1 An Environmental Perspective on Urban Pests and Their Management

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Abstract
It is clear from current experiences that future challenges to managing pests will be determined more by the changing environment than any other factor. Concerns over the environment are at their highest and climate change, among other problems, has taken center stage. Evidence gathered highlights that the climate will have a significant effect on many factors in pest management, including invasion by non-native species, pest life history and behavior, pest redistribution, efficacy of pesticides, application techniques, exposure to pesticides, and pest control operations of practitioners involving their business and health.

Introduction

Concern regarding the environment is at its highest and climate change, among other things, has taken center stage. On the one hand, climate change has brought alterations in the bio-ecology of pests, and on the other it has put all human activities under close scrutiny, thus challenging the business of pest management as never before.

In addition to the shifting climate, use of pesticides – the principal means practiced for pest eradication and management – has not diminished over the years. Reports of exposure of humans to indoor pesticides are constant. According to a recent US Environment Protection Agency (US EPA) survey, 75% of US households used at least one pesticide product indoors during the past year. The most frequently used products are insecticides and disinfectants. Another study suggests that 80% of people's exposure to pesticides occurs indoors and measurable levels of up to a dozen pesticides have been found in the air inside homes. The same survey revealed that the amount of pesticides found in homes appears to be greater than can be explained by recent pesticide use in those households, thus indicating the presence of pesticides in the near environment (US EPA, 2022).

This chapter discusses some critical areas where the changing environment will affect urban pests and their management.

Changing Environment and Invasion From Non-native Species

The impact of climate change on urban pests has been reviewed by Dhang (2016). Climate change can modify pest life history parameters, resulting in increased diversity and density of pests, consequently posing significant risk to humans. A number of reports have also

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discussed the effects of climate change on public health pests (WHO, 1997; Epstein, 2004; Mills, 2005; CIEH, 2008; US EPA, 2010). One aspect where climate change is most anticipated to have an impact is with regard to invasion by non-native species into areas where they were not previously recorded, or were rarely recorded. Such invasions are significant because regular checks are nonexistent, meaning that invading species have the opportunity to establish and cause harm quickly. However, there is considerable disagreement over which species these will be and the effects that each of them is likely to have (Comont, 2016).

It is thought that only a small subset of the non-native species introduced to a new area actually become established, and a yet smaller subset of these will go on to become invasive (Lodge, 1993). This is often referred to as the 'tens rule', whereby one species establishes from every ten introduced, and of every ten established species, one will become invasive, although the exact proportions are often variable (Vander Zanden, 2005). Climate suitability is one of the many factors influencing such invasions and the establishment and spread of non-native invertebrates (Smith *et al.*, 2007). Consequently, very few non-native species are likely to arrive and arise as pests solely because of climate change (Comont, 2016). Therefore, the role of other factors, which include rapid urbanization, increased trade and travel, and socio-economic status of the region, become important in this phenomenon.

A UK report lists 282 non-native species as currently invasive in Great Britain, and these are estimated to have a direct cost of £1.7 billion per year. As this cost is largely related to control measures, an increase in pest species could lead to a considerable rise in the financial burden in the country (Comont, 2016). The same problem may arise elsewhere in the world.

Changing Environment and Pest Distribution

There is little disagreement that as species continue to move northwards with the warming of the climate, more species are likely to arrive and establish in temperate areas (Comont, 2016). Pests which could benefit and expand their distribution the most include mosquitoes, termites, rodents, and flies (Epstein, 2001), among others.

Evidence of climate change and its impact is now visible in many parts of the world, as confirmed in reports of insect vectors and vector-borne diseases in previously unrecorded elevations in eastern and central Africa, Latin America, and Asia. The rising incidence of malaria in highland urban centers such as Nairobi, rural highland areas, and Papua New Guinea (Reiter, 2008) is notable. *Aedes aegypti*, once limited by temperature to approximately 1000 meters in elevation, has recently been found at 1700 meters in Mexico and 2200 meters in the Colombian Andes (Epstein and Mills, 2005). A recent study in Ecuador found that *Ae. aegypti* will expand its range into higher elevations of the Andean foothills. This is estimated to affect 4215 km^2 of new territory and 12,000 people under the most extreme scenario of climate change by 2050 (Lippi *et al.*, 2019).

