MINI REVIEW

Influence of the public’s perception, attitudes, and knowledge on the implementation of integrated pest management for household insect pests

Bruce Schoelitz1,2*, Bastiaan G. Meerbürg1,3 & Willem Takken2

1 Dutch Pest & Wildlife Expertise Centre (KAD), Wageningen, The Netherlands, 2 Laboratory of Entomology, Wageningen University, Wageningen, The Netherlands, and 3 Livestock Research, Wageningen University & Research Centre, Wageningen, The Netherlands

Accepted: 18 July 2018

Key words: IPM, household environment, nuisance, pest control, inspection, identification, threshold level, DNA barcoding, RNAi

Abstract

Households are mini-ecosystems that provide a variety of conditions in which a variety of insect species can develop. Whether these insects are considered pests largely depends on the perception, attitudes, and knowledge of the human inhabitants of the house. If considered unacceptable, residents can attempt to manage the insects themselves, or hire a professional. A pest management professional can provide a quick-fix solution, often relying on the sole use of insecticides, or a sustainable solution through integrated pest management (IPM). In this review, it is discussed how the public’s perception, attitudes, and knowledge affect the implementation of IPM in the household through the following steps: inspection, identification, establishment of a threshold level, pest control, and evaluation of effectiveness. Furthermore, recent and novel developments within the fields of inspection, identification, and pest control that allow to address pest infestations more effectively are described and their implementation in the household environment is discussed. In general, pest management in the household environment is reactive instead of pro-active. The general public lacks the knowledge of the pest insects’ biology to identify the species, perform a proper inspection and identify causes of pest presence, as well as the knowledge of the available tools for monitoring and pest control. The percentage of individuals that seek professional aid in identification and pest control is relatively low. Moreover, the perception of and attitudes towards household insects generally result in low threshold levels. Current developments of methods for monitoring, identification, and control of insect pests in the household environment are promising, such as DNA barcoding, matrix-assisted laser desorption/ionization time-of-flight and RNA interference. Efforts should be strengthened to alter the perception and attitude, and increase the knowledge of the non-professional stakeholders, so that correct pest management decisions can be taken.

Introduction

The presence of household insects is common and affects all human habitations, but with large differences in the level of infestation and associated cultural and societal issues. Households are mini-ecosystems, creating conditions that are favourable to many different families of arthropods (Bertone et al., 2016; Leong et al., 2017). Whereas seasonal outdoor patterns are buffered within the household environment, at a micro-habitat scale, the temperature and humidity can be as variable as outdoors (Martin et al., 2015). For instance, the temperature behind and underneath electrical devices such as refrigerators is higher than in their surroundings and the relative humidity in the bathroom is generally higher than in adjacent rooms. Insects surviving in human-made environments are largely pre-adapted or capable of adapting to changes in these environments (Frankie & Ehler, 1978). The transition of arthropods from nature to the human environment already occurred thousands
of years ago (Panagiotakopulu, 2004; Wilkinson et al., 2014) and many insects are still indeed found in our houses today. In fact, cockroaches, bed bugs, and silverfish still possess characteristics of cave-dwelling insects such as long antennae, flattened bodies, and low active dispersal capabilities (Martin et al., 2015). Many other species that are found indoors, however, do not have these features but are nonetheless capable of colonizing the household environment.

Whether household arthropods are considered as pests largely depends on perception, knowledge, and attitude of the residents. Arthropods that pose a health risk to inhabitants and pets by being a vector, sting or bite, damage the structure of or materials within their house, contaminate food, or are an annoyance because of their abundant presence, may be considered as pests (Baldwin et al., 2008). In rare circumstances, previous experiences with household insects are the cause of delusional parasitosis, a condition that requires medical and psychological care (Donabedian, 2007; Vulink, 2016).

When arthropods in the household environment are unwanted and considered a pest that should best be exterminated, residents may attempt to control the insects and make pest management decisions themselves, or hire a professional operator. Professionals can provide a quick-fix solution, relying heavily on the use of insecticides, or a sustainable solution through integrated pest management (IPM). Instead of merely eradicating the present population, IPM focuses on interrupting and preventing the development of pest populations, while reducing the amount of chemical insecticides. The introduction of IPM has led to an increased interest in alternative measures, including new natural products, biological control agents, and molecular techniques (Rust, 1999). IPM provides a framework consisting of several steps that result in sustainable pest management and requires knowledge of pest insect biology, as well as pest management measures, and relies on threshold levels for the implementation of these measures (Sarisky et al., 2008).

Although it is shown to be successful (Bennett et al., 2016), the implementation of IPM has hardly been studied in situations where home-owners or occupants make pest management decisions, such as single-family housing without routine inspection by professionals. As these decisions are affected by the perception, attitudes, and knowledge of the residents, they are more prone to subjectivity, than when decisions are made by professionals. In this review, the framework of IPM is used to discuss how the perception, attitudes, and knowledge of residents affect the implementation of IPM in the household environment. As IPM focuses on non-chemical control, present and novel pest management developments that are applicable in the household environment are explained and discussed as well.

**Integrated pest management**

Due to the initial success and benefits of synthetic insecticides, compounds such as DDT were used extensively in agriculture. However, the concerns for the environment, health, and emerging insecticide resistance have led to the realization that chemical control measures alone cannot be relied on indefinitely (Carson, 1962; Busvine, 1965; Thomas et al., 2012). The concept of IPM, in which pesticide reduction and environmental protection are major considerations (Robinson, 1995a), initially increased in popularity in agriculture in the 1970's. In agriculture, IPM focuses on understanding the entire ecosystem and using chemical control only to complement biological control, when pests reach dangerous levels (Van Den Bosch & Stern, 1962). The introduction of the economic injury level (EIL), defined as the lowest population density that will cause economic damage, as a decision level offered a practical approach to decision-making (Pedigo et al., 1986). More recently, functional agrobiodiversity was implemented as a strategy in agriculture to make more use of the presence of natural enemies of pests (Bianchi et al., 2013).

Although the main concept of IPM was implemented in the urban context, including the household environment as well, the strategies used within the agricultural context are not necessarily applicable in houses. In both cases, the essential knowledge base of a pest population includes identification of the species, its life history and habits, seasonal cycles, and methods of dispersal (Kogan, 1988). In contrast to citizens in the household environments, however, the farmer is an expert in his field. In agriculture, the goal of pest management programmes is to manage pest populations to remain below a size at which economic damage is caused. In households, pest management decisions are often based on subjective criteria and EILs are not appropriate, because insects are often considered pests because of their presence or aesthetics (Pedigo et al., 1986). Because of a low tolerance for household insects, the goal within urban pest management programmes often is to eradicate the pest population (Rust, 1999). The subjectivity of decision levels for household IPM demands the consideration of sociological and psychological needs of the public (Zungoli & Robinson, 1984).

