making termites change direction and seek untreated soil or gaps in the treatment area to get into structures (Forschler, 1994). Pyrethroid products persist in the soil longer than organophosphates but for a shorter time than organochlorine cyclodienes (Su *et al*., 1999). Pest control professionals who use pyrethroids often report high callback rates and unsatisfied customers (Gold *et al*., 1996).

The next group of termiticides was registered in the 1990s, driven by the impetus for less environmentally toxic but more effective products (McCann *et al*., 2001; Hu, 2005). In this group, the chemicals that were registered as soil-applied liquid termiticides included imidacloprid, fipronil, chlorfenapyr, indoxacarb and chlorotroniliprole. These belong to new classes of chemicals and have novel modes of action. When used according to label (recommended) concentrations, they are considered to be non-repellent and have a delayed action (Osbrink *et al*., 2001; Ibrahim *et al*., 2003; Hu, 2005; Rust and Saran, 2006). These termiticides induce various behavioural changes or behavioural dysfunctions which are harmful to termite survival (Haynes, 1988; Hu and Hickman, 2006). Additionally, their toxic effects are transmissible from poisoned termites to other colony members that are not directly exposed to the treated soil, and this can lead to a catastrophic decline of the termite population and colony. These chemicals have been formulated into liquid, granule, foam and dust products. Reports of their use from termite control professionals have been positive, and are consistent with results from field research trials (Potter, 1999; Hu and Hickman, 2006).

Imidacloprid (Premise®, Gaucho®, Hachikusan®) was first investigated for termites in the late 1980s, and registered for termite treatment in Japan in 1993, and then by Bayer in the USA in 1996 (Potter, 1997; Reid *et al*., 2002). It is a neonicotinoid, targeting postsynaptic nicotinic receptors of neurons, and can cause nervous system impairment and eventual death of the treated insects (Bloomquist, 1996). It has a low vapour pressure (1.0×10^{-7} mm Hg) and high water solubility (514 mg/l at 20°C). Moreover, it has a low affinity to soil particles (low soil adsorption coefficient, K_{oc} = 132–310), thus posing a high potential for leaching into and contaminating groundwater (US EPA, 1996). It has a field dissipation half-life of 26.5–229 days.

Fipronil (Termidor®) is a phenylpyrazole chemical that disrupts the insect central nervous system by blocking the passage of chloride ions through the γ-aminobutyric acid (GABA) receptor and the glutamate-gated chloride channels (Rhône-Poulenc, 1996). It was first investigated for termites in France in the late 1970s, and was registered as a termiticide by BASF in 1999. This termiticide has a relatively low vapour pressure (3.7×10^{-4} mm Hg) and water solubility (1.9–2.4 mg/l at 20°C), but a high K_{oc} value (K_{oc} = 825) (Gunasekara *et al.*, 2007). It tends to be contained where it is applied; thus it has a low potential for groundwater contamination (US EPA, 1996); its field dissipation half-life is of 102–160 days. In addition, some of its metabolites are toxic too. All these physical and chemical properties make fipronil an effective and long-lasting termiticide. It is highly toxic to termites, requiring as little as 0.16 ng per termite to produce a 50% kill of *Reticulitermes hesperus* at day 3 and 1.33 ng to kill 50% *Coptotermes formosanus* workers at day 7 (Ibrahim *et al.*, 2003; Saran and Rust, 2007).

Another termiticide is chlorfenapyr (Phantom®). This is a member of a new class of pyrroles. It interferes with an insect's ability to produce energy by disrupting proton shuttles across the mitochondrial inner membrane (Silver and Soderlund, 2005). Its vapour pressure is similar to that of imidacloprid (1.0×10^{-7} mm Hg) but its water solubility is very low (0.14 mg/l). It has a long field dissipation half-life of 273 days, and a high soil adsorption coefficient (K_{oc} = 12,000 ml/g) (US EPA, 1998). It was first marketed as a soil-applied termiticide by BASF in 2002.

Indoxacarb (Aperion™) and chlorantraniliprole (Altriset™) are two new classes of chemicals that are currently being developed at DuPont. Indoxacarb is an oxadiazine proinsecticide that perturbs voltage-gated Na^+ channels in the insect nervous system by binding receptors at a site different from that affected by pyrethroids (which also target Na^+ channels) (Wing *et al.*, 2000; Nauen and Bretschneider, 2001). It was initially registered with the US EPA in 2000 as a 'reduced-risk' insecticide for use on vegetables and agricultural crops for lepidopteran and sucking insect pests. Chlorantraniliprole is a chemical from the anthranilic diamide class with a novel mode of action: it targets the ryanodine receptor, and causes impaired muscle regulation, paralysis and eventual death of insects (Cordova *et al.*, 2006). The intoxicated termites become uncoordinated or convulsive, which interferes with the normal colony activities such as foraging, grooming, feeding and trophallaxis.

Meanwhile during the 1990s, several chitin synthesis inhibitors were registered as bait toxicants for termites. These chemicals belong to the benzoylphenylurea group, which exploits unique characteristics in the hormonal regulation of insect growth. They are (presumably) safe to humans and have less negative environmental impact (Crosby, 1998; Timbrell, 2000). Compounds that have been marketed include hexaflumuron (Sentricon® Recruit II, Hex-Pro™), diflubenzuron (Exterra™, Advance®, Isopthor®), noviflumuron (Sentricon® Recruit III and Recruit IV), and chlorfluazuron (Exterra™, Requiem™). At least three other chitin inhibitors – lufenuron, novaluron and bistrifluron – are well along in the development pipeline. Bait toxicants are non-repellent and very slow acting. Their effects are not dose dependent. Alternatively, some metabolic inhibitors – such as sulfluramid (FirstLine®, Terminate®) and hydramethylnon (Subterfuge®) – are used as baits as well, although these compounds have a dose-dependent response and are less effective (Glenn and Gold, 2003).

Specificity of Repellent versus Non-repellent Liquid Termiticides

Repellent and non-repellent are relative terms and have been popularly used to categorize termiticides. Although some researchers consider the terms arbitrary and recommend not using them, this chapter will continue to use them because they have been adopted by the pest control industry and they are known to induce distinct behavioural responses in termites.

Repellent termiticides

Repellent termiticides include most of the synthetic pyrethroid insecticides, such as bifenthrin, cyfluthrin, cypermethrin, deltamethrin, fenvalerate, permethrin, tralomethrin, lambda cyhalothrin, teflythrin and flucythrinate. Pyrethroids target the sodium channel of the insect nervous system, and their toxicity is amplified from channel modulation to hyperactive symptoms in termites. These products have been around for a long time and are likely to continue to be used by the termite control industry due to their cost efficiency.

Characteristics of repellent termiticides

Pyrethroid-based termiticides work as repellents and are fast acting. The basic definition of 'repel' means to drive back or ward off, to be repulsive or distasteful to, or to push away from itself (Oxford English Dictionary). In termite control, a repellent causes termites to walk away from the treated zone. The fast killing property means that termites that have acquired lethal doses die within a short period of time (usually within 24 h); however, those surviving the first 24 h of exposure generally do not die. Pyrethroid products bind to the soil but degrade rapidly after exposure to sunlight or other atmospheric elements. Their repellency and toxicity are both dose dependent; thus, a concentration showing no repellency will have little or no toxicity.

The control concept of repellent termiticides

Repellent pyrethroid termiticides, when applied to the soil at the lethal rates mentioned on the label, will provide quick kill to termites that come into contact with the treated substrate, or will cause a directional change in tunnelling, away from the treated area (Su and Scheffrahn, 1990; Gahlhoff and Koehler, 1999). A thorough application of a complete termiticide barrier without gaps can provide long-term protection to the structure concerned.

However, the use of pyrethroids has often been noted to generate the need for retreatment and low satisfaction from customers. The repellent effect is one of the factors that explains this failure. Termites that encounter pyrethroid-treated soil often change directions in searching for untreated soil or for a gap to cross the barrier (Forschler, 1994). They may also seal off tunnels to avoid contact with the treatment site (Su *et al.*, 1982). Termites foraging above ground or within the structure at the time of treatment may be 'locked' inside the property/structure, and hence cause prolonged infestation (Potter, 1999). The trapped groups may trigger and produce secondary reproductives and start new colonies, as in *Reticulitermes* species. Meanwhile, termites coming into contact with the treated zone die quickly, before they are able to retreat back to affect the rest of the colony. This prevents lethal transfer of the insecticide – or 'chain reactions' (Shelton *et al.*, 2005). Another explanation of the failure in control is the ease of barrier disruptions through post-application activities by homeowners, burrowing vertebrates, soil erosion and other physical soil disturbances. Additionally, lower control efficacy may result from cost-driven sub-label rate applications that cause frequent breaches of the chemical barriers (Mampe, 1994).

Furthermore, repellents require rigorous application to all the possible entry points if the application is meant to create a continuous chemical barrier (a 'full-barrier') around and beneath the structure, and to all interior active infestations, in order to have an immediate control effect. To ensure that the structure is thoroughly treated, termite control professionals need an in-depth understanding of the construction type, methods and architectural materials, and the features of the building. Any untreated or poorly treated area or gap can be used by termites to invade and infest.

Non-repellent Liquid Termiticides

Non-repellent termiticides include some of the new chemical classes registered during the last decade. Examples are imidacloprid (Premise®), fipronil (Termidor®), chlorfenapyr (Phantom®), indoxacarb (Aperion™), and chlorantraniloprole (Altriset™). These products have unique modes of action and have proven to have high control efficacy against termites.

Characteristics of non-repellent termiticides

Non-repellent termiticides, when used at the recommended product label rates, are non-repellent, slow acting, and transmissible from poisoned termites to unexposed colony members, and hence cause secondary mortality. They kill termites faster than bait products but slower than repellents. They have a low odour, low volatility and low mammalian toxicity, but high efficacy and long soil persistence. Su *et al.* (1987) defined slow-acting chemicals as those that 'require a longer time to kill termites at low concentrations than at high concentrations'. With acute toxicants, the time required to kill termites is similar at high or low concentration, while the mortality levels are concentration dependent.

The control concept of non-repellent termiticides

Non-repellent insecticides take advantage of the social interactions among termites to amplify the control efficiency of localized treatment, a concept similar to that used in baiting. The non-repellency of the termiticide means that termites are not inhibited from tunnelling, or moving into a treated area, or remaining in contact with the active ingredient long enough to acquire lethal doses. The slow and delayed action allows the contaminated termites to behave normally for an extended period (hours or days), so that they are able to move away from the treated area to other feeding sites or nest sites before becoming physically disabled. In addition, the affected termites can endure the expression of the termiticide toxicity for another extended period (hours or days) before they die (Quarcoo *et al.*, 2010). During the extended period from picking up a lethal dose to death, the poisoned termites have opportunities to share the termiticide with other nest mates through social interactions; this can cause secondary mortality in nest mates that have not been directly exposed to the treated areas. This toxicant transfer effect is an incremental bonus that leads to termite population suppression or even elimination. Sublethal exposure has been shown to affect termite tunnelling and reproduction as well, thereby influencing overall colony health and survival (Thorne and Breisch, 2001; Hu *et al.*, 2006).

The uptake of termiticide by foraging termites from a treated zone, then, is multifaceted. A termite may directly pick up lethal doses either by contact as it tunnels or moves in the treated area, or by ingestion when it moves a treated soil particle using its mouth. A termite may also pick up lethal doses indirectly by contact or touch from contaminated termites (live or dead) or by ingestion when it engages in social interactions with a contaminated termite, such as grooming and trophallaxis.

The indirect acquisition of toxicant is referred to as 'transfer'. Toxicant transfer from poisoned termites to naive (untreated, unexposed, non-poisoned) termites has been used as one of the reasons to explain the control effectiveness of both non-repellent termiticides and baits when they are used in exterior perimeter and localized interior applications (Potter and Hillery, 2002; Waite *et al.*, 2004; Hu *et al.*, 2006). The transfer of toxicant may produce secondary mortality in unexposed termites. This has been demonstrated in subterranean and drywood termites under laboratory conditions (Smith and Rust, 1990; Ibrahim *et al.*, 2003; Kard, 2003; Tomalski and Vargo, 2004; Hu *et al.*, 2005; Shelton *et al.*, 2006; Song and Hu, 2006; Tsunoda, 2006; Spomer *et al.*, 2008; Bagnères *et al.*, 2009). When a group of treated termites was mixed with a group of untreated termites, the treated termites exhibited symptoms of intoxication after 4–15 h and died after 24–64 h, while the untreated termites also expressed symptoms of intoxication and mortality, only these expressions were delayed for 6–24 h. Furthermore, most of the toxicant transfer occurred during the first 6 h following the treatment, and was maximal in 24 h. The walking speed of a normal termite ranges from 0.7 to 8.9 cm/s, varying with species (Reinhard and Kaib, 2001; Saran *et al.*, 2007). Therefore, the potential minimum distance a poisoned termite can travel in 4–15 h (when they can still behave normally without toxic symptoms) is 1.68–21.36 m, which means that the poisoned termites are capable of moving far away from the treated site. However, there have been debates among researchers on whether these laboratory results apply to a real situation. The doubters have legitimate reasons for their concern. All the laboratory studies used a simple donor–recipient model at donor–recipient ratios of 1:1 to 1:20, single exposure and small groups of 50–250 workers confined in small test arenas of Petri dishes or plastic containers connected with Tygon tubing. These conditions bear little resemblance to field colonies.

To empirically evaluate the effects of localized soil treatment on a termite colony, Hu *et al*. (2006) developed a unique design that simulates field settings, and tested *R. flavipes* colonies that were 4–5 years old. Each colony consisted of 6000–8000 individuals that included workers, soldiers, nymphs, reproductives and significant numbers of larvae and eggs. The test arena was composed of a nest site (wood blocks as food and colony harbourage), a foraging area (soil) containing a segment of fipronil-treated soil barrier at the farthest end, opposite to the nest site. The fipronil concentrations of the soil barriers were 0, 1, 60 or 120 ppm. The dynamics of termite–fipronil interactions and termite–termite interactions were observed and recorded for 45 days using a super night-vision camera. Results showed that workers readily tunnelled and repeatedly moved in and out of the treated soil barriers. Depending on the treatment concentrations, the signs of toxicity (behavioural changes) were first observed in workers at the nest-site 8–20 h post-treatment. An observation worthy of noting is that all the poisoned workers managed to go back to their nest site before losing equilibrium and dying.

The observed intoxicated behaviours included erratic walking, body shaking, fluid excretion from the anus and mouth, impaired mobility and lying on the back while twitching and shivering. Survival of the intoxicated termites was at least 26 h before the expression of full toxicity was indicated by mortality. Moribund termites induced intensified care from those that were still acting normally. There was no avoiding of dead termites by the live ones, as shown by the increasing number of dead termites at the nest site and the decreasing number of termites in the foraging and treatment areas. Depending on the treatments, tunnelling stopped at 1–3 days and daily mortality peaked at 6–10 days post treatment. The experiment was terminated at day 45, when the 12 colonies (three replicates per treatment and control) were dissected. All nine of the treatment colonies, regardless of the treatment concentration, had 100% mortality of larvae and an absence of eggs; four colonies were completely dead and the other five had a few survivors nesting inside wood blocks. However, none of the treatment colonies was functional because further observation showed that the surviving reproductives had no fecundity and the surviving workers were not able to tunnel or eat. In contrast to the treatment colonies, the three control colonies remained active and productive, with their populations increasing to more than 8000 termite individuals, including all the castes and eggs, by the end of the experiment.

The Hu *et al*. (2006) study demonstrates that soil-barrier application of fipronil can suppress and eventually kill termite colonies. Control efficiency is achieved through a complex process involving multiple direct and indirect uptakes of toxicant, which both occur repeatedly. Termites will be killed after they have acquired lethal doses. There is no doubt that the direct toxicant uptakes play a key role in the mortality of workers and soldiers that tunnel and/or move through the treatment areas, whereas lethal transfer is the exclusive factor responsible for the killing of larvae and reproductives that confined their activities to the nest site and did not expose themselves to the treated soil. Reproductives and larvae are dependent upon foragers to bring them food, and hence acquire the toxicant from the poisoned feeders through social interactions. Here, the term 'horizontal transfer' is used to refer to the flow of termiticide from worker to worker and soldier. The term 'vertical transfer' is used to refer to the flow of termiticide from worker to reproductives and larvae – because they may be from different generations.

A number of social interactions may play critical roles in facilitating toxicant transfer. These include (i) casual contact; (ii) mutual grooming and contact including antennation; (iii) trophallaxis – mouth-to-mouth (stomodeal) or anus-to-mouth (proctodeal) exchange of food and chemicals; (iv) coprophagy (ingestion of faecal and regurgitated gut contents); (v) necrophoresis (carrying of dead termites); (vi) necrophagy (eating dead termites); (vii) cannibalism (eating other termites alive); and (viii) contacting secondary contaminated surfaces. All of these interactions can lead to the spread of termiticide within the colony. Some may play major roles, while others may be minor. The colony suppression data provide some insight into the field control efficacy reported by Potter and Hillery (2002), Waite *et al*. (2004), Kamble and Davis (2005) and Hu and Hickman (2006).

In spite of the number of studies that have been carried out on termiticide transfer, controversy still persists on various issues. Some of these are whether the transfer of termiticides occurs in field colonies, whether it is external or internal, to what extent the termiticides are transferred, what behaviours play what roles to what degrees, and how important each individual behaviour is to overall control. Researchers are also interested in understanding which castes are better solicitors in the process of toxicant transfer, how long termiticides can persist in individuals, and whether the transmission of toxicity can cause tertiary or even quaternary death in untreated termites. None the less, it is important to remember that there are difficulties in comparing laboratory data with field studies. In the field, colonies can reach populations of thousands (*Reticulitermes*) to millions (*Coptotermes*). Termites create large and complex tunnel systems with multiple satellite locations over periods of many years, develop sub-colonies or new colonies (*Reticulitermes*) through splitting or budding, and may have multiple food sources far away from treatment sites. These factors are compounded by the complex biotic and abiotic factors that affect the acquisition and transfer of lethal doses. Thus, extrapolating data from small-scale laboratory experiments to explain real foraging behaviour should be done with utmost caution (Hedland and Henderson, 1999; Pitts-Singer and Forschler, 2000; Evans, 2003).

Despite this ongoing debate and many unknown factors about termite behaviour and life, both researchers and pest control professionals agree that non-repellent termiticides, when used according to the label instructions, are effective enough to deliver their promise to customers (Nagro, 2008). Further non-repellent termiticides are becoming a popular alternative to the fast-acting repellent pyrethroids owing to their unique combination of characters, including novel modes of action, low application rates, excellent systemic and contact activity, long residual period, strong binding to soil organic matter, and favourable toxicological and environmental profiles. However, caution is recommended before claiming colony elimination. Different termite species may have different susceptibilities to the same termiticide. The goal of termite control is to protect the target structures, not to kill all colonies in the surrounding area.

Advances in Liquid Termiticide Application Methods and A Case Study

Soil application of termiticide is the standard method for protecting structures from termite attack (Potter, 1979; Forschler, 1999). Conventional treatment specifies a 'full barrier' application to the interior locations of entry points, such as joints, settlement cracks and openings for utility conduits. This is done by drilling the structure's foundation wall/slab and then injecting termiticide below the slab and the places where the soil comes in contact with the foundation, in addition to trenching and drenching the exterior perimeter of soil around the structure with the termiticide. This full-barrier treatment is disruptive to properties, invasive to occupants and requires the use of considerable amount of termiticide. Building codes demand both pre- and post-construction treatments. The pre-construction period is considered the most effective and economical time for structure protection. Besides soil treatment, alternative products newly marketed include non-toxic physical barriers (graded particle and stainless steel mesh) (Lenz and Runko, 1994), pyrethroid-impregnated plastic nets (Impasse® Termite Blocker) (Su *et al.*, 2004) and various wood preservatives. Post-construction applications of termiticide can be a preventive or a remedial measure necessitated by termite infestation, limited residual termiticide over time or incomplete pretreatments (Potter, 1997). However, this can be difficult, laborious, and expensive as a result of the following factors: (i) poor soil absorption; (ii) inaccessible areas; (iii) hidden construction faults; (iv) general inability to see where the chemical is flowing; (v) the necessity for more in-depth knowledge of building construction; and (vi) the higher risk of puncturing and contaminating ducts, drains, wells, cisterns, plenums, plumbing and electrical lines (Potter, 1997).

Non-repellent termiticides and other new alternatives introduced in the 1990s have dramatically changed the complexity of termiticide applications. The unique properties and versatile formulations of non-repellent termiticides allow strategic applications. Potter and Hillery (2002, 2003) proposed two types of applications with fipronil: 'Exterior-Only' and 'Exterior Perimeter plus Localized Interior Treatment' (EP/LIT). EP/LIT is a two-phase strategy: (i) a full volume treatment of the soil outside the foundation wall to establish a continuous barrier in the soil on the structure's exterior; and (ii) targeted applications to all known infested areas inside the structure by foaming, injection or dust. The benefits of EP/LIT are reduced labour, lower chemical costs and less intrusion into the structure. Worldwide trials (field experimental use programmes) have proven the considerable control efficacy of EP/LIT, which ranges from 5 to 15 years, unlike 'exterior-only' treatment, which often requires retreatment (Waite *et al.*, 2004; Hu and Hickman, 2006; Wagner *et al.*, 2009).

The EP/LIT strategy with non-repellents has been used against more than 20 species of termites in several countries before making label amendments. The concrete-slab and ground-board test trials conducted in Arizona, Florida, Mississippi and South Carolina by the USDA FS have shown efficacy of these products; however, results have remained inconclusive on the minimal number of years that each non-repellent remains effective (Wagner *et al.*, 2009). The product performance data vary with test locations and application guidelines (federal or state). In general, concrete-slab tests showed a longer residual effect than ground-board trials, and fipronil performed better than other non-repellents. Numerous field researches have demonstrated that EP/LIT can be successfully used to achieve structural protection without requiring the indiscriminate treatment of locations within structures that are not infested by termites. In addition, this method can significantly reduce the population of termites away from the treatment sites (Potter, 1999; Potter and Hillery, 2002; Waite *et al.*, 2004; Hu and Hickman, 2006).

Case Studies: use of EP/LIT in long term termite management

An ongoing IPM programme was initiated in March 2001 in Alabama (Hu and Hickman, 2006; Hu, 2010 unpublished). This programme involved nine termite-infested structures and made use of the fipronil-based EP/LIT method of treatment, along with pretreatment education, modification of landscape and construction features, post-treatment education, training in property maintenance, and quarterly inspections of the structures and in-ground monitors. Cultural measures, such as eliminating water/moisture problems and the removal of wood debris stopped termite activity in the interior in three out of the nine structures within 3 months before chemical application. Fipronil EP/LIT was applied at 0.06 or 0.12% in June 2001. All the original termite activity, interior and exterior, ceased within 1 month of this application. Quarterly inspections found the occasional presence of termites in a few of the in-ground monitoring stations installed a metre away from the treated barriers, although these termite activities often disappeared in no more than two consecutive inspections. None of the structures have had termite reinfestation after the chemical treatment up to the date that this chapter was completed (April 2011).

The effects of EP/LIT have also been investigated by other researchers. Waite *et al.* (2004) reported the elimination of interior infestation 6 months after applying 0.06% fipronil as EP/LIT. Potter and Hillery (2002) observed dead termites inside walls of the treated structures and significant termite population reduction beyond sites treated with fipronil or imidacloprid. Osbrink and Lax (2003) observed imidacloprid-intoxicated workers of *C. formosanus* in independent monitoring stations 46 m from a treatment site, the farthest distance ever recorded in a field situation. Earlier, Reid *et al*. (2002) reported that a single 0.05% imidacloprid EP/LIT treatment showed full control of interior infestation in 44 out of 56 termite-infested structures in Florida, Louisiana and Texas. The remaining 12 structures required a follow-up spot application to newly discovered interior infestations. On average, compared with a conventional treatment method, EP/LIT leads to a 47.2% reduction in termiticide use and a 69.5% reduction in indoor termiticide use (Reid *et al*., 2002). Amendments to the product labels for the use of fipronil in EP/LIT were approved for inclusion by the US EPA in 2004 (Anon., 2004). Other non-repellents have used similar label language. It is important to note that the EP/LIT practices covered here should not be applied to other termiticides, especially the repellent and fast-killing pyrethroids, which are not transferable (Shelton *et al*., 2005).

Considerations on Choosing Treatment and Termiticide

Knowledge

Providing consistent control of a termite population has been a complex and active process. It requires full knowledge on a variety of topics, such as termite biology, control methodologies, soil properties, practices in building construction, the landscaping and hydrology surrounding a structure, the chemistry of termiticides and the assortment of tools required to deliver appropriate treatment options. So pest control professionals should never rely on one source or agency for their information. They should also focus on fundamentals: performing good inspections, communication with the customer, applying continuous treatments around structures and conforming to fair pricing. Good technology does not help to overcome weak practices (Forschler, 1999). It is wise, too, for a practitioner to go beyond termiticide application and to include structural and procedural modifications that reduce the food, water, harbourage and access points used by termites.

Construction patterns

Different techniques may be needed to treat different types of building constructions. Termite entry points into a structure vary according to foundation type (crawl space, basement, monolithic, supported, floating or combined slab), foundation materials (hollow block, brick, solid or poured concrete, or mortar), walls, and flooring. Each of these determines how cracks and voids in foundations should be treated. It is important to know how to calculate linear feet and square feet as well, and how to interpret a termiticide label so that the right amount of termiticide is applied in both vertical and horizontal treatments. When entry points are skipped during perimeter treatment, the chances of achieving good control are minimized.

Soil properties

Soil properties are important factors in determining the application rate, persistence, and movement of a termiticide in soil because these affect termiticide efficacy. The relevant properties are texture, pH, moisture, temperature, particle size, organic matter (OM) and microorganism contents, and compactness (Su *et al.*, 1982). Termiticides generally do not migrate as readily in soil with high clay and OM contents as they do in sandy soil, and clay soil has a low potential for termiticides contaminating groundwater as well. For a general perimeter treatment to penetrate thick organic layers such as mulch, the total volume used should be at the high end of the label range. Soil with a higher OM content generally reduces the likelihood of termiticide uptake from the soil (Forschler and Townsend, 1996; Spomer *et al.*, 2009). The soil pH is known to affect how rapidly a compound degrades too. Finally, modern termiticides in general perform better and persist longer in soil that is slightly acidic ($pH < 7$), has a low OM content (0.8% OM) (Gold *et al.*, 1996), are at low temperatures and have a low moisture content. Warmer and moist soil enhances the activity of termiticide-degrading microorganisms, thereby increasing the rate of termiticide degradation.

Termiticides

Knowledge of termiticide properties have important implications in the mechanisms of uptake and transfer processes, which in turn impact the ability of a compound to control termites and protect structure from infestation (Matsumura, 1985; Narahashi, 2001). The concerned properties include solubility, degradation, microbial degradation, photo-degradation, and volatilization. Different termiticides have different attributes and ideal conditions for application (Ratcliffe and Greaves, 1940; Pitts-Singer and Forschler, 2000; Evans, 2003). Soluble compounds have a strong affinity to adsorb soil particles that subsequently limits their mobility through the soil. Chemicals of higher lipophilicity as measured by solubility, K_{oc} and K_{ow} (the octanol–water partition coefficient, a measure of the hydrophobicity of an organic compound) have a greater affinity for the waxy cuticle of the termite. Hence, the toxicity of termiticide-treated soil is generally negatively correlated with its solubility in water (Harris, 1972). The important process affecting termiticide persistence is chemical degradation, which involves hydrolysis, oxidation and reduction.

Substantial differences have been observed between termite species in susceptibility to insecticides and even between colonies of the same species (Osbrink *et al.*, 2001; Lenz and Evans, 2002). In regions where many termite genera occur, suppression or elimination of one species may quickly result in reinfestation by a succession of different species (Lee *et al.*, 2007). Baiting is relatively successful against the lower termite family Rhinotermitidae, but generally does not work on non-rhinotermitids, particularly those higher termites in the family Termitidae (Ngee *et al.*, 2004), which must be controlled using soil treatment (Lee *et al.*, 2007). Lenz (2002) reported that controlling *Mastotermes* in the Australian tropics requires not only higher chemical rates of soil treatment, but also treatment of surrounding targets owing to the diversity of the local termite community. Lee *et al.* (2007) reported that in Malaysia, Singapore and Thailand, mound excavation is essential in the control of the higher termite species found along the perimeter of baited homes, in order to reduce the chance of these species infesting the premises upon suppression or elimination of rhinotermitid *Coptotermes* spp. The majority of subterranean termites that are pests of wood in service belong to the Rhinotermitidae, in which *Coptotermes* spp. are more tolerant to termiticides than *Reticulitermes* spp. Some studies have shown that termites tend to explore gaps in the soil rather than explore along objects, possibly to minimize energy expenditure (King and Spink, 1969; Pitts-Singer and Forschler, 2000; Evans, 2003).

Temperature and other natural conditions in the field affect control efficacy by affecting the uptake and transfer of toxicants. The effects of temperature may be multifaceted because higher temperatures intensify termite behaviours such as tunnelling, foraging and feeding, and generally make termites more active. This increases the chances of greater toxicant uptake and transfer. Moreover, temperature may have a detrimental effect on the survival of termites (Spomer *et al.*, 2008). Conversely, higher temperatures may promote the chemical degradation of termiticides, resulting in a shorter residual effect, particularly in tropical climates (Reid *et al.*, 2002).

Conclusion

Termiticide application methods are continuously evolving and are increasingly being customized to fit into IPM programmes. IPM holds significance in termite management owing to the characteristic in- and above-ground tunnelling behaviour and the cryptic lifestyle of termites. IPM is not a simple adoption of every alternative but an intelligent selection, integration and use of actions to manage termites while attempting to achieve favourable economic, social and ecological impacts at the same time. It allows use of liquid termiticide only when needed and only to target areas (Hu *et al.* 2006). Termiticide application is aimed at achieving a quick stop to the termite infestation in a structure, with the goal of protecting the structure for as long as possible. Currently, liquid termiticides are often used in combination with other products. For example, a recent survey in the south-east USA (Hu, unpublished) shows that the majority of bait users also apply spot treatment with liquid termiticide for a quick knock-down of structural infestation.

A recent survey of 154 pest control companies in the south-east USA showed that 20% of the companies used termite bait, 40% used liquid termiticide treatment and the remaining 40% used a combination of baiting and liquid termiticide application (Hu, unpublished). Clearly, liquid termiticide application is still the most common practice in the USA, and may remain so for the foreseeable future. This is for several reasons, namely: (i) the need for a fast-killing of termite infestations in structures, particularly when responding to swarmer complaints or real-estate transactions; (ii) the availability of non-repellents that show a similar area-wide control of termites as baits; (iii) the availability of easy-use on-site application formulations; (iv) the reduced cost and volume of termiticide when using the EP/LIT method; and (v) the lower cost compared with bait products.

In effect, it is wrong to believe that once soil treatment is completed, even under ideal conditions, the termite problem is solved. Above-ground infestations are not uncommon, but if termites are found above the second floor, it is unlikely that soil poisoning will affect them. Additionally, many post-treatment activities can cause barrier disruption. Excavation for landscaping next to the foundation of a home, having an in-ground pool installed, and installing a sprinkler system or wooden fence posts are all salient examples of barrier disruption. Thus, termite control remains a continuous maintenance process.

