Carry-over effects of larval microclimate on the transmission potential of a mosquito-borne pathogen

Michelle V. Evans, Justine C. Shiau, Nicole Solano, Melinda A. Brindley, John M. Drake, Courtney C. Murdock

Supplemental Information

0.1 Intrinsic growth rates (r')

We calculated the per capita population growth rate per following Livdahl and Sugihara (1) Eq. 1:

$$r' = \frac{ln(\frac{1}{N_0}\sum_x A_x f(\bar{w_x}))}{D + \frac{\sum_x xA_x f(\bar{w_x})}{\sum_x A_x f(\bar{w_x})}} \tag{1}$$

Where N_0 is the initial number of female mosquitoes (assumed to be 50% of the larvae, n=50), A_x is the number of mosquitoes emerging on day x, D is the time to reproduction following emergence (assumed to be 14 days (2)), and $f(\bar{w_x})$ is fecundity as a function of mean wing size on day x (w_x; Equation 2). This relationship is assumed to be linear and calculated via Lounibos et al. (3):

$$f(\bar{w_x}) = -121.240 + (78.02 \times \bar{w_x}) \tag{2}$$

0.2 Vectorial Capacity

We calculated the vectorial capacity (VC; Equation 3) for each site and season using a temperature-dependent mechanistic dengue model defined in Mordecai et al. (4).

$$VC(T) = \frac{a(T)^2 b(T) c(T) e^{-\mu(T)/EIR(T)} EFD(T) p_{EA}(T) MDR(T)}{\mu(T)^2} \tag{3}$$

Here, mosquito traits are a function of temperature, T, as described in Table 1:

Parameter	Definition	Without carry-over effects	With carry-over effects
$a(T)$	Per-mosquito bite rate	Mordecai et al. 2017	Mordecai et al. 2017
$b(T)c(T)$*	Vector competence	Mordecai et al. 2017	Current Study
$\mu(T)$	Adult mosquito mortality rate	Mordecai et al. 2017	Mordecai et al. 2017
$EIR(T)$	Extrinsic incubation rate (inverse of extrinsic incubation period)	Mordecai et al. 2017	Mordecai et al. 2017
$EFD(T)$*	Number of eggs produced per female mosquito per day	Mordecai et al. 2017	Current Study
$p_{EA}(T)$	Egg-to-adult survival probability	Current Study	Current Study
$MDR(T)$	Mosquito immature development rate	Current Study	Current Study

Table 1: Sources of parameters used in the VC equation. Parameters sourced from (4) were mathematically estimated at a constant temperature of 27 °C. Parameters that included carry-over effects are starred.

Site-level VC was calculated using a combination of traits empirically measured in this study and traits estimated from thermal response models as described in (4). The bite rate ($a(T)$), adult mosquito mortality rate ($\mu(T)$), and extrinsic incubation rate ($EIR(T)$), were calculated for mosquitoes at a constant 27 °C using temperature dependent functions from (4). Vector competence ($b(T)c(T)$) was calculated as the proportion of infectious mosquitoes per site as found by our dengue infection assays. The number of eggs produced per female per day ($EFD(T)$) was calculated by estimating fecundity from average female wing length following Eq. 2, and then dividing this by the expected lifespan of mosquitoes ($1/\mu$). The egg-to-adult survival probability ($p_{EA}(T)$) was defined as the average proportion of adults emerging at a site. The mosquito immature development rate ($MDR(T)$) was calculated as the inverse of the mean time to emergence for female mosquitoes per site, resulting in a daily rate of development.

References

[1] Livdahl TP, Sugihara G. Non-Linear Interactions of Populations and the Importance of Estimating Per Capita Rates of Change. The Journal of Animal Ecology. 1984 Jun;53(2):573–580.

[2] Livdahl TP, Willey MS. Prospects for an Invasion: Competition between Aedes Albopictus and Native Aedes Triseriatus. Science. 1991 Jan;253:189–191.

[3] Lounibos LP, Suarez S, Menendez Z, Nishimura N, Escher RL, O'Connell SM, et al. Does Temperature Affect the Outcome of Larval Competition between Aedes Aegypti and Aedes Albopictus? J of Vec Eco. 2002 Jun;27(1):86–95.

[4] Mordecai EA, Cohen JM, Evans MV, Gudapati P, Johnson LR, Lippi CA, et al. Detecting the Impact of Temperature on Transmission of Zika, Dengue, and Chikungunya Using Mechanistic Models. PLOS Neglected Tropical Diseases. 2017 Apr;11(4):e0005568.