Furthermore, agricultural pest management focuses on a balance between crop plants, herbivores, and natural enemies by plant resistance, biological control, and
cultural methods (Kogan, 1988). In urban systems, including households, IPM focuses on eradication with a minimum of toxic chemicals and physical and mechanical control measures, in combination with preventive measures to reduce the availability of resources needed by the pest species by removing food and water, shelter, and blocking entrances that give access to buildings (Brenner et al., 2003; Kass et al., 2009). IPM has been successfully implemented in the household environment, as shown in multiunit housing facilities with cockroaches and bed bugs (Wang & Bennett, 2006, Wang & Bennett, 2009; Wang et al., 2009, 2014a; Kass et al., 2009; Bennett et al., 2016).

In order to create IPM programmes in urban environments, five steps are defined: inspection, identification, establishment of a threshold level, pest control, and evaluation of effectiveness (Schoelitsz et al., 2018). These steps are used as a framework to structure this review.

**Inspection**

During an inspection, the interior, exterior, and direct surroundings of a building are inspected to proactively identify the presence and distribution of insects or the potential for pest development, that is, (micro-)habitat characteristics that provide insects the conditions needed for introduction, establishment, and reproduction (Sarisky et al., 2008). With the exception of multiunit housing with active IPM programmes, routine inspections and monitoring are generally not performed in the household environment. Detection of insects is based on sightings of arthropods (Romero et al., 2017) or their associated nuisance by the residents.

The information and knowledge about the biology and life cycle of the insect species that is subsequently needed to identify the cause of its presence, is often lacking. The tendency to search for information about pest insects depends on a person’s information sufficiency and the perception of their capability to search for information regarding these pests (Schoelitsz et al., 2018). When searching for information, commercial sources such as websites of pest management professionals (PMPs), PMPs themselves, and the label or quality of information provided by the salesperson of insecticides are considered the most valuable. Information by personnel of universities, museums, and centres of expertise was considered the least valuable (Schoelitsz et al., 2018). This suggests that residents are not interested in information about the insects and the underlying causes of their presence, but mainly in their eradication.

Devices for monitoring of insect populations in the household are readily available from (web)shops and relatively easy to use by the general public. These include sticky traps and interceptors with or without an attractant such as pheromones, baits, and UV-light. The location and number of traps determine the success of trapping, and require knowledge about the target insects (Atakan & Canhilal, 2004; Facchinelli et al., 2007).

More specialized methods that require training for handling, application, or analyses, are available as well. These methods may be more expensive because of the costs of personnel and equipment, and their use is often limited to experts. For example, canines that are specifically trained for the detection of bed bugs, *Cimex lectularius* L., are used to detect bed bug presence (Pfiester et al., 2008). The success in detection varies, however, and active bed bug infestation should always be confirmed by the dog handler (Cooper et al., 2014). Cryptic wood-infesting species, such as termites and larvae of wood-boring beetles, can be monitored using devices that detect sounds emitted by these insects. This method requires software and trained personnel for a correct interpretation of the registered acoustic signals (Mankin et al., 2011). A more novel technique is the detection of DNA in the environment (eDNA). This is becoming widely used for the identification of species in aquatic environments, such as larvae of invasive mosquitoes (Schneider et al., 2016), but is also used to detect bed bug DNA in buildings. DNA is collected from surfaces with a swab and analysed in a laboratory. This can be performed by PMPs as well as residents, as kits including laboratory analysis are available through websites such as amazon.com. It should be noted that this method is only suitable for the detection of DNA that may remain present for extended periods of time, and not for the detection of an active infestation. A positive result should therefore always be followed-up by a visual inspection. The knowledge and information needed for an adequate inspection of causes of pest presence can only be found if it is known which insect is encountered.

**Identification**

A correct identification is crucial for the sustainable management of household insects, as this provides the opportunity to find information about the insects’ biology and life cycle, potential distribution, sources of development, as well as pest status (Sarisky et al., 2008). It has been shown that densities of cockroaches within homes were reduced significantly after a single educational intervention (McConnell et al., 2005) and informing residents on bed bug biology and management has been vital for the success of IPM in multifamily housing (Bennett et al., 2016). Furthermore, understanding the insect’s biology is needed for an appropriate application. Differences in the
distribution of the German cockroach, *Blattella germanica* L., the American cockroach, *Periplaneta americana* (L.), and the brown-banded cockroach, *Supella longipalpa* (Fabricius), within the house require a different distribution of the baits.

There is a wide variety of pest insects that can be found within the household environment. In a study by Bennett et al. (1983), in which multifamily housing was not included, cockroaches were target pests for only 3.5% of respondents, whereas ants, flies, and fleas topped the list of target pests. Dingha et al. (2013) found that ants, mosquitoes, and flies preceded cockroaches as major indoor pests. In addition to bed bugs and cockroaches, the most frequently identified insects collected in houses by the Amsterdam municipal health service (The Netherlands) included the grey silverfish, *Ctenolepisma longicaudata* Escherich, Indian meal moth, *Plodia interpunctella* (Hübner), moth flies (Psychodidae), clothes moth, *Tineola bisselliella* (Hummel), carpet beetles (Megalotini), biscuit beetles, *Stegobium paniceum* (L.), and booklice (*Psocoptera*) (Buijs, 2009). This is only a small selection of insects that can be found indoors and the number of species varies according to geographic region, type of building, and internal environmental conditions (Bertone et al., 2016).

A problem is that the identification skills of the public are generally undeveloped. Only 12.5% of the respondents in a study by Seidel & Reinhardt (2013) were capable of correctly identifying bed bugs, whereas 85% were aware of their existence. Approximately 70% of students thought wasp-mimicking hoverflies would sting, and only 50% correctly identified honey bees (Golding et al., 2005). The success of species identification was positively affected by negative experiences with such species in both studies.

Misidentification results in incorrect pest management and unnecessary costs (Pannkuk, 2010). Therefore, identification should be performed by trained professionals, even when individuals use the internet or an app on their mobile device to identify the encountered insects. Examples of misidentification of household insects by residents using the internet include winged ant queens that were misidentified as termites, biscuit beetles, *Anobiurn punctatum* (De Geer), and the indoor overwintering western conifer seed bug, *Leptoglossus occidentalis* Heidemann, that was mistaken for the much dreaded structural pest insect old-house borer, *Hylotrupes bajulus* (L.). In a study by Bennett et al. (1983), however, only 14% of respondents did seek help in diagnosing the pest problem, of which 77% obtained help from salespersons of pesticides, suggesting that control of many species is attempted without the proper knowledge about the insect species and its ecology.