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9 Sustainable Termite Management Using an Integrated Pest Management Approach

Brian Forschler

Summary

This chapter outlines an integrated pest management (IPM) approach to maintaining termite-free structures termed integrated termite management (ITM). The concept of ITM is based on the following: communication between interested stakeholders; knowledge of the life support requirements for the various species of termite capable of infesting structures; a thorough site-specific inspection; development of an action plan based on the species and site information; enacting the action plan after consultation with stakeholders; and follow-up inspections and communication to revise/modify actions as needed in an ongoing process aimed at sustainable structural protection. Results from the tenth year of a demonstration project are provided to support the viability of the ITM concept.

Introduction

The concept of integrated pest management (IPM) for subterranean termites has been discussed in the US entomological literature for at least 80 years (Snyder, 1927, 1935; Brown *et al.*, 1934; Horner *et al.*, 1934; Anon., 1942; Hartnack, 1943; Johnston, 1960; St. George *et al.*, 1960; Su and Scheffrahn, 1998; Su, 2002; Kard, 2003). However, implementation of the principles outlined in those researches and extension publications is not well documented. None the less, understanding the history of termite treatment practices in the USA is an important prerequisite for explaining the disparity between the theory and practice of termite IPM. The lessons of history should direct the termite management industry towards implementing meaningful and sustainable practices. The beginning of this chapter provides an abridged chronicle of subterranean termite management in the USA. This is followed by a description

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of the elements required for implementing termite IPM. The chapter finishes with a presentation of results from an integrated termite management (ITM) demonstration project in Athens, Georgia.

The first tome written on subterranean termites, entitled *Termites and Termite Control* was published in 1934 (Kofoid, 1934). This book devoted 350 pages to termite biology, 53 to building construction practices and 53 to chemical control methods. The *USDA Farmers Bulletin* No. 1911 published less than a decade later devoted 33 pages to proper construction techniques and cultural control methods while four pages (11%) discussed the application of soil- and wood-borne insecticide treatments (Anon., 1942). The disparity in pages per topic illustrates the impact that construction and building maintenance have on maintaining structures free of subterranean termite infestation, and underscores what entomologists have long understood – the need to include construction and landscaping practices in the process of subterranean termite management. The *USDA Home and Garden Bulletin* No. 64 19 pages on biology and construction while nine (32%) were devoted to chemical treatments (St. George *et al.*, 1960). The introduction and use of insecticides as soil termiticides was the impetus for a new management model using long residual insecticides to create a barrier to subterranean termite incursions into structures (St. George, 1944; Kowal and St. George, 1948; Hetrick, 1950, 1952, 1957; Ebeling and Pence, 1958; Johnston, 1960; Bess *et al.*, 1966). The last Approved Reference Procedures (ARP) for subterranean termite control published by the (US) National Pest Control Association in 1991 had ten pages devoted to construction and cultural control while termiticide application covered 131 pages (92%) (Rambo, 1991). Today, termite management can best be described as an industry-formalized practice based on soil poisoning, although the latest revision of *USDA Home and Garden Bulletin* No. 64 contains slightly fewer pages on treatment techniques versus biology and construction (eight of 26 pages, or 31%) (Peterson *et al.*, 2006).

The application of soil insecticides for termite management was the standard practice for over 50 years in the USA (Moore, 1986; Lewis *et al.*, 1996; Robinson, 1996). The termite management industry accepted their role as palliatives for bad construction and landscape management because they were 'effective' soil insecticides. The termiticides used during that era (1940–1989) had a long residual period and this could mitigate infestations if the soil was properly treated and, over time, not moved or replaced (Hetrick, 1957; Bess *et al.*, 1966). Training for technicians in the termite management service industry involved education on the proper placement of correct volumes aimed at attaining a 'continuous and uniform barrier' of insecticide (Rambo, 1991; Potter, 1997). Regulatory standards in several states, such as Georgia, dictated inspection and treatment specifications and these further codified the soil barrier concept (GSPCC, 2007). The importance of implementing IPM based on knowledge of an insect's life history and behaviour was relegated to a distant memory because the construction and landscape industries abrogated any culpability for subterranean termite infestation in the light of the pest management industry's willingness to accept responsibility for keeping termites out of structures. Unfortunately, termite biology-conscious design, construction and landscape management is unlikely to be a feature of new construction any time in the near future because that educational component of IPM, although attempted for decades, appears to be falling on 'deaf ears' (Ebeling, 1968; Suiter and Forschler, 2004). Today's termite management professional is saddled with the legacy of their industry's genesis during the heady days of long-lived soil poisoning for subterranean termite control.

The pest management industry suffered the consequences of over-reliance on soil termiticides when in the late 1980s chlorinated hydrocarbon insecticides were removed from registration (Su and Scheffrahn, 1990; Lewis *et al*., 1996). The application of soil termiticides moved from trench and treat applications during the 1950s to rodding only, as illustrated by termiticide labels that described 'trenching *and/or* rodding' as an appropriate application technique (St. George *et al*., 1960; Rambo, 1991). The inability of rodding to create a continuous insecticide barrier was highlighted in the early 1990s in the trade magazines (Craft, 1993), but was never discussed in the entomological literature. Nevertheless, appreciation of this fact was reflected in labels published after 1996 that provided instructions for 'trenching *and* rodding' – a subtle semantic difference but very important in influencing proper application of a continuous barrier. The pesticide manufacturers responded to the deluge of reports of subterranean termite infestations with increased funding for research on termite biology and management (Reay-Jones and Mascari, 2007). That influx of investment in investigation has rewritten our understanding of termite biology and provided the impetus for revisiting IPM for subterranean termite management.

The peer-reviewed literature has little information on the field efficacy of termite management practices because the heterogeneous urban habitat prevents meaningful replication and experimentation on valuable property; the latter has been used as a justification to forgo the designation of non-treated controls. The data available on field experiments involving liquid termiticide efficacy are, therefore, most frequently found in pest management trade publications, including the annual USDA Forest Service termiticide reports (Clark, 1993; Mampe and Bret, 1994; Potter *et al*., 1994; Wagner *et al*., 2005, 2008). The commercialization of termite baiting in the late 1990s has produced a wealth of information on bait product efficacy (without controls). That efficacy is assumed to apply to structural infestation but has not been directly tested on infested structures (Su, 1994; Forschler and Ryder, 1996; Getty *et al*., 2000; Gulmahamad, 2003; Messenger *et al*., 2005; Haverty *et al*., 2010). The dearth of information provided by the termite presence/absence data accumulated during the 'monitoring' phase of commercial termite baiting precludes the implementation of meaningful action thresholds because false positive data remain unresolved (Su and Scheffrahn, 1996; Thorne and Forschler, 2000); for instance, the abandonment of a bait station cannot be related to impacts on termite colonies. Subterranean termite baiting must include a thorough inspection programme to ensure structural protection (Thorne and Forschler, 2000; Forschler *et al*., 2007) and when used as 'stand-alone' termite control should not be considered IPM.

The Philosophy of IPM

Stern *et al*. (1959) originally defined integrated control as combining and integrating biological and chemical management practices. The concept of IPM, since its inception, has been refined and redefined to be applicable to a variety of pest management disciplines, and the reader is directed to other sources for a comprehensive review of the evolution of IPM theory (Kogan, 1998; Ehler, 2006). IPM is essentially a knowledge-based decision-making process. The foundation of IPM is an understanding of a pest's biology, which is used to identify vulnerable attributes that can be addressed by an action plan aimed at reducing the economic, public health, regulatory or aesthetic impact of that pest. The implementation of IPM has been driven by monitoring pest populations to measure when numbers, signs or complaints warrant initiation of an intervention based on a predetermined action threshold. The type of intervention is dictated by the available technologies, by economics and by capability for reducing a pest population's ability to sustain numbers relative to an injury index. The injury index is based on attributes of a commodity or some other societal precept of injury or loss of value. Mosts pests' biologically-based vulnerabilities afford action plan developers with several viable intervention options. Targeted application of pesticides is advised only after other interventions fail to provide an appropriate reduction in pest population pressure. Evaluation of a successful urban IPM programme is recorded using two quantifiable measures: first, reduced pest numbers or 'complaints' and, secondly, reduced use of pesticides (Greene and Briesch, 2002).

Termite IPM or Integrated Termite Management (ITM)

Management of termite pests within the framework of the IPM philosophy was addressed by Su and Scheffrahn, (1998) from an economic perspective and they concluded that the use of baits constituted IPM. Termite baiting programmes have been designed around a 'monitoring' procedure that assumes a zero-tolerance action threshold and records only the presence or absence of termites in bait stations (Su, 1994; Su and Scheffrahn, 1996; Thorne and Forschler, 2000). The pragmatic approach by Su and Scheffrahn (1998) assumed that structural or landscape modifications are non-viable interventions for termite management and whole-house soil insecticide barriers are the only chemical-based intervention that can provide reasonable structural protection. An alternative model for termite IPM emerges if one assumes that building practices and landscape conditions can be altered to affect subterranean termite incursions into structures along with placement of chemical barriers only at elements of construction that afford access to a structure. Integrated Termite Management (ITM), using an IPM mind-set, should be an on-going process where the treatment event is considered a single intervention in a site-specific action plan developed from an inspection programme that identifies factors that can be altered to favour a reduction in termite activity (Forschler *et al*., 2007). The process is a knowledge-based programme that involves inspection, action plan development, action plan implementation and continued inspections.

The process of ITM requires a philosophical adjustment to admit that the decision to implement a particular intervention is based on an inspection-driven assessment that takes into account construction, structural maintenance and moisture management issues present at a site. ITM is an exercise in communication and accountability built on the foundation of a thorough inspection. The cryptic lifestyle of termites, in addition to the problems presented by inspection gaps (those areas that could provide termite access to a structure but cannot be visually inspected), prevents consistent verification of the presence or absence of termites in most buildings. An inspection report, therefore, should identify inspection gaps and suggest remedies such as the installation of removable skirting boards (baseboards), bath trap access doors or other inspection ports placed into elements of construction. The inspection report can only record conditions observed at the time of inspection, and thoroughness is critical to developing a site-specific action plan.

Action plan development utilizes information obtained from a thorough inspection to address, in a practical manner, any and all issues that influence termite biology. The knowledge-based decision to include a specific intervention in an action plan against a particular termite infestation is influenced by information from four site-specific areas that must be obtained during the inspection:

- Knowledge of the identity of the termite involved in an infestation.
- Knowledge of the construction practice.
- Knowledge of the landscape conditions that allow termites to be in that area.
- Knowledge of the point(s) at which termites have entered the offended structure.

Action plans should first consider issues relative to moisture management, landscape, building maintenance, alternative food resources and construction before addressing insecticide-based interventions. The cryptic termite lifestyle could require use of more than one type of intervention in order to render a structure termite-free – and maintain it that way. Reducing moisture sources, grading along the foundation, and the removal of stumps or other cellulose resources near the structure are some examples of interventions that could assist the goals of any ITM programme. Interventions using pesticides are only considered under the constraints offered by the attributes and limitations of active ingredients, formulations and the tools that are available for application.

Insecticide interventions can be structure or soil based, and involve altering termite behaviour – not simply killing termites. Structure-based interventions include the topical application of insecticides to wood, which discourages termite feeding or foraging. The use of pressure-treated wood or other non-cellulosic building materials is another choice in a non-palatable-food approach. Termites can be excluded from structures using a variety of physical barriers, including chemically treated plastics, particle barriers (sand, crushed rock, glass beads) or stainless steel mesh. Termites can also be excluded from a structure using termiticides placed into the soil or on to elements of construction, such as expansion joints. All of the aforementioned interventions do not affect termite populations, they simply keep termites away from the structure by altering their collective ability to search an area for food. Termiticidal baits are intended to reduce the number of termites in the vicinity of the structure under the belief that fewer termites provide protection from infestation by reducing the probability of an encounter. The appropriate intervention must always be implemented with care towards the details of proper application and maintenance, which includes a routine of further inspections to ensure efficacy of the original action plan as well as adjustments as new conditions come to light. The process of ITM is continuous because inspections regularly access the site conditions. Findings from an annual inspection may result in alterations to action plans after communication with all involved stakeholders.

ITM Demonstration Project

A review of the literature on subterranean termites indicated the features of their biology that were amenable to exploitation in an ITM demonstration project. Subterranean termites occur in relatively small populations (Howard *et al*., 1982; Forschler and Townsend, 1996; Grube and Forschler, 2004; Parman and Vargo, 2008), follow physical guidelines while foraging for food (Goldberg, 1973; Pitts-Singer and Forschler, 2000; Swoboda and Miller, 2004), and require moisture to survive (Thorne, 1998; Cornelius and Osbrink, 2010). The combination of these three features intuitively increases the probability of structural infestation (Brown *et al*., 1934). Termite life history is also designed for a prodigious increase in population once adequate food and moisture are located (Lenz *et al*., 2009). Therefore, a subterranean termite management programme was initiated with the intent of reducing access to physical guidelines in structures, reducing food resources in 'close' proximity to the foundation, and keeping the soil around the foundation dry (Brown *et al*., 1934; Hartnack, 1943). Targeted application of pesticides was employed to aim at elements of construction that afforded physical guidelines for foraging activity around known or suspected entry points (Ebeling, 1968). Lastly, population reduction using baits was used in cases where entry points were extensive or inspection(s) indicated that the original termite control interventions were moving the foraging activity to other locations around the original infestation site.

In 2000, the Household and Structural Entomology Research Program (H&SERP) at the University of Georgia reached an agreement with the Physical Plant Division (PPD) to conduct all termite management on the 145 primary structures situated over 2.5 km^2 of campus in Athens, Georgia. PPD personnel were to notify the H&SERP staff when termite activity was reported in any campus building. The H&SERP staff would respond by conducting an inspection at the location of the reported sighting aimed at finding the point(s) where termites had entered the structure and complete an inspection report. Inspection reports included information relative to termite activity at each site and used digital photographs along with written descriptions of site conditions. An action plan was developed for each infestation based on the site-specific inspection results and interventions implemented by H&SERP or PPD staff. Inspection reports were, over time, amended to include action plans developed/enacted in addition to listing all the interventions that had been conducted and were, therefore, a running journal of programme activity at each site. Sixty-six action plans were implemented between February 2001 and August 2010 that involved 66 termite infestations in 47 separate structures.

The results of the programme indicated an infestation rate of 32% of the primary buildings over 10 years, with an average of 5% of the buildings reporting subterranean termite activity on an annual basis. Entry points were identified for each of the 66 separate infestations and placed into four categories: expansion joints (83%); gaps in stone foundations (11%); weep holes in brick veneer (2%); and wood to ground contact (4%). Seven types of interventions were implemented: injection of termiticide into infested wooden structural members (n = 19), soil application of termiticides (n = 17), application of termiticide to elements of construction (i.e. expansion joints and wall voids, n = 26), termite baits (n = 10), landscape alterations (n = 4), building repairs (n = 4) and no action (n = 5). Fifty-two infestation sites had action plans that called for only one intervention and these 52 involved all intervention types except for landscape alterations. Six action plans involved the combination of wood injection and soil application. The combination of wood injection and baits was used at one site, and termiticides applied to the elements of construction along with bait were employed at three sites. Two sites had action plans that involved application of termiticides to the elements of construction and landscape alterations, while two other sites used a combination of four interventions.

Treatment success was measured by two methods. The first was callbacks from building occupants reporting a post-intervention swarm or other evidence of continued termite activity. The second was determined by conducting site reinspections using visual inspection and at least one alternative inspection device – either a proprietary acoustic amplification device or microwave device (Termatrac®). The five sites where no action was taken were infestations reported as a result of a swarm that occurred in structures with no wooden structural components. All of the no-action interventions were determined to be successful because termites have not swarmed at any of those locations since the original report – two having gone for 1 year, one for 2 years, one for 8 years and the last for 9 years. Three of the four building-repair action plans (two gutter repairs and one replacement with treated lumber) were successful as 'stand-alone' actions. The fourth building repair action plan (removal of form boards) cannot be deemed a success because termites are still present in the structure, yet the intervention has not been implemented by the PPD. The four landscape interventions were recommended as part of multi-intervention action plans and all involved reducing grade that was above a slab foundation, yet none of those landscape-alteration interventions have been implemented by the PPD. Forty-four of the remaining 48 action plans (that are at least 1 year post-action plan implementation) have been deemed successful because termites are no longer present at the location where they were noted during the original inspection. One failure was a 2009 application of 0.05 l of liquid termiticide to an expansion joint below an exterior door, but termites swarmed again the following year from the same door frame. Failure of this intervention is likely to have been the result of inadequate coverage of the entry point. The volume of termiticide used was not adequate to cover the entire expansion joint – highlighting the importance of attention to the details of insecticide application. The other three failures were wood injections where termites appeared 1–3 years later in other parts of the same room. Most of the buildings involved in this demonstration project were large and termites did return to other parts of the building, albeit many metres away from the original interventions; these were assumed to be separate infestations. The data therefore indicated a 92% success rate for all the initial interventions. However, the success rate of these same action plans, if examined from an industry standard of 'termites not reported from the same building', provided a success rate of only 70%. Another measure of IPM success – reduced insecticide applications – was clearly documented. This ITM programme used 99% less insecticide than required by the Georgia Structural Pest Control Commission standard of whole-house treatment for termite infestation (GSPCC, 2007).

The success of the ITM demonstration project is unequivocal when using the metric of reduced application of pesticides, and validates the principle of 'spot treatments' (Ebeling and Pence, 1965) when managing subterranean termite infestations. The variable success rate for removal of infestation highlights the role of communication in an IPM programme. The industry standard of whole structure contracts provided a 70% success rate, which is an unmitigated failure from any perspective. Yet the same data also provided a 92% success rate of initial intervention, which was accepted by the PPD because the reports documented every step of the process from inspection to action plan development, implementation and reinspection. That 92% success rate was later improved to 98% by re-evaluation of the action plans and implementation of additional interventions (the one failure was the one action plan that the PPD was responsible for conducting – the removal of infested form boards in a cramped, unventilated crawl space). The customer, PPD, was satisfied that termites were removed from the immediate site of infestation and understood that later reports from the same building often constituted separate infestations. This understanding and acceptance of the upper limits of the aforementioned success rates is attributed to the lines of communication that were maintained using updated reports.

Conclusion

Implementation of IPM practices in the human habitat is complicated by numerous factors, including: technical, conceptual, economic, educational and research aspects and public perceptions, (Moore, 1986; Robinson, 1996; Kogan, 1998; Ehler, 2006). Although the concept of using attributes of the biology of termites as the foundation of a management programmme are well known, their use by the pest management professional has been tempered by reliance on chemical treatments. Application of an IPM philosophy for managing termite infestations requires a thorough inspection aimed at identifying known or potential entry points, designing a site-specific action plan aimed at mitigating alternative food sources and based on the construction and moisture issues unique to each infestation. Inspection findings must be communicated along with the interventions enacted to justify ongoing efforts. An ITM demonstration project provided a 98% success in eliminating infestations and 99% reduction in insecticide use, thus validating an inspection-centric, ongoing programme of communicating efforts towards managing termite infestations in structures.

Hagen writing in 1876, stated: 'We live surrounded by such enemies that have the potential to create great damage and the remedy must be a reasonable one'. His words provide sound advice today – over 120 years later (Hagen, 1876). The pest management community has many interactive stakeholders who should be in a dialogue to effect termite management in a cost-effective and environmentally responsible, efficacious manner. The termite management practitioner is operating under a 50-year-old insecticide-based business model that has little relevance to the academic knowledge base, while consumers and regulatory agencies, for different reasons, are largely unaware of the gulf between knowledge and practice. The academic community is remiss in its provision of timely biologically sound information and in combining that with economically pragmatic management practices. The ITM demonstration project outlined in this chapter illustrates a knowledge-based programme based on communication that can realize the goals of the IPM philosophy. Industry acceptance of this model is hindered by a business practice based on one action (insecticide treatment) followed by faith in an outdated lifetime guarantee mentality. The ITM philosophy requires communication and record keeping that has traditionally been the bane of the US termite control practitioner relative to regulatory oversight. The regulatory community must rethink regulations to allow for IPM and consumer protection based on communication and record keeping as the foundation of a new oversight programme. ITM differs significantly from the current termite control business model in that the property owner has responsibilities relative to termite management because the practitioner is not a magician who can use insecticides as a cure-all for bad construction, landscape management or building maintenance. Finally, the academic charge of educating all community members on the role of a termite management professional should be undertaken with a renewed vigour energized by a holistic view that acknowledges the gulf between knowledge and practice, and is fuelled by a sense of responsibility to all stakeholders.

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10 A Stand-alone Termite Management Technology in Australia

Steven Broadbent

Summary

Failures in preventing termite entry in spite of using large volumes of chemicals have stimulated research into more environmentally responsible methods of termite management. This has led to considerable interest in the use of bait technology to suppress and actually eliminate colonies of subterranean termites. Commercial development of termite baiting systems in Australia has proven that bait technology can be used as a stand-alone method for protecting buildings. The degree of future protection provided is at least equal to, and probably better than, that provided by traditional toxic chemical soil barrier systems. Colony elimination rates and ongoing levels of property protection, as measured by lack of further termite damage, are considered to be 100% successful.

Introduction

Australia, officially the Commonwealth of Australia, is located in the southern hemisphere, and comprises the mainland of the Australian continent, the island of Tasmania and numerous smaller islands in the Indian and Pacific Oceans. The current population of Australia is 22.5 million (ABS, 2010), with approximately 60% concentrated in and around the mainland state capitals of Sydney, Melbourne, Brisbane, Perth and Adelaide.

A prosperous developed country, Australia is the world's thirteenth largest economy and, after the USA and Japan, is generally considered as the third largest market in the world for the sales of termite management products and systems. Subterranean termites (hereinafter 'termites') are a key economic pest to structures throughout all the mainland states and territories. This chapter describes a termite management technology that has been proven to be sustainable.

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Termites in Australia

Termites attack and damage sound and decayed timber of native and exotic hardwoods and softwoods. They may also eat any material containing cellulose, such as furniture, paper products, fabrics and even some non-cellulose materials, e.g. soft metal, inferior concrete and plastics. It is estimated that the annual cost of termite damage, treatment and replacement exceeds AU$910 million (Archicentre, 2007). With around 70% of the total timber production used for building and construction purposes (ABARE, 2002), this widespread termite activity has led to increased legislation for the protection of buildings in Australia, and has also created opportunities for innovation. The average cost of rectification of termite-damaged properties is in excess of AU$7000 per home, and an estimated 130,000 new infestations in homes are reported each year (ABCB, 2009).

Building codes

A key aspect of Australian building practices is the amount of structural timber that is used in buildings. This has led to extensive legislation concerning the protection of new buildings, in particular from termite attack. The Building Code of Australia (BCA) requires that all new homes must be protected against termites at the time of construction. This is enforced by building inspectors appointed by local government authorities. The BCA is produced and maintained by the Australian Building Codes Board (ABCB) on behalf of the Australian federal government and the state and territory governments.

This concern with the extent of termite damage has also led to the development of a suite of Australian Standards with respect to termites and their management. These are:

- AS 3660.1 (2000) Termite management – New building work.
- AS 3660.2 (2000) Termite management – In and around existing buildings and structures – Guidelines.
- AS 3660.3 (2000) Termite management – Assessment criteria for termite management systems.
- AS 4349.3 (2010) Inspection of buildings – Timber pest inspections. This is dedicated to inspections, for termites and other organisms that attack timber in service before the purchase of a new home.

Termite biology

Subterranean termites are social insects, closely related to cockroaches. They are part of the Order Blattodea. Several castes, both morphologically and behaviourally specialized, are present to perform different tasks in the colony. These include the foundation or reproductive pair, the queen and the king termite. The queen, in most species of economic import, is physogastric (has an extended abdomen) and lays large numbers of eggs. Eggs hatch into the larval stage which, typically after two moults, develops into either a nymphal or worker line.

Worker termites are wingless, soft-bodied, sterile and blind. As their name suggests, they perform most of the tasks in the colony, including food harvesting, mound building, hygiene and nurturing the other castes. After six or more moults, some worker termites will moult into the soldier line. The initial moult is into a pre-soldier, before the final moult into a true soldier. Soldier termites are the guardians of the colony and have evolved with either a nasute head capsule (a capsule drawn out into a conical organ resembling a great nose), e.g. *Nasutitermes spp*., or with large jaws, often with the ability to emit latex too. Typically, in *Coptotermes* spp., all the soldiers are female (Roisin and Lenz, 1999).

The nymphal line usually comprises six nymphal instars followed by the alate (winged reproductive). The alates are sexually active and will depart from the colony in large swarms to form new colonies. Colonies may be in trees, tree stumps or, in rare instances, they may be in above-ground areas within a property. They tunnel underground to enter the building and then remain hidden within the timber making it difficult to locate their presence.

Termite diversity and damage

Australia has about 30 species of termites that achieve economic importance as pests of timber in service. *Mastotermes darwiniensis* (Froggatt) is the most destructive species, although its natural distribution is generally limited to the less populated regions north of the tropic of Capricorn. Consequently, *Coptotermes* spp., typically *C. acinaciformis* (Froggatt), *C. frenchi* (Hill) and *C. michaelseni* (Silvestri), are responsible for most economic losses; these probably account for more damage to timber in service than all the other species combined (Gay and Calaby, 1970). Other economically important genera include *Nasutitermes*, *Schedorhinotermes*, *Heterotermes*, *Microcerotermes* and *Microtermes*.

The most destructive species live in large colonies containing over a million timber-destroying insects. Evans *et al*. (1999) reported colonies of *C. acinaciformis* containing 358,000–1,600,000 individuals, and *C. frenchi* colonies containing 610,000–700,000 individuals. Problems arise when a nest matures near homes that tend to provide natural shelter and a food source for the termites. The gallery system of a single colony may exploit food sources over as much as a hectare, with individual galleries extending up to 120 m to enter homes. Even concrete slabs used in construction do not act as a barrier. Termites can penetrate through cracks in the slab to gain access. They also build mud tubes to gain access to above-ground timbers. Once in contact with timber, termites excavate it, often leaving only a thin veneer on the outside. If left undiscovered, the economically important species can cause damage costing many thousands of Australian dollars, plus treatment costs of around AU$2000–5000 (or more).

Where timbers are concealed, as in most modern homes, it is more difficult to locate the presence of termites, especially if gardens have been built up around the home and termite barriers are either not in place, or are poorly maintained. The diet of termites in the natural environment is the various hardwood and softwood timbers found throughout Australia, and these same timbers are used in buildings. Worker termites move out from their underground nest into surrounding areas where they obtain food and return to nurture the other castes of termites within the nest. Termites are extremely sensitive to temperature, humidity and light, and hence cannot move over ground like most insects. They travel in mud encrusted tunnels to the source of food. Detection of termites is usually performed by locating these mud tunnels rising from the ground into the affected structure. This takes an expert's eye and often requires the removal of panelling and cladding from walls.

Termite Management in Australia

Chemically treated soil barriers protect a building by forcing termites to reveal their presence. Termites can build mud tunnels around termite barriers to reach the timber above, although the presence of termite tracks or leads does not necessarily mean that termites have entered the timber. A clear view of walls and piers and easy access to the subfloor means that detection should be fairly easy. However, many styles of construction do not lend themselves to ready detection of termites. The design of some properties is such that it makes detection by a pest inspector difficult, if not impossible.

Traditionally, termite management systems have relied on the application of large volumes of toxic chemicals to the soil surrounding buildings. The banning of the cyclodiene termiticides (chlordane, heptachlor, and aldrin) in 1995 led to the introduction of less persistent alternatives, including chlorpyrifos, bifenthrin, imidacloprid and fipronil. Toxic soil termite barriers are typically applied at a rate of 5 l/m^2 in accord with the requirements of the Australian Standard, AS3600 Termite management (2000) and the registered product labels. The Australian Standard confirms that 'the purpose of termite barriers is to impede concealed termite entry into buildings. Termites can build around barriers. Evidence of termites or their workings can then be more readily detected'. It is a well-known fact that, even when correctly applied, as a complete and continuous soil barrier, termites may still gain access to a chemically treated property by bridging this barrier. Termite barriers have no impact on the actual termite colony, which remains active to infest other properties in the area. With termites foraging over distances of 80–120 m (Evans, 2009), this can be a significant threat to properties.

All pesticides in Australia are regulated through the Australian Pesticides and Veterinary Medicines Authority (APVMA), part of the Federal Department of Primary Industries and Energy. Accordingly, it is a legislated requirement that pest management professionals follow the directions of the product label and, as a consequence, the procedures of the Australian Standard, which are called up by the registered product labels. Pest management professionals in

Australia require a pest control licence. The licence is granted where pest managers successfully complete the relevant National Pest Management Competency Standards, which are endorsed by the Australian National Training Authority (ANTA) and administered by state-based Vocational Education and Training Advisory Boards (VETABs) in liaison with the Property Services Industry Training and Advisory Board (PSITAB).

In addition to difficulties in their application, termite barriers remain a passive approach to termite management. This is because termites must attempt to enter a building protected by a barrier to be affected by that barrier. In other words, barriers simply lay in wait for termite attacks – slowly degrading over time. To overcome this situation, termite baiting has been promoted as a more desirable method of termite management. It is generally considered to be more environmentally sound because baiting uses very small amounts of insect-specific toxicants that are administered in stations that are targeted only at the economically important termite species. Station placement is critical to the success of termite baiting, and experience has determined that an ideal placement pattern of one in-ground station every 3 m around the perimeter of a building is optimal. Additional stations may be placed in areas where termites pose a higher than normal risk, or where termite foraging is likely to be high, such as in mulch beds.

Development of Termite Baiting in Australia

Failure in preventing termite entry despite the use of large volumes of chemicals stimulated research into more environmentally responsible methods of termite management, and led to considerable interest in the use of bait technology to suppress and actually eliminate colonies of subterranean termites (Lenz and Evans, 2002). The Sentricon™ Termite Colony Elimination System (Dow Agrosciences LLC, Indianapolis, Indiana) and the Exterra™ Termite Interception and Baiting System (Ensystex, Inc. Fayetteville, North Carolina) are both registered through the APVMA for termite control in Australia. The systems use chitin synthesis inhibitors (CSI) to interfere with the termite moulting process. The active constituents are hexaflumuron, used in the Sentricon® system, and chlorfluazuron, used in the Exterra™ system. The advantage of using a CSI is that they are slow acting and can be transferred between individuals in the termite colony through trophallaxis (Sheets *et al*., 2000). Over time, colony numbers decline to an unsustainable level, and the colony ceases to exist as an organized social structure and dies (Lenz *et al*., 1996).

C. acinaciformis builds above-ground mounds in northern Australia. These mounds provide an opportunity to prove the effectiveness of bait toxicants under field conditions (Peters and Fitzgerald, 1999, 2003). Trials of this nature have demonstrated conclusively that the entire termite colony can be successfully eliminated. In the trials, a 400 mm long pine dowel was placed into a conduit in each test mound and used as a ‘dipstick’ to measure colony health. The presence of termites, faecal mottling and feeding on the dowel was used to indicate an active colony. Commencing at the third inspection, a small section of the mound was separated from the main structure and the presence of live termites was noted. The section was replaced and repairs were noted in the next inspection. Colonies showing decline were destructively sampled during the fourth inspection using a pick and shovel, and a search made for live termites in the mound. Thus, colony elimination could be conclusively confirmed.

