13. Integrating information on the role of mosquitoes for the transmission of pathogens of wildlife

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Abstract

Traditionally, mosquitoes have been studied given their relevance as vectors of pathogens that affect humans. However, in recent decades, their relevance as vectors of pathogens that affect wildlife has become evident. For this reason, multidisciplinary research disciplines have been developed focusing on the ecology, epidemiology and evolution of the interactions between pathogens and their hosts, including the transmission dynamics of diseases. However, there is a gap in the knowledge of mosquito-borne pathogens that affect wildlife, being necessary to study the taxa diversity, using genomic tools and, of course, their life cycles and their vectors. However, the information on the vector competence of mosquitoes for the transmission of pathogens that affect wild animals is certainly scarce. Interspecific and intraspecific differences have been evidenced. This would determine the capacity of mosquitoes to transmit parasites that infect wild animals. Different factors such as physiological and biochemical processes, or the mosquito microbiota could determine these differential capacities of mosquitoes to transmit pathogens.

Keywords: vector competence, ecology of diseases, zoonotic diseases

Introduction

This volume of the *Ecology and control of vector-borne diseases* series includes 13 chapters focused on the study of different factors affecting the role of mosquitoes in the transmission of pathogens, including those that are zoonotic. Traditionally, the study of mosquitoes derived from its role as vectors of a diversity of pathogens affecting humans. However, during recent decades, an increasing amount of evidence supports their relevance as vectors of parasites and other pathogens affecting wildlife. These studies require a multidisciplinary approach, including the collaboration between ecologists, entomologist and parasitologist, among others, to fully understand the different interactions between the three main actors: wild animals as vertebrate hosts, mosquitoes as vectors and pathogens. As a result, different research disciplines have been developed such as *disease ecology,* that focus on the study of the ecology, epidemiology and evolution of the interactions between pathogens and their hosts including the transmission dynamics of diseases.

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Mosquito-borne pathogens of wildlife

Nowadays, a diversity of mosquito-borne pathogens, including parasites, have been described in vertebrate hosts, from fishes and other ectotherms to birds and mammals. However, the lifecycle of most of them is not completely known, including basic information on the mosquito species involved in their transmission. For example, 4,654 different lineages of avian malaria and malaria-like parasites have been described in wild birds according to Malavi, the largest and updated database of these parasites (Bensch *et al.* 2009). However, information of their mosquito vectors is restricted to only 427 lineages, representing the 9.23% of known parasite lineages. In this volume, Paredes and Fuehrer (2022) and Matta *et al.* (2022) (Chapters 2 and 3, respectively) revised the published information regarding the mosquito-borne pathogens of three major vertebrate taxa, mammals, reptiles and amphibians. These authors revealed that there is a gap in the knowledge of blood parasites that affect wildlife. Thus, it is necessary to study the diversity of taxa sampled, especially using new molecular technologies such as genomic tools and, of course, to increase the knowledge on their life cycles, specifically knowing the role of the vectors. In addition to the parasites infecting wildlife in their natural ecosystems, animals maintained in captivity also provide valuable information of the pathogens able to infect these species and circulate in a given area. For example, mortality records of birds in the Bronx Zoo allowed researchers to determine the extent and timing of the WNV outbreak in 1999 in New York city, when the virus was introduced in USA (CDC 1999). The importance of zoos to facilitate transmission of pathogens to animals, has been recently supported by the local transmission of SARS-CoV-2 infections from humans to tigers and lions at the same zoo (McAloose *et al.* 2020). Mosquito-borne pathogens have also important consequences for the maintenance of animals in zoos, including endangered species. This is especially the case for parasites such as avian *Plasmodium* which are common parasites circulating in zoos in different continents and have deleterious effects on the health status of different species such as cranes and penguins, among others (Werner and Kampen 2022, Chapter 4). However, zoos also provide suitable environments to develop studies on the ecology of mosquitoes. For example, because animals are maintained in closed areas, it is possible to easily identify the flight distance of mosquitoes from their hosts to insect traps in order to estimate their flight capacity (Martínez-de la Puente *et al.* 2020), using methods to identify the blood meal origin of engorged mosquitoes (Gutiérrez-López *et al.* 2022, Chapter 6). Using this approach, it is also possible to identify their feeding preferences because the number of susceptible vertebrate hosts (enclosed animals) present in the area is known.