Reports of tropical species, such as *Coptotermes gestroi*, becoming established in the subtropics (Grace, 2006) and subtropical species, such as *Coptotermes formosanus*, expanding their range northwards into more temperate areas (Jenkins *et al.*, 2002) substantiate the role of climate change and urbanization in pest invasion by termites.

A recent study by Buczkowski and Bertelsmeier (2017) on invasive termites revealed that areas that lose many species (e.g. in parts of South America) are those that were previously species-rich. Regions such as Europe, which were not among the invasion hotspots, are now showing increases in invasive species. The researchers further concluded that the substantial economic and ecological damage caused by invasive termites is likely to increase in response to climate change, increased urbanization, and accelerating economic globalization, acting singly or interactively.

Changing Environment and Pest Behavior

Climate change can also initiate a number of behavioral changes in pest species. This is evident in mosquitoes, which have started exhibiting the capacity to breed in new habitats, including slurry pits, rainwater pools, and used car tires (CIEH, 2008), which could influence distribution patterns in a localized area. Behavioral changes and adaptation to changing environments could, triggered by climate change, play a role in species distribution as well. This is evident from the behavior of the Asian tiger mosquito *Aedes albopictus*, which out-competed the local population of *Ae. aegypti* in the United States. *Ae. albopictus* is adapted to breed in large numbers in nutrient-depleted water and shows tolerance to higher temperature, which helped it to displace *Ae. aegypti* (Juliano, 1998).

In addition, tools to manage pests will be challenged by the changing behavior of pests. It is reported that higher rearing temperatures increase pyrethroid resistance in adults of the *Anopheles arabiensis* SENN DDT strain, and increase pyrethroid tolerance in the *An. arabiensis* SENN strain. In addition, increasing temperature also significantly increases nitric oxide synthase (NOS) expression and decreases insecticide toxicity (Agyekum *et al*., 2021).

Temperature can also influence the effect of insecticides on mosquito larvae. Karen *et al.* (2012) examined the effects of increasing larval rearing temperatures on the resistance status of Trinidadian populations of *Ae. aegypti* to organophosphate (OP) insecticides. The study showed a positive association between resistance to OP insecticides and increased activities of α- and β-esterase in larval populations reared at 28 ± 2°C. Although larval populations reared at higher temperatures showed variations in resistance to OPs, there was a general increase in susceptibility. However, increases or decreases in activity levels of enzymes did not always correspond with an increase or decrease in the proportion of resistant individuals reared at higher temperatures (Polson *et al*., 2012).

It is thus evident that the population of mosquitoes could only be classified as susceptible or resistant to a given chemical depending on the temperature at which they were exposed. Glunt *et al*. (2014) showed in their research that lowering the exposure temperature from the laboratory standard 26°C strongly reduced the susceptibility of female *An. stephensi* to the World Health Organization (WHO) resistance-discriminating concentration of malathion. The susceptibility of these mosquitoes to the resistance-discriminating concentration of permethrin was not as strongly temperature-dependent. For permethrin especially, the thermal history of the mosquito was important in determining the ultimate survival outcome after insecticide exposure. This led the authors to conclude that investigations on the performance of insecticides under different temperature conditions is very important to better understand the epidemiological significance of insecticide resistance and to select the most effective products (Glunt *et al*., 2014).

Another unique phenomenon noted as a result of climate change is hybridization among invasive termite species. Chouvenc *et al*. (2015) observed that two invasive species, *C. formosanus* and *C. gestroi*, are hybridizing and producing hybrid colonies with twice the growth rate of incipient conspecific colonies. In parts of Florida, the dispersal flight season of the two species has begun to overlap due to changes in local climate. Mating pairs of heterospecific individuals were observed in the field, with *C. gestroi* males preferentially engaging in mating behavior with *C. formosanus* females. This leads to hybridization between the two species and the potential evolution of highly destructive 'super-termites' due to hybrid vigor (Buczkowski and Bertelsmeier, 2017).

Changing Environment and Quality of Pest Management

The efficacy of a pesticide is determined by its active ingredient. The active ingredient is usually mixed with other materials to make a formulation. Formulation improves the properties of the active ingredient and helps handling, storage, and application, and may substantially influence effectiveness and safety. However, various chemical and physical properties of an insecticide, such as stability, vaporization, penetration, activity, and degradation, are dependent on temperatures at the time of use. A report shows that the effect of insecticides is more rapid on insects at higher temperatures, although they do not always show a linear relationship with temperature (Uddin and Ara, 2006). Temperature has shown a positive effect on organochlorine, organophosphate, and carbamates in general, but has shown a negative effect on synthetic pyrethroids (Uddin and Ara, 2006; Wang and Shen, 2007).