Subsequent urban trials of the Exterra™ system further confirmed the efficacy of this system as a stand-alone treatment method for the elimination of termite colonies infesting structures throughout all regions of Australia (Peters and Broadbent, 2003). Termite species and corresponding numbers of buildings successfully treated with the Exterra™ system in these trials are presented in Table 10.1. Presumed colony eradication was achieved at all sites. In about 15% of these urban sites, the nest of the colony was located, and eradication was confirmed by destructive sampling, the use of temperature probes or borescopic investigation. The average consumption of the Ensystex Requiem™ Termite Bait (1 g/kg chlorfluazuron) was about 1000 g per colony, with one colony of *Schedorhinotermes* sp. consuming 2900 g of bait matrix. Colony eradication during the summer months was less than 50 days, and for all trials was less than 63 days.

Some interesting aspects of termite behaviour were observed during these urban trials. The rate of bait removal was greatest when large amounts of bait matrix were provided; this was also demonstrated by Waller and La Fage (1987). Shortly before colony eradication, thousands of soldier termites were frequently observed aggregating in the baited stations. On some occasions, nymphs and alates were also found (Lenz and Evans, 2002). The Ensystex Requiem™ Termite Bait matrix was seen incorporated into the walls of the royal chamber of the nest (Evans, 2001). On other occasions, termites produced large amounts of 'mudding' external to Above-ground Stations, with worker and soldier termites observed outside this material. Further timber damage was rarely noted after feeding commenced on the termite bait.

Typically *Coptotermes* colonies are eliminated in 6–12 weeks, and the elimination process includes distinct steps, such as behavioural changes in the worker termites, discolouration of termites, a marked increase in the ratio of soldier to worker termites and a rapid decline in termite numbers, leading to

Table 10.1. Termite species and corresponding number of buildings successfully treated with the Exterra™ Termite Interception and Baiting System throughout Australia (Source: Peters and Broadbent, 2003).

Termite species	Number of buildings/colonies
Coptotermes acinaciformis	85+
C. a. raffrayi	5+
C. frenchi	21+
C. michaelseni	10+
Nasutitermes exitiosus	6+
N. walkeri	3+
Schedorhinotermes spp.	17+
Total	152+

colony elimination. However these indicators are often not so evident with *Nasutitermes* species. If left undisturbed, these termites may sometimes continue feeding 9–12 months, or longer. Field trials undertaken with CSIRO (Commonwealth Scientific and Industrial and Research Organisation) have explained this further. In these trials, *N. exitiosus* were still feeding in the In-ground Stations after 6 months. Destructive sampling of the mounds revealed no queen, no brood (early or late instars), no young workers and no nymphs within the core of the colony, although many final instar soldiers and workers were found concentrated around the outer extremities of the nest/ mound. The central nest (nursery) was 'decayed' and moulds were found. The CSIRO researchers (unpublished data) assessed that the colonies had probably been in that state for some time and that they would have had no chance of recovery, even if exposure to Requiem™ had ceased, as there were no young and no nymphs. With no nymphs present, the colonies were doomed.

This situation provided evidence that when a colony feeds readily on termite bait, it negatively affects the fertility and fecundity of the queen, thus affecting the population of the young instars. As time progresses, the later instar termites are also eliminated. During this period, the larger, final instar (non-moulting) termites migrate towards the outer edge of the colony and continue feeding at the bait because it provides them with all the nourishment they require. By about 3 months after the treatment starts, the queen and other reproductive caste termites are also eliminated. Thus, the colony itself is moribund. As the number of dead termites in the colony rises, bacterial infection or fungal infection of the nursery quickly ravages any remaining termites, leading to rapid colony elimination.

In the case of *Nasutitermes*, while bacterial or fungal infection of the nursery also occurs, this sometimes has no impact on the final instar workers and soldiers, as they are only present in the stations or the outer edge of the nest, and do not return to the central nursery. Total colony elimination can be quickly achieved by simply removing any remaining termite bait. This removes the food and moisture source for the remaining final instar termites (CSIRO, unpublished data).

Exterra™ Termite Interception and Baiting

The Exterra™ In-ground Station represents a simplified approach to termite baiting designed to enhance termite transition to and consumption of the bait matrix. The Station consists of a patented hollow body with perforations in the sides and bottom to allow termite entry, an opening opposite the bottom, and a removable, tamper-resistant cover that is affixed over the opening. Termites are intercepted in these In-ground Stations with timber interceptors (*Eucalyptus regnans* F. Muell. or *E. delegatensis* R.T. Bak.) that are placed inside the Station, but are accessible to termite attack through the perforations in the Station sides. Interception is the process by which termite activity is established at an In-ground Station before the addition of termite bait. Termites are intercepted as they randomly forage. For baiting to work successfully, termites must find the bait stations so that the matrix with toxicant can be added for the termites to consume and transfer back to the nest. These requirements are important, because a successful baiting programme of this nature can take 3–9 months (Su, 1994), 7 months (Tsunoda *et al.*, 1998) or 3–7+ months (Su and Scheffrahn, 2000), which is much slower than other methods.

Carbon dioxide (CO_2) has been shown to work as an attractant for the termite species *R. flavipes* (Kollar), *R. virginicus* (Banks) and *R. tibialis* (Banks) in the USA (Bernklau *et al.*, 2005), and for the species *C. acinaciformis*, *S. intermedius* (Brauer), *Microcerotermes turneri* (Froggatt) and *N. exitiosus* (Hill) in Australia (Broadbent *et al.*, 2006). The most attractive concentration of CO_2 is 5–10 mmol/mol for *R. tibialis* and 10 mmol/mol for *R. flavipes* and *R. virginicus*. As an attractant, CO_2 has proven effective in reducing the time interval between station placement and the introduction of the termite bait.

The Exterra™ system is unique in that it incorporates Focus Termite Attractant™, a natural, food-based product that produces CO_2 as a termite attractant. Once in contact with the soil, the Focus Termite Attractant™ works with soil microorganisms to slowly release a small, precisely determined amount of attractant CO_2 into the soil to mimic the levels naturally given off by rotting wood and termite nests. This allows active interception of termites by attracting the termites to the In-ground Stations more quickly. The CO_2 gradient from each Focus™-baited Station effectively creates a larger 'footprint', with the termites following the CO_2 gradient to the Station. The presence of the Focus Termite Attractant™ effectively decreases the time required for termites to discover the bait Stations. Early interception in a Station further reduces the risk of termites entering a structure and enables the earlier placement of termite bait to ensure colony elimination. Several studies have also shown that termites are more likely to discover larger stations and remain actively feeding in them (Lenz *et al.*, 2003; Evans and Gleeson, 2006).

It is after the interception of termites that the termite bait (Requiem™) is added to the Station. Termites readily move from consuming the timber interceptors to consuming the Requiem™. These termites then guide other colony members to the Station, where they also consume Requiem™. As the Requiem™ is only made available for consumption after interception of a termite colony, very few In-ground Stations have the Requiem™ added. When the Requiem™ is added to the Station, it is placed in the vacant centre cavity, so no contact is made between the soil and the Requiem™. After termite activity has been absent from a baited Station for a few weeks, the interception/monitoring process is resumed by replacing the vacated Station with a new station. Any remaining Requiem™ is then safely disposed of.

Termites are also baited within above-ground stations. Above-ground stations are a valuable tool, particularly when termites are infesting a structure and a point of active infestation can be located. With the above-ground stations, interceptors are not used; instead, termites are intercepted with the Termite Bait itself. The above-ground stations must be placed on a point of active termite feeding to allow rapid elimination of termite colonies, typically in just 6–8 weeks for *Coptotermes* spp. (Peters and Broadbent, 2003).

Benefits of Baiting to the Environment

Termite baits are targeted specifically at termite species that cause economic damage to properties. If termites are in the building, then the bait is made available immediately – by definition, such termites would only be a species of economic importance and capable of damaging the property.

In the case of in-ground stations, the bait is only applied after identification of the species. If a non-economic species is present, then bait is not added. However, if an economically damaging species is present then it is treated with a minimal amount of product. Bait is used sparingly and only when required. Once feeding ceases, unused bait is removed and discarded properly to avoid affecting the environment. Additionally, the currently registered active constituents, hexaflumuron and chlorfluazuron, are of low toxicity, as recognized by their being exempted from poison scheduling by the Australian National Health and Medical Research Council (NHMRC), and also from requirements for safety directions under their registrations with the APVMA. The amount of reduction in actual insecticides used by employing baiting rather than conventional chemical treatment is shown in Table 10.2. The table compares the amounts of various products required for treatment in accord with the Australian Standard for a typical 70 linear metre home (250 m^2) with crawl space.

Typically, termite treatments have also raised various occupational health and safety (OHS) concerns. For instance, liquid-based treatments usually require the use of special chemical-resistant clothing, buttoned to the neck and wrist, in conjunction with a washable hat, elbow length PVC or nitrile gloves and, at times, even a half-face piece respirator with combined dust/gas cartridge. This creates an image of a professional pest manager bringing home dangerous chemicals. In contrast, the label for all termite baits reveal no safety precautions. This means that the installer of the Exterra™ system does not need any personal protective equipment. In fact, there are no OHS considerations in using termite baiting, whereas some liquid-based treatments are so toxic that they require homeowners to vacate their premises. These concerns do not exist when termite baiting is performed.

Table 10.2. Amounts of chemical used to treat a typical home in Australia.

Product	Concentration	Amount required	Total active weight required
Chlorpyrifos[a]	10.0 g/l	1,620 l	16,200 g
Bifenthrin[a]	1.0 g/l	1,620 l	1,620 g
Imidacloprid[a]	0.5 g/l	1,620 l	810 g
Fipronil[a]	0.6 g/l	1,620 l	972 g
Chlorfluazuron[b]	1.0 g/kg	1 kg	1 g[c]

[a]Used for conventional chemical treatment (as soil barriers).
[b]Used as Requiem™ Termite Bait in the Exterra™ Termite Interception and Baiting System.
[c]This is the maximum amount that tends to be required; moreover it is not placed in the soil but in a termite baiting station.

Thus, termite baiting truly meets the concepts of integrated pest management (IPM) which has led to its widespread acceptance in many sensitive environments, for example, zoological gardens, national parks (including the Great Barrier Reef Marine Park Authority, marine reserves (e.g. Goat Island, Cockatoo Island, Fort Dennison Island in Sydney Harbour National Park, and a jetty in the Great Lakes National Park), centres of the Australian Wildlife Conservancy (AWC) and more.

Conclusion

The commercial development of termite baiting systems in Australia has proven that these can be used as a stand-alone method for protecting buildings. The degree of future protection provided is at least equal to, and probably better than, that provided by traditional toxic chemical soil barrier systems. Colony elimination rates and ongoing levels of property protection, as measured by a lack of further termite damage, are considered to be totally successful.

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11 Encapsulation: an Effective Environmentally Friendly Technology for Delivery of Insecticides and Repellents

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Summary

The evolution of encapsulation for the delivery of insecticides has significantly influenced a number of key formulation parameters concerning safety and the environment. The first parameter is the release of the active ingredient at a fully controlled concentration, thus increasing the life of the formulation after treatment. The second is the reduction of the concentration of the active substances used for a treatment. This prevents the risk of exposure of applicators and homeowners alike. The advantage of encapsulation is slowly being recognized worldwide by the pest control industry, and the number of patents granted for microencapsulated insecticide products has become increasingly important as proof of the orderly progress of the technology.

Introduction

The development of an insecticide formulation is essentially to ensure uniform distribution of that insecticide over a treated area. Early formulations used dust as a spreader for the insecticide, and dust was followed by water. However, the choice of water is limited to insecticides that are water soluble and hydrolytically stable. Wettable powders (WP) were soon developed for water-insoluble solid insecticides, while emulsions were used for water-insoluble liquid insecticides. Emulsifiable concentrates (EC) became popular with the availability of surfactants, and these possibly became the most commonly available form of insecticide formulation.

Basic formulations based on WP and EC are still used around the world. However, their use has given rise to a number of environmental and health

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concerns. As substitutes, newer formulations such as suspension concentrates (SC), microgranules, emulsion concentrates in water (EW), microemulsions (ME), capsule suspensions (CS), gels and others were developed. These new formulations are characterized by their higher safety standards, optimized efficacy and overall precision. This chapter aims to elucidate the process of microencapsulation and its advantages in developing a new generation of formulations specifically for urban pest control.

Microencapsulation as a Technology

The first research on microencapsulation technology started in the mid 20th century in the USA. In Poland, it began in the 1970s, when for the first time the encapsulation of therapeutic substances such as vitamins and antibiotics in microcapsules was attempted. Encapsulation is a method of wrapping a core substance or particles in walls formed from one or more covering substances. Currently, most insecticides can be delivered in an encapsulated form. However, development of microcapsules loaded with a known insecticide which will function effectively and also meet the majority of conditions that would be expected from a product (including safety, cheaper production costs, etc.) is a complex task. The difficulty lies in selecting both an appropriate capsule size and a compound that will act as the capsule's shell.

Capsules are split into three categories depending on their capacity. These are classified as macrocapsules with sizes of over 5000 μm, microcapsules with sizes of 0.2–5000 μm and nanocapsules with sizes of under 0.2 μm. The shape of the microcapsules depends on the method of microencapsulation, the nature of the core substance and the composition of its walls. The core can take up 10–90% of the total weight of the microcapsule. A capsule may consist of a single substance or a mixture of solid, liquid or gas substances. The material that constitutes the shell may be either natural, such as gelatin, arabic gum, fats or cellulose derivatives, or synthetic compounds, such as resins, polyethylene and polyurea, among others. A comparative study of four insecticides (fenthion, mevinphos, acetophenate and methylparathion) with two wall types (polyurea or gelatin with gum arabic) reported that a microcapsule wall made of polyurea performed well. The use of polyurea as a shell guaranteed low toxicity in laboratory studies on mice when the test substance was administered orally, topically or through inhalation. In contrast, a gelatin shell collapsed quickly, thus releasing insecticide into the digestive tract of the mice (Gao and Wang, 1989).

By altering the chemistry of the polymer shell or the core, capsules can be made to vary in size, solubility, wall thickness and degree of penetrability. All of these features are crucial for the release time of the active substance. A major step forward in this field was the development of a solid core encapsulation technology that has become available as a Slow Release technology®. This method allows a further improvement over the existing technology. Solid core encapsulation can be considered as a breakthrough in increasing the effectiveness of a formulation through extended release. In this technology, a core is built from hydrophobic, biodegradable soft polymeric gel saturated with biologically active constituent(s). Generally, the wall of a capsule is made of a porous layer of a highly cross-linked polymer that encloses the active content. The wall enables the controlled diffusion of the active substance into the body of the target species in the right concentration, while at the same time preventing exposure of the active substance to non-target organisms. Capsules also have the property of aggregating allergens, such as those from dust mites, cockroaches and bed bug droppings, thus indirectly reducing the amount of allergens in the environment.

In addition, certain pesticides such as trichlorfon can be microencapsulated by a double-walled encapsulation technology. This unique encapsulation technique is based on covering a solid active ingredient (in a crystal state) suspended in the liquid core of the capsule with a double polymer shell. This has proved to be a very worthwhile solution against Pharaoh ants. The technique reduces the hazard of exposure to the insecticide and generally diminishes the repellent effect that may occur once the compound is used in formulating a food-based bait.

Release Mechanism

Microencapsulated capsules require a trigger mechanism to release the content of capsules. This is critical in determining the efficacy of the formulation. The mechanisms which can trigger a release are:

- Mechanical stress.
- Use of external pressure.
- Diffusion of substances constituting the core of the microcapsule.
- Wall degradation caused by chemicals, enzymes or external factors such as temperature, pH and light.

All capsule walls that show sensitivity to an alkaline ambient pH were considered as an excellent choice for developing formulations against insects. This is because the potential release site for microcapsules, in the insect gastrointestinal tract, has an alkaline pH. Therefore, a suitable capsule wall was designed containing a group that splits under the alkaline conditions prevailing in the insect gut. As a result of wall degradation, the active substances constituting the core escape into the gut and eventually cause death of the insect. This type of microcapsule is extremely safe to use as it acts selectively only on ingestion by the insect pest. The technology has a patent in Poland (PL 198545).

Another method for releasing the contents of a microcapsule is through extraction of the material from the capsule core by placing it in a suitable liquid. If the core of the microcapsule is soluble in water, it is surrounded by a wall made from, for example, ethylcellulose which lets water through. The content of the microcapsules can be extracted or released either just by using water or by rupture of the microcapsule walls through swelling of the water soluble substance constituting its core. The release speed of the substance contained in the microcapsule may be regulated by the type of polymer that forms the shell, its thickness or the diameter of the microcapsule itself. Generally, nanocapsules act as quick-release capsules, whereas microcapsules provide slow and extended release of the substance carried within the core.

One of the most advanced technologies that uses microencapsulation is the 'Attract & kill' technique. This is a novel approach to cockroach control and is available under the product name 'Attracide'. Attracide is a sprayable encapsulated film. It uses solid core microcap technology to hold the active ingredient on both porous and non-porous surfaces for a much longer period of time than a conventional formulation (Fig. 11.1). Effective and prolonged control is ensured by the food-grade solid core nano-size capsules with an attractant that lures the insects to the treated site. Passing and crawling insects then carry the capsules loaded with toxicant on their bodies into their nest and unknowingly pass them on to the other members of the colony (Fig. 11.2). A spot and strip application has been further developed as a gel application. Gel applications reduce the amount of formulation used per treatment; thus, reducing the risk of exposure while providing an extended release of up to 60 days of residual action (Fig. 11.3).

Microencapsulation and Lowering the Toxicity of Insecticides

One of the first microencapsulated insecticides introduced into central Europe in the early 1990s for urban pest control was Empire 20CS. This is a liquid concentrate containing microcapsules of chlorpyrifos, an organophosphorus

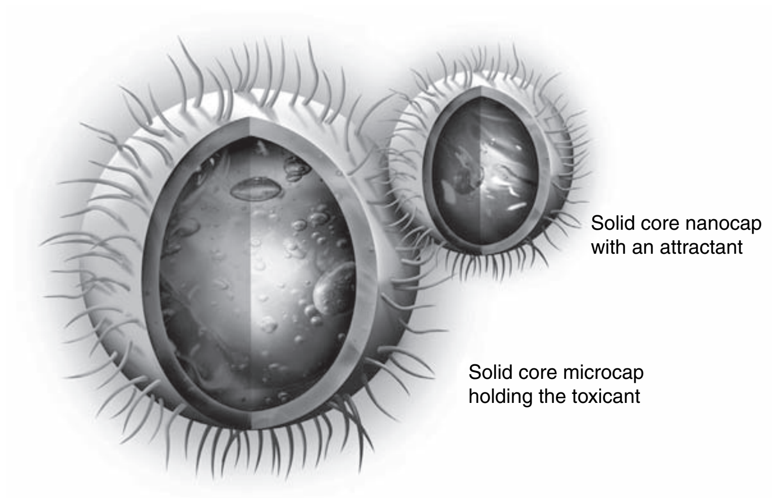

Fig. 11.1. A unique mixture of food-grade solid core nanocap (nano-size capsules) with an attractant that lures the insects to the treated site and the associated solid-core microcap (microcapsule) that holds the active insecticidal ingredient.

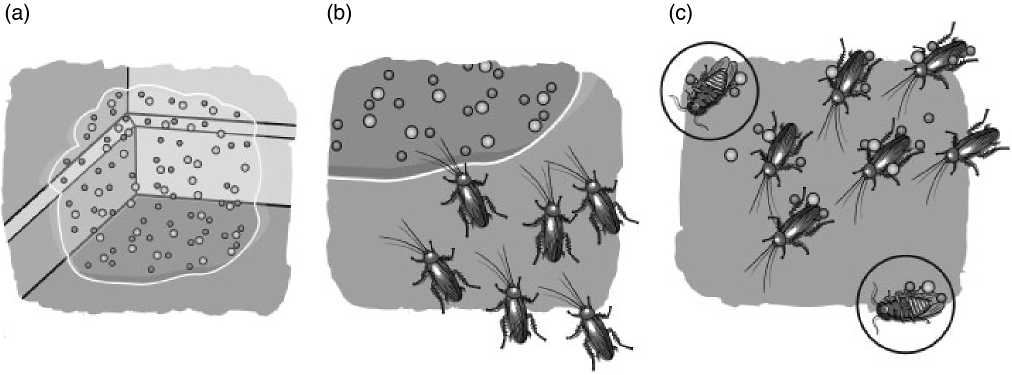

Fig. 11.2. (a) On the treated surface, the microcapsule application creates an active encapsulated film that carries encapsulated attractants (as nanocaps) and the insecticide (as microcaps). (b) The attractant lures the insects to the treated site. (c) The insects passing over the application site pick up and carry on their bodies the capsules loaded with toxicant, thereby taking it back to the nest and unknowingly passing it on to other members in the colony. After 48 h there is a significant reduction in the population – significantly more than is caused by a conventional formulation.

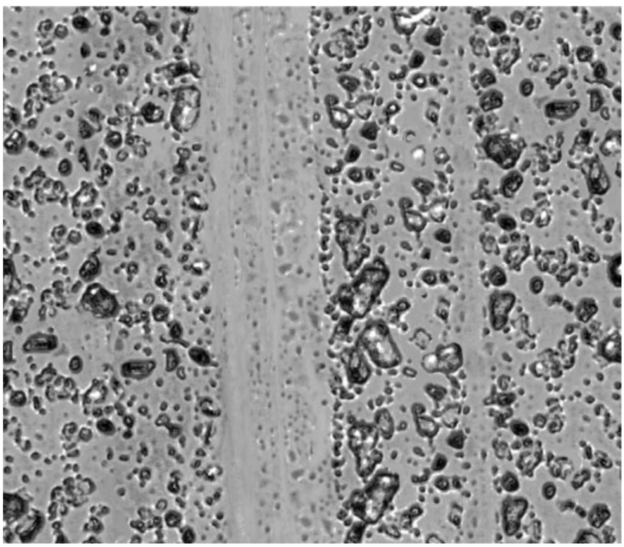

Fig. 11.3. A spot and strip gel application: photograph of the treated surface (glass) 36 h after application, with a gap made by a hair (300× magnification).

insecticide. The product is diluted with water and used as a surface spray. Chlorpyrifos as a non-microencapsulated insecticide is a highly toxic chemical for both humans and animals; experiments on rats have shown an oral toxicity of 135–163 mg/kg. After placing the toxic chlorpyrifos inside a polymer microcapsule, the overall toxicity decreased to 5000 mg/kg, and in the final preparation it was reduced to 25,000 mg/kg. A similar effect was obtained by formulating the bait 'Faratox Turbo' against Pharaoh ants; the bait contains trichlorfon as the insecticide. The active substance has a high oral toxicity to rats at doses of 560–630 mg/kg. However, after placing it in a nanocapsule, the toxicity fell to below 5000 mg/kg (unpublished research data).

The encapsulation of what is currently one of the most effective repellents against mosquitoes, diethyl-*m*-toluamide (DEET), is considered to be a very promising delivery system with reduced risk. DEET is an effective and generally well tolerated insect repellent applied to human skin. Documented undesirable effects such as tingling, mild irritation, and sometimes desquamation, follows with repeated application. In some cases, DEET causes contact dermatitis and exacerbation of pre-existing skin disease. It is also known to be efficiently absorbed through the skin and by the gut. Moreover, a blood concentration of about 0.3 mg/dl has been reported several hours after dermal application in the standard prescribed format. The amount absorbed increases as the concentration of DEET rises. In addition, many commercial formulations are prepared with ethanol as a solvent, thus further increasing DEET absorption.

Solid-core microencapsulation and nanoencapsulation of DEET encase the chemical in a slowly dissolving polymer. The active ingredient diffuses out of the solid core and the capsule shell at a rate determined by the permeability of the release matrix and the diffusion properties of the carried substance (in this case DEET). In this way, a very low percentage of DEET penetrates the epidermal layer of the skin. This advanced concept provides long-term anti-biting protection without any undesirable effects. The application of DEET in encapsulated form reduces absorption of this substance through the skin by 25–35%, as shown by the studies of Kasting *et al*. (2008). This reduces the potential harmful effects of DEET on the human body, as it is released at a controlled concentration, and only very minimal amounts may be in contact with skin at any one time, thus reducing the likelihood of possible absorption.

In the traditional repellent formulation of DEET, all of the applied DEET is present directly on the skin, hence the chances of absorption are greater. In addition, the alcohol-based DEET formulation has to be reapplied two to three times to give 8 h protection. This, in turn, creates more possibilities for DEET absorption, and an increase in the total absorption of DEET. In contrast, in microencapsulated DEET, the extended release time of up to 10–12 h makes reapplication unnecessary. This might be a crucial characteristic for application on children as, under similar conditions of exposure, children will absorb more DEET through the skin than adults; thus, encapsulated DEET would be a highly promising formulation for children. As a result of its controlled and sustained release properties, the formulation has also become particularly suitable for people suffering from dermal hypersensitivity reactions.

Efficacy of Microencapsulation Against Pests

Microencapsulation allows the release of insecticide precisely and slowly. The breakdown of a capsule might be designed to take place only when it gets into contact with the surface of the insect's body or when it reaches its digestive tract, either by a mechanical or enzymatic mechanism. Upon reaching these target sites, the microencapsulated formulation releases its active ingredient. Generally, when insects pass over a zone treated with microcapsules, these adhere to the insects' hair, legs and antennae. Once released, the insecticide diffuses from the capsule surface, is absorbed by the cuticle and penetrates the body of the pest. This process can also take place during food consumption when, together with the food, insects also ingest the microcapsules attached to their appendages; they may also consume microcapsules during the cleaning or grooming process. In this way, the insecticide gets into the digestive system.

The insecticide fenthion used as a microcapsule formulation can be effective as an insecticide for mosquitoes (*Culex pipiens* and *Cu. quinquefasciatus*), the American cockroach (*Periplaneta americana*) and bed bugs (*Cimex lectularius*). For these pests, microencapsulation extended the killing effect by 2–12 times, increased the safety to people and reduced the odour of the insecticide, all at a lower production cost (Gao *et al.* 1984). In another study, it was observed that lower doses of the microencapsulated active substance fenitrothion (0.25 mg/m^2) caused greater mortality among German cockroaches (*Blattella germanica*). Four weeks after the initial application, the effectiveness of the formulation was 60%. Moreover, the effectiveness was lower when the same insecticide was used with the same dosage in a powder form; in this case insect mortality after 4 weeks was recorded as 40%. Extending the test further to 8 weeks to determine residual insecticide activity revealed that the microencapsulated formulation caused 10% mortality while the powder formulation gave only 3% mortality (Fuyama *et. al.*, 1984).

Furthermore, studies by Kubota *et al.* (2007) showed that treating a strip of soil with a formulation of microencapsulated fenobucarb can repel and act as a barrier to the termites *Coptotermes formosanus* for a period of 7 days. Microcapsules protect the active ingredient against rapid decomposition resulting from adverse weather conditions such as sunlight and rain. Research was also conducted on the use of microencapsulated permethrin applied against stable flies (*Stomoxys calcitrans*), a troublesome cow parasite. This experiment compared the effectiveness of the permethrin as an emulsifiable concentrate on and in a microencapsulated formulation. The formulations were carefully applied to the surface hair of the legs and shoulders of cows. Studies were then conducted to evaluate the residual effect of the products and also on the insecticidal effect of the application. A high mortality of the pest was observed. Further analysis performed by gas chromatography of the insecticide-treated hairs showed the presence of microencapsulated permethrin on the hair surface in 50% of the tests after 3 days; after 7 days, the level of the insecticide had decreased by up to 31%. In comparison, chromatographic studies of the cow hair treated with the conventional emulsion permethrin formulation was found to last for 3 days only (Meyer and Hunter, 1991).

Insecticides with inherent repellent effects can lead to pests avoiding exposure to lethal doses in residual sprays. This has been associated with the dry deposits often encountered with pyrethroids. In contrast, a microencapsulated formulation containing lambda-cyhalothrin remained intact for several months on a variety of surfaces and provided control of pests including the mosquito *Aedes aegypti* and the cockroach *B. germanica* (Wege *et al*., 1999). Microencapsulation delayed the release of active ingredient, which allowed the insects to acquire a lethal dose before any repellent took effect.

Microencapsulating and Overcoming Resistance to Insecticides

Bingham *et al*. (2007) showed that treating insects with piperonyl butoxide (PBO) in emulsion form 5 h before a conventional alpha-cypermethrin treatment caused breakdown of resistance in the insect to the insecticide. Further, microencapsulation of alpha-cypermethrin could be used to delay the operation of the insecticide if combined with the synergist as a mixture, thus resulting in a greater susceptibility to the action of a conventional insecticide to which the insect had been resistant in the past.

In this experiment, field studies were undertaken on different methods of administering a combination of PBO and alpha-cypermethrin to both resistant and susceptible strains of the peach aphid, *Myzus persicae.* In the first variant (treatment 1), the experiment used a non-microencapsulated form of the insecticide and PBO as a mixture. In the second test (treatment 2) the insecticide was applied 5 h after the treatment with PBO. In the third treatment (treatment 3) a mixture of PBO in the form of an emulsion and microencapsulated alpha-cypermethrin in a ratio of 1:9 was administered. The highest mortality of resistant insects was observed with treatment 2, in which the coefficient of resistance decreased to 2. In treatment 3, the coefficient of resistance decreased to 3.7 in the same resistant insect. Although treatment 3, the combination of a mixture of PBO and microencapsulated alpha-cypermethrin at a 1:9 ratio did not give the best results, it was found the most cost justified in terms of practical use because it only required a single application.

Encapsulation as a Controlled Delivery System Against Urban Pests in the Field

Insect bites are a serious epidemiological issue. Mosquitoes, ticks and blackflies, which have worldwide distribution, not only cause impairment and fatality but also injury through allergic or toxic reactions. Bites from these pests can often cause serious allergic reactions, often accompanied by pain, severe itching, swelling and erythema; in some cases, people who are susceptible suffer from allergic conditions, swelling and erythema that can last for more than 48 h. Consumer products available over the shelf as repellents are often the best way that individuals keep themselves free from insect bites. However, the real challenge is to design a formulation that can repel biting insects effectively, while being well tolerated by people with a sensitive skin and who may be prone to allergies. An intolerance of many repellent products designed for direct skin application can considerably limit the ability to prevent insect bites and their results. Use of microencapsulated formulations is of considerable help in such a situation.

Mosquitoes

Control of flying insect pests by using microencapsulated insecticides in attractant baits is a method which brings rapid and systematic elimination. This method is particularly useful in controlling flying insects such as flies in enclosed livestock areas. Until recently, dichlorvos (DDVP), an organophosphorus insecticide, was used partly for its fumigant properties in vacant indoor areas. However, microencapsulation of DDVP has transformed the formulation of this insecticide from a gas to a pseudo-solid substance which can now be used in baits. Researchers in China have examined the effectiveness of microencapsulated DDVP in combating the mosquito *Cu. pipiens*. They found that this form of insecticide provides a longer duration of action than the standard form of insecticide in the form of an emulsion (Jibo *et al*., 1999).