Even for professionals, correct insect identification to a sufficient taxonomical level, based on morphological characteristics, is not always possible. Highly damaged insects, certain life stages of specific species or lacking taxonomic keys hinder identification. In these cases insects can be identified with molecular tools. DNA barcoding has shown potential in identification of various life stages of Coleoptera, Diptera, and Hymenoptera to species level. A genetic region of the cytochrome c oxidase subunit I (COI) gene of individual insects is compared to genetic barcodes of species in a database (Ratnasingham & Hebert, 2007; Ashfaq et al., 2016). With this method, it was possible to confirm the identification of the invasive species *Periplaneta japonica* Karny in New York City (USA) (Evangelista et al., 2013). This technique may be very valuable in the rapid identification and detection of newly introduced (invasive) species in the household environment, due to increased international travel and trade as well as climate change (Suckling et al., 2013; Medlock et al., 2015).

The proteome-based linear matrix-assisted laser desorption/ionization time-of-flight mass spectrometry technology has been suggested as a cheaper and faster method for species identification than molecular techniques. This technique is generally used for identification of microbes, but has been shown to be robust and accurate in the identification of various arthropod ectoparasites to species level. The analysis can be performed on whole bodies or haemolymph from dissected body parts (Yssouf et al., 2014; Murugaiyan & Roesler, 2017). Identification of species requires a reference library, which needs to be developed for insect pests, as the database of manufacturers exclusively includes microbes. This method would benefit from an open source library for other groups of organisms, including insects (Murugaiyan & Roesler, 2017).

These techniques are not expected to be directly available to the general public, but indirectly through extension entomologists from universities, personnel of natural history museums, national research institutes, and pest control organizations. With the small percentage of residents seeking help with identification, and because it may be faster and less expensive for entomologists to identify household insects themselves, it is not expected that these techniques will be widely used for household insect pests.

**Establishment of threshold level**

Not all populations of household insects are considered pests. By establishing a threshold level, the insect population size that is still acceptable is determined (Sarisky et al., 2008). If this threshold level is exceeded, curative measures...
are performed, whereas preventive measures are implemented to prevent exceeding these threshold levels.

The threshold level provides the IPM programme with objectives and is determined by all persons involved. This may be very challenging in situations where several stakeholders with different interests, for instance tenants and housing authorities, are involved. For instance, the contracts that are economically interesting for housing authorities prevent PMPs from adequately addressing the pest problem that the tenants have to cope with (Wang & Bennett, 2009), resulting in the persistence of a perceived problem. On the other hand, sometimes some tenants are not following the rules as provided by the housing authorities, which may also result in persistence of the problem. In some cases, tenants do not provide access for the PMPs to do their work, so that the pest problem cannot be brought under control.

The tolerance of people for arthropod presence determines whether these arthropods are regarded as pests or not. In general, arthropods, such as crickets, ants, and spiders, are far less popular than mammals and birds (Byrne et al., 1984; Driscoll, 1995; Bjerke et al., 2003). Insects and spiders in particular are associated with negative feelings by the general public (Byrne et al., 1984). A range of emotional and psychological responses are caused by the presence of bed bugs (C. lectularius) (Goddard & De Shazo, 2012), and persons can have sleepless nights because of the knowledge of larvae of the old-house borer (H. bajulus) or termites eating their wooden construction. Negative emotions have been shown to affect the tolerance for household insects (Schoelitz et al., 2018), which, in general, is low. The number of cockroaches that is considered acceptable is often zero (Wood et al., 1984; Zungoli & Robinson, 1984) and one or two cluster flies (Pollenia pseudorudis Rognes) in the house can be perceived as an intolerable nuisance for the residents (Heath et al., 2004). The low tolerance for selected insects results in a strong urge to eradicate them among a large part of the general public (Kellert, 1993).

There is, however, variation in attitudes towards urban insects. This variation has been related to a wide range of factors, which may make it difficult to predict or quantify the tolerance levels for household insects. These factors include differences in gender, education, size or location of the house, whether the house is owned or rented, experience with certain pests and present pest infestations, perceptions regarding insecticide usage, negative feelings, and risk perception (Wood et al., 1981; Byrne et al., 1984; Grace & Cutten, 1990; Baldwin et al., 2008; Schoelitz et al., 2018).

The reasons for performing control measures include visible or potential damage by insects, knowing that insects are a health hazard and may pose a danger to the family, and seeing dead or live insects in or around the home (Baldwin et al., 2008). Low tolerance for insects may even result in the application of insecticides, without reported sightings of pests (Whyatt et al., 2002), and it is known that sometimes families preventively apply insecticides as a pre-vacation annual ritual.

If the threshold level for household insects is exceeded, or tends to become exceeded, pest management decisions are affected by costs. The initial costs of IPM may be higher than pest management that relies solely on insecticides, and although IPM is more effective (Miller & Meek, 2004) its higher costs may prevent the implementation of IPM and non-chemical programmes (Bennett et al., 2016; Romero et al., 2017).

**Pest control**

Pest control should not only focus on the eradication of the pests present in the household, but on the underlying causes as well. By pro-actively removing the factors that enable the introduction, establishment, and development of a population, pest development and its associated nuisance can be prevented. If a pest population is present, curative control measures may be necessary to quickly reduce the population size to acceptable levels.

Persons that make decisions on pest control need to be aware of the various options, including measures that prevent the introduction of insects and development of populations (Dingha et al., 2013). However, this knowledge is often absent in the general public (Wang & Bennett, 2009).

**Habitat management and prevention of introduction**

Many pest species are capable of colonizing and quickly developing a population that is considered a nuisance if suitable habitat characteristics are present (Begon et al., 1996). Specific, local conditions within a house determine the potential for the development of insect populations that exceed threshold levels. Pet animals may allow the development of ectoparasites such as the cat flea, *Ctenocephalides felis* (Bouché) (Robinson, 1995b), stored food is readily fed upon by larvae of multiple species of beetles and moths, whereas woollen materials, hides, and skins are fed upon by insects capable of digesting keratin, such as dermestid beetles (Rajendra & Hajira Parveen, 2005). The development of multiple species of filth flies (Haines, 1953), cockroaches, and stored food pests is associated with the level of food hygiene, as well as cracks and crevices where insects can hide and oviposit. Heating and ventilation policies determine habitat characteristics by affecting temperature and humidity. The development of central
heating in buildings, for instance, resulted in year-round problems of bed bugs in the early 1900’s (Zhu et al., 2016). The improved energy labels and constant room temperature of modern houses, result in household environments that select for insects preferring warm and dry conditions (Martin et al., 2015), such as the grey silverfish (Schoelitz et al., in review).