The effects of temperature on the efficacy of insecticides on various pest species are available. Also, many of the studies have mentioned its relevance to climate change, particularly when used against vectors. Climate change could significantly affect the efficacy of insecticides and alter the result of a pest control activity because temperature will influence its storage, transportation, and application. The examples discussed below indicate that temperature has a significant synergetic influence on the efficacy of insecticides and should now be taken into account while planning a treatment.

Surface sprays using pyrethroid are a common method used for cockroach control and ambient temperature of the application area could influence the efficacy of the insecticide. Toxicity of DDT and pyrethrins when applied topically reduced with increasing temperature (Guthrie, 1950). The toxicity of two pyrethroid insecticides, *S*-bioallethrin and cypermethrin, was investigated over time at 12°C, 25 and 31°C in susceptible and *kdr*-resistant strains of *Blattella germanica* (L.) by Scott (1987). Both strains showed greater kill with decreasing temperature for *S*-bioallethrin. The susceptible strain had a negative temperature coefficient for knockdown but a positive temperature coefficient for mortality towards cypermethrin. The resistant strain had a negative temperature coefficient towards cypermethrin at all times. Resistance to *S*-bioallethrin was generally greatest at 25°C initially, although the difference between temperatures and the level of resistance diminished with time. Resistance to cypermethrin was significantly less at 12°C, than at 25°C or 31°C.

Insecticides are commonly used to control house flies. Khan and Akram (2014) showed a positive temperature coefficient with regard to toxicities of chlorpyrifos, profenofos, and emamectin in a temperature regime of 20–34°C, whereas the toxicities of cypermethrin, deltamethrin, and spinosad decreased, showing a negative temperature coefficient.

Termiticides have been the mainstay for controlling termites and are applied to the soil. Termiticide performance is dependent on a number of soil parameters, predominantly soil properties such as moisture and temperature (Kamble, 2006). Wiltz (2012) highlighted the importance of temperature, among other factors, on the efficacy of soil termiticides and showed that soil temperature affects termiticide bioavailability through its influence on solubility and adsorption. Temperature also has an effect on the physical and chemical properties of the pesticide and the rate of microbial degradation. Several studies have demonstrated that temperature affects adsorption of pesticides to soil, but that the nature of this effect varies among pesticides. In general, termiticides will remain more efficacious and persistent in soils with low temperatures and low moisture content. Warm soil temperatures and moist conditions can enhance the activity of insecticide-degrading microorganisms, thereby increasing degradation of the compound (Kamble, 2006).

Changing Environment and Exposure to Pesticides

Pest management has become a necessity for humans due to their choice to live in urban areas. Consequently, human dependence on pesticide use indoors has not diminished. In spite of efforts to reduce pesticide use through education, regulation, and alternative technologies, exposure to pesticides through occupation, home, and garden use, or indirectly through spray drifts, residues in household dust, food, and water, are common. In addition, the human behavior of choosing toxic chemicals out of anger and disgust on sighting pests is almost involuntary. All of these conditions have made exposure to pesticides a common phenomenon in the home environment.

Increased urbanization, travel, and transportation and improvements in people's socioeconomic conditions and awareness about pests mean that pesticide use is common (Table 1.1). Most pesticides are considered toxic to humans – they are known to have a wide range of harmful effects on human health, including causing nausea and vomiting, skin ailments, impaired immune function, birth defects, neurotoxicity, and cancer. Although acute poisoning from pesticide exposure can be treated symptomatically, the effects from long-term exposure remain a concern. The International Agency for Research

Table 1.1. Number of US households using pesticides by pesticide type. From Atwood and Paisley-Jones (2017).

Pesticide type	Households
Insecticides	82 million
Fungicides	16 million
Herbicides	52 million
Repellents	57 million
Disinfectants	66 million
Any pesticide	88 million

on Cancer (IARC, 1999) classifies most of the common active ingredients used in urban pest control in the Group 3 category, meaning agents not classifiable as carcinogenic to people. Most recently, dichlorvos, an organophosphate, was put in a category under Group 2B, meaning it is an agent possibly carcinogenic to humans (Maroni *et al.*, 2008). In spite of this categorization, differences in opinion exist between countries because of considerations of its economic implications (Okoroiwu and Iwara, 2018). Although all pesticides are toxic to humans and the environment, their method of use will make them harmful or safe, and determine exposure.