A nanoencapsulated formulation of lambda-cyhalothrin is also considered to be highly effective against mosquitoes and other flying insects, and has shown over 15 weeks of residual efficacy. Moreover, thanks to the solid core encapsulation technology applied, exposure to lambda-cyhalothrin and to the solvents used (through inhalation, dermal absorption or ingestion) has been significantly reduced (unpublished data).

In order to meet the expectations of current safety standards set for mosquito repellents that are applied directly on skin, a nanoencapsulated DEET formulation with a slow release and solid core technology was developed in 2004 in Poland. Subsequent laboratory bioassays were conducted to assess the efficacy of this product against *Ae. aegypti* and dog ticks (*Rhipicephalus sanguineus*) in terms of repellent effect. Application of the formulation resulted in a 100% repellent effect against mosquitoes for 8 h over the entire duration of the experimental period, i.e. it was highly effective. However, the repellent effect on dog ticks was lower, at 60%, immediately after treatment, and decreased thereafter over the 8 h period. The poor repellent effect against dog ticks was attributed to the already well-known inefficient repellent properties of DEET against dog ticks (unpublished data).

A coating formulation of microencapsulated DEET with prolonged repellent release on to fabric was also developed; the application of repellents to clothing fabrics can significantly help to reduce the direct use of repellents on skin. There have also been attempts to obtain microencapsulated DEET that would open slowly and over a prolonged period of time to gradually release the repellent on to fabric. According to Fei and Xin (2007), the research they conducted on *Ae. albopictus* mosquitoes using microencapsulated DEET with polymer walls showed a 100% effective repellent effect, lasting for more than 8 h after application to the fabric. This effect was also observed when microcapsules of DEET were tested on polyester net (mesh diameter 1 cm) that was similar to mosquito nets. The walls of the capsule polymer used were considerably thicker than the standard thickness, which allowed diffusion of the repellent to last for several months (N'Guessan *et al.*, 2008). The microencapsulated repellent substance remained stable and maintained an average level of performance for more than 6 months after application to the fabric. In comparison, a standard formulation showed rapid decline in effectiveness over time, and after 6 months its presence on the net was negligible.

Fleas, bed bugs and dust mites

Encapsulation of pesticides is effective in the control of various developmental stages of dust mites (*Dermatophagoides*), cat fleas (*Ctenocephalides felis*) and bed bugs (*C. lectularius*). Allergoff, a highly advanced formulation introduced into Europe, consists of nano-sized capsules containing a pure isomer of *trans*-permethrin, benzyl benzoate and pyriproxyfen. The applied formulation permeates into the environment of dust mites, where nanocapsules stick to infested surfaces such as the mite faeces, discarded epidermal fragments and the dust mites themselves. A study on the efficacy of a nanoencapsulated mixture of *trans*-permethrin, benzyl benzoate and pyriproxyfen demonstrated high acaricidal activity on mites up to 3 months after application; for a nanoencapsulated benzyl benzoate formulation high acaricidal activity was demonstrated over 12 months (unpublished data). The mode of action of these formulations in direct killing and population reduction of dust mites takes place in the following three ways:

- The nanocapsules penetrate into the body through the body wall.
- Nanocapsules stuck on various particles such as skin fragments and body parts of the mites are directly consumed by all active life stages.
- The juvenile hormone contained in the formulation inhibits development, thereby limiting mite population growth over a period.

In addition to their direct effect on the mite population, microcapsules also help to eliminate mite faeces from homes, which is often a complex problem. Owing to the small size of the faeces, most vacuum cleaners are not able to physically remove them. Capsules of Allergoff bind with the mite faeces, making larger particles that are incapable of becoming airborne under normal conditions, and are easily collected by a vacuum cleaner. However, it is vital to control the mite population in the long term in order to obtain significant clinical relief for chronic asthma sufferers. A number of tests on encapsulated Allergoff have shown a considerable improvement in the management and control of house dust mites compared with conventional methods (unpublished data).

An in-house laboratory bioassay was also conducted to assess the efficacy of Allergoff as a formulation against bed bugs and cat fleas, in terms of knock-down and mortality. The product was applied directly on to the test insects. Knock-down and mortality were assessed at 1, 24 and 48 h after treatment. Application of Allergoff resulted in 100% mortality in cat fleas and 85% mortality in bed bugs 1 h after treatment. In bed bugs, there was 100% mortality 48 h after application.

Termites

Transfer of insecticide indirectly from insects that have been in contact with the formulation to another member far from the application site, during regular touch and grooming activities, is another significant advantage of microencapsulated formulations. Using this method, the effect of the formulation can reach far from the area of the treatment and into pest harbourages and hideouts. In this way, pests can be controlled even without coming directly into contact with an insecticidal substance. This approach is very much applicable to cockroaches and social insects such as ants and termites. The control of termites using a permethrin bait in microencapsulated form was reviewed by Schoknecht *et al.* (2006), who noted a significant transfer of insecticide into the termite nest that affected individuals which were not foraging. The use of encapsulated insecticides delays the time of their action and reduces the repellent properties of the insecticides, which enables the transfer of the substance into a nest in sufficient quantity to be effective.

Ants

The encapsulated granular bait formulation ‘Faratox Turbo’ is successfully used to control Pharaoh ants. This unique formulation contains trichlorfon within double-walled microcapsules, and gives the product a very high efficacy and low toxicity. Because of the effect of the encapsulation in reducing the repellency effect of the insecticide, the product is very attractive to Pharaoh ants even in the presence of regular food products. Ant workers that come into contact with Faratox Turbo transfer the poison to the nest for storage and consumption by all members of the colony. This process eventually brings about total colony elimination. The formulation has proved to be a more efficient control method than conventional formulations against Pharaoh ants, with elimination of the entire nest within 2 weeks.

Conclusions

The introduction of the microencapsulation and nanoencapsulation technology of insecticides is a new opportunity to save both the environment and humans while at the same time maintaining an effective method for combating insect pests. The evolution of encapsulation has also significantly influenced a number of key formulation parameters concerning safety and environment. The first is the release of the active ingredient in a fully controlled concentration, thus increasing the life of the formulation after treatment. The second is the reduction of the concentration of the active substances to be used for treatment, which prevents the risks of overexposure to pesticides of the applicators and homeowners alike.

The advantages of encapsulation are slowly being recognized worldwide by the pest control industry, and the number of patents granted for microencapsulated insecticide products has become increasingly important as proof of the orderly progression of the technology. Microencapsulation and nanoencapsulation have shown great promise for the development of targeted substance delivery, not only in the field of public health, but also in many other sectors. It is believed that this technology will add new functions and features that will be useful in the control of insect pests.

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12 Pheromones: a Resourceful Tool in Modern Urban Pest Management

Alain VanRyckeghem

Summary

The impact of the anti-pesticide movement on the perceptions of people regarding chemicals has gained substantial momentum throughout the USA. The pest management industry is now caught in a dilemma with the responsibility of protecting human health and property on the one hand and the need to use more progressive strategies on the other. Progressive strategies include the judicious use of less toxic materials, environmentally compatible alternatives and patience. People have always desired a pest-free living environment and an insect-free food supply without the hidden fear of potentially hazardous chemical residues. This growing public sentiment has driven enterprising pest control companies to shift into using bio-rational pest control alternatives. At the forefront of these alternatives is monitoring for the presence or absence of insect pests using pheromones and traps. According to Phillips *et al*. (2000) innovative and effective alternatives to chemical insecticides are needed for stored product pest management. The current use of pheromones of stored product insects as monitoring tools does not represent a direct alternative to chemical control. However, pheromones are clearly an important component of decision-making methods, which indicates that these and other methods could be applied in practice. Pheromone technology has been significantly refined in both science and delivery, and with continued research, it will no doubt be a major player in bio-rational pest control strategies for a large group of pests.

Introduction

Insect pests of stored products cause significant economic losses because they feed on products that are grown, harvested, processed, packaged, transported

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and stored in some facility. Those products that become infested are discarded as a result of the insect damage, causing losses of thousands of dollars. It is estimated that 5–10% of all stored food products are discarded in the USA each year at a cost of billions of dollars. Museum and wardrobe pests can destroy irreplaceable artefacts of historical value. Similarly, damage to ornamental and landscape plants results in spoiling the beauty of the landscape, and replacements of large trees, shrubs or tracts of plant growth could be expensive. To abate these losses caused by insect pests the urban pest control industry has predominantly used pheromones in the management of pests of stored foods, 'stored culture' (in museums and historic houses) and horticultural or landscape plants.

According to Tom Phillips (Indianapolis, 1994, personal communication): 'Presently, pheromones are not used to suppress insect pest populations in urban environments. Rather, these are routinely used in traps baited with non-pheromone food attractants, [and in] unbaited traps and as a luring method in integrated pest management (IPM). In fact, researchers have begun to explore the potential of developing pheromone-based methods for pest population suppression'. In 2007, the US Environmental Protection Agency (EPA) registered the first pheromone for indoor use; it was designed to control stored food moths using a mating disruption technique. This combination of pheromone dispenser and pheromone-baited traps is expected to open doors for the extensive use of this technology within a comprehensive IPM programme focusing on prevention, monitoring and other rational control strategies.

Pest Identification

A key element of using pheromones in a pest management programme is the correct identification of the insect species. Many of the pheromones available to the pest management professional (PMP) or pest control operators (PCO) are species specific and, occasionally, are suitable for closely related species of the same genera. Misidentification can result in the incorrect lure selection and a failure in attracting and trapping the target pests.

Knowledge of the biology and behaviour of a particular insect species is also critical for selecting the type of trap. A species of beetle that is incapable of flight, such as the red flour beetle (*Tribolium castaneum*) or the adult khapra beetle (*Trogoderma granarium*), cannot be trapped by using a hanging trap. A trap at floor level, or one attached to a surface that crawling beetles can climb, would be appropriate in these cases. In another example, webbing clothes moths (*Tineola bisselliella*) are poor fliers, while case-bearing clothes moths (*Tinea pellionella*) are excellent fliers. The difference between them allows glue traps with lures placed on flat surfaces to catch *Tineola* moths effectively, while hanging traps are more effective for the flying *Tinea* species.

The Insect Pheromone System

Insect activity is directed by a number of different pheromones. Two types of pheromones are commonly released by stored product insects and by a few urban pests: these are sex pheromones and aggregation pheromones. Another broad category of chemical attractants are kairomones, which are chemicals produced by one species (insect or plant) that attract a different species. A kairomone benefits the receiving insect but is frequently a disadvantage to the organism releasing it.

Sex pheromones

Sex pheromones are produced by the female to attract mates. These pheromones comprise specific compounds or a highly specific combination (blend) of compounds. They are usually produced by adults with short lifespans of only a few weeks, e.g. stored food moths, the cigarette beetle (*Lasioderma serricorne*) and warehouse beetles (*Trogoderma variabile*). This short lifespan makes the sex pheromones highly active and attractive to male insects, which are estimated to show sensitivity to the pheromones at a level as low as a few nanograms. The pheromones are active over a long distance as well, and can draw moths with plume distances of over 100 m and, in some cases, as in gypsy moths (*Lymantria dispar*) even kilometres away (Shuker, 2001).

Aggregation pheromones

Aggregation pheromones are typically released by males and both attract male and female individuals. These pheromones are produced by species with long adult lifespans of several months to years, as in most stored food beetles. Certain aggregation pheromones are not species specific, e.g. those of *Tribolium* flour beetles, and a cross-attraction exists especially among closely related species, such as red flour beetle and the confused flour beetle (*Tribolium confusum*). The range of attraction of these types of pheromones is much shorter than that of sex pheromones. Often the distance is measured in a few metres (< 7 m); mostly, however, foods synergize the effect of aggregation pheromones, as in the case of the red palm weevil (*Rhynchophorus ferrugineus*), where a combination of fermenting food and aggregation pheromone generates a significant attracting response (Hallett *et al.*, 1999). Although aggregation pheromones increase the likelihood that an individual will find a mate, the role of these substances in mating may not be their primary function. Aggregation pheromones attract insects to locations where mating occurs and where females find ideal egg-laying sites in the presence of food products.

Food attractants and kairomones

Kairomones are chemicals that are produced by one species that attract a different species, usually to its advantage. Many food-based odours will enhance the attractiveness of pheromones, while many economically important pests exist for which no sex or aggregation pheromone has been identified. In the absence of a pheromone, it is useful to substitute a preferred food source. Merchant grain beetles (*Oryzaephilus mercator*) that feed on wheat daily can be attracted quickly with the highly desirable odours emanating from oat or carob bean oils. Other insects, such as the dermestid odd beetle (*Thylodrias contractus*) would quickly switch from consuming 100-year-old lambskin on old books to fresh dry fishmeal. In the absence of an available pheromone, a preferred food attractant placed inside a pitfall or sticky trap can yield excellent results. In a few cases, as with the German cockroach (*Blattella germanica*), food attractants are more effective than a species' aggregation pheromones (Nalyanya and Shal, 2001). Food attractants can also attract the females that produce the pheromone, to which they are not attracted (Papadopoulou and Buchelos, 2002).

Recent investigations on attractants for the bed bug, *Cimex lectularius*, have shown several kairomones that are present in the sweat of humans. These have been put in lures and combined with heat and carbon dioxide to produce an effective trapping device for bed bugs (Bennett *et al.*, 2007).

Lure and Trap Designs

There are a number of pheromone lure manufacturers around the world. It is, however, important to choose a lure design/brand that provides sufficient response to attract individuals into the trapping mechanism over the desired timespan. The selection of a trap is dependent on the target pest and environment. Small differences between traps of a similar design from different manufacturers can have significant differences in trapping efficiency (the percentage of individuals that actually become trapped when interacting with the trap). Experimentation with different trap models and manufacturers can help to select the best combination for capturing a large sample of the population.

Lure loads and release rates

After a pheromone is synthesized in a laboratory, it is placed into a delivery device or lure. This device comes in various forms: as rubber septa, hollow fibres, flakes, tape, laminated plastics, membranes over reservoirs and polyethylene vials with acetate beads. The lure design should deliver the pheromone into the environment in a manner that mimics natural release rates and concentrations from the target insects. Lures vary in their duration of effectiveness and distance of attraction owing to differences in pheromone load and release rates. Many insects can be overpowered and repelled by too much pheromone, e.g. *Tribolium* flour beetles and granary weevils (*Sitophilus granarius*). A controlled-release lure will allow the pheromone to be released in smaller concentrations to lure the pest into the trap, but is strong enough to reach out and attract pests from a reasonable distance. In addition, the lure needs to remain effective over a period of time.

The quality of pheromone is important for some species, such as the cigarette beetle, flour beetles and warehouse beetles. Some impurities in synthetic products are repellent unless they are at concentrations of less than 5%. Good-quality pheromones have high purity of the desired chemical structure, while some pheromones are a blend of chemicals and require a specific ratio to be effective. Lures containing a blend are more attractive than lures that use only one common compound that attracts several related species. Furthermore, the use of species-specific blends in lures may reduce the catch of closely related species. For example, the Indian meal moth (*Plodia interpunctella*) and almond moths (*Ephestia cautella*) are attracted to a common pheromone that is widely sold as such. Substituting the common pheromone with a blended pheromone that is specific to the Indian meal moth will repel the almond moth and reduce its catch.

It is important to establish a number of factors before a pheromone lure is used. These are shelf life, duration of pheromone release, recommended spacing of lures, production dates and general composition (e.g. blended or single compounds) of the pheromone. This information is critical in order to obtain consistent, long-term pheromone release and attraction of the insects to the lures. Cheaply made lures have very little pheromone and no control over release rates, are poorly packaged and have often been on retail store shelves for many months. Users should be careful in selecting these poorly made products, which both have comparatively very poor results and could have an expired shelf life by the time they are purchased.

Trap designs

Pheromone traps for flying insects come in many shapes and sizes. It is, however, critical to know the biology of the pest to select the trap properly (Howse *et al*., 1998).

Role of environment in trap design and selection

Choosing the appropriate trap design is crucial for a pest monitoring programme. It is important both to match the specific trap to the environmental conditions in each situation and to match it to the behaviour of the target pest. Some examples are: (i) dusty versus non-dusty areas, (ii) hot versus cold temperatures, (iii) outdoor versus indoor use, and (iv) crawling versus flying insects. Finally, the size or capacity of the trap may be a factor in mass trapping too. In addition, too much dust can make sticky traps ineffective, and dusty warehouses offer challenges for conventional sticky glue traps. Under these extreme conditions, a sticky trap may become useless after several days, or even after several hours. In such cases, the use of pitfall-type or funnel trap that does not include glue as the entrapment mechanism is suitable and efficient.

Some flying moths exhibit an attraction to visual cues, such as colour, lines and silhouettes, and these may enhance attraction from long distances (Levinson and Hoppe, 1983; Quartey and Coaker, 1992). Colour is an important visual cue for certain flies as well. Most traps designed for capturing fruit flies (*Drosophila* spp.) contain kairomones or food attractants, rather than the less effective sex pheromone and have yellow or orange colouring.

Floor-level traps for crawling insects

Many important food pests are beetles that do not fly or will fly and then crawl to a food source or mate. In these situations, hanging traps designed for flying insects are either useless or less efficient. Long-living beetles such as confused flour beetles and saw-toothed grain beetles (*O. surinamensis*) do not fly and they need to be trapped in a floor-level trap. Moreover, the pheromone and food attractants may draw these crawling beetles to an area but the beetle may refuse to go into a sticky trap. To overcome this behaviour, both the species are best trapped using pitfall traps.

Floor-level traps include flat open glue boards, covered glue boards and pitfall traps. Insects such as flour beetles, granary weevils, rice weevils (*S. oryzae*), khapra beetles, saw-toothed and merchant grain beetles are more effectively caught with pitfall traps than flat glue boards. The glue surface is often thick and will repel the beetle before it sufficiently crawls on to it, and the catches might be limited right at the edges. Most cockroach species, including at the small instar stages, are easily lured on to glue boards that have aggregation pheromone or food attractants available. Cigarette beetles can easily fly into hanging traps but will also land and crawl into pitfall traps or glue traps. These trap catches are frequently higher than those of hanging traps in the same location. Clothes moths, which are poor fliers, have higher catch rates on floor-level glue traps too.

The main disadvantages of floor-level traps over hanging traps is the likelihood of damage and loss due to human activity and of unintentional hazard to pets and children. Alternatively, these traps can be placed on level flat surfaces above the floor out of reach of people, pets and equipment, if conditions allow.

Trapping efficiency

The design of a trap to capture a particular species or type of insect greatly influences its efficiency in capturing insects. Assuming that insects have been attracted to the trap with a lure, a trap with excellent trapping efficiency is expected to capture 75% or more of the insects getting into it. More often than not though, this is not the case. Early designs of new traps can have zero efficiency due to poor communication between the entomologist, designer and manufacturer. Designing a trap requires actual observation of the insect's response when it encounters the trap. Data need to be collected on a number of behavioural parameters, such as an insect's refusal to enter the trap or flying away because the entrance is too small or in a poor position, or because there is a high concentration of pheromone in the trap. Changing lure types or the position of traps may elicit positive effects. Such observations will help in deciding which type of trap is more efficient and where to place it correctly. An efficient trap allows the detection of insects much more quickly and a more accurate comparison of insect activity and population trends. Hence, a trap with poor trapping efficiency gives little information and unreliable data.

Pheromones as a Monitoring Tool

Use of pheromones provides PMPs with large amounts of data, but the PMP must then have a purpose for using those data. The amount of effort and cost of a programme will be determined by the information that is gathered, and this can vary from simple observations to detailed numerical records for statistical analysis. Also, the degree of effort that is exerted in monitoring is determined by the goals of the PMP and client. Some examples of how monitoring data may be observed or collected are as follows:

- Monitoring for the presence or absence of a quarantine pest such as the khapra beetle requires regular observation and identification without recording data. The presence or absence of any pest in a quarantine area of a pharmaceutical facility may be recorded without collecting numbers too.
- Early detection of a pest species (by noting only the time and location of traps with insects) can be accomplished with well-placed traps. Monitoring of a residential pest such as the webbing clothes moth can be done by observing moths in the various locations where the traps are placed. The data may not be recorded but the information provides a measure of when and where infestations arise before significant damage can occur to garments or floor coverings.
- Converting data into different levels of infestation/required action is another way of recording trap data. The monitoring of important stored food pests, such as the Indian meal moth, is done regularly and infestations classified as low, medium or high, rather than keeping track of the actual numbers caught. These classifications are associated with required levels of action. Each level initiates various control strategies that vary from sanitation and inspection to fogging, fumigation or disposal.
- Typical monitoring of stored food pests such as the cigarette beetle requires that the individual trap catch is recorded on a weekly basis. The purpose of this is to help time fogging or fumigation activities. Numerical data are recorded before and after treatment to evaluate effectiveness. This method provides a more effective and judicious use of pesticides in an urban environment. Long-term monitoring and recording of insects captured can provide historical data that can help in tracking seasonal activity, generation peaks and population trends. This information

provides the opportunity to predict when to do fumigation or measure the effect of other control measures, such as sanitation. These types of data are frequently organized in graphical form to show trends and spatially map the location of activity.

- Monitoring traps can be used for research purposes. The data from a large number of traps are gathered and analysed statistically to evaluate aspects such as trapping efficiency, luring attraction and changes in population resulting from implementing a new control strategy.

Application of Pheromones in an Urban Environment

Five basic strategies may be used by PMPs in the urban environment. These are pest monitoring, pinpointing infestations, mating disruption, mass trapping, and luring and killing.

Pest monitoring

Pheromones are most useful when pests are detected and monitored early. Placing a trap containing a pheromone in an identified area can easily indicate pest activity. Traps may be placed in a grid pattern and spaced appropriately for the pest type so that there is uniform coverage and a high probability of detecting an insect infestation. As more traps are placed in a site, the degree of interception increases and so does the level of confidence that the trap catch contributes to a certain trend in insect activity. A standard grid pattern may often cover areas of low-risk infestation and some with a high risk of infestation. The number of traps for a given site depends on the mobility of the insect (highly mobile insects need fewer traps per unit area) and the value of the product that needs to be monitored. High-value products should be monitored with more traps to detect early infestations and pinpoint locations. Trap counts with this method may result in a lot of 'zero' captures and a few 'hot spots'. In some situations, the value of the product does not warrant the use of either a large number of traps or a systematic grid placement.

Another approach to monitoring is to put traps only in locations with higher chances of encountering pests, such as harbourages, food spills and hot or moist areas. This 'targeted monitoring' is based on the biological preferences of the pest that is being monitored. It is most often used when monitoring cockroaches, but can be applied to the monitoring of stored product pests such as *Tribolium* beetles as well. This helps the efficient use of the technician's monitoring time and reduces the number of traps in a facility. However, monitoring of this nature can result in undetected infestations in low-risk areas.

In the case of an increase in the number of insects captured from previous catches, additional actions may be undertaken. These include closer inspection of the area or product, improved exclusion methods, alternative pesticide application, use of fumigation, or a change in pest control programme or service provider.

Pinpointing infestation

One use of pheromone traps that is not practised very much is their application for pinpointing an infestation. After a series of traps have captured insects, it may be necessary to know more precisely the location of the infestation. A typical lure for flying stored food moths and beetles will attract insects from 8–16 m or more, depending on the situation. This is a very large area to look over with a flashlight in a warehouse or grocery store full of food products. It is also possible that the range of attraction from one trap is overlapping that of another and that the other trap will 'poach' moths from the trap closer to the infestation (Howse *et al.*, 1998). To compound the problem, almond and Indian meal moths have been observed travelling over 300 m in only 10 min (Hagstrum and Subramanyam, 2006). This long range attraction of highly mobile insects can often make pinpointing infestations difficult.

To overcome this problem, use of low-dose lures is suggested. The smaller dose emits less pheromone and the plume of pheromone diffuses or becomes disrupted at a shorter distance from the lure. These lures typically have 10% of the normal pheromone load and an attraction range of 2–3 m (Mankin *et al.*, 1999). Such lures can be obtained from Trecé (Microdot™) and Agrisense (SP Locator™ with minimoth lure), or can be custom made by some other pheromone manufacturers. As an alternative, regular lures that are 2–4 months old could be used. With these lures, numerous small traps are placed at convenient locations about 1–2 m apart around the areas where standard traps indicate activity. The key to pinpointing the infestation is to return within 24 h (or even a couple of hours) to observe trap catches. Insects closest to the infestation have the shortest distance to fly to a trap and will be in/on the closest traps first. More insects on the traps will reflect a greater abundance of insects too, most likely because they are closer to the source. Leaving the traps too long may saturate them with insects and prevent new insight into the situation.

Mating disruption

Mating disruption is frequently used in agriculture, and also in some forestry applications, to suppress the population of economically important pests such as the grape berry moth (*Lobesia botrana*), pink bollworm (*Pectinophora gossypiella*) and the gypsy moth (Howse *et al.*, 1998). Early observations on the Indian meal moth showed mating disruption effects in the presence of a higher number of moths and pheromone concentration in an enclosed space (Sower *et al.,* 1975). This approach was investigated more recently, and changing the delivery method and doses gave promising results (Ryne *et al.*, 2001; Fadamiro and Baker, 2002).

The principle behind a mating disruption strategy is to delay the mating of the female moth sufficiently to affect the number of egg deposits and percentage viability of the eggs. Hagstrum and Subramanyam (2006) showed that egg viability was reduced by 22% a day when mating was disrupted or delayed.

After 5 days of delay, no viable eggs were laid and male moths were unable to mate successfully with females. A long-term study of mating disruption for Indian meal moths, almond moths and Mediterranean flour moths (*Ephestia kuehniella*) showed a significant decrease (75–90%) in male captured moths. This was a good indicator that male moths had less ability to find female moths. The other important result of this 3 year study was a 49% decrease in customer complaints (Ryne *et al*., 2007).

In 2007, the first federal registration was issued of a pheromone for indoor use to control insect pests by mating disruption. The product, under the brand name of Allure MD™, entered the market in 2008. However, successful implementation of this technology has required a sophisticated monitoring approach within the IPM programme. Using traps to catch male moths in a mating disruption programme may be misleading as the trap catch is not independent of the mating disruption effect. As a result, trap catches should be combined with alternative monitoring techniques, such as the use of female attractants, water traps or visual inspection to confirm population reduction or reduced mating.

Mass trapping

Mass trapping is directed towards reduction of insect numbers in a population by using pheromone traps only. Several researchers have demonstrated that this strategy is successful (Buchelos and Levinson, 1993; Pierce, 1994; Trematerra, 1994). The best mass trapping system is to catch both male and female insects. In one study, it was demonstrated that using a single lure and sticky trap in two areas captured over 59,000 cigarette beetles over 15 months of trapping. When the single lure was assembled with five sticky traps (arranged in a cross-like mobile) in the same two areas, over 500,000 cigarette beetles were caught – an 8.5-fold increase. This is an example of how trap design can dramatically improve capture efficiency and achieve mass trapping (Buchelos *et al*., 2003).

In another experiment, traps were set up in a food storage warehouse for phycitid moths, and each month, a new trap and lure were added near the older ones. After 8 months of adding traps, 372 traps had been placed (one trap/70 m^3) in the warehouse (Pierce, 1994). When a similar programme for cigarette beetles was included that used pheromone and insect light traps (to capture fertile females), more than 500 insects per week were caught at the start. After 2 years, the weekly catch was reduced by 96% for the moths and 99% for the cigarette beetles. The population was reduced significantly without conventional insecticide application.

Mass trapping may not be a very effective strategy with insects that produce aggregation pheromones, such as flour beetles, weevils and grain beetles, unless it is done in a contained and limited situation (Mueller and VanRyckeghem, 2006). Mass trapping for the lesser grain borer (*Rhyzopertha dominica*) has greater potential, however, because of the female's strong response to the pheromone (Phillips *et al*., 2000).

'Lure and kill'

Pheromone traps do not usually capture every insect attracted to a trap. A recent evaluation of a trap in a wind tunnel showed that only 10% of the cigarette beetles placed in the chamber were captured after 24 h (Finkleman *et al*., 2007). Often, the insects were found perching on the wall or on a vertical surface near the trap for long periods of time without going any closer to the trap, or hovering in space near the entrance. Pierce (1994) used a method for several years that he called pheromone-enhanced mortality (PEM), also known as 'lure and kill'. The concept works unlike an 'attracticide', where pheromones are actually incorporated into the pesticide matrix. This technique requires the placement of the pheromone traps near a vertical surface (e.g. a vertical post or wall). Directly behind the traps, a small spot of a residual insecticide is then applied. This two-part approach is effective in capturing the insects that fly into the sticky glue and kills those that perch on the nearby wall. The technique has also been employed with timed pyrethrin mist generators hanging above the lures along the wall.

Trematerra (1994) showed that a small patch of a pyrethroid insecticide (e.g. cypermethrin) could be applied to a piece of cardboard while a pheromone lure was placed in the centre of the cardboard. He put the treated pieces of cardboard containing a pheromone lure into flour mills in Italy. This method proved so effective in the flour mills that the population of Mediterranean flour moths dropped dramatically. The way to test whether the method is working is to place a sheet of white paper or cloth under the trap to capture the insects that fall on to the floor.

Lure and kill strategies can be combined with mass trapping. Even the pinpointing of infestations could be used with this method when necessary. The concurrent use of mating disruption for the same species would, however, be incompatible. Hence, PMPs must carefully plan the combination of methods to use such that one method does not cancel out the others.

Case Studies

The following case studies illustrate how each of the five basic strategies discussed above have been used in the urban pest control industry. Some cases were acquired from journals, but most are based on the practical experience of the author.

Webbing and case-bearing clothes moths

A common pest of wardrobes and floor coverings in North America and Europe is the webbing clothes moth, *Tineola bisselliella*, along with the case-bearing clothes moth, *Tinea pellionella*. These moths are attracted to a blend 2*E*,13*Z*-octadecadienal and 2*E*-octadecenal compounds. The use of pheromone baited traps to capture and monitor these pests has been steadily increasing over the past decade.

The webbing clothes moth is considered to be truly associated with humans more than the case-bearing moth. While it is easy to find the *Tinea* complex of moths in their natural habitats, such as bird and mammal nests, *Tineola* is rarely found outside a structural environment. The habit of these pests is to attack and feed on natural materials containing keratin, such as wool, feathers, furs and animal hair. Woollen garments, floor coverings, tapestries and a variety of household items containing feather or hair can also be damaged by these moths. The nature of these materials precludes the use of residual insecticides. Most insecticides are not used directly on clothing and only limited application is done on floor coverings. As such, homeowners most often incorporate the use of pheromone traps to help direct other management strategies for the control of these moths.

The prime targets of the moths for egg laying are in clothing cupboards and wardrobes or in rooms with oriental and woollen rugs. The challenge for the homeowner begins by locating those areas where infestations may occur and evaluating the effect of the control strategies they may implement. The homeowner would mostly set out one trap for each bedroom wardrobe and each room with stored woollen materials or woollen floor coverings. An average 100 m^2 home may require five to ten traps, with larger homes requiring more. Older homes from the 1800s and early 1900s may have added natural hair felt in the flooring to dampen noise, or wall plaster containing horsehair. These types of situations require constant monitoring to prevent severe outbreaks that may damage personal belongings.

