Supplemental Appendix A: Data Sources, prior specification, further methods.

Understanding uncertainty in temperature effects on vector-borne disease: A Bayesian approach

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A.1 Data Sources

Parameter	Definition	prior species	prior sources	main species	main sources
a	biting rate	*Aedes albopictus*	Calado and Navarro-Silva [2002], Delatte et al. [2009]	*An. pseudopunctipennis*	Lardeux et al. [2008]
MDR	mosquito development rate	*An. gambiae*, *An. quadrimaculatus*, *Aedes triseriatus*, *Aedes aegypti*, *An. superpictus*	Jepson et al. [1947], Love and Whelchel [1957], Jalil [1972], Joshi et al. [1996], Briegel et al. [2001], Aytekin et al. [2009]	*An. gambiae*	Bayoh and Lindsay [2003]
p_{EA}	egg to adult survival	*An. quadrimaculatus*, *Aedes triseriatus*, *Aedes albopictus*	Love and Whelchel [1957], Jalil [1972], Delatte et al. [2009]	*An. gambiae*	Bayoh and Lindsay [2003]
EFD	fecundity	*Aedes aegypti*	Joshi et al. [1996]	*Aedes albopictus*	Calado and Navarro-Silva [2002], Delatte et al. [2009]
μ	mosquito mortality rate	*Aedes aegypti*, *An. superpictus*	Joshi et al. [1996], Aytekin et al. [2009] Costantini et al 1996, Gary & Foster 2004, Impoinvil et al 2004, Midega et al 2007, Okech et al 2003	*An. gambiae*	Bayoh [2001]
bc	vector competence	*P. relictum* in *Culex quinquefasciatus*	LaPointe et al. [2010]	*P. vivax* in *An. quadrimaculatus*	Stratman-Thomas [1940]
PDR	parasite development rate	*P. vivax* in *An. quadrimaculatus*, *P. falciparum* in *An. gambiae*	Stratman-Thomas [1940], Cambournac [1942] (see Boyd [1949])	*P. falciparum* in *An. gambiae, An. culicifacies, An. stephensi, An. quadrimaculatus, An. atroparvus*	Boyd and Stratman-Thomas [1933], Knowles and Basu [1943], Siddons [1944], Shute and Maryon [1952], Vaughan et al. [1992], Eling et al. [2001]

Table A.1: Sources of data for each component of R_0, including which species were used, for both the prior and main data sets.

A.2 Functional Forms, and default priors

Name	Functional form	Default Priors	Component
Brière	$\begin{cases} cT(T-T_0)\sqrt{(T_m-T)} & \text{if } T_0 < T < T_m \\ 0 & \text{otherwise} \end{cases}$	$T_0 \sim \text{Unif}(0,24)$ $T_m \sim \text{Unif}(25,45)$ $c \sim \text{Gamma}(1,10)$	a, MDR, PDR, (bc)
Quadratic (ccd)	$\begin{cases} a(T-T_0)(T-T_m) & \text{if } T_0 < T < T_m \\ 0 & \text{otherwise} \end{cases}$	$T_0 \sim \text{Unif}(0,24)$ $T_m \sim \text{Unif}(25,45)$ $-a \sim \text{Gamma}(1,1)$	p_{EA} , EFD, bc
Quadratic (ccu)	$\begin{cases} aT^2+bT+c & \text{if } aT^2+bT+c > 0 \\ 0 & \text{otherwise} \end{cases}$	$a \sim \text{Gamma}(2,2)$ $-b \sim \text{Gamma}(1,1)$ $c \sim \text{Gamma}(2,2)$	μ

Table A.2: Functional forms, default priors, and the components which assumed each form; ccd: concave down, ccu: concave up. T_0 corresponds to the lower temperature at which a function reaches zero, and T_m to the higher temperature at which the function goes to zero. (bc) indicates that vector competence was fit using a Brière function for comparison, but this was not used for the main analysis.