Epidemiological evidence shows a relationship between certain children's ailments and chemicals (Maroni *et al.*, 2008). In a structured telephone questionnaire, domestic use of insecticides (used in homes, on pets, or on garden crops), herbicides, and fungicides during pregnancy strongly supported the etiology of childhood hematopoietic malignancies (Rudant *et al.*, 2005). A more conclusive review and meta-analysis reveals positive associations between exposure to residential pesticides and pregnancy and childhood leukemia, with the strongest associations observed for insecticides (Turner *et al.*, 2010). This study performed a comprehensive search of MEDLINE and other electronic databases between the years 1950 and 2009 to draw the above conclusion.

WHO cites that over 30% of the global burden of disease in children can be attributed to environmental factors, including pesticides (WHO, 2006). Children are highly vulnerable to pesticides due to their proximity to surfaces and the ground. Because of their play close to the ground, hand-to-mouth behavior, and unique dietary patterns, children absorb more pesticides from their environment than adults (Landrigan *et al.*, 1999). In addition, children spend most of their time indoors, allowing greater exposure. Compounding this fact is children's decreased ability to detoxify and excrete pesticides. Their rapid growth and development, which include rapid differentiation of organ systems, create early windows of vulnerability (Landrigan *et al.*, 1999).

Exposure to pesticides also originates from contaminated outdoor environments. The US Department of Agriculture has estimated that 50 million people in the United States obtain their drinking water from groundwater that is potentially contaminated by pesticides and other agricultural chemicals (Nielson and Lee, 1987; Ward *et al.*, 2000).

Changing Environment and Running Pest Management Operations

The world has noticeably changed in terms of weather events in the past few years. Science has gathered evidence that indicates these changes are directly linked to human activities, particularly dependence on fossil fuels and emission of greenhouse gases such as CO_2. The pest control industry, like many other industries, is dependent on energy and oil, and can be considered a producer of CO_2. Operators of pest management businesses will need to scrutinize their activities more closely, due to increases in costs, restrictions, regulations, and awareness from various stakeholders. The high cost of service may force consumers to shift to alternative methods, which could be pest-proofing buildings, physical barriers, and even do-it-yourself (DIY) products.

Generating CO_2 by running an office

Like most businesses, pest control operations are run from offices. Buildings and offices use energy to be functional. It has been estimated that 36% of the EU's total CO_2 emissions comes from buildings. According to a EuroACE report, 57% of the energy used in buildings is for space heating, 25% for hot water, 11% for lighting and running electrical appliances, and 7% for cooking (Airaksinen and Matilainen, 2011), whereas in the tropical world energy is used for cooling the building.

Offices are thus considered to be CO_2 producers. For example, the energy needed to operate an office in an Australian building has been estimated to be between 400 and 700 Mega Joules (MJ)/m^2/year (Aye *et al.*, 2002). With the current mix of fossil fuels in energy production, and their emission intensities, 1 MJ causes 77 g of CO_2 to be produced. Some emissions are also produced while energy is being used, such as when lighting a bulb. This is roughly equivalent to an excess of 30–53.9 kg of annual CO_2 production per square meter of office space (Aye *et al.*, 2002). This number will vary depending on the region, country, quality of construction, building engineering, and how the energy was sourced.

Generating CO_2 by office lighting

Lighting is a vital component when measuring workplace productivity and health. Improper lighting can lead to various types of strain and fatigue that can in turn lead to low employee morale and an unhealthy work environment. Electric power generation accounts for the second largest share of greenhouse gas emissions. In the US, approximately 60% of electricity comes from burning fossil fuels, mostly coal and natural gas (US Energy Information Administration, 2022). Replacing incandescent lamps with LED lamps, which consume a fraction of the energy consumed by incandescent bulbs, provides double benefit in that LEDs last longer and are safe for the environment. By doing nothing except installing LEDs in the buildings, it is possible to reduce carbon footprint.

Generating CO_2 by transportation

The pest control business is a service business. It involves traveling and use of vehicles to carry personnel and equipment between offices and sites. It involves various forms of travel, including by road, rail, and air. Using vehicles involves burning fuel, which is one of the biggest generators of CO_2 (Table 1.2). However, it must be noted that the climate effect of non-CO_2 emissions from aviation is much greater and significant, as greenhouse gases formed at higher altitudes persist for longer than at the surface and have a stronger warming potential.