Lures are used to attract male moths to the trap from a distance of 3 m. Webbing cloth moths are not considered strong fliers and are mostly found crawling quickly over horizontal surfaces, clothing piles or along hanging garments. Their flight is short and erratic. The recommend trap type is one that is flat and horizontal and can be placed near the moth's food sources. The traps can be placed on multiple levels, including on the floor, under dressers and couches, under/on shelves and in darker storage locations. It has frequently been observed that the moths have an attraction to television and computer monitors in dark rooms. However, this is not sufficient to indicate that these may be modified into a moth trap. Case-bearing clothes moths are much stronger fliers, and these moths are able to hover and fly easily and prefer to enter into hanging traps. Moth traps are set in place for approximately 2 weeks. If no moths are caught, it is suggested that the trap be moved 3 m in one direction or another to continue the monitoring.

Once the traps capture some moths, the homeowners are advised to clean the area and the infested items by vacuuming, washing or dry cleaning. Some materials can be steam cleaned or exposed to sunlight or heat to dehydrate and kill the eggs and larvae. Proper storage after cleaning prevents reinfestation and ongoing use of these monitoring traps should continue to give the homeowner information on the success (or otherwise) of their efforts.

This form of pest management programme emphasizes the use of monitoring traps to direct a non-chemical approach to controlling urban pests. The effect of losing expensive and often personal or family heirlooms to these insects can be devastating. As with any good non-chemical programme, education in the use of pheromones and the strategies of control is a key component of success.

Almond moths

A frequent pest of stored nuts and fruits is the almond moth. This species is attracted to a blend of *Z*,*E*-9,12-tetradecadienyl-acetate and *Z*-9-tetradecenyl acetate. The male moth is very sensitive to pheromone and responds quickly to synthetic lures. It can be a good candidate for use of the pinpointing method when the need arises.

The case of a warehouse food processor who stored dried almonds and raisins is presented here. Widely separated monitoring traps in the warehouse indicated a spike in activity which coincided with several shipments that had been rejected owing to the presence of live moths under the storage lids. Difficulty of inspecting these arose from the large volume (approximately 10,000 covered cardboard containers containing 300 kg) of the products. Some of the options available included fumigation of the entire 10,000 pallets of product after loading them into approximately 200 trailers, fumigation of the entire warehouse, or physical inspection of all the pallets as they were loaded for shipment. Loading into trailers would require 9 days with a fumigation cost of €85,000. Fumigation of the entire facility would entail 3 days, costing €185,000. Inspection of all outgoing pallets would require 21 days with a labour cost of €45,000.

In implementing the last of these three options, detection of the infested pallets was accomplished with the use of approximately 1000 inexpensive sticky traps and low-dose lures. Deployment of the traps with lures took approximately 2 h. A follow-up inspection of the traps after 4 h indicated two separate areas of high activity. Inspection of 48 pallets showed that 16 pallets had active infestations. Over the remainder of the 21 days there was only one additional rejected pallet. The advantage of this pinpointing strategy was that the most likely infested pallets were identified and removed within a day. The additional use of temporary low-dose lures and traps cost an extra €1000. The main advantage of this strategy was that fumigation was not required, and the direct and indirect cost savings were directed to the labour required for the visual inspection phase.

Indian meal moth

The Indian meal moth is the number one pest of stored food products in North America. However, it is easily attracted to lures containing *Z*,*E*-9,12-tetradecadienyl acetate, a pheromone that was registered with the US EPA in 2007 and labelled as a pesticide to control stored food moths. Several products are now available to use in mating disruption, which is the principal strategy used to control the population of moths within a structure over time. These products release pheromone from dispensers in concentrations higher than that released by lures for monitoring purposes. The plumes or ‘threads’ of pheromone are spread throughout the air space, resulting in male moths following false trails. One problem here is that exposure to plumes with high concentrations of pheromone can disrupt the sensitivity of the receptors on the moths’ antennae, leading to overloading and inability to detect or follow the trail, often resulting in ‘grounding’. Moths literally stop flying and remain stationary on the surfaces of walls and product packaging. This behaviour results in immediate and nearly total shutdown (> 90% reduction) in capture rates for standard pheromone traps.

A mating disruption strategy was used in a five-floor warehouse that stored various vegetable seeds for the agricultural and horticultural industries. Before its implementation, Indian meal moths were captured in monitoring traps at a rate of 113 per week, despite the weekly use of pyrethrin fogging during the summer months. Shortly after implementation of the mating disruption strategy, the deployment trap catch was reduced to nine moths per week. Only two more fogging operations were performed before cool temperatures slowed down flight activity. In the following spring, trap catches remained low. The infestations were minimal and no fogging was performed for the entire year. Savings of €36,000 and of approximately 200 l of insecticide were realized.

It was critical that the warehouse personnel understood that the mating disruption did not kill moths and that there would be live moths present initially. After the first generation under mating disruption, the numbers of live moths would be reduced greatly, but all incoming and outgoing products would still require a visual inspection for recent infestations. The pest control technicians had to increase the number of monitoring traps owing to the reduced detection range of male moths, and the action thresholds had to be adjusted to reflect reduced moth capture rates. Money saved from insecticide application was redirected to increased monitoring (including monitoring female moth mating status) and inspection protocols. Over 2 years, this work helped to reduce both customer complaints and rejected shipments.

Cigarette beetles

One of the few stored food pest beetles that produce a sex pheromone to which males are highly attracted is the cigarette beetle. Serricornin is the name given to the pheromone most often used as a lure for monitoring this beetle. A couple of cases illustrate where the lures can be used effectively in mass trapping programmes.

The first situation was that of a PMP capturing large numbers of cigarette beetles in monitoring traps, despite the regular application of pyrethrin. The client did not want to fumigate but wanted to reduce pesticide application. The PMP decided to double the number of traps which, correspondingly, doubled the trap catches. The PMP continued to add traps weekly, but the number of beetles caught per trap per week remained constant. At some point later, the capture rate of the nearly 400 traps reached a plateau, with the total catch exceeding 2000 beetles per month. Over the next 9 months, traps and lures were replaced at regular intervals and, during this time, the capture rate and total catch began to fall. The client allowed the PMP to experiment with the strategy without applying any insecticide.

The result of this mass trapping programme was a complete elimination of the infestation over 2 years with no insecticide application. A portion of the savings from the insecticide fogging was applied to the cost of extra pheromone traps placed during the project. In this case, a large number of beetles were caught in the traps yet no immediate reduction in trap catch was observed, as would usually be anticipated in mating disruption. While mating disruption for cigarette beetles may have been an option in a such a case, it was not the mechanism needed in this situation.

In the second case study, pheromone lures were used to capture cigarette beetles in a tobacco storage house. The strategy was to increase trap capture rates to achieve control with mass trapping. Over a 15 month period, more than 500,000 beetles were caught, but this still failed to control the population. In the first example (above), it was observed that a sufficient number of traps were used to capture newly emerging male beetles and, over time, the population declined making the trap catch rate increasingly greater than the rate of emergence. In the case of the tobacco storage house, the rates of emergence exceeded the capture rates greatly. Thus, the relative rates of emergence and capture are key to effectively implementing a mass trapping strategy.

Houseflies

The housefly (*Musca domestica*) is a cosmopolitan pest of the urban environment. Among several natural pheromones, it is attracted to the synthetically manufactured pheromone, *Z*-9-tricosene. Unlike many pheromones that attract the species over a distance, *Z*-9-tricosene causes the housefly to remain in contact (arresting behaviour) with the treated location for an extended time. This pheromone is best suited to combination with an insecticide bait or with a residual insecticide application to use a lure and kill strategy (Butler *et al.*, 2007). The effectiveness of the insecticide bait or application is enhanced by the behaviour resulting from the detection of and extended contact with the pheromone. This is an example of target application of insecticide, which eliminates widespread application, waste of insecticide and the killing of non-target species.

In recent years, however, a misunderstanding of the role of this pheromone has led to the marketing of sticky traps ‘enhanced’ with pheromone to attract houseflies to insect light traps. A simple comparison test was made between a pheromone-baited glue traps and glue traps without pheromone, both without additional attracting elements (light, food odours, etc.) in a stable. The result was virtually zero; no flies were caught on either of the glue traps.

Emerging pests and the use of pheromones

In recent years, the bed bug has made a dramatic resurgence. Research has shown that the female produces an arresting pheromone that may have an aggregating effect as well. Bed bugs are also attracted to natural compounds that are produced by human hosts, which, collectively, are a blend of kairomones. In addition, it has been observed that bed bugs respond to a blend of *E*-2-hexenal and *E*-2-octenal, which cause a rapid running response to escape the point source. This is considered to be an alarm pheromone (Benoit *et al.*, 2009).

Several strategies could be employed with the newly discovered pheromones should they become commercially available. Needless to say, a monitoring programme with both aggregation pheromones and kairomones that can help clients to determine the presence of bed bugs in a residence, apartment, hotel room, hospital, nursing home or other commercial facility in a matter of minutes or hours would be of huge benefit. Aggregation pheromones could also be used with the lure and kill strategy, drawing bed bugs from sensitive areas (such as beds and furniture) to patches of insecticides discretely placed nearby. Pyrethrin is often used to flush out hidden pests in order for them to encounter a recently applied residual pesticide in addition to direct contact killing. The use of an alarm pheromone as the main ‘flushing agent’ may be a new strategy that has not been previously used in the urban pest control industry.

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13 Insect Baits and Baiting: Novel Technology for Managing Urban Pests with Less Insecticide

Partho Dhang

Summary

Insect baits are formulations based on combined information from insect sensory physiology, gustatory chemistry, semiochemicals and many other sources. Baits are target specific and allow easy application; thus, they are recognized as a safer alternative than liquid sprays. They are also more practical and popular for use against pests that live in colonies and groups, such as cockroaches, ants and termites. Consequently, these pests have drawn the most attention from manufacturers in developing bait formulations. A number of important factors are critical in developing baits and baiting systems: a suitable active ingredient, a readily acceptable bait matrix and an understanding of the biology of the pest. Bait development has significantly improved and baits now support the practice of integrated pest management (IPM). In addition, they can be used as an excellent tool for monitoring and managing pests, as well as reducing the amount of insecticide used in urban areas.

Introduction

Insecticide application with sprayers, aircraft, spray rigs, knapsacks and hand-held devices is a common practice. However, this form of application causes enormous waste of vital active ingredients, allows non-target organisms to be exposed and contaminates the whole general area of application. This has been recognized by public, industry and policy makers, and has led to a number of modifications in formulation development and application methods.

Earlier insecticide formulations were designed for the broadest possible usage primarily owing to economic constraints. However, because of the gradual increase in market demand and pest prevalence, manufacturers have been motivated to develop custom-designed formulations for specific pests and

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geographical regions. This has allowed dramatic improvements in formulation technology. With these came new regulatory issues, particularly on environmental and human safety. One of these issues is the growing concern about various non-pesticidal additives that are categorized as ‘inert materials’ but, when combined with various active ingredients, can become toxic to animals at genetic, physiological and endocrine levels. Scrutiny by regulators of additives of this nature has further transformed the formulation industry. In short, today’s insecticide formulations have been subject to more evaluation and are target specific, making them far safer than they were a few decades ago.

The pressure for better environmental stewardship forced the chemical industry to look both for safer formulations and much safer application techniques. An insect bait is a unique formulation that is based on combined information from insect sensory physiology, gustatory chemistry, semiochemicals and many other sources. Baits are target specific and easy to apply, and are being recognized as a safer alternative to liquid sprays. Although the popularity of insect baits is now more in urban pest management than elsewhere, the initial attempts to develop bait were for agricultural use.

This chapter will restrict the term ‘bait’ solely to food-based matrices with an insecticide component. Excluded are various insect baits and traps that work purely as attractants.

History of Commercial Insect Baits

Modern food-based bait for large-scale commercial use against insect pest was developed little more than a decade ago. Development was made possible because of advances in research on insect-feeding behaviour and the identification of various food chemicals and feeding stimulants. In the past, the process of bait preparation depended on mixing insecticide with a regular food or a food base. This type of bait was easy to develop, and the earliest record of such a bait can be found in the mid 19th century. Phosphorus, borax, boric acid and sodium fluoride were regularly used in baits for pest control (Mallis, 1969). A poisonous bait using arsenic as the active ingredient in a matrix was made available for controlling termites in 1921 in Australia (Lenz and Evans, 2002). Another public use of bait for the control of termites was the use of dechlorane (mirex)-based bait. Mirex-treated wooden blocks were used as baits for termite control in the USA, and the slower acting nature of mirex assisted in the process (Esenther and Beal, 1974).

The first large-scale commercial usage of baiting was possibly undertaken for the control of the Mediterranean fruit fly [*Ceratis capitata*] in the 1950s. Insecticide was mixed with protein hydrosylate as the attractant or food bait in Hawaii (Berenbaum, 1995). This technique was used frequently in later years for the control of fruit flies (Tephritidae) around the world. In 1957, the US Congress initiated a cooperative programme aimed at eradicating fire ants [*Solenopsis* spp.] in 126 million acres over a 12 year period. Various baits, such as kepone formulated with peanut butter bait and, later, mirex incorporated into a soy/maize cob grits mixture was developed in the 1960s and was widely used in the fire ant control programme (Berenbaum, 1995).

In later years, research on food stimulants, feeding stimulants and the identification of suitable matrices helped to commercialize more refined and sophisticated bait formulations that could be produced on a large scale and helped to transform insect baiting as part of integrated pest management (IPM). The field of baiting for insect pests was further helped by the discovery of insecticidal compounds that were not contact poisons. These were slow poisons that worked purely as growth and metabolic regulators when ingested. The compounds were found to be suitable for bait development as indicated by their higher efficiency in causing mortality. In the 1990s, the commercial development of baits took on a new dimension and became a key component of IPM programmes on a worldwide scale.

Baits for Urban Pests

The development of commercial bait for household pests was, in part, seriously boosted because of increased public and governmental intent to reduce insecticide usage in urban areas. The harmful effects of insecticides on human health and the environment were coming to light as a result of advances in research in the field of analytical chemistry. Baits were thought to be acceptable as they limit the actual amount of insecticide usage, allow the effective use of active ingredients of low mammalian toxicity, are target specific and easy to use.

The major reason, however, for the shift of opinion on and acceptance of baits was the detection of insect resistance, particularly in the German cockroach (*Blattella germanica*), against most contact insecticides. Furthermore, the withdrawal of persistent organochlorine compounds as barrier chemicals against termites, and the emergence of ants as structural pests that were difficult to control using conventional sprays, made baits popular. Baits suitably controlled large populations of German cockroaches, ants and termites, which are mostly cryptic in nature. A bait formulation was recognized as the best delivery system for these pest populations, as the insects continue to disperse the toxicant after they have picked it up owing to various elements of their social behaviour.

Development of a Bait Formulation

Lenz and Evans (2002) listed a number of important factors in developing a bait, namely suitable active ingredient, readily acceptable bait matrix and understanding the biology of the pest. In fact, these parameters are critical prerequisites for developing any baiting system.

Choice of insecticide in bait

Today, baits for household insects are sophisticated formulations that have proven to be successful in controlling a number of pests, such as houseflies (*Musca domestica*), German cockroaches and various species of ants and termites. Baits are also the chosen method for controlling minor pests, such as wasps (yellow jackets) (Reierson *et al.*, 2008). The active ingredients used in these bait formulations include metabolic inhibitors, insect growth regulators and microbial derivatives that represent a diverse group of compounds. Each of the active ingredients has a separate mode of action in an insect system and works by following specific pathways to kill the insect.

The choice of an insecticide to use in a bait is very important in the overall success of the bait formulation. It should have low detection or a non-repellent effect and be slow acting (Reierson, 1995; Lenz and Evans, 2002). High potency of the active ingredient is another important factor in determining bait efficacy; this helps to compensate for low consumption of bait matrix. Appel (1990) suggested that the toxicity and repellency of the active ingredients in baits are probably the most important factors affecting bait performance. Earlier research with cockroaches showed that not all insecticides are suitable for incorporation into baits. Chlordane, diazinon, propoxur and boric acid were not consistent in their efficacy owing to unwanted repellent effects; these insecticides rendered the bait unpalatable to cockroaches (Ave, 1995).

The discovery of various analogues and antagonists of insect growth regulators (IGRs), such as juvenile hormone (JH), ecdysone, chitin synthesis inhibitors (CSIs) and related compounds has helped in the development of newer bait formulations and in overcoming rejection of the bait. Because of low toxicity to mammals and selective toxicity towards insects, these compounds have proved safer to the environment and assumed a prominent role in IPM programmes. CSIs, among the aforementioned IGRs, have become more useful in developing bait formulations for urban pests, particularly termites. Some of these have been successfully commercialized. Among them are hexaflumuron (Su, 1994) diflubenzuron (Rojas and Morales-Ramos, 2004), chlorfluazuron (Peters and Fitzgerald, 2003; Sukartana *et al.,* 2009; Dhang 2011), and noviflumuron (Sajap *et al.*, 2005).

Another compound, which belongs to the amidinohydrazone group, hydramethylnon, has proved to be an excellent inhibitor of the electron transport chain (Hollingshaus, 1987). Hydramethylnon works as a slow-acting stomach poison and has been reported as effective against ants and cockroaches (Lucas and Invest, 1993); it is used presently in bait formulations for both pests. In addition, IGRs such as methoprene have shown mortality in Pharaoh ants (*Monomorium pharaonis*) (Rupes *et al.*, 1978), and termites (Howard and Haverty, 1978). Both methoprene and fenoxycarb were effective against Formosan termites (*Coptotermes formosanus*) (Jones, 1987). Also abamectin, a microbial derivative, proved to be effective as a bait toxicant for German cockroaches (Appel and Benson, 1995). Many more compounds have been discovered and made use of in commercial baits for ants. The most notable among them are sulfluramid against fire ants (Banks *et al.*, 1992) and Pharaoh ants (Rupes *et al*., 1997), while thiamethoxam is used against Argentine ants (*Linepithema humile*) (Rust *et al*., 2004).

More recently, insecticides such as fipronil and imidacloprid, though not belonging to the IGR category, have proved promising as effective bait toxicants. Imidacloprid bait was effectively used against houseflies (Pospischil *et al*., 2005), whereas fipronil baits have been evaluated for ants (Collins and Callcott, 1998) and cockroaches (Kaakeh *et al*., 1997). Both are now available as commercial products.

Choice of bait matrix

Bait manufacturers have strived to develop a single universal bait matrix to fit a particular pest group. The challenge for this matrix remains predominantly to serve as the best food source for the pest in the feeding site (Forschler, 1996). An ideal bait matrix should not only be nutritionally adequate for sustained feeding, but should also contain the essential chemical mixture to orient the insect towards it. The need for stimulating a positive orientation towards bait is partly overcome by proper bait placement, design of the baiting station, the addition of attractants or increasing the number of baits used.

Cockroaches

For cockroaches, which are generalist feeders with no distinct food choice, selection of a good bait matrix is never easy. The basic feeding stimulants of cockroaches consist of fat, protein or carbohydrate, or a combination of these (Ave, 1995). Rust and Reierson (1981) compared 14 bait mixtures available as commercial bait and inferred that each makes use of one of the following materials: maize grits, bran, fishmeal, waxed dog food, peanut butter, boiled raisins and white bread. In another study (Appel, 1990), peanut butter was found to be present in three out of six commercial baits. Innumerable patents have been granted to various mixtures making up baits for cockroaches. Most make use of one of many sources of sugar, protein, fat and preservatives in a water base to make the final bait have a gel-like consistency. Gel matrices are easy to apply to cracks and crevices where cockroaches mostly inhabit, and gels also act as a good source of moisture. A dry flowable powder formulation recently introduced for crack and crevice treatment combines the ease of application and spreading that has been found limiting for gels. The dry flowable powder acts as the bait. Cockroaches are affected by either active feeding on the bait or by grooming of their contaminated bodies (Lupo, 2006). However, research to develop newer bait formulations that are acceptable continues, as cockroaches from different locations show different food preferences.

Ants

Ants, being social insects, show differential levels of food choice. In fire ants, proteinaceous food is primarily allocated to larvae and the queen, while sugar is allotted to workers (Tschinkel, 2006). Interestingly, the feeding pattern of worker ants is not determined by larval hunger, but by the workers themselves. Consequently, workers are recruited more strongly to a food type that is novel to them (Tschinkel, 2006). While most entomologists divide ants into primary sugar feeders and insect feeders, virtually all ants are opportunistic feeders and will take whatever foods are available (Shetlar, 2002).

Ants also show a variable preference to food presented in a solid or a liquid form. Lee (2008) reported that a 30% w/w sucrose liquid base bait without a toxicant was the most attractive base to species of common household ants belonging to the genera *Monomorium*, *Tapinoma*, *Anoplolepis* and *Paratrechina*. However *Pheidole* sp. and *S. geminata* were attracted to a granular form of the same bait base. Preference for a liquid food base could be a physiological response to the possibility for easy distribution among nest mates. This is inferred from an observation on fire ants that strongly prefer sharing liquid food among colony members (Tschinkel 2006). Solid food pellets were distributed parsimoniously among the members even when present in excess. This study further observed that the larval diet shows a very strong preference for food in solutions.

Reports of the successful use of solid baits for controlling ants are also available. Solid protein-based baits have been effective against Pharaoh ants (Oi *et al.*, 1994) and southern fire ants (*S. xyloni*) (Hooper *et al.,* 1998). A toxicant mixed in soybean oil on defatted maize grits has been successfully used for controlling imported fire ants (Banks *et al.*, 1985). Solid baits incorporating slow-acting toxicants such as hydramethylnon, IGRs and indoxacarb into soybean or peanut oil have been extremely effective against Pharaoh ants (Oi and Oi, 2006), and harvester ants (Wagner, 1983). A fishmeal-based pelletized bait with fipronil as the active ingredient was used recently for controlling an invasive species of yellow crazy ants (*A. gracilipes*) in Christmas Island (Green and O'Dowd, 2009).

Termites

Termite preference for food varies significantly between species and geographical regions (Lenz, 1994). Thus, developing a universal matrix remains a challenge. Although the commercial development of bait for termites has remained focused on selected species, such as invasive termites, it is increasingly being noticed that additional termite species are acquiring pest status. In the Philippines, *C. gestroi* selected and consumed significantly more processed wood from a timber yard than other forms of cellulose, such as tissue paper, newspaper, paper cartons, tree branches and wood barks that were offered in a choice test (Dhang 2007, unpublished). Such a distinctive choice was not visible in *Microcerotermes losbanoensis* and *Macrotermes gilvus* under the same conditions. All three of these termite species are predominantly encountered in structures and cause significant damage in urban areas of the Philippines. Feeding diversity, with notable differences between regions and species, have also been well documented in earlier studies (Delaplane, 1991; Lenz, 1994).

Cellulose forms the basic diet of all termite species. In a review, Lenz and Evans (2002) emphasized the importance of the physical and chemical characteristics of the cellulose matrix, and the source or species of wood, as factors determining termite feeding. The identification of specific chemical supplements, such as urea (Waller, 1996), amino acids (Chen and Henderson, 1996), fungal extracts (Rust *et al.*, 1996), nutritional supplements (Rojas and Morales-Ramos, 2001) and different semiochemicals (Grace, 1991) has helped in formulating and mass producing bait matrices in the form of processed cellulose.

Bait Performance

The performance of a bait is best evaluated in the field, although field results are often found to be lower than those from laboratory studies. However, field data are also hard to collect and their reliability is always doubted owing to various difficulties in developing a perfect experimental protocol. This aspect is more profound in ants and termites because of their cryptic nature. Thus, performance is measured by taking into account a number of parameters; for instance, in termites it is primarily dependent upon observing foraging activity, foraging territory and foraging population size (Su and Scheffrahn, 1996), and noting caste ratio (Jones, 1989).

Generally, the performance of a bait is dependent on a number of factors which are critical in determining its overall efficacy. These include a biological component, such as an insect's food-finding and food-associating behaviour, learning behaviour and nutritional status. Bait performance also includes a human component, such as the intensity of the baiting programme, the accuracy of bait placement and the type of bait used (Ballard and Mares, 1993).

Food finding and food association

Locating the bait and choosing to feed on it are two distinct aspects of behaviour that any good bait should overcome. Food-finding and food-association behaviour is well demonstrated in termites. It has been shown that termite foragers discriminate against smaller volumes of bait wood in favour of larger volumes by abandoning them (Lenz *et al.*, 2000). This behaviour makes baits presented in small amounts or contained within a smaller station less attractive to termites. The reason for such a distinction appears to result from a need to maintain a basic minimum wood consumption rate by the foragers (Lenz, 1994). Food finding and food association could also be moisture dependent. Moisture could help bait detection and sustain long-term feeding. When presented with bait matrix of varying moisture contents in a multiple choice test, the termite *C. gestroi* preferred to initiate feeding in all the baits with higher water contents (Dhang 2007, unpublished data). This observation could be a result of a situation where moisture is critical in the immediate environment.

The scenario is completely different in cockroaches, where a lack of recruitment behaviour makes the task of baiting more challenging than in social insects. Hence, bait design needs to integrate knowledge of cockroach feeding preferences, patterns of movement, resting behaviour and physiology (Schal and Hamilton, 1990). In the case of German cockroaches, the fact that they are not attracted to bait over a long distance makes bait performance dependent on proper placement of the bait (Reierson, 1995).

Learning behaviour

The learning behaviour of an organism is an innate trait developed to increase survivorship. This behaviour could work against baits if insect pests can associate bait with death. As consumption of bait is a voluntary act on the part of the insect, overcoming negative learning will increase bait efficacy. It has been observed that bait which failed to kill on its first encounter provided an opportunity for the cockroaches to learn to avoid subsequent contact (Reierson, 1995). This learned avoidance to bait can be overcome by periodically moving baits to new locations (Reierson and Rust, 1984), and also by rotating (switching) baits with different matrices and active ingredients.

Learning visual cues associated with feeding sites, and the importance of feeding experience, also help the German cockroach in its food choice as shown by Durier and Rivault (1999). This study showed that cockroaches were able to associate visual cues with food and use these learned cues to forage. A new food type placed in a new site attracted more cockroaches than a known food type in a known site. When the known food type was in a new site and the new food type in the known feeding site, most of the cockroaches oriented towards the known food type and neglected the new one. These results revealed that many factors influence the discovery and ingestion of a food source and that cockroaches take different foraging decisions in relation to the existing environmental situation. They are able to distinguish a novel food placed in a novel site from a novel food placed in a site previously occupied by another food type. The study concluded that cockroaches learn the location of specific food resources and associate particular locations with particular resources. This associated learning behaviour is useful in optimizing bait application.

Among social insects, behaviours such as regurgitation and self-grooming are major pathways of bait transfer. However, there could exist a great deal of flexibility in the behaviour of individual members which can be attributed to the process of learning. This is evident in ants, which are also capable of associative learning; they can associate a simple reward such as sugar or water from a meaningless stimulus (Holldobler and Wilson, 1990). Such associative learning is an important criterion determining bait performance and could be made use of in bait location and recruitment.

Nutritional status

The physiological need for food by insects varies constantly owing to changing factors such as their nutritional and developmental state, food deprivation and food experience (de Boer, 1995). In addition, larvae and adults of most holometabolous insects have very different feeding behaviours and dietary requirements. It can be concluded that nutrition-related cues in bait are predominant in feeding decisions made by insects, and that acceptability of the bait is possibly governed by complex physiological functions.

Feeding preferences of *Monomorium floricola* (ant) workers were correlated with the nutrients of which they were deprived in their diets (Eow *et al.*, 2005). This study found that when starved of all nutrients, lipid-based food remained their favoured choice. However, nutritional satiation made them forage for either lipid or proteinaceous food. In contrast, *M. pharaonis* consistently showed preference towards proteinaceous food irrespective of the nutrient that they were starved of or satiated with. *M. destructor* workers were different again and foraged primarily towards both carbohydrate- and protein-based foods under both starved and satiated feeding conditions. Also, results showed that satiation would not merely reduce their foraging activity, but actually improve recruitment activity if the colony was induced under satiation of certain nutrients. These observations lead the researchers to postulate that satiation behaviour could be exploited in baiting strategies as it could alter the feeding response of the ants towards different nutrient types. Conversely, in fire ants, length of starvation period had an effect on food consumption and sharing among colony members irrespective of the food type (Tschinkel, 2006). This demonstrates both satiation and starvation can reduce food discrimination and increase bait selection.

Higher energy needs in insects can also make them feed more often, thereby making bait acceptance easier. Daily intake rates of male German cockroaches which mated twice a week were found to be a third greater than in cockroaches that were allowed to mate only once (Hamilton and Schal, 1988). In another study, it was inferred that a high protein bait would be highly acceptable to nymphs that had not yet reached their protein requirement intake, but aversive to those that had done so, thus emphasizing the importance of protein regulation in German cockroach nymphs (Jones and Raubenheimer, 1999). Furthermore it was concluded in this study that food intake rates may be regulated by meal size and meal frequency, which may have implications for baiting. A generalized concept that providing the nutrients lacking in the environment may lead to greater bait intake, as noted by Kells and Bennett (1998), could also be key in increasing bait performance.

Inter- and intra-species variation

Inter- and intra-specific variations are very noticeable in social insects. Bait developed for one species may not be suitable for another species within the same insect group, and there may even be differences in bait suitability between different strains of the same species. This is evident with cockroaches, ants and termites.

German cockroaches, for example, are well known in showing a wide range of feeding variation. This has often made bait selection a challenge.

Added to this is the number of reports of specific strains of German cockroaches which had developed an aversion to commercial baits. Behavioural resistance, more specifically an aversion to glucose (Silverman and Biemen, 1993), in the bait matrix accounted for these failures. In addition, bait efficacy showed inter-strain variation between insecticide-susceptible and physiologically resistant strains (Ross, 1996). Similar variation in insecticide susceptibility is also reported between bait-averse and bait-non-averse strains (Wang *et al*., 2004). The same study further demonstrated a particular strain with aversion to the sugars fructose, glucose, maltose and sucrose in agar – sugars that acted as phagostimulants in the laboratory strain. These behavioural aversions are often complex phenomena that can render new or future baits totally ineffective. It has also been noted that most commercial cockroach baits developed for German cockroaches have limited effectiveness against brown-banded and American cockroaches (*Supella longipalpa* and *Periplaneta americana*) (Wang, 2010, personal communication).

In ants, differences in feeding choice among bait bases (e.g. liquid or granular; Lee, 2008), and among matrices of different composition (e.g. protein or carbohydrate; Loke and Lee, 2004; Lee, 2008) can generate variable responses. These sorts of differences have meant that most commercial ant baits are made to be species specific, addressing the feeding behaviour of the ant species concerned.

Termites too do not behave in a uniform manner and show clear differences in behaviour and biology between species. Responses to the nature of the cellulose used, to moisture content and to baiting station design can affect bait choice among termites. Recently, a processed cellulosic bait containing the bait toxicant chlorfluazuron has been shown to work in a wide range of termite species (Peters and Broadbent, 2005; Peters *et al*., 2008; Dhang, 2011). The acceptance of this bait is further enhanced by a new design of the baiting station. The bait station for higher performance incorporates critical factors of termite feeding behaviour such as easy food association, minimum disturbance while baiting, use of a large bait mass and control over bait moisture.

