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Mosquito travel diaries: destinations, routes, stowaways, and … cost

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Half the world's population is at risk of illness or death from malaria, dengue, and other mosquito-borne diseases. This study shows that mosquitos are able to travel hundreds of kilometers- far longer than previously expected- forcing us to rethink how mosquitoes and pathogens travel.

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Although grappling with a viral pandemic, half the world's population is at risk of illness or death from malaria, dengue, and other mosquito-borne diseases. Therefore, it's no surprise that controlling mosquitoes is a top global health priority. But there's a lot we don't know about these disease-carrying insects. For example, it has long been believed that mosquitoes disperse over only short distances (fewer than 5km). Still, this belief reflects the lack of effective methods for tracking mosquitoes over more considerable distances. Our study sought to determine whether mosquitoes really are homebodies or if they are sometimes long-distance jet-setters.

In the semi-arid African Sahel, seasonal rains provide surface water essential for mosquito larvae to develop into (malaria-transmitting) adult mosquitoes. After this water dries up, mosquitoes seem to vanish. Our recent studies suggest certain species of malaria-carrying mosquitoes recolonize the Sahel by migrating from distant locations where larval sites are available year-round. To find out if malaria-transmitting mosquitoes in the Sahel arrive there after long-distance, wind-assisted journeys, we designed a study to capture and record high-flying insects.

We set up aerial sampling stations in four Sahelian villages located in central Mali. Flying insects were collected in ten-night periods each month from March to November during the study period, which ran from 2013 to 2015. We captured mosquitoes on glue-coated mesh panels attached to the cord of a tethered helium balloon. The 11 ft helium balloon was kept stationary at 200 or 300m above ground. Each balloon carried 3 to 5 panels at heights between 90 and 290m above ground. Each morning upon balloon retrieval, glued insects were removed and preserved. To account for insects trapped near the ground, we raised control panels and immediately retrieved them during the launch and retrieval operations.

For each captured mosquito, we recorded species, sex, physiological state (blood-fed, egg-laden), infection with malaria-causing parasites, and the blood meal source. We converted the number of mosquitoes per panel (panel density) to aerial density based on the air volume that passed through the net overnight. Because a mosquito's flight speed (1 m/s) is slower than wind speed at altitude (5-12 m/s), mosquito movement is governed by the wind and flight duration. Thus, we simulated flight trajectory using a computer model developed and used by
National Oceanic and Atmospheric Administration, USA. Such a model predicts the windborne spread of particulate matter in the atmosphere based on the winds during the night of capture at the interception's location and altitude.

This study provided many surprises. We expected to capture just a handful of mosquitoes representing a few species, at best. In fact, we intercepted nearly 3,000 mosquitoes amongst half a million insects over 617 nights. The mosquitoes included 235 from the genus *Anopheles*, including the primary malaria vectors, *Anopheles coluzzii* (23) and *An. gambiae* s.s. (1) and secondary vectors *An. pharoensis* (40), *An. coustani* (30), *An. squamosus* (100), and *An. rufipes* (24). Additional noteworthy surprises included that over 80% of all mosquitoes collected were females, and more than 90% were egg-laden. This indicates that they had taken one or more blood meals before their journey and could be carrying malaria parasites or other pathogens. We searched for infection with malaria parasites in the *Anopheles* mosquitoes. However, we didn't find any infected mosquitoes, likely due to the low numbers of primary malaria vectors and commonly low rates of infection in the secondary vectors. We captured no mosquitoes on the control panels, indicating that we intercepted them at altitude rather than near the ground.

Mosquito density increased during the rainy season and with altitude, but the variation among years and localities was minimal, suggesting that migration magnitude is even more extensive than observed both vertically and horizontally. Yet, our conservative estimation pictures tens of millions of mosquitoes migrating each year, surfing the winds between 50 and 250m above ground over a section of 100km perpendicular to the wind. Way beyond our expectations. Furthermore, estimated nightly travel from simulated backward trajectories of captured mosquitoes revealed potential displacements of up to 300km for 9-hour "red-eye flights."

The capacity to travel over hundreds of kilometers allows mosquitoes to reach plentiful resources in the Sahel following the monsoon rains as they drift northwards and southwards seasonally. Such movements of individual mosquitoes are well beyond what had previously been considered possible. These new findings make us rethink how mosquitoes and pathogens travel. Windborne migration of malaria-carrying mosquitoes may explain the rapid spread of insecticide resistance over a large area and the dogged persistence of malaria in countries with effective intervention, such as South Africa, and should be considered in future malaria elimination efforts.