Complexity of malaria dynamics under climate change

The transmission of malaria is highly variable and depends on a range of climatic and anthropogenic factors. For more than two decades, there has been a growing concern and hot debate over the impact of global warming on this deadly mosquito-borne disease. It is now widely recognized that while malaria risk could be limited by economic growth, changes in climate suitability in poor regions remain a significant challenge for malaria control.

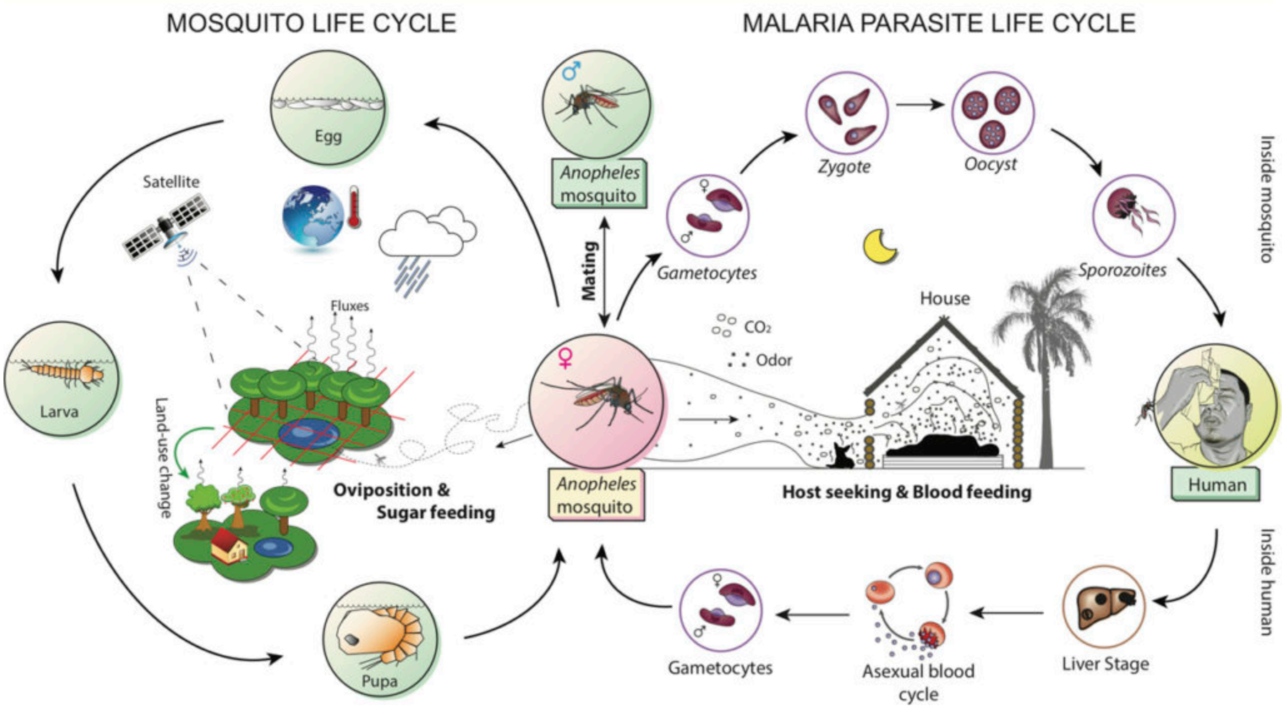

Fig. 1. Life cycles of Anopheles mosquitoes and Plasmodium parasites. Female mosquitoes seek humans and animals for their blood feeding required for egg production. Plasmodium is transmitted into hosts through the saliva by an infectious carrier mosquito during its blood feeding. The parasites then advance through several stages and can multiply inside the host before being transmitted to other mosquitoes through their blood meals. Inside the mosquito, Plasmodium continues developing with a degree-day air temperature dependence until the mosquito becomes infectious to humans. The parasite life cycle is completed when these parasites are injected to another human by this mosquito, perpetuating transmission. For oviposition, gravid females randomly search for larval habitats and deposit eggs. The eggs then advance to larval and pupal stages before emerging as adult mosquitoes. After emergence, female mosquitoes mate once with males during their entire life for producing eggs. Climate change as manifested through elevated atmospheric CO2, higher temperature, and altered precipitation magnitude induce vegetation acclimation through change in energy and hydrologic fluxes. Changing landscape may even affect local weather more acutely than long-term climate change. Along with socioeconomic activities, these processes have potential impacts on malaria transmission [Credit: Phong V. V. Le and

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The ecology of malaria is markedly complex, involving two different replication cycles of the *Plasmodium* parasite alternating in human hosts and *Anopheles* vectors (Fig. 1). These cycles are often controlled by fluctuations dominated by the random nature of population events and the space-time variability of environmental conditions. While 3/4 of the mosquitoes' life stages are aquatic, the life cycle of *Plasmodium* inside the mosquitoes, that are ectothermic or cold-blooded insects, is air-temperature dependent. So, it is very likely that ecohydrological shifts in response to global warming will have a significant impact on the dynamics of malaria.

We investigated the complexity and ecological aspects of climate change's impacts on malaria transmission. Specifically, we analyzed modification in (i) the sporogonic cycle of *Plasmodium* induced by air temperature increase, and (ii) the life cycle of *Anopheles* vector triggered by changes in natural breeding habitat arising from the altered moisture dynamics. We developed a stochastic modeling approach to capture uncertainty and the interaction between malaria dynamics and the life cycles of both vectors and parasites. Our model consists of two stochastic time-continuous, space- discrete models: one for vector dispersal that represents the entomological life cycles of female *Anopheles*, and a second for malaria dynamics that simulates the circulation of the *Plasmodium* pathogen between host and vector populations. We also coupled this framework with a sophisticated ecohydrologic model to incorporate climate-driven hydrologic and ecologic processes as factors that determine mosquito population and malaria transmission dynamics. Our study was performed in a coastal area in Kenya.

This research revealed for the first time the complicated role of vegetation acclimation under climate change on malaria and indicated an indirect but often ignored impact of air temperature increase on malaria transmission through reduction in breeding habitats and vector density. Particularly, we showed that elevated atmospheric CO_2 concentration increases the habitat availability for mosquito reproduction, which leads to higher density of vectors and an increase in malaria incidence. Unlike the elevated CO_2 condition, the increase of air temperature has two distinct effects on malaria dynamics. First, higher air temperature shortens the life cycles of *Anopheles* and *Plasmodium*. Second, it also reduces soil moisture, thus decreasing the habitat availability for the vector. Our findings shed light on better understanding the linkage between climate change and the infection dynamics of malaria.

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Publications

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