Bait application

A critical part of a bait and a baiting programme is the quality of the bait application and the technical skills of the bait applicator. Factors such as identification of the species, determination of the pest population level, harbourage location, sanitation of the area, bait placement, follow-up monitoring and environmental conditions are crucial for bait performance.

It is well known that German cockroaches are reluctant to venture far from the harbourage area to forage, and this makes the process of baiting more inspection oriented. Failure to determine harbourages and the application of bait far from harbourages renders the bait ineffective. Bait placed even a few feet away sometimes has no effect on German cockroaches (Reierson, 1995). Bait placement guides accompany most bait products and inability to use them strictly can reduce bait performance.

The importance of area of application and age of the bait can also have an influence on bait performance. In a field trial with carpenter ants (*Camponotus modoc*) it was found that exposure of bait to sun, shade, moisture and dry conditions produced differences in efficacy irrespective of the active ingredients used. The same study also showed that gel baits and granular baits differed in their efficacy with ageing and exposure (Hansen, 2008).

Toxicant Transfer in a Pest Population

Baits developed for insect pests are not only effective in killing the insect directly through ingestion, but also show a killing effect on individuals that have not ingested the bait directly. This process, termed a 'transfer effect or secondary effect', further enhances the efficacy of the bait against insects that are social or live in groups. This transfer effect is best elucidated in cockroaches, ants and termites because all of these insect groups exhibit trophollaxis – mouth-to-mouth (stomodeal) or anus-to-mouth (proctodeal) feeding/transfer of liquid food. Termites and the young development stages of cockroaches have an ethological similarity, which may be the basis for many common behaviours such as proctodeal feeding. Similarly, termites and ants share a characteristic eusocial behaviour because they live in an organized society. To a great extent bait development has utilized these strong behavioural similarities to be effective.

Bait transfer in the German cockroach

Cockroaches have shown horizontal transfer of insecticides contained in baits (Kopanic and Schal 1997; Buczkowski and Schal 2001; Buczkowski *et al*., 2001). This horizontal transfer in cockroaches usually involves dead or dying donors, or simply excretions left behind by the donors (Buczkowsk *et al*., 2008). The process of secondary killing takes effect as a result of the presence of unmetabolized slow-acting insecticide in the bait formulation, in the faeces or in oral secretions, or it may simply remain in the body of the dead cockroaches. By the processes of coprophagy and necrophagy, the leftover insecticide is distributed in the infested location and brings about secondary kills. Transfer effects or secondary killing increases the overall control efficacy of the bait; however, the efficiency of the secondary kill can be dependent on the active ingredient and on other influencing factors such as developmental stage, strain and donor/recipient ratio (Wang *et al*., 2008).

Emetophagy, the ingestion of insecticide-induced regurgitate, may also constitute an important mechanism by which fast-acting, emetogenic insecticides could be disseminated within a cockroach population (Buczwoski and Schal, 2001). However, this observation was not made from a study involving insecticide bait. Instead, the observation was from [^{14}C]fipronil-fed female German cockroaches that showed more than 74% of the total radioactivity excreted within 48 h. The radioactivity was recovered from the oral region of the cockroaches. Time-lapse video analysis in this study showed that first instars were highly attracted to these excretions and imbibed the liquid exudates.

Bait transfer in social insects

Ants and termites have evolved as major structural pests in recent times around the world. The management of these social insects by using baits to suppress and eliminate the colony has provided a long-term solution that has proved to be relatively more easy to implement than other methods.

Trophallaxis is extremely well developed among social insects such as ants and termites. In the higher myrmecioid subfamilies, such as the Dolichoderinae and Formicinae, the exchange of food is frequent and prevalent enough to result in a fairly even distribution throughout the worker force of the colony (Wilson, 1975). In the lower group of termites belonging to the families Rhinotemitidae and Kalotermitidae, the members of the family feed one another by both stomodeal food (food originating from the salivary glands) and proctodeal food (food originating from the hindgut). Higher termites, however, do not exhibit proctodeal food transfers (Wilson,1975).

Studies have been published on the successful transfer of bait toxicant in the field to control ant populations (Banks *et al.,* 1992; Collins and Callcott, 1998; Green and O'Dowd, 2009) and termites (Su, 1994; Forschler, 1996; Peters and Fitzgerald, 2003; Peters *et al*., 2008; Dhang, 2011). Bait transfer is also evident in higher groups of termites, such as *M. gilvus*, an emerging pest in South-east Asia (Figs 13.1 and 13.2).

Advantages of Baits in Pest Management

Baits have been integrated into modern IPM to effectively manage urban pests. Conventional insecticides are not often effective in managing structural pests such as ants and termites because the disturbed colony frequently moves out of the treated zone. Baits have provided a rational solution for such hard-to-control pests, have treated inaccessible areas and save cost. In addition, baits offer no odour problems, no translocation and no potential for staining (Naffziger, 1993). They also leave lower or no residues. Moreover, baits also present a unique opportunity to control the population of pests inside a structure using exterior treatment (Williams *et al*., 1999). Furthermore, baiting is very suitable for treating sensitive locations such as those with a high-density human population, and in close proximity to a freshwater source (Dhang, 2009). However, the most significant aspect of insect baiting is in its dramatic reduction of insecticide use. Baiting could possibly replace the application of indoor residual sprays against crawling pests. Thus, the full impact of baits on urban pest management is yet to be realized.

Fig. 13.1. Dead caste members of *Macrotermes gilvus* after treatment with a chorfluazuron-based termite bait.

Fig. 13.2. Caste members of *Macrotermes gilvus* with distinct body colour and pigmentation after treatment with a chorfluazuron-based termite bait.

Termite baiting and reduction of insecticide use

Around the world, baiting technology has proved to be a success, aside from it being friendlier to the environment. The best example of insect baiting and reduction in insecticide use in urban areas is possibly in termite management. Termite control is estimated to be the largest segment in the global pest control industry and is worth US$8 billion (Anon., 2009). It can be safely concluded that termite control also accounts for the largest use of insecticides in urban areas. Termite baiting is viewed as a more environmentally acceptable alternative to the application of soil termiticide, which requires the drilling of floors and injection of chemicals into the soil. Within a few years of its introduction, bait application has gained significant popularity, and in many areas termite baiting is becoming a stand-alone measure for long-term protection of structures (Thorne and Forschler, 2000).

The reason for the shift from conventional methods to baiting is partly owing to the difficulty in conducting a foolproof treatment on existing structures. Conventional soil treatment requires the injection of a toxic chemical mixture into the soil around the perimeter of a building to form a continuous barrier. It has been estimated that a 10 × 10 m single-storey house would require 200 l of diluted termiticide to treat the soil along the exterior perimeter; in cases of severe infestation, additional chemical solution is applied into holes drilled into concrete slabs and into suspected points of entry of termites inside the house (Garcia *et al*., 2007). This is similar to the concept of whole-house treatment, which is equivalent to applying 15 l of termiticide solution per 3 m of linear foundation (Forschler, 2008).

Reduction of insecticide application is possible by use of baits and by implementing IPM codes (Forschler 2008). Dhang (2009) compared the usage pattern of major termiticides in the Philippines and concluded that baiting can drastically bring down the urban insecticide load. A soil injection for a 100 m^2 house required a minimum of 117.6 g of active ingredient if fipronil is used. The values can be higher if soil treatment is done using other active ingredients, such as bifenthrin (150.4 g), imidacloprid (200 g) and chlorpyrifos (1920 g). By using baiting, insecticide use was brought down significantly, to only 2.3 g.

Examples of a number of successful public usages of termite baiting in replacement for liquid termiticides are available from around the world: from Chile (Smith *et al*., 2006), the USA (Ring *et al*., 2001; Su *et al*., 2003), New Zealand (Ross, 2005), Japan (Tsunoda, 2005), Australia and South-east Asia (Peters and Broadbent, 2005). As already stated, termite baiting allows lower application of insecticides, which is important in situations where environmental pollution is a concern. Baiting also offers advantages over soil treatment using repellent termiticides, which faces application constraints due to construction patterns, the presence of common walls and utility pipes, and other situations, which make uniform treatment near impossible. On the other hand non-repellent termiticides have failed to fit into the liquid bait model owing to their failure to show horizontal movement of the active ingredient a reasonable distance (Su, 2005).

Conclusion

The concept of insect baiting has widely integrated itself into modern IPM. It is inspection driven, friendlier to the environment and precise. Though the technology is restricted to a few pests, it has made significant progress as a tool in urban pest management. In addition, baiting is responsible for bringing about a drastic reduction in the use of toxic chemicals in urban areas and in the vicinity of humans.

In conclusion, baiting has improved and supported implementation of IPM. However, its overall efficiency still depends on the bait applicators. The applicator's knowledge and skills are of paramount importance for baiting to be successful. The concept of baiting is a dynamic field, which is constantly evolving and being adjusted for changes in insect behaviour and location. The human component involved in baiting is possibly the single factor against its popularity among pest control practitioners, but this could be resolved by training.

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14 Present and Future Approaches to Urban Pest Management: a Global Pesticide Regulatory Perspective

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Summary

Global demand for pesticide products characterized by low toxicity, short residual life and an increased specificity for the pest(s) is increasing. At the same time, the public desire for highly efficacious products that can eliminate pests efficiently, but without pesticides, or with the use of only 'green' products, is at its height. Future pest control solutions will not come solely from conventional pesticides and/or green pest management practices but also from advances in biotechnology and new applications for nanoparticles. This new paradigm brings challenges to regulatory systems, pesticide developers and pesticide applicators during a time when the emergence and resurgence of urban pest problems and vector-borne diseases throughout the world is intensifying. Precaution will be the underlying theme of pesticide legislative mandates and regulatory agencies, which will take a more conservative approach to pesticide risk and exposure assessments where uncertainty exists. Risks to vulnerable populations such as children and the elderly will be emphasized. Shifts towards precautionary principles will make benefit assessments essential, together with research to support the continued use of pest control products and methods. There is an immediate need to develop benefit models for the control of urban pests. Urban pest management programmes must emphasize sustainable practices that include new approaches, technologies and strategies, and integrated pest or vector management principles and practices to help reduce risks in order to satisfy possible future regulatory mandates. This chapter discusses outlooks and trends for pest management and regulatory policy, and suggests recommendations for meeting future challenges.

[1] Disclaimer: The findings and conclusions in this article are those of the author and do not necessarily reflect the views of the United States Environmental Protection Agency (EPA).

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Introduction

Since the turn of the 21st century, public health pests in urban areas have undergone a global resurgence and new species continue to emerge (Bonnefoy *et al.*, 2008). The number of pest species infesting urban environments is actually greater now than in the past. In many cases, this results from the movement of pests from one region to another, as with mosquitoes, while in other cases it has been caused by the local resurgence of pests such as bed bugs, sandflies, lice and rodents. Other pest problems have arisen from new human settlements and from the development of areas that resulted in exposures to new pests and diseases or the transport of vectors from one region of the globe to another. Taken together, these conditions present urban pest managers and regulatory systems with many challenges. All of these must be overcome to accomplish control of urban pests of public health significance and achieve the subsequent public health benefits.

Future trends in pesticide regulation and the formulation of new regulatory policies will emphasize the reduction of risks from pesticide use. These risk reduction measures may include: requiring pesticide registration; establishing a framework to ensure compliance with existing regulations; refining risk assessment and risk characterization practices to decrease uncertainty in safety recommendations; mandating the adoption of integrated pest management (IPM) and/or integrated vector management (IVM) principles and practices; educating applicators by putting training and certification programmes into place, together with extension service-based information modules; establishing consumer outreach through Internet-based activities; encouraging better application technology while improving existing practices; implementing systems to collect and dispose of used pesticide containers and obsolete pesticide inventories; and advocating research and development that will support the use of IPM/IVM and related risk reduction methods and technologies.

With pesticide use comes risk to users and the public. In order to reduce pesticide risks while maintaining the sustainability of pesticide use, rigorous registration and compliance programmes are required, together with an expansion of the use of IPM/IVM. International organizations serve as a neutral forum where nations can meet as equals to negotiate agreements, formulate policies and draft guidance documents. Many international organizations have been involved in the development of overarching risk-reduction measures while leaving implementation and refinement of these to country-level regulatory agencies. Organizations that have been actively involved include: the Organisation for Economic Co-operation and Development (OECD); the Food and Agriculture Organization of the United Nations (FAO); the World Health Organization (WHO), and the United Nations Environment Programme (UNEP). Regional organizations such as the European Union (EU) and Association of Southeast Asian Nations (ASEAN) have also been important in developing regional schemes and advising on their implementation. All of these organizations work cooperatively with their member states to harmonize standards, policies and strategies to reduce pesticide risks and costs associated with registration on national and regional levels. Establishing a Globally Harmonized System of Classification and Labelling of Chemicals (GHS), also known as the 'Purple Book' (UN, 2009), is common to many of these organizations, but progress towards implementing this goal varies greatly among countries.

Organizations Important to Pesticide Regulation and Public Health

The Organisation for Economic Co-operation and Development (OECD)

The OECD is an intergovernmental organization that comprises 34 member countries in North and South America, Asia and the Pacific. The organization provides a forum for governments to work together and share experiences as well as solutions to common problems (OECD, 2011a). Through its environmental programme, the OECD works with countries to manage the risk of pesticides as effectively as possible. The Working Group on Pesticides (WGP) leads these efforts and was formed to help countries cope with the workload associated with conducting risk assessments for new and existing pesticides. The OECD WGP conducts activities on conventional and biological pesticides as well as biocides. These activities cover five major areas: (i) agricultural chemical pesticide registration/reregistration; (ii) biopesticide registration; (iii) testing and assessment; (iv) risk reduction; and (v) the biocides programme. The WGP's activities are supported by three steering committees: registration, biological pesticides and risk reduction (OECD, 2011b). Public health insecticides are considered 'biocides' by the OECD but its Task Force on Biocides has, to date, focused only on antimicrobial products.

Risk-reduction initiatives and activities are of particular interest to urban pest management programmes. In 2009, the OECD published its *Strategic Approach in Pesticide Risk Reduction* (OECD, 2009). In this report, the OECD broadly identified four core elements that contribute to the reduction of risks arising from the use of pesticides. These are: (i) high standards in legally based registration and placing on the market of active substances and products; (ii) a package of mandatory and voluntary provisions and requirements for proper use of pesticides; (iii) promotion of alternative methods such as non-chemical plant protection measures wherever possible; and (iv) control and monitoring through implementation of risk indicators to describe progress of risk reduction programmes. With regard to risk reduction, pesticides should only be registered and marketed so that when properly used they have no adverse effects on human or animal health and have an acceptable level of effects on the environment.

The 'necessary minimum' in pesticide use is defined by OECD as 'pesticide use intensity where optimum efficacy is combined with the minimum quantity necessary. It depends on application parameters (pesticide selected, dosage, time, application equipment available), local conditions, and using alternatively reliable non-chemical measures'. Sustainable use of a pesticide may be accomplished through little misuse, enforcement of regulations and use at ‘necessary minimum’ levels.

Work in residential settings has focused on modelling pesticide emissions in order to estimate possible exposures over time, and on IPM to reduce pesticide risk. Work has begun recently to develop testing guidance for insecticides used to control urban and public health pests.

Food and Agriculture Organization of the United Nations (FAO)

FAO promotes sound pesticide management and sustainable pesticide use practices that have minimal impact on human health and the environment. It first published its *International Code of Conduct on the Distribution and Use of Pesticides*, or ICC, in 1986. The code established a voluntary standard of conduct for all public and private entities engaged in, or associated with, the distribution and use of pesticides. It recognizes that ‘training at all appropriate levels is an essential requirement in implementing and observing its provisions. Therefore, governments, pesticide industry, users of pesticides, international organizations, non-governmental organizations and other parties concerned should give high priority to training activities related to each Article of the Code’. This has become commonplace in many regulatory agencies and in the pesticide industry. The ICC was revised in 2002 and reprinted later (FAO, 2005). WHO and FAO jointly published the *Guidelines for the Registration of Pesticides* in 2010 (FAO/WHO, 2010a), and this provided guidance to national governments on how to establish a regulatory framework for pesticides. FAO urges regulatory agencies and the pesticide industry to promote IPM and IVM for public health pests, and to ‘adopt the “life-cycle” concept to address all major aspects related to the development, regulation, production, management, packaging, labelling, distribution, handling, application, use and control, including post registration activities and disposal of all types of pesticides, including used pesticide containers’ (FAO, 2005). Proper and safe handling of pesticides should be emphasized, including minimizing adverse effects on humans and the environment while preventing accidental poisoning resulting from improper handling. In fact, an industry e-learning tool on the ICC is available online from CropLife International (CropLife, 2011a), along with a guide to the ICC for industry that can be downloaded as a pdf file (CropLife, 2004). Cooperative efforts with the Rotterdam Convention on the Prior Informed Consent (PIC) Procedure for Certain Hazardous Chemicals and Pesticides in International Trade are also important (Secretariat for the Rotterdam Convention, 2006). Other FAO pesticide activities and programmes include IPM (FAO, 2011a), obsolete and hazardous pesticides (FAO, 2011b), and the Codex Alimentarius (Codex Secretariat, 2006).

The FAO/WHO Pesticide Specifications (FAO/WHO 2010b) serve as global benchmarks for pesticide product quality. These specifications are important to risk-reduction efforts and chemical safety because only those products that meet these specifications are marketed, thus helping to maintain a high level of product quality. These specifications are important to pesticide manufacturers, pesticide vendors and consumers because they protect them from inferior generic products. Because the specifications are a product of FAO and WHO, there is a link to efficacy against agricultural and public health pests. A joint FAO/WHO meeting on pesticide specifications is held periodically to consider specifications for new products and updated specifications for existing products. This meeting is especially important with regard to technical-grade active ingredient formulations.

World Health Organization (WHO)

WHO is the leader and coordinating authority for health under the United Nations System of Organizations. With this role, WHO leads the efforts on disease vector management and public health pesticide use, testing, specifications and life-cycle management. The leading WHO authority for these efforts is the WHO Pesticides Evaluation Scheme (WHOPES) (WHOPES, 2011). WHOPES makes recommendations on pesticides (primarily insecticides) used for public health following consultations with experts, other WHO programmes/regional offices and WHO collaborating centres. These recommendations assist regulatory authorities and public health agencies with the selection and registration of public health pesticide products. Recommendations are not binding, nor of a regulatory nature. WHO's current programme has a four-part evaluation process: safety, efficacy, operational acceptability, and developing pesticide specifications with FAO for quality control and international trade. The efficacy and operational acceptability part of the programme is extensive in scope and depth. Public health pesticides are tested in the laboratory and under actual conditions in the field through a multi-phase process that can last 3–5 years. Pesticides are tested using standardized protocols that are published on the WHOPES web site (WHOPES, 2011). After data are collected and organized, WHOPES works with panels of experts to evaluate these data and makes recommendations for pesticide use by national regulatory agencies, public health officials and vector control specialists. WHOPES also publishes many guidelines on testing and other aspects of pesticides, manuals on equipment and pesticide application, and information on insecticide resistance to assist national authorities in decision making.

United Nations Environment Programme (UNEP)

Chemicals management is led by the UNEP Chemicals programme (UNEP, 2011). UNEP programmes on pesticide management of interest to urban pest management practitioners and the public include: the Stockholm Convention on Persistent Organic Pollutants (Stockholm Convention, 2011a); the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, jointly with FAO (Secretariat for the Rotterdam Convention, 2006); the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Basel Convention, 2011); and the Strategic Approach to International Chemicals Management (SAICM) (UNEP, 2006). Both the Rotterdam and

Stockholm Conventions came into force as treaties in 2004. The Rotterdam Convention purports prior informed consent principles and practices that contribute to the sound environmental management of hazardous chemicals by facilitating information exchange and providing decision-making processes for national governments. In contrast, the Stockholm Convention is more focused in facilitating the elimination of persistent organic pollutants (POPs) from the environment. POPs may consist of persistent chemicals, and relevant pesticides include aldrin, chlordane, dichloro-diphenyl-trichloroethane (DDT), dieldrin, endrin, heptachlor, mirex (dechlorane), toxaphene and lindane.

DDT is still widely used in malaria-endemic areas for indoor residual spraying to control mosquitoes, and remains recommended for mosquito control by WHO (WHO, 2005). In response, the Stockholm Convention has initiated the Global Alliance for DDT Alternatives (Stockholm Convention, 2011b) in order to help find suitable alternatives for DDT in malaria control programmes, thus, keeping the phase-out of DDT on schedule by 2020. Following the DDT business plan meeting in 2008 (Stockholm Convention, 2008), the Alliance formed thematic groups to study: the cost-effectiveness of alternatives to DDT; the strengthening of in-country decision making on IVM; malaria vector resistance patterns and mechanisms; the reduction of barriers to bring new chemicals and products to market; and the development of non-chemical products and approaches. The Basel Convention is concerned with the transboundary movement of hazardous wastes, and the agreement includes strong controls on storage, disposal, treatment, recycling and reuse of pesticides, including those used in urban pest management (Basel Convention, 2011).

Future Regulatory Outlooks and Trends for Pest Management

Availability of pesticides

Conventional pesticide availability for urban pest management is likely to stay at the same level in the foreseeable future. Some new products may be produced but these gains may be offset by loss of older chemistries. Contributing factors are listed below and then discussed (mostly under separate headings) in terms of related regulatory outlooks and challenges:

- Investment in conventional insecticide chemistry for many non-food uses is declining owing to a lack of profitable returns on these use patterns.
- Products cancelled during national reregistration efforts.
- Societal demand for non-pesticide remedies to pest problems.
- Poor pesticide management practices and misuse.
- Lack of a pesticide regulatory and compliance framework.
- Public perception of pesticide health risks.
- Legislative implementation of precautionary principles and practices.
- Special considerations for children's health.
- Inexpensive generic products reduce economic incentives in many markets.

- Reduced economic and public health incentives resulting from successful pesticide products.
- Shift from conventional pesticides to biochemical/genetic level solutions.
- Difficulty of transferring new agricultural pesticide chemistry to urban pest management.
- Need to control communicable human diseases.
- Investment in conventional insecticide chemistry for many non-food uses is declining owing to a lack of profitable returns on these use patterns.

Investment in conventional insecticide chemistry/transfer of agricultural pesticide chemistry

New conventional insecticides with novel modes of action cost at least US$200,000,000 (CropLife, 2011b) to develop, register and market. Companies must seek markets from which they can gain returns on this investment. As a result, nearly all insecticides are developed for use in agriculture. Termiticides are the only non-food use insecticide for which a major investment is made during product development. Public health, turf, veterinary and other non-food insecticide uses are usually developed later owing to the small sizes of these markets. With the global food crisis, it is not likely that this paradigm will change significantly despite the resurgence of urban pest infestations and urban vector-borne diseases.

Products cancelled during national reregistration efforts

Many older products require new data to meet current safety standards. The cost of generating these data is often more expensive than product sales can justify. As a result, registrants do not support many older products and product cancellations occur primarily as a result of a lack of data to support their registration.

Societal demand for non-pesticide remedies to pest problems

The demand for non-pesticide remedies to pest control is increasing (Schweer, 2010). The public believes that exposure to toxic chemicals contributes to the increase in cancer and endocrine disruptor effects (NPR, 2009a). Exposure to pesticides occurs from foods we eat and from the environment we live in. This has led to an increasing demand for products, technologies and approaches to pest control that are perceived to reduce exposures via the above routes (PAN International, 2007a). Organic food, 'green technology' and control of pests by using interventions other than pesticides are in demand. Such non-pesticide interventions include traps, exclusion, sanitation, physical removal and 'natural' products used as repellents or feeding deterrents. These have become popular in the consumer market for use in residential settings. Widespread incorporation of non-pesticide interventions has also enhanced IPM practices.

Poor pesticide management practices and misuse

Proper management of pesticides using a 'life-cycle' approach, as advocated by SAICM (UNEP, 2006) and many national governments, is a cornerstone of sustainability. Many users may practice good application practices but fail to manage pesticides properly through their entire life cycle. Compounding management challenges are the incidents of misuse when users apply pesticides to a site for which a product is not registered or can no longer be used. This may be done because the application is less expensive but, quite often, pesticides are misused because they are more efficacious than registered alternatives. Agricultural or unregistered products continue to be misapplied in residential settings to kill pests that are difficult to control (as evidenced by collected residue data or enforcement cases), especially when residents or applicators become desperate (Julien *et al.*, 2008).

Lack of a pesticide regulatory and compliance framework

Many nations in developing areas of the world lack a pesticide regulatory framework and a lead compliance organization. For applicators, pesticide registrants, distributors, philanthropic organizations and pest management businesses, this condition is usually unwelcome. Absence of regulatory frameworks often results in poor pesticide stewardship, lack of pesticide management, the availability of counterfeit products that do not meet WHO/FAO specifications, misapplications, lack of training and certification, and absence of any central authority responsible for the application of toxicants to food crops and residential settings (FAO, 2007; Stewardship Community, 2011). This scenario discourages pesticide development and entry into these markets, which is a disadvantage both as far as the applicators' and the public's health are concerned. FAO/WHO (2010a) has recently introduced guidance on regulatory frameworks for developing countries.

Public perception of pesticide health risks

The public is becoming more sensitive to risks from pesticides (NPR 2009a; OneWorld South Asia, 2009). Even the smallest exposure to these chemicals can be considered to be risky (PAN International, 2007a). Health risks from pesticide exposure have been heavily researched and regulated in many countries. In response to legal mandates and public perceptions, programmes in many national agencies have placed great emphasis on assessment of the risks resulting from pesticide exposure. For instance, such programmes now include developmental neurotoxicity studies and screening for endocrine disruptor effects (US EPA, 2010a,b). Hence, assessments used in regulatory decision making are well developed, peer reviewed and credible. Results from these assessments are presented in the media and elsewhere where they are not always fully understood in the context of risk-management decisions. Furthermore, changing public perceptions may be difficult as a result of the large number of adverse effect incidents occurring in developing countries – where regulatory frameworks capable of assessing risks and enforcing safety requirements either do not exist or have been ineffective. So, governments need to educate the public about the risk-assessment process and about the factors that are important in making decisions as they relate to protecting the public's health and the substantial benefits derived from pesticide use.

Legislative implementation of precautionary principles and practices

Precautionary principles, which are best defined by Principle #15 of the Rio Declaration of 1992 (UN, 1992), are the basis of pesticide regulation. Precaution shall be applied when scientific data are not available to characterize risk with certainty. The acceptable level of risk varies from one regulatory agency to another for many pesticides but the trend will remain towards less risk. OECD guidance (OECD, 2009) mentions no adverse risk when a pesticide is used properly. This trend will present challenges to the urban pest management industry because most of the services that this industry delivers are made for human dwellings. Such an approach is legally mandated in some regulatory schemes. As analytical methods become more sensitive, making it possible to detect smaller and smaller amounts of pesticide residues (it is common to see measurements at the ppb and even at the ppt level), the regulatory end points may decrease. However, regional and global harmonization efforts by organizations like the OECD, ASEAN and the EU and their participating national regulatory agencies will increase the level of standardization in risk-assessment approaches and risk-management end-point determinations. Standardization should bring more transparency to regulatory decision making; thus, businesses will succeed in making their future plans because regulatory outcomes will be easier to anticipate.

Special considerations for children's health

Children are considered to more susceptible to the hazards and risk associated with chemicals than adults. Early exposure to toxicants, especially in situations where doses may accumulate in the body over time, may be more likely to cause ailments later in life. The neural and endocrine systems appear to be highly susceptible and many regulatory agencies already require toxicology testing to address these concerns. Developmental toxicity testing and endocrine disruptor testing are two examples. Risk characterization and assessment also take children's susceptibility into consideration by adding tenfold safety factors to regulatory end-points to guard against the effect of pesticides as most of a child's exposure to these occurs in the home. Exposure from pesticide applications in residential settings is by hand-to mouth transfer from treated surfaces, dermal absorption or inhalation. These residential assessments are likely to become more refined (US EPA, 1997, 2009; EC, 2007) and conservative in their outlook so as to be protective of children. Hand-to-mouth transfer exposures from pet treatments, crack and crevice applications, and outdoor perimeter and turf treatments will be more closely scrutinized. Also, child-resistant packaging may be become more prevalent to insure that children are protected from professional and consumer products brought into the home and into schools.

Inexpensive generic pesticide products reduce economic incentives in some markets

Generic pesticide products often gain market dominance because of their lower costs. This usually happens when a patent or a regulatory policy that provides for exclusive use of a pesticide active ingredient expires. Generic pesticide product sales bring competition to a formally exclusive use market that may have been dominated by one or two companies. Increase in supply of the pesticide and lower production costs usually result in lower costs to the consumer. The downside is that when generic products are performing well there is little room in a market for new active ingredients because their cost is likely to be much higher than that of a generic product. Innovations such as baits can change this paradigm, as can insecticide resistance. Otherwise, the incentive to produce new chemicals for a market dominated by generic products is low. This has generally been the case in many urban pest control consumer product markets owing to the availability of low cost pyrethroid-based products.

Reduced incentives resulting from successful pesticide products

When a pesticide product or product formulation works so effectively that it becomes preferred by users over all other products, there is little incentive to produce new products or explore new use patterns. Many examples can be found in a variety of pest management markets. To illustrate this, approaches to the control of German cockroaches were changed in a matter of a few years by the invention of effective insecticide bait products. Also, non-repellent bait formulations were created that competed with other food sources and could be applied through child-resistant stations or by crack and crevice gel applications. In many cases, insecticide bait formulations were preferred to other food sources. As it turned out, many insecticides could be formulated in baits that were non-repellent at levels capable of killing German cockroaches. This diverse insecticide portfolio has helped to curb physiological resistance and led to the successful implementation of IPM programmes that are likely to continue into the future unless cockroaches develop behavioural resistance to these product types. Therefore, the incentive to research and create new German cockroach products has decreased considerably.

The same is generally true of products for flea control when insect growth regulators were introduced for use in residential settings and on pets. Another example is the termiticide market, where chlordane was used globally for termite control for decades. When chlordane was removed from the market by many regulatory agencies, a gap in technology was created because very little research had been done to support product development for termite control. Ten years passed before this gap was filled by soil applied insecticides such as fipronil, imidacloprid, permethrin and bifenthrin, among others.

Malaria control has a history of indoor residual spraying (IRS) for the control of mosquito vectors. Despite the increased demand for products over the last 7 years, product development has been slow. Personal protective measures such as pyrethroid-treated long-lasting bed nets have emerged as one of the primary treatments because of their low cost and consumer-level application. DDT application for IRS (WHO, 2005) returned throughout malarious areas in 2005, and as DDT is inexpensive, can act as a spatial repellent and toxicant (Achee *et al.*, 2009); it also has a long residual life, so there was little interest in research for replacements. However, with resistance against DDT and pyrethroids now documented (Yewhalaw *et al.*, 2011), a critical gap in control products and strategies for malaria will develop. Owing to a lack of investment in developing other active ingredients, new pesticides will be slow to market, so new control strategies will need to be developed with existing alternatives and insecticide resistance management implemented.