In general, the design of the construction affects the short-range, active migration of insects from outside or neighbouring properties into the home. Leong et al. (2017) showed that indoor arthropod diversity is strongly influenced by access to outdoors and increased with increasing number of doors and windows. Many of the insects found indoors are trapped and are not capable of surviving (Bertone et al., 2016). Other species, such as the American cockroach, enter houses from yards and are capable of colonizing homes (Carlson et al., 2017), or use the house as an overwintering site such as the yellow swarming fly, *Thaumatomyia notata* (Meigen) (Parkin, 1958), Asian ladybird beetle, *Harmonia axyridis* (Pallas) (Nalepa, 2007), and lacewings of the species *Chrysoperla affinis* (Stephens) (Thierry et al., 1994). Openings, cracks, and crevices do not only allow outdoor to indoor movement, but from one house to the other as well. Owens & Bennett (1982), for instance, showed a dispersal of up to 30% of adult German cockroaches per week between apartments through wall voids and along plumbing and untreated premises with bed bugs are the cause of re-infestation for others in multifamily housing (Bennett et al., 2016). Closing gaps, cracks, and crevices prevent active introduction of arthropods into the indoor environment, although treatment of surrounding reservoir populations may be needed as well (Bennett et al., 2016). Screening of windows and doors prevents flying insects from entering houses through open doors and windows (Busvine, 1965; Tusting et al., 2015). To aid in the categorization and prioritization of constructional flaws that may lead to the introduction of a pest species, the Scientific Coalition of Pest Exclusion (SCOPE) developed a pest exclusion worksheet for multifamily housing, that may be useful for smaller properties as well (www.northeastipm.org, visited on 4 March 2018).

The introduction and development of pest populations can be prevented if the habitat is rendered unsuitable for the specific species (Lindsay et al., 2017). By removing or altering the factors that drive the presence of insects in the household environment, insects are controlled from the bottom-up, that is, a pest population will not develop. The wood-infesting deathwatch beetle, *Xestobium rufovillosum* (De Geer), for instance, has become far less common inside houses, since the predominant use of brick instead of wood for house construction – wood is a food source for the larvae (Buckland, 1974). Because of the bottom-up control, habitat management can be applied as a preventative measure and should be implemented in any situation to achieve sustainable pest management. However, this requires identification and understanding of the factors that affect the presence of the encountered pest insect.

The measures that are being taken to alter the habitat are often of sanitary, mechanical or cultural nature. For cockroach management, Kass et al. (2009) managed the habitat by cleaning kitchens and bathrooms mechanically and with steam and soap, sealing cracks and crevices in base boards, plumbing joints, within kitchen cabinets, and between kitchen cabinets and the wall, as well as storing food in sealed containers, covering garbage containers, and frequently disposing of garbage to prevent cockroaches from finding food, sheltering, and oviposition sites. The remaining cockroaches were killed with boric acid and cockroach baits.

These measures are still reactive, however. As the quality of housing is a predictor of the number of insect sightings, which increases with poorer quality (Whyatt et al., 2002), a pro-active prevention of pest introduction and development starts with considering pest management during the development of the building plans. Clever design of the constructions aids in the prevention of future pests, as is also done in the food industry (Fields & White, 2011). With recent building developments and the tendency to use organic building materials other than wood, taking pest management into account during the architectural phase counts for high-quality housing as well. The use of construction felt with animal hair, green roofs, and sheep wool as a sustainable source of insulation material has already led to development of pest populations of the case-bearing clothes moth, *Tinea pellionella* L., the brown ant, *Lasius brunneus* (Latreille), and the larder beetle *Dermestes* sp., respectively.

Finally, behavioural factors such as travelling and consumption drive the passive introduction of both exotic and native species such as bed bugs with luggage, furniture, and clothing (Reinhardt & Siva-Jothy, 2007), German cockroaches (*B. germanica*) with second-hand furniture, and tropical ants with plants or even in a football shoe from Brazil (Boer & Vierbergen, 2008). The increased popularity of the concept in which citizens facilitate overnight stays of (international) travellers in their houses, poses a risk of pest infestation for both the homeowner and the guest, as it is unlikely that the public is aware of the existence of common pests and best practices in the hospitality industries.

The implementation of habitat management may be hindered by the idea of investing money and energy in interventions that, in contrast to insecticides, do not show direct results. This does not only apply to pro-active
concentrations of active ingredients (0.5 – 1%), are available for the general public as sprays, dusts, gels, liquids, crystals, baits, and foggers (Maroni et al., 2008). PMPs may have access to more potent active ingredients or concentrations than the general public.

Insecticides are widely used in western households (Bennett et al., 1983; Ralph & Kelvin, 2013) and their usage is dependent on a person’s perception, attitudes, and knowledge regarding these products. Respondents who denied risks of pesticide usage applied them more frequently and with fewer self-protective behaviour (Griethop & Stiles, 1989). Steer & Grey (2006) showed that the main users of pesticides seemed to be older, Caucasian, better educated, had higher incomes, and were more likely to own a private home than less frequent users. Socio-demographic and economic factors, however, do not always seem to explain differences in pesticide usage (Adgate et al., 2000).

Important sources of information about pests and pesticides were found to be friends and neighbours. These were consulted more frequently than, for example, shop assistants, books, magazines, newspapers and television, city buildings departments, and the Ministry of Environment (Grace & Cutten, 1990; Grey et al., 2005), although this may have changed in more recent times due to the appearance of the internet (Mankin, 2005). Participants were not interested in attending a presentation about termites and pest control companies were rarely named as source of information in a study of the attitudes towards termite control (Grace & Cutten, 1990).

Do-it-yourself insecticide application in households is more common than treatments performed by professionals. Bennett et al. (1983) showed that only 27% of the respondents had their premise treated by a professional, whereas 78% used pesticides in a single year. In New York City, over half of the respondents had their premise treated with chemical insecticides in a period of 3 months. Nearly 40% of the homes were treated with insecticides by residents, approximately 28% and 16% were treated by a professional or a combination of a professional and resident, respectively (Ralph & Kelvin, 2013). A vast majority (89%) of residents with bed bugs first applied insecticides themselves within their homes to control these pests (Wang et al., 2014b).

