Chapter 15
Assessing the Impact of Temperature Change on the Effectiveness of Insecticide-Treated Nets

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ABSTRACT

Malaria is a vector-borne illness affecting millions of lives annually and imposes a heavy financial burden felt worldwide. Moreover, there is growing concern that global climate change, in particular, rising temperature, will increase this burden. As such, policy makers are in need of tools capable of informing them about the potential strengths and weaknesses of intervention and control strategies. A previously developed agent-based model of the Anopheles gambiae mosquito is extended, one of the primary vectors of malaria, to investigate how changes in temperature influence the dynamics of malaria transmission and the effectiveness of a common malaria intervention: insecticide-treated nets (ITNs). Results from the simulations suggest two important findings. Consistent with previous studies, an increase in mosquito abundance as temperature increases is observed. However, the increase in mosquito abundance reduces the effectiveness of ITNs at a given coverage level. The implications and limitations of these findings are discussed.
INTRODUCTION AND BACKGROUND

Malaria is a vector-borne illness infecting over 500 million people and directly causing over one million deaths each year (WHO, 2004). The primary vectors of malaria are Anopheline mosquitoes and the risk of infection is largely dependent on the abundance of these mosquitoes. As such, huge efforts have been made at reducing the transmission of malaria by developing interventions that directly target vector populations. The most common of these interventions in use today are insecticide-treated nets (ITNs), indoor residual spraying of insecticides (IRS) on the walls of human dwellings, the development of chemical and biological larvicides, and reducing the availability of mosquito breeding sites through effective land-use and management strategies. However, in areas where malaria continues to be endemic, vector abundance exceeds resources necessary and available to implement effective control strategies.

There is growing concern that the difficulties in controlling malaria transmission may be exacerbated by environmental changes such as increasing temperature (Chaves & Koenraadt, 2010; Hay et al., 2002; Lindsay & Martens, 1998; Rogers & Randolph, 2000). Empirical evidence in these studies suggests that rising temperatures may not only influence transmission rates, but also increase the spatial distribution of malaria. These concerns arise because temperature can influence the abundance of mosquitoes in a number of important ways.

First, the development rate of aquatic mosquitoes (those in the egg, larva, and pupa developmental stages) is directly related to temperature within feasible ranges necessary for development (16-40°C) with mosquitoes reaching adulthood more quickly at higher temperatures (Bayoh & Lindsay, 2004; Depinay et al., 2004; Hoshen & Morse, 2004; Impoinvil, Cardenas, Gihture, Mbogo, & Beier, 2007). Second, the exoskeleton of newly emerging adults may harden more quickly, thus facilitating development to reproductive viability. Finally, female mosquitoes develop batches of eggs more quickly at higher temperatures once they have successfully obtained a bloodmeal (Hoshen & Morse, 2004). Combined, these temperature-driven effects not only shorten the time it takes a female mosquito to lay eggs for the first time, but also potentially allows for more reproduction attempts across an individual mosquito’s lifespan.

The importance of these temperature-drive effects becomes even more apparent when considering that only a subset of the mosquito population is actually capable of transmitting malaria. The transmission of malaria from human to human begins when a female mosquito takes a bloodmeal from an infectious human, thus acquiring gametocytes of the malaria-causing parasite. The mosquito must then survive long enough for the gametocytes to develop into sporozoites, which then migrate to the salivary glands of the mosquito (the extrinsic incubation period, EIP). The sporozoites are then transmitted to humans upon subsequent bloodmeals. The parasite EIP is also temperature dependent with development occurring more rapidly as temperature increases. Thus, changes in vector abundance due to temperature should, in theory, be accompanied by a shift in the proportion of mosquitoes that can potentially transmit malaria.

The goal of the present study is two-fold. First we attempt to characterize how temperature can alter the abundance and structure of mosquito populations. Subsequently, we investigate whether changes in temperature impact the effectiveness of intervention strategies involving ITNs. ITNs function by killing mosquitoes as they attempt to gain a bloodmeal from humans that are covered by them. Given that both the duration of time between bloodmeals for a mosquito and the length of the EIP varies with temperature, it seems reasonable that the effectiveness of a control strategy employing a given distribution of ITNs may also vary. This