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Mosquito matters

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Three studies of disease-carrying mosquitoes in this issue illustrate the need for both interdisciplinary approaches and more research into fundamental biology.

Mosquitoes are a large family of dipterans with a cosmopolitan distribution. Although they occupy a range of niches and provide certain ecosystem services, their best-known – and most unfortunate – role is as vectors of infectious disease. Species mainly from three genera – *Aedes*, *Anopheles* and *Culex* – transmit a range of parasitic and viral diseases that are responsible for high burdens of mortality and morbidity, predominantly in warm climates. And, of course, their ranges and potential impacts are shifting with climate change (Ryan, S. J. et al. *PLoS Negl. Trop. Dis.* **13**, e0007213; 2019).

Despite some major wins, such as the malaria vaccine that was recently approved by the WHO (Ledford, H. *Nature*, https://doi.org/10.1038/d41586-022-02902-6; 2022), widespread management of mosquito-borne diseases with medical intervention is expensive and still needs to be complemented by a range of vector-control strategies. Strategies will differ in rural and urban settings, but with urbanization (and urban mosquitos) on the rise it is especially timely to consider mosquito control in urban areas. Cities have high densities of mosquito hosts (that is, people), fewer predators, often suitably warm microclimates, and abundant still-water containers, and are more interconnected than rural areas. Although these properties are beneficial to mosquitoes, they are also all aspects of urban geography that we can modify and control. Kache et al. argue in a Perspective in this issue that an integrative ecological and urban systems approach is needed to control *Aedes*-borne disease. Patterns of human movement and employment, water management, and buildings and local-area infrastructure are all parts of this complex urban system that contribute to mosquito-borne disease as an emergent property. These human dimensions can be mapped and modelled using tools from landscape ecology, and the authors make the case for a coordinated effort across disciplines and different types of local actors.

Far from the complexities of urban systems and practicalities of vector control, there is still much we do not understand about the fundamental biology of mosquitoes. Also in this issue, and focusing on *Anopheles* in a rural region of Africa that is heavily burdened by malaria, Faiman et al. investigate where mosquitoes go during the dry season, when they seem to disappear and are yet able to rebound rapidly when the rains return. One tentative explanation for this unexplained adult persistence is a form of dormancy known as aestivation. The authors developed a deuterium-based isotope tracking approach that allowed them to show that at two village sites in Mali, aestivation by *Anopheles coluzzii* accounts for at least 20% of the rapid rebound. This insight into how mosquitoes endure the dry season could be important in refining control measures, such as more targeted insecticidal applications to stymie population explosions at the start of rainy seasons. However, more research is needed to identify the actual locations where the mosquitoes aestivate.

Also in this issue, Poda et al. examine another aspect of fundamental mosquito biology with applied implications: how mosquitoes aggregate for mating. Several *Anopheles* species exist in sympatry yet maintain premating barriers, and hybrids are rare. It is not known how species-specific mating swarms of *Anopheles gambiae* and *Anopheles coluzzii* maintain their monospecific nature, but several types of cue might be involved, including acoustic, visual and chemical. Many of these work only over short distances, so long-distance pheromones have been suggested. Poda et al. note that the evidence for these pheromones is not conclusive, so they set out to test for them using a range of different behavioural, physiological and chemical analyses under conditions that they argue maximize the chance of success. Included within their analyses are replications of an earlier study in this journal (Mozūraitis, R. et al. *Nat. Ecol. Evol.* **4**, 1395–1401; 2020), in which the authors concluded in favour of long-distance pheromones. On the basis of all their new analyses, Poda et al. conclude that there is currently no evidence for such pheromones, although they are careful to note that absence of evidence is not necessarily evidence of absence, and that further work is needed. They identify differences in the timing of observation and the control experiments that may explain the discrepancy with Mozūraitis et al. The study by Poda et al. is not an exact replication of Mozūraitis et al., because it includes a wider range of assays. In doing so, it has shifted the evidence considerably against the existence of long-range pheromones, but it neither invalidates the specific results of Mozūraitis et al. nor provides the final word on the subject. For a start, even if long-range pheromones do not contribute to species segregation in *Anopheles*, we still need an alternative explanation for what does.

As with the location of aestivating mosquitoes, the mechanism of mating is a potential target for control interventions, so further research understanding the basic biology of these species is essential. Some of these interventions could be low-tech (such as nets and responsibly applied sprays), but another major topic of mosquito research is into high-tech genomic solutions, including transgenic gene drives and the use of reproductive parasites such as *Wolbachia* (Wang, G.-H. et al. *Nat. Commun.* **12**, 4388; 2021). Although all of these biological approaches should continue apace, the Perspective by Kache et al. makes the important point that, alongside them, there are huge gains to be made from an interdisciplinary approach that considers mosquito-borne disease as an emergent property of coupled socioecological systems.

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