Optimizing malaria vector control in the Greater Mekong Subregion: A systematic review and mathematical modelling study to identify desirable intervention characteristics

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1 Equations in the intervention model

We use an *Anopheles* feeding cycle model first described in Chitnis et al. [1] and Briët et al. [2]. The framework for intervention effects has previously been utilized and described in Denz et al. [3] and Fairbanks et al. [4]. Here we provide an overview of these frameworks. A detailed description of parameters are listed in Table S1.

Vectorial capacity are calculated as

$$\Psi_{ij} = \overbrace{\frac{N_{v0}}{1-P_A-P_{df}}}^{\Psi_{ij}^{(A)}} \times \overbrace{\frac{P_{A^j}P_{B_j}P_{C_j}P_{D_j}P_{E_j}}{N_j}}^{\Psi_{ij}^{(B)}} \times \overbrace{\left[\left(\sum_{h=0}^{k_+}\binom{\theta_s-(h+1)\tau+h}{h}P_A^{\theta_s-(h+1)\tau}P_{df}^{h}\right)\right.}^{\Psi_{ij}^{(C)}\ldots}$$
$$\underbrace{\left.+\sum_{l=1}^{\tau-1}\left(\sum_{h=0}^{k_{l+}}\binom{(\theta_s+l)-(h+2)\tau+h}{h}P_A^{(\theta_s+l)-(h+2)\tau}P_{df}^{h+1}\right)\right]}_{\ldots\Psi_{ij}^{(C)}} \times \underbrace{\frac{P_{A^i}P_{B_i}}{1-P_A-P_{df}}}_{\Psi_{ij}^{(D)}}. \quad (1)$$

In the vectorial capacity equation, $\Psi_{ij}^{(A)}$ represents the number of mosquitoes seeking for a host in a single day, $\Psi_{ij}^{(B)}$ indicates the probability of mosquitoes bite a type j host during that day and live through a feeding cycle, $\Psi_{ij}^{(C)}$ is the probability of mosquitoes survive enough time to become infective, and the total number of potential bite on type i host is calculated as $\Psi_{ij}^{(D)}$ [1].

The host availability rates are calculated as

$$\alpha_i = \frac{1}{N_i}\left(\frac{P_{A^i}}{1-P_A}\right)\left(\frac{-\ln P_A}{\theta_d}\right). \quad (2)$$

Derivation of host availability rate can be found in Additional file 2 in Briët et al. [2].

Then we can consider the intervention effects as

Host availability rate of protected hosts:

$$(1-min(\beta_r+\beta_m+\beta_d,1))\times\alpha_{Hb},$$

where α_{Hb} is the availability rate of a human host not protected by the intervention, β_r is the repelling effect, β_m preprandial killing effect, and β_d is the disarming effect. The reduction in biting is set to a maximum of 1, since the host availability rate is larger than or equal to 0.

Probability of surviving to lay eggs after biting a protected human host:

$$(1-\xi) \times P_c,$$

where P_c is the probability for a mosquito that finds a resting place after biting a unprotected human host and ξ is the probability a mosquitoes, which would have survived biting a human host without the intervention, dies postprandially if they bite a protected host.

Rate of disarming or preprandial killing: This is modelled as a dummy host, which does not contribute to malaria transmission, with an availability rate of

$$(\beta_m + \beta_d) \times \alpha_{Hb}. \tag{3}$$

Probability of surviving to lay eggs, given the mosquito is preprandially killed or disarmed:

$$\left(\frac{\beta_d}{\beta_d + \beta_m}\right).$$

References

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Table S1: Detailed parameter definition, default value and range of vectorial capacity model and intervention model.

Symbol	Parameter definition	Default value	Range	Ref.
	Bionomic parameters			
χ	Human blood index	0.5	(0.01, 1)	
M	Parity proportion	0.5	(0.39, 0.78)	
A_0	Sac proportion	0.5	(0.16, 0.88)	
τ	Resting period duration	3 days	(2, 6)	
	Standard parameters			
θ_d	Maximum time a mosquito unsuccessfully searches for a blood meal per day	0.33 days		[2]
θ_s	Duration of the extrinsic incubation period	10 days		[2]
P_B	Probability that a mosquito bites after encountering a host	0.95		[2]
P_C	Probability that a mosquito finds a resting place after biting	0.95		[2]
P_D	Probability that a mosquito survives the resting phase	0.99		[2]
P_E	Probability that a mosquito lays eggs and returns to host-seeking	0.88		[2]
N	Total number of hosts	1000		
N_{v0}	Total number of emerging mosquitoes that survive to seek for blood meal each day			
	Derived parameters			
P_A	Probability of a mosquito that does not find a host or die after searching for blood meal for one night			
P_{A^i}	Probability of a mosquito finds a type i host during one night blood meal search			
P_{df}	Probability of a mosquito encounters a host and live through the whole feeding cycle			
P_f	Probability of a mosquito lives through a feeding cycle			
	Intervention parameters			
β_r	Repelling effect		(0, 0.6)	[4]
β_d	Disarming effect		(0, 0.6)	[4]
β_m	Preprandal killing effect		(0, 0.6)	[4]
ξ	Postprandal killing effect		(0, 0.4)	[4]