Shift from conventional pesticides to biochemical/genetic level solutions
New technologies utilizing gene activation, gene expression or gene suppression provide an opportunity to develop biopesticides with a higher degree of pest specificity and efficacy (WHO, 2009a). Targets will be discovered that use gene silencing to interfere with pest functions. Delivery of the agent is the greatest challenge where environmental and storage stability will be hurdles. Moreover, a lack of human and non-target toxicity, if agreed upon by regulators, would lead to arguments being made for reduced toxicity testing, which is normally a very large portion of the cost of product development for conventional pesticides. Conversely, the use of these technologies is seemingly opposed because of uncertainty associated with their human health effects and gene distribution in the environment (PAN International, 2007a).

Need to control communicable human diseases
Tuberculosis and HIV/AIDS have reached epidemic levels in many parts of the world (Kaiser Foundation, 2011). Public health systems will continue to be organized and funded to deliver a level of services to combat these diseases (Global Fund, 2011). These programmes are growing in size and cost, and this is likely to limit the resources available to develop new public health pesticides to combat many pests or vectors with the major exception of malaria, where there is research ongoing into new control strategies and pesticides. Given the disease burden associated with malaria (Roll Back Malaria, 2010; Kaiser Foundation, 2011), the primary responses to malaria have been new drug treatments, vaccine development, pesticide control strategies and public health pesticide formulations. As resistance to DDT and pyrethroids continues to increase, the investment in new pesticide chemistry and biotechnology may expand. However, the degree of investment may be largely tied to donor investment, and if donor fatigue occurs as a result of a malaria resurgence, despite donor investment in bed nets and IRS, the funds for future research and development may not be forthcoming for new solutions.

Implementation of IPM and IVM Practices and Programmes

Educating the public and decision makers

In the future, pest management practitioners and regulators will increase their advocacy of IPM or IVM as the primary approaches to solve pest management problems. These practices should decrease the application of pesticides and lead to the use of less hazardous chemicals, but before that effort can be successful, a large public education campaign will need to take place in order to fully inform citizens, public health officials and elected representatives about the scope and meaning of the acronyms IPM and IVM and the terms that they represent.

Most people remain unaware of these acronyms and terms as do many decision makers. Internet search engine results indicate that the term IPM is recognized as referring to integrated pest management, though in other business sectors, this acronym may refer to many other things. In total, there are at least 300 meanings for this acronym (Acronym Finder, 2011a). The acronym IVM is best known in the pest management industry as referring to integrated or industrial vegetation management, which is widely used by applicators specializing in rights of way and other commercial vegetation control programmes. A few other examples of the use of IVM include: In-Vitro-Maturation; Internet Voice Mail; Indie Vision Music; In Verbund Met (Dutch, meaning concerning); and In Verbindug Mit (German, meaning in conjunction with.) (Acronym Finder, 2011b). These other usages could have been the reason why the acronyms IPM and IVM are not widely known to the public; hence it is unlikely that they will be widely understood as a reference to pesticides. Owing to the confusion surrounding the use of acronyms, advocating education on the meaning of the full terms will have much better success.

To make matters even more confusing and challenging, these two terms do not have a globally recognized definition. Different regulatory, agricultural and public health agencies define them differently and the terms are often customized to fit specific programmes (FAO, 2011a). Some examples are listed below.

FOOD AND AGRICULTURAL ORGANIZATION OF THE UNITED NATIONS. FAO (2011a) defines 'Integrated Pest Management (IPM) to mean careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms'.

US ENVIRONMENTAL PROTECTION AGENCY. The US EPA (2011a) defines 'Integrated Pest Management (IPM) as an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. IPM programs use current, comprehensive information on the life cycles of pests and their interaction with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means, and with the least possible hazard to people, property, and the environment'.

NATIONAL PEST MANAGEMENT ASSOCIATION. The NPMA in the USA (Baumann, 2011a) defines IPM, as 'a process involving common sense and sound solutions for controlling pests. The focus is upon finding the best strategy for a pest problem, and not merely the simplest. Pest professionals never employ a "one-size-fits-all" method in IPM, but rather, utilize a three-part practice: 1) inspection, 2) identification and 3) treatment by a pest professional. Treatment options in IPM can vary from sealing cracks to removing food and water sources to employing pest products, when necessary. … IPM programs should be designed within the comprehensive and holistic definition provided above, a definition, which provides associated managers with a multitude of proactive and reactive measures to protect their residents from the risks associated with pest infestations. Further, the "integrated" in Integrated Pest Management does not merely describe the three-part practice of inspection, identification and treatment. … Cooperation is critical because it sustains the individualized approach of IPM. A multi-party effort to implement IPM encourages a stronger commitment to assessing each situation uniquely and developing a comprehensive cure to each pest problem'.

WORLD HEALTH ORGANIZATION – REGIONAL OFFICE FOR EUROPE. WHO (Sarisky *et al.*, 2008) defines IPM as 'a common-sense approach to pest management. By using a hierarchy of control practices – including public education, sanitation, pest exclusion, and other biological and mechanical control methods, while limiting pesticide application – long-term pest management can be achieved while minimizing environmental and public health hazards'.

For IVM, WHO offers the following definition (WHO 2004, 2011a; PAHO, 2011):

> Integrated vector management (IVM) is a rational decision-making process for the optimal use of resources in the management of vector populations, so as to reduce or interrupt transmission of vector-borne diseases. Its characteristics features include:
>
> - Selection of methods based on knowledge of local vector biology, disease transmission and morbidity.
> - Utilization of a range of interventions, often in combination and synergistically.
> - Collaboration within the health sector and with other public and private sectors that impact on vector breeding.
> - Engagement with local communities and other stakeholders.
> - A public health regulatory and legislative framework.
> - Rational use of insecticides.
> - Good management practices.

Reviewing the definitions and approaches above, a common theme is shared by all of these organizations, but there is no agreement on a single definition. Generally, the definitions lack specificity and the terms used are not widely understood by consumers. This condition will make public education challenging. Widely recognized training modules need to be developed so a consistent message is sent to the public and public health community.

Implementation of IPM/IVM by regulatory agencies

Implementation of IPM/IVM may be mandated by many regulatory agencies in the future. The creation and implementation of IPM/IVM programmes will help to sustain urban pest management and related vector control programmes.

These programmes will ensure that best management practices are used, pesticide use is reduced, and concerted efforts are made to eliminate conditions conducive to pest infestations. Formalized approaches to resistance management will become an integral part of this effort. Source reduction will be a challenge for many nations lacking the expertise, funding and infrastructure needed to correct conducive conditions at the municipal level, but with a limited selection of public health pesticides, source reduction will become a more significant part of control programmes (Stockholm Convention, 2008; WHO, 2011a).

Regulatory agency methods and databases for tracking pest management work and pesticide application recording keeping will become increasingly sophisticated and informative. Electronic pesticide application record databases will include global positioning system (GPS) coordinates. Geographical information systems (GIS) will be developed to easily depict the spatial and temporal components of these applications and IPM practices. These parameters will be needed to satisfy regulators, meet contract requirements and decrease liability from civil litigation. Electronic signatures made by using devices such as a personal digital assistant (PDA) or the equivalent hand-held device are likely to become widely accepted for documenting pesticide applications instead of using paper copies. For most businesses, these will become essential to the management of pesticides and business accounts.

IPM/IVM certification is likely to become widespread as an applicator or advisor category that may be part of many pesticide applicator-licensing programmes. Certified applicators will need to be trained to design and/or implement IPM or IVM programmes and improve pesticide management practices. Technicians tasked to execute many of these practices will require detailed guidance. IPM plans will be needed on a site-specific basis. A generic framework for IPM/IVM for commercial facilities and residential housing types will be developed as a building block for site-specific plans. National IPM standards may emerge to provide for consistent expectations and to set benchmarks for training and management programmes.

Regulatory Challenges Faced by New Technology

Despite the fact that the use of nanotechnology in pesticides is in its infancy, many regulatory and international organizations have been proactive in addressing the future possibilities (OECD, 2011c). Concerns about public health are at the forefront of this effort. Nanotechnology applies to the use of extremely tiny particles that measure 1–100 nm in size, equivalent to one billionth of a metre, in the manufacture of materials such as antimicrobial food packaging, enhanced delivery mechanisms to improve absorption of a nutrient, drug or toxicant by an organism, and surface coatings (FAO/WHO, 2010c).

Many other applications for this technology are being researched. Applications for urban pest management may be pesticide baits, pesticide formulations for controlled release and better absorption by the target pest, and pesticide formulations for improved delivery of fogging particles to pests. Related applications exist for agricultural pests and vector management (Bhattacharyya *et al*., 2010). Conversely, regulatory agencies are struggling with how to assess the hazards and risks of nanoparticles in food and food packaging, and for use as pesticides to control microbes, weeds and insects. Unlike macro- or micro-particles, nanoparticles have a very large surface-to-volume ratio and this helps to confer differing physical properties that are advantageous to engineering of new materials and improving existing products. At the same time, nanoparticles move through the human body easily. They can enter cell membranes easily and pass through the blood–brain barrier undetected.

Assessing these risks may mean creating new paradigms for understanding and assessing dietary, occupational, and residential exposure scenarios via oral, inhalation and dermal absorption (US EPA, 2008, 2010c; OECD, 2011c). For instance, what personal protective equipment might be required for applicators that were not needed before? How can release of nanoparticles in the environment be controlled and its impacts measured? It is unclear how regulatory and public health agencies will work through these challenges, but it is clear that nanotechnology is advancing quickly on a global scale and that applications for its use are expanding. Urban pest management programmes may have to be better educated on nanotechnology and regulators will be challenged to better inform the public and stakeholders on the implications associated with it and ways of regulating it. At the same time, nanotechnology, if properly engineered and implemented, may improve the tools already available for pest management professionals. This will, hopefully, lower pesticide application rates.

Biotechnology

Biotechnology for control of urban pests holds great promise but implementation may be difficult owing to the high degree of uncertainty associated with human and environmental health effects (PAN International, 2007b; WHO, 2009a). Prospects for developing targets that may affect many insect functions such as feeding, absorption or digestion of nutrients, mating, sterility, oogenesis, protein production, olfactory function, flying and fecundity will exist. In theory, these technologies have many advantages: (i) pest resistance to these modes of action is unlikely; (ii) the high degree of specificity makes non-target effects much less likely; (iii) these tools are unlikely to affect humans, especially if the affected genes do not occur in humans; and (iv) the initial cost of genome mapping is expensive but production and delivery costs may be considerably less when compared with conventional pesticide products.

Non-pesticide population suppression techniques have relied on the radiation-induced sterile insect technique (SIT). This has been applied for insect control for many years and involves large-scale releases of sterile male insects. Furthermore, biotechnology has been applied to modify SIT and produce *Aedes aegypti* mosquito products for use in dengue control systems in Latin

America and Asia (Phuc *et al.*, 2007). These population suppression products have been tested in limited field trials, and permission for importation and limited use or testing in many countries has been granted (Oxitec, 2011a,b). Other products under development include those for *A. albopictus* and malaria vectors (Oxitec, 2011c,d). Remembee™ was the first RNAi (ribonucleic acid interference) product marketed as a drug to kill honeybee pathogens (Beeologics, 2011). RNAi (Nature Publishing Group, 2011) is now being explored for mosquito control (USDA, 2010). Proof-of-principle production of malaria- and dengue-resistant mosquitoes has been accomplished. Other applications of biotechnology have been for agricultural pests, but the technology is likely to be developed for urban pest control in the future.

Population replacement or manipulation is another control technique that has been explored using biotechnology. *Wolbachia* sp. endosymbionts mediated heritable biocontrol (Xi *et al.*, 2005) of *Aedes* mosquitoes is under development (McMeniman *et al.*, 2009). Field trials have been conducted in Australia to test the efficacy and impact of this biocontrol technique (Enserink, 2010).

Biotechnology applications for urban pest management exist and many more will be developed in the near future. Biotechnology products present many regulatory challenges and it is not always clear to regulatory agencies whether these products are pesticides or not. Pesticide regulatory agencies and corresponding regulations are established and funded to regulate pesticides. If a biocontrol technology does not produce a product that fits the definition of a pesticide at the country level, then it is likely that another agency will need to regulate the importation, research, development and release of the product. Otherwise, a new regulatory framework may need to be established. Comprehensive national and international standards do not exist and need to be developed as quickly as the technology under development as many of these products may have the potential to suppress vectors of human disease and agricultural pests. Much of the world is affected by vector-borne disease, and the demand for food continues to grow as populations increase. At the same time, there is a great deal of uncertainty associated with regulatory frameworks, health effects, ecological diversity and ethics (PAN International, 2007b; WHO, 2009b). This can make the fate of large scale application of this technology questionable in many parts of the globe.

‘Green’ Pest Management Programmes

Use of the term ‘green’ with reference to the management of urban pests is a relatively new concept. The meaning and application of the term have been transformed in the past 40 years (NPR, 2009b). At the onset the use of the term, ‘green’ referred to the application of pesticides and synthetic fertilizers to grow lush crops in an effort to raise production, thus defining the ‘The Green Revolution’. Today, the term ‘green’ has nearly the opposite meaning. ‘Green’ and ‘Green Revolution’ are now associated with terms such as organic, safe, natural, eco-friendly and environmentally favourable – even pesticide free. For this reason, ‘green products and services’ are sought after by many consumers. There is currently no government regulation of green pest management programmes. These are an extension of IPM programmes that use less toxic pesticide products, some which are exempted from pesticide regulation. At the same time, 'green services and products' may intersect with other novel technologies, such as use of nanoparticles (Bhattacharyya *et al.*, 2010) or genetically modified organisms (PAN International, 2007b), which makes the regulation of these products and services more complex. Many claims are associated with these services. In some cases, these may be meaningful, but in other situations, they can be used in a misleading manner to convince a customer that they are receiving a product or service that is safer and better than other services for controlling urban pests when this is not the case. Pesticide regulators understand the implications of these types of claims and advertising, and in the future they are likely to address them through regulation. Regulating such practices will be necessary because this segment of the urban pest management services market is likely to continue to grow in the future.

An example of a 'green' urban pest management is the programme recently established by the NPMA that is known as the 'GreenPro Certification Program' (NPMA, 2011). This is the largest 'green' pest management certification in the world. Pest management companies receiving the certification are known as 'GreenPro'. They voluntarily agree to employ 'green practices' and meet the standards established under this programme. Regulatory agencies such as the US EPA are encouraging these types of certification programmes. In November 2009, the US EPA awarded NPMA a National Honor Award for its efforts in this area: for promoting IPM principles and practices together with the use of pesticide alternatives and low toxicity products as part of the 'GreenPro' programme.

Environmental Justice and Human Ethics Issues

Environmental justice issues

Social and economic inequalities have long been recognized as having effects on the health of individuals living in underprivileged communities. The US EPA (2011b) defines environmental justice as: 'the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. EPA has this goal for all communities and persons across this Nation. It will be achieved when everyone enjoys the same degree of protection from environmental and health hazards and equal access to the decision-making process to have a healthy environment in which to live, learn, and work'.

Essentially, environmental justice refers to resolving social inequalities that lead to increased risk for exposures to environmental risk factors such as toxicants and pollutants, which thus become causal factors for health inequities

(WHO/Europe, 2011). These exposures are likely to occur in the housing and communities of underprivileged populations located throughout the world. FAO has established the Obsolete Pesticide Program (FAO, 2011b) to address these issues in Africa, where many obsolete pesticides exist and are often disposed of illegally. With regard to urban pest management, environmental justice can refer to not only to the manner in which a pesticide is stored and disposed of, but also to its application and the types used. Very often pesticides that were formally banned by a regulatory system are detected in many underprivileged communities, especially in government-owned public housing (Julien *et al*., 2008). These communities also tend to be subjected to illegal sales of pesticide products not registered for an intended use pattern. Language barriers and illiteracy are the barriers to a fundamental understanding of pesticide hazard and proper use. In the future, regulators will need to develop strategies on ways to address these inequalities. These may include: (i) expanding the scope of educational materials available through work with housing and health agencies; (ii) the translation of educational materials into many languages; (iii) working with urban pest management companies to institute informed consent procedures before contracted pesticide application work can be conducted; and (iv) stepping up enforcement and compliance efforts at the national and local levels.

Human ethics issues

International and national efforts are underway to more closely examine the scope and regulation that is related to the use of human subjects in pesticide studies (US EPA, 2011c; WHO, 2011b). Pregnant women and children are not to be used as subjects in human studies or research with pesticides, and these data cannot be used to support pesticide registration. The scope of the US EPA Human Studies Rule also applies to field testing of insecticides and other pesticides in residential areas, and with recent expansion of the protection for adult volunteers (US EPA, 2011c), these tests are now conducted under the highest ethical standards. Researchers and companies that wish to evaluate new urban pest control pesticide products are urged to gain regulatory agency permission and informed consent from residents who live in housing where the study will be conducted. Regulations provide the utmost consideration for pesticide exposure to susceptible populations such as children, pregnant women, the elderly and the infirm. In most instances, Institutional Review Boards must be consulted. If the study data collected is to be used for pesticide registration protocols, ethics materials may need to be reviewed and approved by the US EPA Human Studies Review Board before commencing work. Vector control studies that express epidemiological outcomes, such as reduction of disease transmission or cases of a vector-borne disease, unless carefully regulated, are unlikely to be considered in support of registration because they may include data from sensitive populations. The WHO provides additional information on international human ethics policies and regulations (WHO, 2011c). Environmental justice concerns and human ethics issues are likely to become more important in regulatory decisions for urban pest management products, and the scope and geographical range of their implementation are likely to expand dramatically.

Insecticide Resistance Detection and Management

In urban pest management and vector control programmes, insecticide resistance is likely to develop against many important pests unless applications and programmes are properly managed to ensure sustainability. To date, the pesticide industry has taken the lead on guidance and guidelines for resistance management because many national pesticide laws do not mandate the regulation and management of pesticide resistance. The Insecticide Resistance Management Committee (IRAC, 2011a) is a technical work group of CropLife International that was formed in 1984 to provide a coordinated industry response to the development of insecticide resistance. IRAC group committees reside in many parts of the world to research resistance issues. IRAC (2011b) defines resistance as 'a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species'. In relation to the occurrence of cross resistance, IRAC says: 'Cross-resistance occurs when resistance to one insecticide confers resistance to another insecticide, even where the insect has not been exposed to the latter product. Clearly, because pest insect populations are usually large in size and they breed quickly, there is always a risk that insecticide resistance may evolve, especially when insecticides are misused or over-used'. IRAC researches and provides resistance information and guidance on insecticides for use in agricultural and public health pest control, together with resistance management recommendations for products derived from biotechnology. It also serves as a source of information on insecticide classification and modes of action. In 2010, IRAC published the 2nd Edition of the *Prevention and Management of Insecticide Resistance in Vectors of Public Health Importance* (IRAC, 2010). Other IRM recommendations for other pests of public health significance are also available (IRAC, 2011c). Future publications on public health insecticide resistance are expected.

Many national agencies have addressed insecticide resistance, but only from a voluntary guidance approach. The North American Free Trade Agreement Technical Working Group on Pesticides has published guidelines on voluntary insecticide resistance management labelling but these do not apply to urban and public health insecticides. The US EPA has mandated insecticide resistance management for *Bacillus thuringiensis* (*Bt*) plant incorporated pesticides, including Bt corn and Bt cotton products (US EPA, 2006a,b), and also provides voluntary resistance management labelling guidance US EPA (2001). However, it has not made similar recommendation or mandates for public health insecticides used for vector control and urban pest management. Regulatory agencies may need to address this concern in the future to support the continuance of urban pest management practices and ensure that pesticide application remains effective.

Use of Pesticide Benefits in the Risk-management Decision-making Process

Measuring pesticide benefits has been possible for agricultural use but has been very difficult in most of the public health/urban pest management sectors. Risks from exposure to urban pest infestations have probably not been quantified because the acceptable level of exposure is usually no exposure at all. This is especially true in vector-borne disease control programmes where elimination of a vector and the disease it can transmit is the goal. Unlike agricultural pest management programmes, economic thresholds rarely exist in urban pest control programmes, and an acceptable level of vector-borne disease transmission has not been established. Despite the recognized risks from pest-borne allergens and disease transmission (Bonnefoy *et al*., 2008), quantifiable benefits assessments have never been done, at least in a manner where they can be incorporated into national agency risk-management decision making. Therefore, it is nearly impossible to compare the risk from pesticide exposure to that of pest exposure in like units and terms.

Pesticide risk assessments continue to be refined through computer modelling and exposure measurement, for example the project 'HArmonized environmental Indicators for pesticide Risk' conducted under the European Commission 6th Framework Programme (HAIR, 2011), and are often communicated in terms that the public and media understand. Pest-borne risks, in contrast, remain largely qualitative, except for malaria, where epidemics and mortality are so large as to be quantified in statistical terms that are easily understood (Kaiser Foundation, 2011). Work needs to be done to better assess risks from pests and to express these risks in terms other than mortality – such as lost work days, psychological and mental health impacts, dollars spent on allergy medication and control efforts. Most importantly, public health professionals need to explain to regulatory agencies and the public that there are health impacts associated with not using pesticides – when they are needed – to prevent or cure pest infestations. Until that task is accomplished, regulatory agencies will rely on quantifiable assessment methods as the basis for pesticide risk management decisions, as will the public. Benefits will therefore remain somewhat recognized but not measurable.

Pesticide regulatory agencies must do their best to consider the consequences of their regulatory actions in the context of protecting public health from pests (Bonnefoy *et al*., 2008). Often, many regulatory agencies do not have the statutory authority or mechanisms in place to consider benefits where pesticide risks exist. To date, many national pesticide regulatory agencies have worked cooperatively through a number of international organizations to make significant progress towards harmonization of approaches to pesticide registration and risk assessment, while progress towards an evidence-based approach to the benefits from urban and public health pest control has been very slow. If regulators simply measure risks from pesticides without considering the benefits of their use in urban settings, it may be difficult to sustain the use of all but a few products for residential use. Therefore, the challenge for regulatory authorities is to determine how the benefits of urban pest control pesticide applications can be considered during risk management decisions. Likewise, the pest management community must also invest to better describe the benefits of the work they do.

Re-emergence of Diseases and Pests of Public Health Significance

Vector-borne diseases continue to expand their range (Gubler, 2002). Introductions of pests and diseases of public health significance are being reported from urban areas where they have never occurred. Other regions of the world report re-emerging pests and disease in previously endemic regions. These occurrences are especially critical when there is no drug treatment regime or vaccine available for the susceptible human population. Vector control then becomes the primary method for controlling disease transmission.

There are many examples of these introductions and re-emergences. The 1999 West Nile fever and encephalitis outbreak in New York City caused many cases and spread westward across North America for years afterwards (CDC, 2011a). Chikungunya fever was introduced into north-eastern Italy in 2007 (CDC, 2011b). In South-east Asia, Chikungunya fever re-emerged at about the same time as it occurred in Italy following a 20 year absence (WHO, 2009b). These introductions and outbreaks suddenly challenged public health authorities and pesticide regulators because the framework to perform the needed control was not always in place, and the efficacy of registered pesticides against new pests was not immediately known. This resulted in a gap in response time between the outbreak of disease and control efforts. The same situation has arisen from the re-emergence of bed bugs in many North American and European countries. Few data exist on product efficacy against these bugs because they have not been a pest of public health significance in over 40 years. Cross resistance to pyrethroids from previous exposure to DDT in the 1950s is also prevalent (Busvine, 1958; Romero *et al*. 2007.)

Most agencies have been reactive in their responses, but future challenges will need them to be proactive. Pesticide registrations for use against urban pests of public health significance should be conducted with a global perspective instead of with strictly a national perspective with regard to efficacy. Also, more work needs to be done to regionalize pesticide efficacy data requirements in a manner that enables the bridging of efficacy on a regional and inter-regional basis where possible. Harmonization of these data requirements will be necessary and indicator species will need to be identified for testing in order to have greater confidence in the product performance database. This will also eliminate redundancy of testing within regions. Regulatory agencies will need to interface with public health organizations to determine which registered pesticides are most useful against new pests before their introductions occur so that reaction time will decrease significantly. In the USA, a multi-agency effort is coordinating the preparation of response plans for vectors and diseases of public health significance, such as Rift Valley fever (Britch *et al*., 2007).

Implementation of the Globally Harmonized System of Hazard Classification and Labelling (GHS) of Chemicals

Overview of the GHS

The GHS is a system for standardizing and harmonizing the labelling and classification of chemicals. This will be discussed here as it applies to pesticides. The GHS is not a regulation but a voluntary international approach to defining pesticide hazards, creating a classification process with the available data in order to compare these hazards with already defined hazards, and communicating hazard information and protective measures on labelling and Material Safety Data Sheets (MSDS) in the same manner (UN, 2009). Many countries have regulatory systems of this type but they often differ significantly (CropLife, 2011c), and these differences are significant enough for labels approved by one country to be unacceptable in another. For instance, the US EPA and EU systems of hazard classification differ in terms of hazard end-points and categories. For a public health pesticide, the same product, when evaluated in these two systems, could be assigned different precautionary labelling and signal words. The same applies to physical and chemical hazards where one system would consider a product flammable while another may not (OSHA, 2011). This, in turn, will affect how the applicator handles the product and which safety equipment will be required.

The GHS provides the foundation for synthesis or modification of national regulatory programmes to implement an internationally recognized classification system, the elements for effective hazard and risk communication strategies, and the use of protective safety measures. The GHS applies to the entire product cycle, as defined by the International Code of Conduct, and adheres to the following key guiding principles for the harmonization process:

- Protection will not be reduced.
- The GHS will be based on intrinsic properties (hazards) of chemicals.
- All types of chemicals will be covered.
- All systems will have to be changed.
- Involvement of all stakeholders should be ensured.
- Comprehensibility must be addressed.
- The GHS will be adopted and implemented.

The GHS was designed to provide the hazard end-point and communication tools necessary to adopt it to existing regulatory systems. Adoption of this GHS by national pesticide regulatory systems and their competent authorities is not required, but the EU adopted Regulation (EC) No 1272/2008 on 'the classification, labeling and packaging of substances and mixtures in 2009' (EC, 2011). In doing so, hazard criteria, classification processes, labelling, and safety data sheets are expected to be harmonized accordingly with the GHS (OSHA, 2011). This includes hazard communication processes. This will result in substantial changes in labelling, to include pictograms representing certain hazards – such as toxicity, flammability, cancer, etc. For instance, there will be only two signal words: 'Warning' and 'Danger'. These changes will take place in a transitional period, and in 2014 previous regulations will be repealed. Changes will result in a period of applicator and public education to learn and interpret the pictograms, and the urban pest management industry will be challenged with new hazard and risk communication education programmes for their applicators and customers.

Benefits of the GHS

The goal of the GHS is to improve hazard communication; the implementation of effective hazard communication strategies will benefit all segments of society. It is anticipated that application of the GHS will: (i) enhance the protection of human health and the environment by providing an internationally comprehensible system; (ii) provide a recognized framework to develop regulations for those countries without existing systems; (iii) facilitate international trade in chemicals whose hazards have been identified on an international basis; and (iv) reduce the need for testing and evaluation against multiple classification systems. The immediate benefits from GHS will be in the form of improved protection of workers and the public from chemical hazards, and in avoiding duplication of effort in creating national systems.

Meeting all the country level and international organization requirements for the same product sold in different markets places a large burden on registrants and slows the global pace of pesticide registration. However, the industry will see an increase in efficiency and reduced costs from compliance with hazard communication regulations, and will also be able to expand the use of existing training programmes on health and safety. Moreover, greater awareness of hazards will result in safer use of pesticides in homes by consumers, while consistent and simplified communications on chemical hazards and practices to follow for safe handling and use will improve safety for workers performing pesticide application against urban pests.

Conclusion

The regulatory landscape for urban pest management will become increasingly complex as new policies and legal mandates are implemented. Development and establishment of IPM/IVM programmes and practices will be needed to sustain pesticide tools, reduce exposure to pesticides, manage resistance, reduce environmental impacts and meet public demands for alternatives to conventional pest control practices. Implementation of these programmes may evolve voluntarily in response to market demands or may be legislatively mandated to meet risk reduction goals and support environmental justice efforts.

Urban pest management professionals will be expected to provide more sophisticated service types and fully embrace information data management practices for the purposes of: recording pesticide applications and pest management activities; mapping spatial and temporal attributes of inspections and control work, especially when sensitive populations are involved; providing online and practical educational modules to enhance worker skills; conducting public education; and as acting as a hazard and risk communication tool. Regulatory agencies will begin to implement harmonization systems to standardize hazard classification, labelling and risk/hazard communications that are likely to alter public perception of some pesticide products depending on how pictograms are interpreted. These systems will bring significant changes in labelling and material safety Data Sheets, while public and worker education will be required for a smooth transition to occur. Public health programmes, regulatory agencies and urban pest management specialists will need to work together to develop strategies for responding to newly introduced pests and vector-borne diseases, anticipate re-emerging pests and disease of public health significance, and consider these possibilities whenever possible during risk management decision-making processes.

The number and diversity of conventional insecticides for use in urban pest management programmes is likely to remain at current levels. Insecticide resistance management strategies and consideration of pesticide benefits and pest risks will be needed to preserve pesticide use patterns and allow consideration of new pesticide products. The benefits of pesticide use and risks from public health pests need to be better measured and quantified where possible so they may be fully incorporated into regulatory decisions instead of these relying on pesticide risks only.

Nanotechnology may provide some opportunities for enhancing the efficacy of insecticides, but it is unclear how regulatory agencies will assess the possible health implications associated with this technology. Genetically modified organisms and/or products capable of silencing genes, using RNA interference, or affecting biochemical targets in pests all hold promise; but are likely to progress slowly through regulatory review and approval processes owing to their novel modes of action and much public opposition.

Precautionary principles and practices are likely to become more prevalent on a global basis. Pesticide regulation will expand to consider life-cycle approaches to pesticide management practices and risk reduction. Meanwhile, urban pest infestations will intensify as cities grow and new pests will emerge as human populations expand into regions where diseases and vectors have been maintained in enzootic cycles.

Recommendations for future work

Precautionary principles should be retained where uncertainty exists, but regulatory decisions should rely on data and quantitative risk assessments. Data should be developed in residential settings to fully characterize the nature of pesticide residues and exposures from products used to control public health pests in urban areas.

Public education should be conducted on IPM principles and practices to enable the public to better understand this strategy as a means of controlling pests in urban settings. The GHS should be implemented for products used for public health pest control in urban settings as soon as possible, using existing regulatory systems to help in this effort.

Insecticide resistance management strategies should be developed for urban pest control and incorporated into IPM programmes as soon as possible. Standardized approaches to identifying insecticide resistance should be established and resistance ratios identified that confer resistance at a level that is likely to translate into a failure of effectiveness in the field.

Regulatory systems should support the development of new public health pesticide products and organize the framework necessary to consider genetic-level pesticide solutions to pest problems while retaining precaution where uncertainty exists. Harmonization of efficacy data requirements, and the testing of methods and representative public health pest species should be done on a regional basis wherever possible to reduce redundancy in testing. Harmonization may also allow more insect species to be tested to enhance the database on insecticide susceptibility.

