1. Strategic use of chemical ecology for vector-borne disease control

Willem Takken and Bart G.J. Knols

Abstract

In the epidemiology and control of vector-borne diseases an accurate estimate of parasite and pathogen transmission is required. This can be achieved by monitoring the vector population using traps provided with attractive cues. Volatile chemicals are the principle cues with which the disease vectors locate their vertebrate hosts. Natural and synthetic blends of such chemicals can be used to manipulate the vectors, so that transmission risk can be determined and, in some cases, the vector population can be killed. Novel scientific developments, including molecular genetics, analytic chemistry and odour-release technologies provide opportunities for the effective use of chemical ecology in vector-borne disease control.

Keywords: olfaction, insects, ticks, behaviour, disease transmission, nuisance, attractant, repellent

Introduction

In the last decade nuisance insects and disease vectors have received increasing attention because of their continuing and devastating effects on human and animal health. Examples are recent outbreaks of chikungunya fever in the Indian Ocean, SE India and Italy (Erin Staples et al. 2009), the large number of recorded dengue outbreaks in South America (Barclay 2008) and the arrival of bluetongue virus in NW Europe (Carpenter et al. 2009). In addition, the rapid growth of the world population coupled with increasing poverty in resource-poor countries is the cause of much suffering from neglected vector-borne diseases such as malaria, leishmaniasis and trypanosomiasis (Mathers et al. 2007). Lastly, the current debate on climate change and its potential effects on human health is causing global concern about emerging diseases such as West Nile virus, Lyme disease and other tick-borne diseases (Epstein 2001, Gould and Higgs 2009, Jones et al. 2008). Whereas for several of these diseases effective intervention strategies are available, and hence their control can be implemented, for many of them the current control strategy is inadequate. With some exceptions, effective vaccines are lacking, parasites have developed resistance against drugs, and vector control efforts are hampered by insecticide resistance, technologically inadequate tools and lack of resources.

It is widely agreed that the first step in monitoring vector-borne disease is accurate risk assessment (Hay et al. 2004, Mathers et al. 2007). This information is needed to study the epidemiology of the disease, and to predict its course in time and space. The basic reproductive number \( R_0 \) (Hartemink et al. 2008, Smith et al. 2007) is used to express disease risk, and as the biting rate of disease vectors is one of the critical parameters in \( R_0 \), tools to accurately measure this are essential. Examples in which these data are being widely used are malaria and dengue control programmes: in endemic situations vector densities provide knowledge on spatial and temporal distribution of biting intensities, while in epidemic situations, vector populations are measured so that the course of the outbreak can be monitored. Also, the outcome of vector-targeted interventions, aimed at the interruption of parasite/pathogen transmission, can be assessed when accurate data on vector densities are available. Vectors are also collected to determine their infections with disease agents: the intensity of disease transmission the product of vector density and parasite/pathogen infection rate. In spite of the importance of accurate sampling of disease vectors, the methodologies used for insect collection are in many cases based on perception rather than on
accurate knowledge of vector behaviour. This is because information on vector-host interactions (at which level the parasites/pathogens are being transferred) is in many cases poor or lacking. It is therefore of relevance that this knowledge be expanded in order to obtain better, more precise, data on vector biting density and intensity of parasite transmission.

Since the discovery of the role of arthropods in disease transmission, entomologists have worked on the development of tools for vector surveillance, and a wide range of traps is available with which the vector population can be monitored (Qiu et al. 2007, Service 1993). Traps are designed to attract the target insect(s) using sensory cues such as sound, colour and odour. As chemical signals are the principal cues with which arthropods identify their blood hosts, many traps employ odorants to lure the vectors to the trap. The odorants used vary from natural host odours, synthetic blends of compounds mimicking host odours, or non-host related chemical compounds that have been found to be attractive to the vectors. Harris (1938) and Van Thiel (1935) were among the first to report on the use of host odours to trap tsetse flies and mosquitoes, respectively. It was also established that carbon dioxide (CO$_2$) acts as a universal attractant for many blood-feeding insects, and many traps are baited with this compound. For example, the Centre for Disease Control miniature light trap (CDC light trap) (Sudia and Chamberlain 1962) was reported to produce significantly-enhanced catches of mosquitoes when baited with dry ice (Newhouse et al. 1966). The CO$_2$-baited CDC trap was the gold standard for establishing mosquito densities for many years. In the tropics, CO$_2$ was replaced by natural human emanations by operating the CDC trap next to a bed net under which a human spent the night (Garrett-Jones and Magayuka 1975). Although these odour-baited traps collected disease vectors, the trap collections represented only crude data on vector densities, and more accurate measurements were needed.

In the 1970s, Vale (1974), dissatisfied with the variable results of odour-baited traps, began to experiment with natural host odours to investigate the behaviour of tsetse flies in Zimbabwe. By using an elegant design of electrified grids and artificial host models, Vale demonstrated that natural host odours were the principle cues that led tsetse flies to the vicinity of their blood hosts (Vale 1993). The studies on tsetse olfactory behaviour are still considered to be classic methods for investigating insect behaviour with respect to their vertebrate hosts. Gillies and Wilkes (1968) demonstrated that mosquitoes could also be manipulated with host odours, and it was soon found that synthetic blends of odorants could be used to manipulate mosquito populations (Takken and Kline 1989). These behavioural studies were gradually augmented with physiological studies to reveal the sensory processes that made the insects respond to the odorants (Cork 1996, Davis and Sokolove 1976). The advent of molecular genetics has allowed for detailed insight in the genetics and molecular regulation of insect olfaction, which provides fundamental knowledge on the regulation of insect behaviour (Jacquin Joly and Merlin 2004, Lessing and Carlson 1999, Touhara and Vosshall 2009). This, in turn is being used for the identification of chemical compounds that affect vector-host interactions, so that the target vectors can be more effectively lured to sampling devices and/or removed from the environment as a tool for disease control.

In future, odorants will increasingly be used for the monitoring of vector-borne disease transmission risk as well as for vector control. It is therefore appropriate that the current volume of the Ecology and Control of Vector-borne Diseases has brought together reviews of the state-of-the-art of this topic, from the molecular regulation of olfactory senses (Chapter 2) to field applications of odorants for disease control (Chapter 17). As many disease vectors belong to the insect order of Diptera, this group of insects is discussed in detail, with mosquitoes being the example for detailed explanation of olfactory regulation. Chapters on blood-feeding bugs, vectors of Chagas disease, and blood-feeding ticks, vectors of a variety of parasites and pathogens, are
included as well. Finally, as it is increasingly becoming apparent that the olfactory behaviour of insects and ticks is often mediated by parasites, a chapter on the latest knowledge of this field of science is also included. Odorants are not only used to attract insects and ticks, but they can also be used to protect blood hosts from being attacked (Katz et al. 2008). In many cases odorants act as deterrents or repellents, and where applicable, this aspect of olfaction is discussed as well.

The ecology of vector-borne diseases is much determined by the association between vectors, parasites and hosts, which is in turn strongly mediated by chemical cues. The chapters in this volume demonstrate that detailed studies on insect olfaction contribute to our understanding of the individual components regulating this process, and contribute to finding effective solutions for disease control.

References