A.3 Informative Priors

After fitting the functional responses to the "prior data", the posterior distributions for each parameter describing the functions were used to obtain informative priors for use with the main data sources. The procedure used was based on a simple moment matching approximation to the posterior distributions, with inflated variances (typically doubling the variance). Moment matching is an approach for estimating a distribution from data by using the calculation of important moments from a set of samples (e.g., the mean and variance) and equating these with the parameters or function of parameters for a particular distribution. This was followed by visual inspection of the posterior distributions of parameters overlaid by the informative prior to confirm that the shape of the informative prior looked like the posterior (especially for cases where the parameter is bounded). In some cases the distributions appeared to be approximately normal, but were bounded due to the nature of the default parameters, and so truncated distributions were used for the priors. For the quadratic curve, the prior for the c parameter was usually chosen to be uninformative even in the second step, as bounding all 3 parameters resulted in poor convergence and mixing.

Comp.	B/Q	Informative Priors
a	B	$T_0 \sim \mathrm{Unif}(0, 24)$, $T_m = 25 + t_m$, $t_m \sim \mathrm{Gamma}(8.45, 0.65)T(, 20)$, $c \sim \mathrm{Exp}(200)$
MDR	B	$T_0 \sim \mathrm{N}(15, 9^2)T(0, 24)$, $T_m \sim \mathrm{N}(37, 2^2)T(25, 45)$, $c \sim \mathrm{Exp}(1000)$
PDR	B	$T_0 \sim \mathrm{N}(14, 3.5^2)$, $T_m = 31 + t_m$, $t_m \sim \mathrm{Gamma}(14.7, 3.1)$, $c \sim \mathrm{Exp}(100)$
p_{EA}	Q	$T_0 \sim \mathrm{N}(12, 5^2)T(0, 24)$, $T_m \sim \mathrm{N}(36, 3^2)T(25, 45)$, $-a \sim \mathrm{Exp}(100)$
EFD	Q	$T_0 \sim \mathrm{N}(17, 3^2)$, $T_m \sim \mathrm{N}(33, 3^2)$, $-a \sim \mathrm{Gamma}(4, 13)$
μ	Q	$a \sim \mathrm{N}(2.3, 0.3^2)$, $-b \sim \mathrm{N}(0.21, 0.02^2)$, $c \sim \mathrm{Gamma}(2, 2)$
bc	Q	$T_0 \sim \mathrm{Gamma}(128, 8)$, $T_m = 30 + t_m$, $t_m \sim \mathrm{Gamma}(42.25, 3.25)$, $-a \sim \mathrm{Exp}(100)$
	B	$T_0 \sim \mathrm{Gamma}(26, 2)$, $T_m = 30 + t_m$, $t_m \sim \mathrm{Gamma}(10, 1)T(, 15)$, $c \sim \mathrm{Exp}(100)$

Table A.3: Informative priors used for the final analysis of each component. B/Q indicates if the component was modelled with a quadratic or Brière function, as specified in Table A.2. $T(a, b)$ indicates that a distribution is truncated below or above a or b, respectively. If truncation occurs only at the upper end, the notation used is $T(, b)$. This notation is taken from JAGS. For definitions of each component see Table A.1 and the main text.

A.4 MCMC in `JAGS`

All of the MCMC simulations were implemented in `JAGS/rjags` [Plummer, 2013]. The basics of the MCMC algorithm can be found elsewhere [e.g. Clark, 2007]. Here we give a few details of our implementation to compliment the example code that can be found in the supplementary files. For each component, we started five independent chains, and initialzed the change with 5000 adaptive samples. After obtaining these samples, we confirmed convergence, or, if it had not converged, increased this initial number of adaptive samples until convergence. We then collected 5000 samples after convergence for each of the five chains, for a total of

25000 samples. These full 25000 samples were used to calculate the posterior distributions for each individual component. For the full analysis (i.e., for the HDP intervals for R_0, and for uncertainty and sensitivity analyses) we thinned the samples, taking every 5th sample, for computational tractability.