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15 Effective Regulation in the Practice of Structural Pest Management

Steven Dwinell

Summary

Effective regulation of the practice of structural pest management is an essential part of a rational urban pest management system. An effective, local regulatory presence is needed to ensure an acceptable level of compliance with human health and environmental protection standards. Elements of effective regulation include clear legal authority to take disciplinary action, rules developed with input from the regulated community, licensure to verify appropriate training, adequate resources for inspection and investigation, and transparency and predictability for disciplinary actions that result from documented violations. It is important that violations of standards such as pesticide misapplication or over-application are addressed through this process, but it is equally important to have the capability to address under-application or undertreatment that results in consumer fraud or failure to manage pest problems adequately. These types of malpractice can ultimately result in increased risks of pesticide exposure for citizens or environmental damage when the pest problem is unresolved and consumers (or desperate pest management personnel) resort to over-application or the use of illegal products. Protection of the consumer from fraudulent or misleading practices, and from practice by unlicensed or unregulated persons or companies is also important in order to protect the integrity and fairness of the regulatory system. Finally, it is necessary to have mechanisms in place for routine input from the regulated community and for the incorporation of the results of pertinent scientific research that allow the modification and revision of the applicable standards, laws and rules that define the regulation of pest management in an urban environment.

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Structural Pest Control Practice: Introduction and Definition

Management of pests that have become adapted to harbouring and feeding in human structures, or directly on humans, is essential for human health and economic success, and is the purview of structural pest control practice. This term includes the control of rodent pests (mice, rats), household insect pests (cockroaches, stored food pests, fleas, ants, bed bugs, lice, flies and commensal mosquitoes such as *Aedes aegypti*), pests that damage structures (termites, wood-destroying beetles), nuisance wildlife (birds and bats that roost in buildings, mammals that raid food sources), and pests of ornamental plants that are integral to many habitations.

The practice of pest management, at its most basic, includes the identification of the pest, using an understanding of its biology to devise a means of management, and the application of the control methods so devised. As the tools available for pest management have become more sophisticated (pesticides versus fly swatters), the sophistication of the profession of pest management has had to increase as well.

With modern technology, the practitioners of pest management have many tools to choose from. Some of these tools, however, can have dangerous side effects or impacts on non-target sites. For example, organophosphate insecticides (e.g. malathion or diazinon) are very effective in controlling many insect species, but some of these are also toxic to humans and commensal mammals, for instance cats and dogs. Misapplication can result in illness in persons or animals living in the areas where pests are meant to be controlled, and if applicators do not use proper precautions, they can suffer ill effects from overexposure. Another example of toxic pesticides is rodenticides that act by causing internal bleeding, such as warfarin or brodifacoum. It is extremely important that these products be used in a way that prevents accidental ingestion by non-target animals or children living in areas where they are applied.

Pest management practice has established itself as absolutely essential to the health and well-being of people. It is the thesis of this chapter that, in order for it to be truly effective and provide its benefits, pest management services and providers need to be effectively regulated by an impartial third-party authority.

Why Effective Regulation is Needed

Regulation is needed for two reasons: because pest management is an increasingly technical enterprise requiring adequate education and training of its practitioners; and because of the economics of the provision of pest management services. An independent regulatory entity, with an active presence in the community that is being served by pest control operators, is needed to ensure first that practitioners know what they are doing and, secondly, that they do it properly, even though there may be economic pressures that may tempt them to not do so.

The necessity for adequate training and expertise is obvious, and an effective regulatory agency must exist to verify that pest management practitioners have received the training and experience needed before offering services to a public that will be likely not be able to differentiate between properly trained and improperly trained pest control operators. The basis for the argument that regulation is also needed for economic reasons may, however, require some explanation. Pest management is provided in most societies as a service for which the recipient pays. In some countries, some portion of pest management (rodent control, mosquito control, etc.) may be provided as a public service by a governmental or quasi-governmental organization; it is unlikely, though, that all necessary pest management services (household pest control, public health pest control, termite control) will be provided in this manner. As a result, competition for paying customers will force pest management service providers to try to make their services as price competitive as possible.

Those who practise pest management face two types of economic pressure – they need to minimize costs to maximize profits, and they need to compete against other pest management providers for customers in order to make enough money to survive. These pressures can have negative effects on the conduct of pest management. Practitioners may not perform services properly in order to minimize costs or avoid the expense of safety equipment. Pest management operators have, for example, not applied the required amount of an expensive pesticide, or have substituted an inexpensive, but illegal, pesticide for the one approved for that use, or have been found to not replace worn-out or inoperable safety equipment such as respirators or monitors in order to save costs.

Those operators who refuse to conduct themselves in this improper manner have to compete against those who do. If pest management practitioners want to maintain proper pest management and safety practices they may not be able to compete effectively against other practitioners who are willing to cut corners in order to charge lower prices. One example of this is the provision of termite protective services during the construction of new residences. If a pest management company provides these services at a fixed price, that company will make more profit if it applies less than the required amount of insecticide. Companies that make it a practice to apply the proper amount of insecticide will both have to charge a price to cover the costs of this amount of insecticide and compete against other companies that may choose to under-apply in order to charge a lower price. This has been a constant problem for pest management regulators in some parts of the USA where termite treatments are needed to protect buildings.

Effective regulation by an authority that can take civil or criminal action against a pest management company that breaks the rules can mitigate the effects of these competitively driven unethical practices. Pest management operators who are found to under-apply pesticides, use illegal pesticides or skip safety procedures can then be prevented from operating through the application of administrative, civil or even criminal penalties.

Effective Regulation of Pest Control

Effective regulation compels and encourages pest management providers to operate in compliance with appropriate health and safety rules and with the consumer protection requirements that have been established by the appropriate legal authority. The regulatory authority needs to address three areas in order to be effective: safety, environmental protection and consumer protection.

Safety

The regulatory authority needs to ensure the safety of the pest management practitioner and the persons to which the service is provided. This requirement is most obviously applicable to the use of pesticides such as insecticides and rodenticides. The safety of these tools for pest management can be assured through (i) regulation of the availability of these products, (ii) required training for applicators, (iii) required personal protective equipment for applicators, (iv) inspection of the application of these products to ensure that they are used properly, and (v) public education on how to use and store pesticides properly.

Environmental protection

Protection of the environment includes avoiding impacts on non-target organisms from improperly applied pesticides or improperly deployed traps (e.g. sticky traps deployed for catching rodents that have been misplaced and capture birds instead), preventing the contamination of soil, water and air through over-applications, spills or improper disposal, and ensuring the proper management of empty containers and unusable pesticides or pesticide/diluent mixtures.

Consumer protection

Consumers of pest control services need protection from unsafe pest management practices such as over-application or the application of pesticides not approved for use around consumers, in addition to protection from fraudulent practices. Consumers will, in most cases, not understand or be familiar with the tools and techniques of pest control, and, therefore, will be vulnerable to misrepresentation of services or the efficacy of these services. They may not be able to detect when a pest management operator is performing unsafe or inadequate services, deliberately not complying with the terms of contracts, overcharging for contracted services, or simply failing to provide contracted services.

If the above three areas are addressed, the regulatory agency can then realize three goals: the preservation of management options, the preservation of fair competition and the implementation of green practices and integrated management.

Preservation of management options

If society loses confidence in the ability of pest management practitioners to safely and fairly use one or more of the management options available, then that option may be lost. A good example is the use of structural fumigation using toxic gases such as sulfuryl fluoride to control wood-destroying insects. This technique poses potential dangers both to the applicators and the consumers whose homes are being treated. If not conducted properly, injury or fatalities can occur and have occurred. In the state of Florida, there were nine fatalities and injuries associated with this management technique between 1997 and 2001. The state regulatory authorities considered removing this form of treatment as an option. However, after strict new regulations and increased enforcement efforts were made, the safety record of the fumigation practice improved, and there have been no incidents from 2001 to 2010, so this pest management method continues to be available (personal experience of the author as a senior regulator in Florida).

Preservation of fair competition

The regulatory authority must determine if practitioners are choosing to not provide required services and thereby attaining an unfair competitive advantage. Some pest management services need to be deemed incomplete or improper in order to prevent all practitioners moving to that unacceptable level of service. The requirement for licensing to perform pest control is the most basic means of ensuring some level of professionalism and competence in providing pest management services. If there is a cost to such licensing, then those practitioners who choose to forgo licensing can achieve a competitive advantage by not having to incur those costs. The regulatory authority must, therefore, have a means of enforcing the requirement for licensing to provide for this basic level of competitive equality.

Implementation of green practices and integrated pest management

The concept of 'green' practices has gained popularity in many sectors, even if the definition of 'green' is somewhat vague. The area of pest management is no exception to this. Many organizations and governments have expressed strong interest in supporting 'green' options for pest management. Yet without a clear definition of green pest management, the potential exists for individuals and companies to provide services with this description that either are not, in actuality, beneficial or less detrimental to the environment, or are so ineffective that pests are not controlled. Lack of pest control can, in turn, lead to unnecessary expense or to consumers resorting to detrimental methods to control severe pest infestations.

Regulatory activity can, if applied correctly, allow legitimate green pest management and integrated pest management practices to be developed and implemented. By clarifying, defining and enforcing the standards that are applicable to these approaches, improper and ineffective pest management practices can be avoided.

Elements of Effective Regulation

In order to be effective over time, the regulatory authority must have a number of attributes. Chief among these is clear legal authority, but elements such as reasonable rules, adequate provisions and resources for licensing and for certification and training, adequate inspection capabilities, effective but fair and consistent enforcement procedures, and public review of activities and effectiveness, are also necessary.

Legal authority

There must be a clear and direct basis in law for the regulatory authority to authorize persons or companies to provide pest management services and to inspect, investigate and take enforcement action. Typically, this authority will be provided by a law or statute adopted by a national, regional or state legislature. In some cases, regulatory authority has been limited to licensing, inspecting and enforcing pesticide use. In these cases, the enforcement of conditions that limit consumer fraud, require enforceable service contracts and promote fair competition are not clearly provided for in the authorizing legislation. When the ability to enforce these components of pest management regulation is included, regulation is more likely to accomplish the goal of fair and effective provision of pest management to society.

In the USA, for example, there is no federal regulation of pest management. Regulation of this activity is based instead on laws adopted by individual states. A review of these regulations from a resource on the Internet which was maintained until 2010 by LIPCA (then the Louisiana Insurance Pest Control Association Self-Insurers Trust, but now strictly an insurance provider) showed that only 12 of the 50 US states have provisions written into their statutes that allow direct regulation of contractual relationships between pest management providers and the consumers of these services (LIPCA State Regulations, 2010). The other states have to rely on generalized consumer fraud protection in other consumer protection legislation, if applicable.

Rules

Rules are needed to provide clear standards and the necessary details to implement, interpret or prescribe the procedures or practices necessary to achieve compliance with the authorization statute. For instance, a statute may require continuing education to maintain eligibility for a licence to operate. The details of how many hours of education, what topics should be covered in this education, and how this education is verified can be provided in a rule or regulation established under the authority of the statute. Clear standards, and the necessary details needed to implement, interpret and understand what is needed to comply with a pest management statute, can be developed solely by the regulatory authority, but there are important benefits to be gained by involving the regulated community.

Involvement of the companies and individuals who will be most affected in the development of rules improves rule adoption and implementation in the following ways:

- The active practitioners can identify problems in their industry that need to be addressed in rules.
- The language used in the rules and the definitions of the terms used will be understood by the regulated community.
- Unintended consequences of rule language can be avoided.
- The regulated community will understand the intent of the rules and is more likely to be willing and able to come into compliance.

Once rules are established, it is important to regularly review and revise these as necessary. As new technology (or new pests!) become a reality, regulatory authorities need to adapt as necessary to maintain adequate and effective regulation.

The introduction and adoption of termiticide baiting systems in the USA provide a good example of this process. These systems were developed and introduced in the early 1990s as an alternative to the liquid formulations of insecticides that had been applied to soil under and around foundations, often in large quantities (pounds or kilograms of active ingredient per structure). Baiting systems, in contrast, use only very small amounts – fractions of an ounce or grams per structure, placed in specially designed bait housings (stations) around a structure (US EPA, 2004). They are effective in protecting structures when foraging termites encounter the bait matrix in the installed stations and consume toxicant, which results either in direct toxicity or in toxicant transfer through the colony via the sharing of food (trophallaxis) (Thorne, 1998).

Once introduced, baiting systems had a major impact on the termite protection market, with rapid adoption by many pest control companies. What became apparent, though, was that these systems have requirements for routine inspection and maintenance that are not needed in more conventional soil residual insecticide applications. These requirements had important implications for the regulation of pest management. Some of systems required inspection every 3 months, or more frequently when active termite infestations were discovered. Treatment of active infestations with soil insecticides could reduce or eliminate foraging on the toxicant in the baits, and thus had to be avoided. Also, if the baiting system or the toxicant was removed from the structure, there was no residual activity to protect that structure (Forschler, 1998).

These major differences resulted in a need to change regulations. In the USA, the Association of Structural Pest Control Regulation Officials (ASPCRO) responded with a set of recommended regulations for adoption by states to address this issue, which recommended written contracts specifying inspection intervals, increased consumer education regarding the way that baiting systems worked, monitoring of and record keeping for the baiting system, and improved training for the pest control technicians who installed and monitored the systems (ASPCRO, 2000). These recommendations were developed using input from state regulators as well as from pest management professionals and associations.

Licensing

As noted above, the most basic level of effective regulation is the establishment of the requirement that individuals and companies that perform pest control be licensed by the regulatory authority to perform those services. Licensure is the only practical way to prevent untrained or inexperienced personnel from offering potentially dangerous services to an unsuspecting public. Making licensure work, however, requires a consideration of licence categories.

Categories of licensure

Differences in the level of training and experience needed to provide different forms of pest management should be reflected in licensing and certification categories. The highest level of requirements should be for the selection of and instruction in the use of pesticides. High levels of training and experience are also appropriate for the application of highly toxic pesticides, such as sulfuryl fluoride or methyl bromide for structural fumigation, or for pesticide application in sensitive environments, such as hospitals or children's nurseries. Lower levels of training and experience can be established for persons responsible for lower risk pest management activities, or for those operating under the direct supervision of more highly credentialled individuals.

One example of a hierarchy of licensure and of the attendant responsibilities, is given below:

- Certified operator: responsible for training and supervision of certified and apprentice technicians, and the selection of pest management materials and methods. This requires multiple years of experience as a certified technician, and successful completion of specialized training and examination.
- Certified technician: responsible for providing routine pest management services under the supervision of a certified operator. This requires successful completion of a term as an entry-level technician, receipt of training in pesticide safety and pest management methods, and the completion of examination in these areas.
- Entry-level technician: responsible for providing a limited range of basic pest management services under the supervision of a certified operator or certified technician. This requires receipt of basic training in pesticide safety and pest management methods, and the completion of basic examination in these areas.

- Specialized categories, for example fumigation technician or operator, termite control specialist, etc., can be established as necessary with the appropriate levels of training and supervision.

Certification and training of practitioners

Appropriate levels of training and experience can best be established through the drafting of regulations that include the input of the regulated industry. Practitioners of pest management will have the best sense of what is appropriate and practical regarding training. Regulators should be alert, however, to any attempt to limit competition by establishing unreasonable or unnecessary requirements. One example of this occurred in Florida for several years. In an attempt to prevent competition from some providers of lawn care services, the pest management industry was successful in requiring the demonstration of 3 years of experience in mowing lawns before these providers were allowed to take a certification course and examination that would have allowed them to apply certain low toxicity pesticides to ornamental plants and herbicides to plant beds. After numerous attempts, this requirement was replaced with one for training and examination without the extraneous ‘experience’ that had previously been necessary (personal experience of author as a senior regulator in Florida).

The regulatory authority needs to be actively involved in the provision and oversight of the certification and training of pest control practitioners. This training may be provided by another agency or entity, such as a university or non-profit association, but the regulatory authority must establish enforceable requirements for content and duration of this training. Regular review of what is offered in these courses, and the quality of the instruction, is needed to assure quality. Persons who have already attained credentials as certified operators or technicians also need to regularly attend continuing education. New pests emerge constantly, and technology for control advances over time. As with the basic certification and training, regular review of what is offered and the quality of the instruction is needed. Once again too, active participation by the pest management practitioners is needed to make the training regime practical and responsive to their needs.

Inspection and investigation of practitioners

The regulatory authority must be able to regularly inspect pest management practitioners and receive and investigate complaints about the conduct of these practitioners from consumers. Complaints may be about the quality or effectiveness of the services provided, or about the safety or environmental impact of these services. If the statute authorizing regulation of pest control extends to protecting consumers from unethical practices, complaints may also be about contractual obligations, misleading or misrepresentative statements or advertising, or other types of consumer fraud.

Regular inspection of practitioners is needed both to establish a regulatory presence and to obtain a baseline knowledge of the level of compliance with the basic provisions of applicable law. Inspections carried out on a regular basis let the practitioners know that the regulator is checking to make sure that licensing is maintained, and that basic safety and training requirements are being met. In addition, routine inspections allow the regulator to become aware of changes in practices by an operator or a segment of operators that require an adjustment on the part of the regulator. Ideally, the regulatory authority can conduct these inspections with the cooperation of the regulated community. Respectful, professional inspections conducted with adequate coordination with the pest management practitioner should be the normal procedure. The regulatory authority should have the option, when and if needed, to conduct inspections with little or no previous notice. If, for example, a pest management company is suspected of or has been reported to be using an illegal pesticide, the regulator should have the authority to inspect without prior warning to prevent destruction of the evidence. These tactics should only be used when absolutely necessary, however, to avoid the creation of an adversarial relationship between the regulator and the regulated community.

Investigations of complaints need to be a major part of any regulatory programme. The public and other government agencies need to know that if they are the victims of improper conduct by a pest management practitioner, or if they observe improper or potentially dangerous or unsafe procedures, they can contact the regulatory authority, who will then investigate and take appropriate action. Examples of the types of complaints routinely received and investigated by regulators are discussed below. These complaints or referrals may arise from consumers, from other pest control operators trying operate in compliance (and perhaps at a competitive disadvantage compared with those who are not), or from other government agencies with information on pest control activities.

Misapplication/over-treatment

Application of a pesticide to a site not included in the approved directions for use for that pesticide or the application of too high a rate of active ingredient constitute misapplication. This aspect is a basic component of virtually all pest control regulation and is essential to protecting the health and safety of applicators and consumers, as well as to preventing environmental damage. Cases alleging human exposure to pesticides should be treated as a top priority for any pest control regulatory agency. Investigations of such complaints must be done in a timely manner so that physical samples can be collected to determine whether an over-application or application to an improper site has occurred.

Under-application/undertreatment

Complaints that pest control operators failed to conduct a treatment properly and thereby did not achieve control of a pest are not uncommon. This is a particular concern of pest control regulators in areas where termites are a problem: that pest control operators may not apply a sufficient amount of termite control product (either soil applied or applied as a wood treatment) and may thereby put a structure at risk of termite damage years after the treatment. The determination of under-application is more difficult than that of over-application. Typically these investigations require an observation of the entire application, careful measurement of the treatment area and calibration checks on the application equipment. These investigations can be time and resource intensive.

Misleading advertisements/claims

Misleading advertisements and claims by pest management providers include such statements as 'completely safe' pest control, '100% effective' treatments and guarantees of pest protection that are not warranted by the level of technology available. Investigations and sanctions against such claims aim to protect consumers from potentially fraudulent practices, in addition to preserving a level playing field for fair competition among pest control firms.

Consumer fraud

Consumers can be defrauded by pest control firms or individuals when these operators do not provide the services that have been contracted for, overcharge for services or substitute inferior products or services. Elderly consumers can often be the victims of such activities, such as when they are convinced to contract for expensive services which are then are only partially provided. Uninformed consumers can be victimized too. When confronted with an infestation of wood-destroying organisms, homeowners may be easily persuaded to purchase costly services, and when these are not provided, the purchase may not be recognized as fraudulent until it is too late to prevent damage. The advent of 'green' pest management as a service preferred by some consumers increases the opportunities for such dishonest activities. One recent incident involved a treatment of wood flooring for wood beetles using a 'green' product that provided no control. The homeowner is then faced with multiple costs – the cost of the ineffective treatment, the cost for damage repair and the cost for subsequent, effective treatment.

Illegal pest control

Allegations that pest control services are being performed by persons or firms not licensed to perform such services are common. Providing pest control without an appropriate licence, or after a licence has expired but has not been renewed, is the basic violation of pest management regulation. In the USA, after over 50 years of pest control regulation, this is still a common violation of regulations.

Illegal pest control is also potentially the most serious violation. Operators who do not bother to obtain a licence are likely not to pay particular attention to the requirements for training and certification, safety procedures, or pesticide application directions. In the south-eastern USA in 2009, it was discovered that a firm was providing services to scores of healthcare facilities for the elderly under a multi-state contract with a national healthcare provider. In at least five of the states in which this firm operated, they had not obtained licensure. During the investigation, it was discovered that they were applying an insecticide labelled for outdoor use only to the interior of patients' rooms and living areas, as well as a rodenticide, in violation of label directions.

Additionally, regulatory agencies need to be diligent in investigating reports of illegal activities and take effective action, including the imposition of criminal penalties when appropriate, to stop such activities. The importance of this was illustrated in 1994 in the USA when it was discovered that a number of individuals were operating an illegal pest control enterprise that spanned multiple states. This particular enterprise specialized in providing low-cost control of cockroaches in economically limited communities. Its method was to use a highly toxic agricultural insecticide, methyl parathion, which it could obtain very cheaply (and illegally) from associates who worked on farms. This material was applied in homes and day-care centres. During the investigation it was discovered that up to 1500 persons were exposed to the insecticide. The potentially exposed persons had to be relocated, and many homes and day-care facilities were so contaminated that they had to be condemned and razed at a cost to the US government of over US $90 million. The individuals performing these activities were convicted and sentenced to prison terms (US EPA, 1997; Rubin *et al*., 2002). Very recent experiences (2010) with control of bed bugs (*Cimex lectularius*) in the north-eastern USA show that this problem still persists. In New Jersey, a pest control operator was cited for using pesticides not labelled for use for indoor control in an attempt to control bed bugs (NJDEP, 2010).

Training of inspectors

Training of inspectors and investigators is a critical component of an effective regulatory programme. The quality of the enforcement programme hinges on the ability of inspectors to adequately collect evidence of compliance or non-compliance. They are the front line of the effort and, if they are not adequately trained, the regulatory authority cannot have confidence in the effectiveness of the programme.

Training needs to include information that allows the inspector/investigator to understand the pest control practices being observed, the applicable laws and regulations with which the pest management provider must comply, and inspection and investigative techniques. These include how to conduct interviews, how to collect evidence and how to collect physical samples. For these reasons, it is usually best that the inspector be dedicated to the inspection of the pest management industry, rather than be also responsible for inspecting other industries or activities, such as public health, agricultural production, workplace safety, etc.

As with the development of rules, and the development of industry training and certification requirements, inclusion of the regulated community in some aspect of the training of inspectors is a good idea. As the regulated community comes to know and trust the corps of inspectors, they are more likely to cooperate, and to provide information on any improper practices that they observe.

Disciplinary actions

When inspections and investigations reveal evidence of violations of relevant law or rules, it is necessary that disciplinary action is taken against the violator. Laws and regulations only have meaning if they are enforced. If the regulated community knows that violations have no consequences, they will ignore the requirement.

Determination of evidence of a violation must be done carefully. Separating the collection of evidence from the determination of violation and the assessment of disciplinary action is a basic step in preventing persons and companies who have not committed violations from being penalized in error. The apparent violation that an inspector observes may, in fact, not be a violation when all the facts are known. An impartial reviewer, not involved in the actual investigation, is in a better position to make such a determination than an inspector in the field, who may have drawn a conclusion without considering all the facts. For example, an inspector may conclude, based on observations and testimony in an investigation, that a misapplication of a pesticide has occurred. Upon further review, though, a case processor may determine that the inspector made a miscalculation of the appropriate dose, misinterpreted the label directions for use or made some other mistake. Independent review of a case file, will, if the reviewer or reviewers concur with the inspector's determination of a violation, strengthen the regulatory agency's case against a violator.

Disciplinary actions can take the form of fines, probation, suspensions or revocations of licensure, or requirements to take corrective action – for instance, increased training, purchasing of safety equipment or compensation of a consumer. Typically, the first detection of an offence should result in a warning and an opportunity to correct the non-compliance without a monetary penalty. This is appropriate for most types of violations. If, however, the violation is severe or systematic, or results in extreme consequences (e.g. death or injury to a worker or consumer) or in environmental damage (e.g. contamination of a water body), then the appropriate penalty may be a fine on the first offence. Multiple offences of the same character within an appropriate time frame, say 1–3 years, should result in progressively more severe penalties. The purpose of such a progressive penalty system is to encourage compliance. Persons or companies that commit violations under this kind of system recognize that coming into compliance after a first offence will avoid more costly penalties later.

In a progressive penalty system, some types of violations should result in more severe penalties, even on a first offence. An example would be violations that result in risks to health, safety or the environment. Such violations can be characterized as 'major' violations and can result in fines on the first offence, rather than a warning to come into compliance. Within the category of 'major' violations, some may be considered more dangerous than others and require a higher fine than a less dangerous one. The relative training and experience of the violator can also be taken into account, with a certified operator held to a higher standard and, therefore, subject to a stiffer penalty than a certified technician or the equivalent. Based on the rules currently effective in Florida, Table 15.1 provides examples of minor and major violations and the penalties for a first offence. Ideally, the consequence of a violation will be clearly spelled out and known to those who are licensed to operate. The establishment of published guidance on which violations are considered major and minor, and the expected penalties for these violations are important tools to improve compliance.

While it can be assumed that the vast majority of pest management professionals maintain compliance with laws and regulations, there will always be a few who choose not to be in compliance. These operators are the 'bad actors' in pest control, and one of the main reasons why effective pest control regulation is a necessity. If repeat violators are discovered, given a reasonable chance to operate in compliance with the law and rules, but do not come into compliance, the most severe civil or administrative penalties need to be applied. In some cases, elevation of the violations to that of a crime punishable by the penal code is necessary. My experience with persons or companies that operate in this way is that regulatory agencies have to invest considerable time and resources on these cases. If the regulator is diligent, however, over time, the person or company will conclude that the costs of this behaviour outweigh the benefits and will leave the industry.

In contrast to the 'bad actors' are those in the industry that want to comply, but may not fully appreciate how to do so. Regulators of many industries

Table 15.1. Examples of major and minor violations of pest control regulations and applicable penalties as established in Chapter 5E-14.149, Florida Administrative Code (2010).

		Penalty for first offence	
Violation	Category	Certified operator	Entry level technician
Misuse of highly toxic pesticide	Major	Up to US$5000	Up to US$2000
Causing serious harm to an ecological system	Major	Up to US$5000	Up to US$2000
Making false or fraudulent claims with respect to pest control	Major	Up to US$5000	Up to US$2000
Failure to provide true information to an inspector on written request	Major	Up to US$5000	Up to US$2000
Performing pest control without a licence	Major	Up to US$5000	Up to US$2000
Failure to lock pesticide storage areas, but no exposure to bystanders documented	Minor	Administrative warning	Administrative warning
Failure to wear required personal protective equipment, but no injury documented	Minor	Administrative warning	Administrative warning
Failure to display licence or carry state-issued identification card	Minor	Administrative warning	Administrative warning
Failure to apply pesticide according to label directions (if pesticide not highly toxic)	Minor	Administrative warning	Administrative warning

provide ‘compliance assistance’ types of activities to assist these operators. In a compliance assistance activity, an experienced inspector will arrange a visit to a firm and, during the inspection, point out areas that are in compliance, areas where improvements are needed, and areas where violations are noted. Time is given for corrective action, without any assessment of disciplinary action, and a follow-up inspection is arranged. If severe health and safety violations are noted, immediate corrective action can be required. The regulatory agency should always reserve the right to take disciplinary action if the person or firm being investigated will not correct the non-compliance or does not cooperate in the inspection.

Public review of activities and effectiveness

Public disclosure of the results of inspection and investigation activity is important for continued effectiveness. Measures of the number of inspections, types of inspections, and numbers and types of disciplinary action should be published regularly. The names of those persons and firms for which disciplinary action has been taken and the nature of the violation and penalty should be published. In a competitive pest control market, firms and individuals will be highly motivated to avoid publication of their names on a disciplinary action list.

Determining whether a regulatory programme is being effective depends on measuring the rate at which firms are found to be in compliance. It is beyond the capability of most authorities to measure compliance with all the applicable rules and laws, but those of most significance should be tracked. For example, the rate at which licensed individuals and companies comply with the requirements for relicensing, continuing education and technician training should be carefully monitored. If these rates drop, other non-compliance is likely. The numbers of violations of certain sensitive activities should also be measured; the numbers of cases of violations in pesticide applications to sensitive facilities such as schools, hospitals, etc. are an example, as well as such activities as structural fumigation. Authorities can shift resources to focus on these activities until compliance rates improve. These measures of programme effectiveness should be published. If an advisory body composed of individuals who are knowledgeable of the pest management industry exists then these performance measures should be reported regularly to that body.

Constant Review and Adaptation of Pest Control Programmes

Just as pest control practice will change over time, pest control regulation programmes must change and adapt. The regulatory agency should review and change, as necessary, which pest control activities are monitored, what standards need to be met and the means of ensuring compliance. Furthermore, the regulatory agency must keep in close communication with the regulated community and the consumers that they serve in order to know what the current situation is and what changes are occurring.

One way to accomplish this to involve the stakeholders in professional associations that meet openly and discuss pest control issues in a professional, cordial manner. Such associations have been formed in most developed countries where the pest management industry has already been established, or is being formed. The regulatory agency should become involved with these associations in a manner that allows the free exchange of information and opinions, and leads to increased mutual understanding, increased cooperation and the identification of common goals. Examples of such associations are the Association of ASPCRO and the National Pest Management Association (NPMA, 2011) in the USA, and the Confederation of European Pest Control Associations (CEPA, 2011). It is not appropriate for regulatory personnel to become official members of professional associations of commercial pest management providers. Regulators must remain independent of and able to take enforcement action impartially against any pest control management individual or firm. Membership of an association could lead to conflicts of interest.

Regulators can and should attend association meetings, when appropriate, to share information and learn about the issues affecting pest management professionals. While this is occurring, however, it is important to avoid conditions that could lead to ethical conflicts for regulators. Acceptance of honoraria, gifts or meals should be avoided. Arrangements can be made in advance to provide for the opportunity to socialize while not creating potential ethical conflicts. In addition, regulators must be careful not to be subject to the condition of 'regulatory capture', where familiarity and development of relationships between the regulator and the regulated community interfere with the ability to regulate the industry effectively. By maintaining a careful balance of open communication and impartiality, the pest management regulator can learn from pest management professionals as well as providing the regulatory services that they need.

Conclusion

Pest management is integral to the health and economic well-being of an urbanizing world. Regulation of pest management is also essential so that this vital service is provided competently, safely and without economic distortions resulting from unfair competition. A successful regulatory programme will be fair and effective and its methods and results will be transparent to both the public and the regulated community.

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