Most pesticides for indoor use are obtained from do-it-yourself shops and supermarkets. When deciding on what product to purchase and use, a safe product image is an important determinant; many consumers acquire pesticides without consulting an information source, because it is thought the right knowledge is already possessed, pesticides are often used based on past experience, or because consumers are influenced by advertisement and observation of what is available (Bennett et al., 1983; Grey et al., 2005). The product label, however, is an important information source for consumers who gather information before using the product, but the label is often not completely understood or is found to be incomplete by the user (Grey et al., 2005).

This may lead to improper use of insecticides, and may not only result in the inability of controlling insect populations, for instance through excessively spraying winged individuals of the black garden ant, Lasius niger (L.), but in an elevated exposure to the active ingredients of (banned) products as well. The application of a concentrated formulation by residents, that should be diluted by label directions, results in an increased exposure to the active ingredient (Julien et al., 2008). The Centers for Disease Control and Prevention (CDC) (2011) reports 111 cases of illnesses associated with bed bug control in 2010 in the USA. Pyrethroids and pyrethrins were used in the majority of cases and most illnesses occurred within private homes, because of excessive insecticide application, failure to wash or change pesticide-treated bedding, and insufficient information of pesticide application methods. This resulted in at least one fatality (CDC, 2011). Furthermore, banned and restricted products were found in the home inventory, that were recently used by residents (Adgate et al., 2000). Especially when insects have become resistant to insecticides available for the public, this may result in extensive use of insecticides and/or neglect of label directions (CDC, 2011).
Non-chemical control

Because of the negative effects of insecticides on health and the environment, and the development of insecticide resistance, the use of non-chemical control measures is an important component of IPM. Insects can be removed from the population by capturing them (mass trapping). Trapping cockroaches with pheromone-based sticky traps and a vacuum cleaner was as effective in reducing the population size as a traditional control programme based on insecticides (Kaakeh & Bennett, 1997). By using a vacuum cleaner to remove debris and cockroaches at the start of an IPM programme, cockroach populations were effectively disrupted (Miller & Meek, 2004).

With the recent resurgence of bed bugs (Potter, 2011; Davies et al., 2012), the use of temperature treatments increased in interest because of the difficulty to eradicate them solely with insecticides. Heating is effectively applied locally through steam and high levels of mortalities of all stages of bed bugs can be achieved (Puckett et al., 2013). By washing laundry at 60 °C and dry cleaning it afterwards, all stages of bed bugs are exterminated (Naylor & Boase, 2010). Whole-room treatments can achieve complete eradication within rooms including their contents, if temperature and time of exposure are sufficient (Kells & Goblirsch, 2011). Low-temperature treatments are effective as well, as bed bugs are killed when exposed to –17 °C for 1–2 h (Benoit et al., 2009; Naylor & Boase, 2010). Except for washing, drying laundry in a heater, and freezing, these methods should be performed by professionals to prevent damage to materials and the building.

Because of their low toxicity to mammals, essential oils and diatomaceous earth dust are interesting materials for application within the household environment. Both essential oils and diatomaceous earth dust show potential in effectively reducing household insect populations, including German cockroaches, bed bugs, and silverfish (Faulde et al., 2006; Wang et al., 2009, 2014b; Phillips & Appel, 2010; Politi et al., 2017) and are readily available for the general public.

The efficacy of insecticides can be enhanced if pests are lured towards the insecticide, as has been shown with the Argentine ant, *Linepithema humile* (Mayr). The amount of insecticide that is used to control ant populations can be effectively reduced by attracting the ants with a trail pheromone component to the location where insecticides are applied (Choe et al., 2014). This method may be effective for other ant species as well, if general or species-specific trail pheromone components are identified and commercially available.

Biological control is not as common within the household environment as within agriculture, because the biological killing agent may be considered a nuisance as well. Therefore, the acceptance of the biological control agent by the target audience is of importance if biological control is to be successfully implemented in the household environment. The evaniid parasites of cockroaches were considered a greater nuisance than the oriental cockroaches in the basement, for instance (Edmunds, 1953), although variation in tolerance for these wasps exists between groups of people (Thoms & Robinson, 1986). This may be especially true for the use of insect pathogens, but studies about public perception and attitudes regarding these biological agents were not found. The use of entomopathogenic nematodes, fungi, and bacteria for the control of indoor insects has received relatively little attention (Lacey et al., 2015).

If accepted by the public, they may prove to be effective tools within IPM programmes for certain species, as experimental studies show promising results. The application of entomopathogenic nematodes through bait stations, for instance, showed an efficacy comparable to chemical bait stations for cockroach control (Manweiler et al., 1993). Additionally, entomopathogenic fungi have shown potential for the control of bed bugs, cockroaches, and termites. The conidia are suspended in oil and can be sprayed or fumigated. One of the great advantages is that the fungi are transmitted horizontally from live and dead individuals in aggregation sites and if insects show grooming behaviour. Before fungi can be widely used in buildings, however, more studies are needed to discover more potent strains, determine virulence, dose–response effects, and rate of horizontal transmission, as well as avoidance, recognition, and fungal survival in the household environment (Rath, 2000; Barbarin et al., 2012; Hubner-Campos et al., 2013), as well as health aspects of humans and pets.

Whether non-chemical methods are used depends on the attitudes towards both these methods and chemical methods, as well as tolerance for the pest species. In a study by Verbrugge et al. (2013), it was shown that people were more willing to accept pesticide control of invasive species if they thought this species should be eradicated, such as the Asian tiger mosquito, *Aedes albopictus* (Skuse), suggesting that if people feel that a certain household pest should be eradicated, they tend to choose for insecticides.

**Novel methods: RNAi and nanotechnology**

Young (2017) stresses the need for studying new IPM tools and approaches for household IPM. The development of insecticides based on nucleic acids is gaining interest. One of the techniques that receive increased attention for pest control is RNA interference (RNAi). With this technique, specific genes within the target organism are silenced,
which may result in disruption of developmental processes and mortality. By feeding double-stranded RNA (dsRNA) molecules to the target insect, an antiviral defence mechanism is activated that cuts the dsRNA in small interference RNAs, that bind to their supplementary messenger RNA, which is cleaved. This results in a reduced expression of the target gene (Rodrigues et al., 2017). By injecting dsRNA into bed bugs, oogenesis of bed bugs was significantly reduced after a 2-week period, effectively inhibiting bed bug reproduction (Moriyama et al., 2016). However, injecting dsRNA into insects is not a viable method in practical situations. Exposure to environmental RNAi through ingestion may provide a more practical solution (Darrington et al., 2017). The efficacy of RNAi is affected by various factors, including the target gene, life stage of target organism, and dsRNA length and concentration (Rodrigues et al., 2017). Furthermore, dsRNA is degraded in midgut juices and methods have to be developed to protect it from degradation. Lin et al. (2017) protected the dsRNA by encapsulation in liposomes, which significantly increased the mortality when fed to cockroaches for 16 days. RNAi shows promise as a pest control method, because of its specificity. In vivo synthesis of dsRNA by bacteria that are fed to target insects may be of special interest because of its cost effectiveness as compared to in vitro synthesis (Whyard et al., 2015). Because of the specificity of this technique, identification of the pest species is extremely relevant, and it is unlikely that RNAi will be applied for all household insect species.