Table 1.2. Emission of CO_2 per individual per kilometer traveled. From Ritchie (2020).

Mode of transport	CO_2 emitted in grams
Car	171
Short-haul flight	156
Long-haul flight	150
Bus	105
Rail	41

Generating CO_2 by pest control operation

Pest control is a fossil fuel-driven business. One liter of an emulsion concentrate (EC) formulation contains between 500 g and 900 g of a petrochemical solvent. To produce one liter of a petrochemical, roughly 325–500 g of carbon is emitted. The surfactant and stabilizers added are also derived from petrochemicals. The products are packaged in plastic bottles, which are a petroleum derivative. The carbon footprint of plastic (LDPE or PET, polyethylene) is about 6 kg CO_2 per kg of plastic (Dormer *et al.*, 2013). The product may then be transported to a far country using a ship that burns diesel fuel. A liter of diesel, which weighs around 840 g, produces 2.7 kg of CO_2. Once received, the pest controller takes the product to a site 10 km from his office, emitting more CO_2 in the process, and then loads it into a steel fogging machine with a diesel diluent and uses it to control mosquitoes. Production of 1 kg of steel leads to 1.9 kg of CO_2 emission. The entire process of this business is carbon intensive.

Generating CO_2 by doing business online

Business believed that going online would help the climate, but this is not the case. A Purdue University study says that 1 hour of video conferencing or streaming, for example, emits

150 g–1 kg of CO_2. But leaving your camera switched off during a web call can reduce these footprints by 96% because data processing uses a lot of electricity and any production of electricity has carbon, water, and land footprints (Obringer *et al*., 2021).

Every human action and activity can be optimized to generate less greenhouse gases. For example, an hour of high-quality video streaming uses 7 gigabytes per hour, which translates to an average of 441g CO_2 per hour. If someone is streaming for 4 hours a day at this quality for a month, the emissions amount to 53 kg CO_2. However, switching to streaming in standard definition would bring down the monthly CO_2 footprint to 2.5 kg. It would save emissions equivalent to driving a gasoline car for about 150 km (*ScienceDaily*, 2021).

Changing Environment and Occupational Hazards for Pest Managers

Pest managers mostly work outdoors and each one will therefore be directly exposed to the weather components of a warming climate (Sims and Appel, 2016). Climate change will make it more difficult and expensive for pest control managers to insure their businesses or other valuable assets, particularly in risk-prone areas. Insurance is the primary means used to protect a business against weather-related disasters. Climate change will increase the frequency and intensity of extreme weather events and these changes are likely to increase property losses and cause costly disruptions to operations. Escalating losses in many areas have already affected the availability and affordability of insurance (Sims and Appel, 2016).

Conclusion

The environment is changing quickly, triggering changes in pest bio-ecology and distribution. It is also facing an inestimable possibility of invasion from non-native species as a new threat. With increasing threats from invasive species and expected growth in pest populations, an increase in the use of pesticides and in turn pesticide exposure for humans and the environment is certain. The direction for the pest management industry and pest management practitioners is towards environmentally sustainable methods. Substituting conventional pesticides wherever possible with alternative methods, such as the use of baiting technology, improving building designs, installing physical barriers, use of pest proofing, installing traps and monitors, is now a global trend. As a positive step in this direction, termite control work, which involves a large volume of termiticide injection into the soil, is currently being replaced by baiting to treat existing buildings that have infestations. Baiting is now viewed as a more environmentally acceptable alternative to soil termiticides. Within a few years of its introduction, bait application has gained significant popularity. In many areas, termite baiting is also becoming a stand-alone measure for long-term protection of structures (Thorne and Forschler, 2000) and pests in general (Dhang, 2016). Su (2011) estimated that a baiting program uses 600-fold less pesticide than conventional soil treatment. Likewise, baits are extensively used to control German cockroaches and ants. In each of these cases, baits have proven to be a stand-alone method. Baits will remain the best example where the practitioner's approach to pest management is in an environmentally responsible direction.

The environment has changed for running businesses, in particular service-based businesses, in the past decade. Besides increased awareness towards climate change, the COVID-19 pandemic created an environment of restrictions. Businesses had to learn new ways to manage themselves and provide services. Learning from current experiences, it can be said that the challenges to managing pests will now be determined more by the changing environment than any other factor.

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