The role of mosquitoes in the transmission of pathogens

Vector competence is a key factor determining the ability of mosquito to transmit specific pathogens as a result of complex co-evolutionary processes (Leggett *et al.* 2013). Despite its relevance for parasite epidemiology, information on the vector competence of mosquitoes for the transmission of pathogens affecting wild animals is scarce, at least, compared to those affecting humans. Among the diversity of vector-borne pathogens infecting wild animals, only a fraction of them are able to be transmitted by mosquitoes. For example, wild birds are commonly infected by haemosporidians of the genera *Plasmodium*, *Haemoproteus* and *Leucocytozoon* (Valkiūnas, 2004), even coinfections by parasites belonging to these genera are common in nature (Marzal *et al.* 2008). Despite the similarities of these parasite genera in their transmission cycles, different insect groups are considered their main vectors. While *Plasmodium* is transmitted by mosquitoes, *Haemoproteus* is transmitted by louse flies and *Culicoides* and *Leucocytozoon* by black flies. As a result, when a mosquito feeds on individuals coinfected with different parasite genera, only *Plasmodium* parasites are able to complete their development (Gutiérrez-López *et al.* 2016), and

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only abortive forms of *Haemoproteus* could be found (Valkiūnas et al, 2013), further supporting the role of different insect groups in the transmission of phylogenetically related parasites infecting the same host species.

In addition, recent studies have provided evidence for interspecific differences in the vector competence of mosquitoes for the transmission of avian *Plasmodium*. For example, the identification of parasite DNA in the saliva of mosquitoes allowed Gutiérrez-López *et al.* (2020) to identify *Culex pipiens* as a competent vector of four parasite linages of *Plasmodium* infecting house sparrows (*Passer domesticus*) while this was not the case for mosquitoes of the species *Aedes caspius*. However, only a fraction of individuals of the same mosquito species fed on the same infected bird develop infective forms of the parasites, suggesting that intraspecific differences may also determine the ability of mosquitoes to transmit parasites infecting wild animals. Various factors may determine these differential abilities of mosquitoes to transmit pathogens, both at interspecific and intraspecific levels including physiological and biochemical processes (Abraham and Jacobs-Lorena 2004), such as the interactions of pathogens with membrane proteins of the mosquito midgut epithelium (Povelones *et al.* 2009). In addition, mosquito microbiota, through their effects on the immune responses of insects, may affect the development of parasites such as avian *Plasmodium* in mosquito vectors (Martínez-de la Puente *et al.* 2021).

Surveillance and control strategies of mosquitoes

Due to the reported importance of mosquitoes for the transmission of mosquito-borne pathogens and their impact on human and animal health, it is necessary to develop new technologies that focus on their surveillance and control of their populations. Urban areas represent suitable environments for mosquito populations, with some species being favoured by the occurrence of artificial containers and other water sources for breeding (Ferraguti *et al.* 2022, Chapter 8). This is clearly the case for *Aedes* invasive species, such as *Aedes albopictus* which has spread from the western Pacific and South-east Asia to countries in Europe, America and, Africa where it has established populations (Paupy *et al.* 2009). Among these technologies, González *et al.* 2022 (Chapter 11) highlight the role of artificial intelligence which could be an excellent tool for entomologists for the monitoring of mosquito population dynamics in the field, with the ability to detected earlier those mosquito species of interest. This would be beneficial for the design and implementation of risk assessment programs. In addition, Bueno-Mari *et al.* 2022 (Chapter 12) report the possibility of using predators, pathogens or microorganism toxins as biological control strategies to reduce mosquito populations, especially in the case of invasive species such as *Ae. albopictus*, which could be a key vector in the transmission of zoonotic pathogens from wildlife to humans.

Concluding remarks

Mosquito-borne pathogens are commonly found infecting wild animals, from ectotherms to mammals, some of them being reported as zoonotic. A growing body of evidence supports the importance of these pathogens, including mosquito-borne pathogens, as drivers of the ecology and evolution of wildlife (Rivero and Gandon 2018). Despite this, basic information on the epidemiology of these pathogens, from identification of natural reservoirs to the mosquito species involved in their transmission, is still unknown. Thus, the screening of parasite and other pathogens in wildlife is critical, especially considering that nearly 75% of emerging infectious diseases have a zoonotic origin. These studies should be complemented by those addressing the impact of environmental variables affecting the distribution and abundance of mosquitoes,

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considering the impact of global change potentially affecting the epidemiology of pathogens affecting wildlife (Garamszegi 2011). We hope that this volume of the *Ecology and control of vector-borne diseases* series represents a step forward in contributing to the general knowledge on this research topic.

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