Finally, the use of insecticidal or carrier nanoparticles may become an important component for pest management. Nanoparticles have dimensions of 1–100 nanometer and possess characteristics that are not present within larger particles of the same chemical structure. Advantages of nanoparticles as insecticides include increased solubility, stability, mobility, and insecticidal activity. Plant-synthesized nanoparticles were effective in controlling urban pests, such as mosquitoes and the house fly, Musca domestica L. (Athanassiou et al., 2018). The combination of nanotechnology and RNAi may be of special interest, as the advantages of both developments can be combined. Negatively loaded nanoparticles carry the positively loaded is-RNAs to target sites with enhanced solubility, stability, and affinity to targets (Bapat, 2013) for very specific control of pest insects.

Although these techniques have been studied in more detail in other fields of pest management, it is not known when they will be available for application in practice. More studies are needed to assess the efficacy in the field and application on a larger scale, before registration of these products can be considered. If an individual’s perception and knowledge allows for the use of these methods, they must be able to compete in efficacy and costs to be considered a relevant alternative for chemical insecticides.

**Evaluation of effectiveness**

The process of IPM needs to be evaluated to assess whether the management strategy is implemented as designed and whether the objectives are being met. To evaluate whether the objectives are met, monitoring surveys are conducted to determine whether the pest population has been reduced to a level below the threshold level (Sarisky et al., 2008). This requires knowledge on both pest species biology and monitoring methodology. As a large part of the public is unable to identify the pest species correctly (Bennett et al., 1983; Seidel & Reinhardt, 2013), and therefore lacks the knowledge to apply the appropriate monitoring method, the assessment of the objectives is reactive as it is likely based on whether the pest species is re-encountered. Depending on the species, it may take a considerable amount of time before insects re-emerge following local eradication, especially with holometabolic insects. The eggs, larvae, and pupae of beetles, moths, and flies develop in or near their food source, whereas the mobile adults are found crawling or flying in the living space of residents (Robinson, 2005). Pest control aimed at eradicating and monitoring the visible adults provides a false indication of its results.

To assess whether the applied pest control measures are efficient, the options for the specific pest need to be known by the person making the pest control decisions. This is often not the case and the sources from which the information is valued the most are commercial, such as PMPs and salespersons of insecticides (Schoelitsz et al., 2018), which are biased towards the options they provide, or lack expertise, such as friends and family (Grace & Cutten, 1990).

It is likely that if the insect presence remains above the threshold level, or the insect pest re-emerges within a short time period, people tend to seek help with identification and pest control more often. Depending on the professionals that are consulted and the costs (Miller & Meek, 2004), IPM may be implemented more effectively.

**Conclusions**

Integrated pest management is a sustainable approach of pest management that does not only consider reactive top-down control, but also focuses on pro-active bottom-up population management to prevent a population to exceed a threshold level and considers different pest control
methods. With professional support, IPM can be successfully implemented in the household environment. The general public’s perception, attitude, and knowledge, however, make IPM difficult to implement because in general pest management in the household environment is generally reactive, instead of pro-active. The public does not possess the knowledge base of household insect biology and life history, identification skills, and awareness of multiple methods of monitoring and control that is needed for sustainable pest management. Furthermore, the information sources that are valued the most, that is, PMPs, salespersons of insecticides, family, and friends, are biased towards the pest management methods they supply or lack expertise. Pest management decisions are based on subjective feelings and initial costs instead of rationale and attitudes may prevent the implementation of various methods of pest management, such as biological control. Furthermore, chemical insecticides fulfil the urge to eradicate household insects, whereas effects of preventive measures through habitat modification are less visible. Therefore, efforts should be strengthened to alter the perception and attitude, and increase the knowledge of the non-professional stakeholders, so that correct pest management decisions can be taken.

Acknowledgements

The authors thank Françoise Kaminker, Mike Brooks, and Cindy ten Broeke for their feedback on the draft version of this article. Moreover, we thank the anonymous referees for their comments to improve this manuscript.

References

Adgate JL, Kukowski A, Stroebel C, Shubat PJ, Morrell S et al. (2000) Pesticide storage and use patterns in Minnesota households with children. Journal of Exposure Analysis and Environmental Epidemiology 10: 159–167.

Ashbrook AR, Scharf ME, Bennett GW & Gondhalekar AD (2017) Detection of reduced susceptibility to chlorfenapyr and bifenthrin-containing products in field populations of the bed bug (Hemiptera: Cimicidae). Journal of Economic Entomology 110: 1195–1202.

Ashfaq M, Hebert PDN & Naum A (2016) DNA barcodes for bio-surveillance: regulated and economically important arthropod plant pests. Genome 59: 933–945.

Atakan E & Canhilal R (2004) Evaluation of yellow sticky traps at various heights for monitoring cotton insect pests. Journal of Agricultural and Urban Entomology 21: 15–24.

Athanassiou CG, Kavalleratos NG, Benelli G, Losic D, Usha Rani P & Desneux N (2018) Nanoparticles for pest control: current status and future perspectives. Journal of Pest Science 91: 1–15.

Baldwin RW, Koehler PG, Pereira RM & Oi FM (2008) Public perceptions of pest problems. American Entomologist 54: 73–79.

Bapat VA (2013) Recent advances in ribonucleic acid interference (RNAi). National Academy Science Letters 36: 1–8.

Barbarin AM, Jenkins NE, Rajotte EG & Thomas MB (2012) A preliminary evaluation of the potential of Beauveria bassiana for bed bug control. Journal of Invertebrate Pathology 111: 82–85.

Begon M, Harper JL & Townsend CR (1996) Ecology. Individuals, Populations and Communities. Blackwell Scientific Publishers, Oxford, UK.

Bennett GW, Runstom ES & Wieland JA (1983) Pesticide use in homes. Bulletin of the Entomological Society of America 29: 31–40.

Bennett GW, Gondhalekar AD, Wang C, Buczkowski G & Gibb TJ (2016) Using research and education to implement practical bed bug control programs in multifamily housing. Pest Management Science 72: 8–14.