A.5 Equations and methods for sensitivity analysis of R_0

Recall that we define R_0 as

$$R_0 = \sqrt{\frac{M}{Nr}\frac{a^2bce^{-\mu EIP}}{\mu}} \tag{A.1}$$

We used a local sensitivity analysis to examine how R_0 depends on temperature, and each component. The full derivative of R_0 with respect to temperature can be found using the chain rule:

$$\begin{aligned}\frac{dR_0}{dt} =& \frac{dR_0}{da}\frac{da}{dt} + \frac{dR_0}{d(bc)}\frac{d(bc)}{dt} + \frac{dR_0}{dEFD}\frac{dEFD}{dt} + \frac{dR_0}{d(e2a)}\frac{d(e2a)}{dt} \\ &+ \frac{dR_0}{dMDR}\frac{dMDR}{dt} + \frac{dR_0}{d\mu}\frac{d\mu}{dt} + \frac{dR_0}{dPDR}\frac{dPDR}{dt}.\end{aligned} \tag{A.2}$$

The derivatives of R_0 with respect to each component are calculated from Equation A.1:

$$\frac{dR_0}{da} = \frac{R_0}{a} \tag{A.3}$$

$$\frac{dR_0}{d(bc)} = \frac{R_0}{2(bc)} \tag{A.4}$$

$$\frac{dR_0}{dEFD} = \frac{R_0}{2EFD} \tag{A.5}$$

$$\frac{dR_0}{d(e2a)} = \frac{R_0}{2(e2a)} \tag{A.6}$$

$$\frac{dR_0}{dMDR} = \frac{R_0}{2MDR} \tag{A.7}$$

$$\frac{dR_0}{d\mu} = \frac{R_0}{2}\left(\frac{-3}{\mu} - \frac{1}{PDR}\right) \tag{A.8}$$

$$\frac{dR_0}{dPDR} = \frac{R_0\mu}{2(PDR)^2} \tag{A.9}$$

The derivatives of each component with respect to temperature depends on the particular temperature response chosen (Table A.2). For the basic quadratic response (for EDF):

$$\frac{d(\cdot)}{dT} = \begin{cases} a(2T - T_0 - T_m) & \text{if } T_0 < T < T_m \\ 0 & \text{otherwise} \end{cases} \tag{A.10}$$

which is further modified for the responses truncated at 0 and 1 such that this derivative must be zero if $a(T - T_0)(T - T_m) > 1$. For concave up responses (μ):

$$\frac{d(\cdot)}{dT} = \begin{cases} 2aT + b & \text{if } aT^2 + bT + c > 0 \\ 0 & \text{otherwise.} \end{cases} \tag{A.11}$$

Similarly, for the Brière function

$$\frac{d(\cdot)}{dT} = \begin{cases} c(-5T^2 + 3TT_0 + 4TT_m - 2T_0T_m)/(2\sqrt{(T_m - T)}) & \text{if } T_0 < T < T_m \\ 0 & \text{otherwise.} \end{cases}$$

When fitting bc with a Brière function, we must truncate this at 1, *i.e.* the derivative is zero if $cT(T - T_0)\sqrt{(T_m - T)} > 1$.

Combining the appropriate functions for each component thus gives the full derivative with respect to temperature for R_0. By plugging the posterior samples for each component into this formula we are able to obtain the full posterior distribution for $\frac{dR_0}{dt}$. That is, we obtain the i^{th} posterior sample of R_0 by plugging the i^{th} posterior sample of each component's parameters into the formula. If we are interested in how the uncertainty in the j^{th} component contributes to the overall uncertainty, we set all but the j^{th} component to its mean response (*i.e.*, we find the posterior mean of each component AND the posterior mean of the derivative of that component to temperature), and only plug in the posterior samples of the focal component. We can then calculate the width of the 95% highest posterior density (HPD) interval across temperatures, and compare the width of $\frac{dR_0}{dt}$ overall to its width when only one component is allowed to vary. Due to the nature of the numerical approximation (and the fact that the means of the components are NOT the same as any of the individual trajectories), it is possible that at the edges of the range of R_0, the calculated width of the full posterior of $\frac{dR_0}{dt}$ can be numerically zero before the HPD interval of the single component interval is zero. Thus, we add a very small constant, ϵ, to the denominator to keep the ratio from artificially going to infinity.

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