Benoit JB, Lopez-Martinez G, Teets NM, Phillips SA & Denlinger DL (2009) Responses of the bed bug, Cimex lectularius, to temperature extremes and dehydration: levels of tolerance, rapid cold hardening and expression of heat shock proteins. Medical and Veterinary Entomology 23: 418–425.

Bertone MA, Leong M, Bayless KM, Malow TLF, Dunn RR & Trautwein MD (2016) Arthropods of the great indoors: characterizing diversity inside urban and suburban homes. PeerJ 4: e1582.

Bianchi FFJ, Mikos V, Brussaard L, Delbaere B & Pulleman MM (2013) Opportunities and limitations for functional agrobiodiversity in the European context. Environmental Science and Policy 27: 223–231.

Bjerke T, Ostdahl T & Kleiven J (2003) Attitudes and activities related to urban wildlife: pet owners and non-owners. Anthropoës 16: 252–262.

Boer P & Vierbergen B (2008) Exotic ants in The Netherlands (Hymenoptera: Formicidae). Entomologische Berichten 68: 121–129.

Brenner BL, Markowitz S, Rivera M, Romero H, Weeks M et al. (2003) Integrated pest management in an urban community: a successful partnership for prevention. Environmental Health Perspectives 111: 1649–1653.

Buckland PC (1974) Archaeology and environment in York. Journal of Archaeological Science 1: 303–316.

Buijs J (2009) Arthropods that annoy Amsterdam people. Proceedings of the Netherlands Entomological Society Meeting 20: 31–44.

Busvine JR (1965) Wire mesh screening for the exclusion of houseflies. Journal of Hygiene 63: 305–309.

Byrne DN, Carpenter EH, Thoms EM & Cotty ST (1984) Public attitudes toward urban arthropods. Bulletin of the Entomological Society of America 30: 40–44.

Carlson JC, Rabito FA, Werthmann D & Fox M (2017) The distribution and movement of american cockroaches in urban niches of New Orleans. Clinical Pediatrics 56: 1008–1012.
Carson R (1962) Silent Spring. Houghton Mifflin Company, Boston, MA, USA.

CDC (2011) Acute illnesses associated with insecticides used to control bed bugs - seven states, 2003-2010. Morbidity and Mortality Weekly Report 60: 1269–1274.

Choe AD, Tsai K, Lopez CM, Campbell K & Choe DH (2014) Pheromone-assisted techniques to improve the efficacy of insecticide sprays against *Linepithema humile* (Hymenoptera: Formicidae). Journal of Economic Entomology 107: 319–325.

Cooper R, Wang C & Singh N (2014) Accuracy of trained canines for detecting bed bugs (Hemiptera: Cimicidae). Journal of Economic Entomology 107: 2171–2181.

Darrington M, Dalmay T, Morrison NI & Chapman T (2017) Implementing the sterile insect technique with RNA interference – a review. Entomologia Experimentalis et Applicata 164: 155–175.

Davies TGE, Field LM & Williamson MS (2012) The re-emergence of the bed bug as a nuisance pest: implications of resistance to the pyrethroid insecticides. Medical and Veterinary Entomology 26: 241–254.

Dingha B, Jackai L, Monteverdi RH, Ibrahim J & Carolina N (2013) Pest control practices for the German cockroach (*Blatella*; *Blattellidae*): a survey of rural residents in North Carolina. Florida Entomologist 96: 1009–1015.

Donabedian H (2007) Delusions of parasitosis. Clinical Infectious Diseases 45: e131–e134.

Driscoll JW (1995) Attitudes toward animals: species ratings. Society and Animals 3: 139–150.

Edmunds LR (1953) Some notes on the Evanidae as household pests and as a factor in the control of roaches. Ohio Journal of Science 53: 121–122.

Evangelista D, Buss L & Ware JL (2013) Using DNA barcodes to confirm the presence of a new invasive cockroach pest in New York City. Journal of Economic Entomology 106: 2275–2279.

Facchinelli L, Valerio L, Pombi M, Reiter P, Costantini C & Della Torre A (2007) Development of a novel sticky trap for container-breeding mosquitoes and evaluation of its sampling properties to monitor urban populations of *Aedes albopictus*. Medical and Veterinary Entomology 21: 183–195.

Faulle MK, Tisch M & Scharninghausen JJ (2006) Efficacy of modified diatomaceous earth on different cockroach species (*Orthoptera, Blattelidae*) and silverfish (*Thysanura, Lepismatidae*). Journal of Pest Science 79: 155.

Fields PG & White NDG (2011) Alternatives to methyl bromide treatments for stored-product and quarantine insects. Annual Review of Entomology 47: 331–359.

Frankie GW & Ehler LE (1978) Ecology of insects in urban environments. Annual Review of Entomology 23: 367–387.

Goddard J & De Shazo R (2012) Psychological effects of bed bug attacks (*Cimex lectularius*) L. American Journal of Medicine 125: 101–103.

Golding Y, Ennos R, Sullivan M & Edmunds M (2005) Hoverfly mimicry deceives humans, Journal of Zoology 266: 395–399.

Grace JK & Cutten GM (1990) Public perceptions of termite control practices in several Ontario (Canada) municipalities. Journal of Environmental Management 30: 131–138.

Grey CNB, Nieuwenhuijsen MJ & Golding J (2005) The use and disposal of household pesticides. Environmental Research 97: 109–115.

Grieshop JI & Stiles MC (1989) Risk and home-pesticide users. Environment and Behavior 21: 699–716.

Haines TW (1953) Breeding media of common flies. I. In urban areas. American Journal of Tropical Medicine and Hygiene 2: 933–940.

Heath ACG, Morris JWM & Harris AC (2004) A cluster fly, *Pol lenia pseudorugos* Rognes, 1895 (Diptera: Calliphoridae): its history and pest status in New Zealand. New Zealand Journal of Zoology 31: 313–318.

Hubner-Campos RF, Leles RN, Rodrigues J & Luz C (2013) Efficacy of entomopathogenic hypocrealean fungi against *Peri planeta americana*. Parasitology International 62: 517–521.

Julien R, Adamkiewicz G, Levy JL, Bennett D, Nishioka M & Spengler JD (2008) Pesticide loadings of select organophosphate and pyrethroid pesticides in urban public housing. Journal of Exposure Science & Environmental Epidemiology 18: 167–174.

Kaacke W & Bennett GW (1997) Evaluation of trapping and vacuuming compared with low-impact insecticide tactics for managing German cockroaches in residences. Journal of Economic Entomology 90: 976–982.

Kass D, McKelvey W, Carlton E, Hernandez M, Chew G et al. (2009) Effectiveness of an integrated pest management intervention in controlling cockroaches, mice, and allergens in New York City public housing. Environmental Health Perspectives 117: 1219–1225.

Kellert SR (1993) Values and perceptions of invertebrates. Conservation Biology 7: 845–855.

Kells SA & Goblirsch MJ (2011) Temperature and time requirements for controlling bed bugs (*Cimex lectularius*) under commercial heat treatment conditions. Insects 2: 412–422.

Ko AE, Bieman DN, Schal C & Silverman J (2016) Insecticide resistance and diminished secondary kill performance of bait formulations against German cockroaches (*Dictyoptera: Blattelidae*). Pest Management Science 72: 1778–1784.

Kogan M (1988) Integrated pest management theory and practice. Entomologia Experimentalis et Applicata 70: 59–70.

Lacey LA, Grzywacz D, Shapiro-lilan DI, Frutos R, Brownbridge M & Goettel MS (2015) Insect pathogens as biological control agents: back to the future. Journal of Invertebrate Pathology 132: 1–41.

Leong M, Bertone MA, Savage AM, Bayless KM, Robert R & Trautwein MD (2017) The habitats humans provide: factors affecting the diversity and composition of arthropods in houses. Scientific Reports 7: 15347.

Lin YH, Huang JH, Liu Y, Belles X & Lee HJ (2017) Oral delivery of dsRNA lipoplexes to German cockroach protects dsRNA from degradation and induces RNAi response. Pest Management Science 73: 960–966.

Lindsay SW, Wilson A, Golding N, Scott W & Takken W (2017) Improving the built environment in urban areas to control *Aedes aegypti*-borne diseases. Bulletin of the World Health Organization 95: 607–608.
Health Organization Regional Office for Europe, Copenhagen, Denmark.

Schneider J, Valentini A, Dejean T, Montarsi F, Taberlet P et al. (2016) Detection of invasive mosquito vectors using environmental DNA (eDNA) from water samples. PLoS ONE 11: 1–18.

Schoelitz B, Poortvliet PM & Takken W (2018) Factors driving public tolerance levels and information-seeking behaviour concerning insects in the household environment. Pest Management Science 74: 1478–1493.

Seidel C & Reinhardt K (2013) Bugging forecast: unknown, disliked, occasionally intimate. Bed bugs in Germany meet unprepared people. PLoS ONE 8: 4–9.

Steer CD & Grey CNB (2006) Socio-demographic characteristics of UK families using pesticides and weed-killers. Journal of Exposure Science & Environmental Epidemiology 16: 251–263.

Suckling DM, Stringer LD, Stephens AEA, Woods B, Williams DG et al. (2013) From integrated pest management to integrated pest eradication: technologies and future needs. Pest Management Science 70: 179–189.

Thierry D, Cloupeau R & Jarry M (1994) Variation in the overwintering ecophysiological traits in the common green lacewing West-Palaecrtic complex. Acta oecologica 15: 593–606.

Thomas MB, Godfray HCJ, Read AF, van den Berg H, Tabashnik BE et al. (2012) Lessons from agriculture for the sustainable management of malaria vectors. PLoS Medicine 9: 7–10.

Thoms EM & Robinson WH (1986) Distribution, seasonal abundance, and pest status of the oriental cockroach (Orthoptera: Blattidae) and an evaniid wasp (Hymenoptera: Evaniidae) in urban apartments. Journal of Economic Entomology 79: 431–436.

Tusting LS, Ippolito MM, Willey BA, Kleinschmidt I, Dorsey G et al. (2015) The evidence for improving housing to reduce malaria: a systematic review and meta-analysis. Malaria Journal 14: 209.

Van Den Bosch R & Stern VM (1962) The integration of chemical and biological control of arthropod pests. Annual Review of Entomology 7: 367–386.

Verbrugge LNH, van den Born RJG & Lenders HJR (2013) Exploring public perception of non-native species from a visions of nature perspective. Environmental Management 52: 1562–1573.

Vulink NC (2016) Delusional infestation: state of the art. Acta Dermato-Venerologica 96: 58–63.

Wang C & Bennett G (2006) Comparative study of Integrated Pest Management and baiting for German cockroach management in public housing. Entomological Society of America 99: 879–885.

Wang C & Bennett GW (2009) Cost and effectiveness of community-wide integrated pest management for German cockroach, cockroach allergen, and insecticide use reduction in low-income housing. Journal of Economic Entomology 102: 1614–1623.

Wang C, Gibb T & Bennett GW (2009) Evaluation of two least toxic integrated pest management programs for managing bed bugs (Heteroptera: Cimicidae) with discussion of a bed bug intercepting device. Journal of Medical Entomology 46: 566–571.

Wang C, Saltzmann K, Grondhaldekar A, Gibb T & Bennett G (2014a) Building-wide bed bug management. Pest Control Technologies 42: 70–74.

Wang C, Singh N & Cooper R (2014b) Efficacy of an essential oil-based pesticide for controlling bed bug (Cimex lectularius) infestations in apartment buildings. Insects 5: 849–859.

Whyard S, Erdelyan CNG, Partridge AL, Singh AD, Beebe NW & Capina R (2015) Silencing the buzz: a new approach to population suppression of mosquitoes by feeding larvae double-stranded RNAs. Parasites and Vectors 8: 1–11.

Whyatt RM, Camann DE, Kinney PL, Reyes A, Ramirez J et al. (2002) Residential pesticide use during pregnancy among a cohort of urban minority women. Environmental Health Perspectives 110: 507–514.

Wilkinson TJJ, Philip G, Bradbury J, Dunford R, Donoghue D et al. (2014) Contextualizing early urbanization: settlement cores, early states and agro-pastoral strategies in the fertile crescent during the fourth and third millennia BC. Journal of World Prehistory 27: 43–109.

Wood FE, Robinson WH, Kraft SK & Zungoli PA (1981) Survey of attitudes and knowledge of public housing residents towards cockroaches. Bulletin of the Entomological Society of America 27: 9–13.

Young SL (2017) A systematic review of the literature reveals trends and gaps in integrated pest management studies conducted in the United States. Pest Management Science 73: 1553–1558.

Yssouf A, Parola P, Lindström A, Lilja T, L’Ambert G et al. (2014) Identification of European mosquito species by MALDI-TOF MS. Parasitology Research 113: 2375–2378.

Zhu F, Lavine L, O’Neal S, Lavine M, Foss C & Walsh D (2016) Detection of invasive mosquito vectors using environmental DNA (eDNA) from water samples. PLoS ONE 11: 1–18.