2 Geographical distribution figures

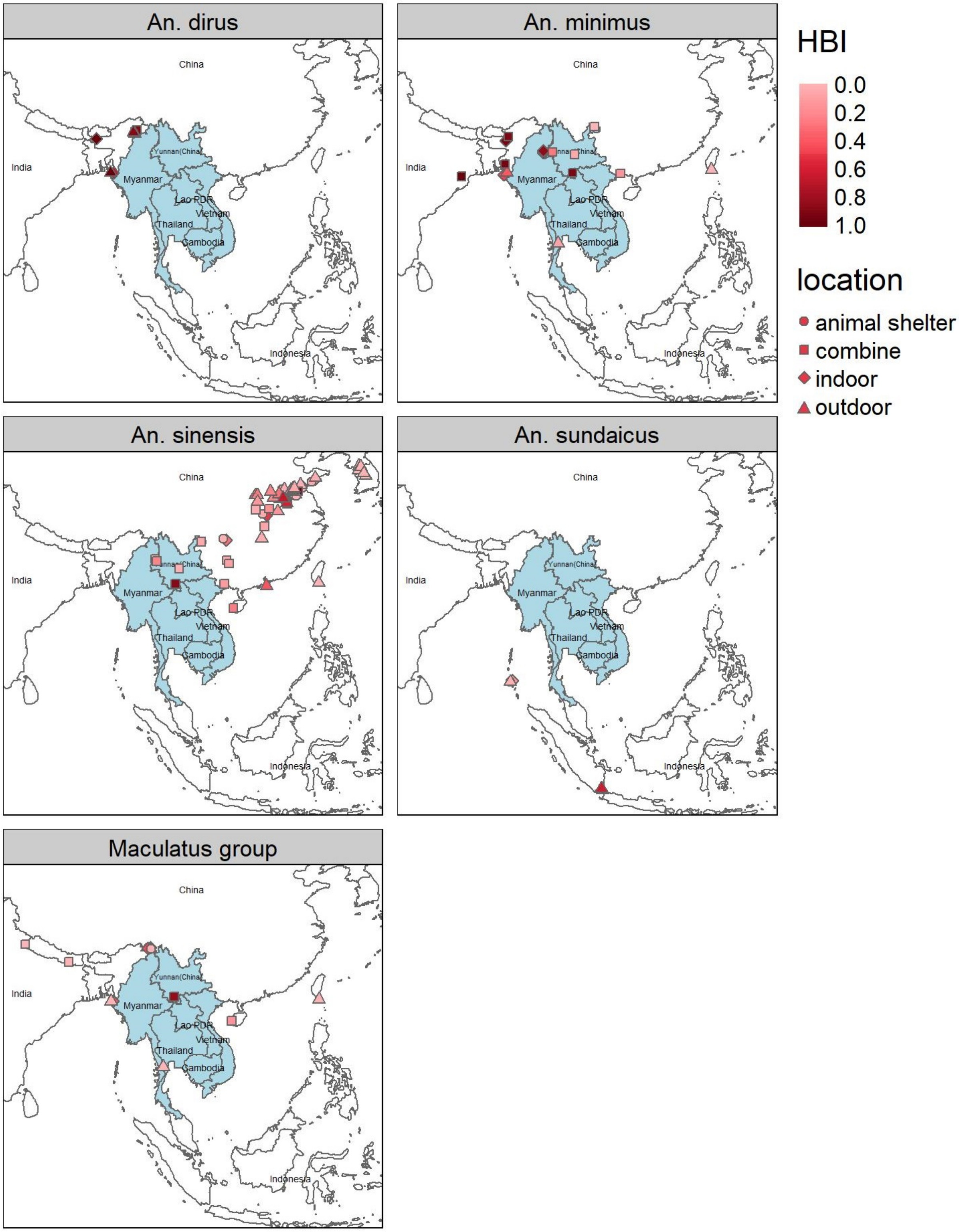

Figure S1: Geographic distribution of HBI data points for different species complexes

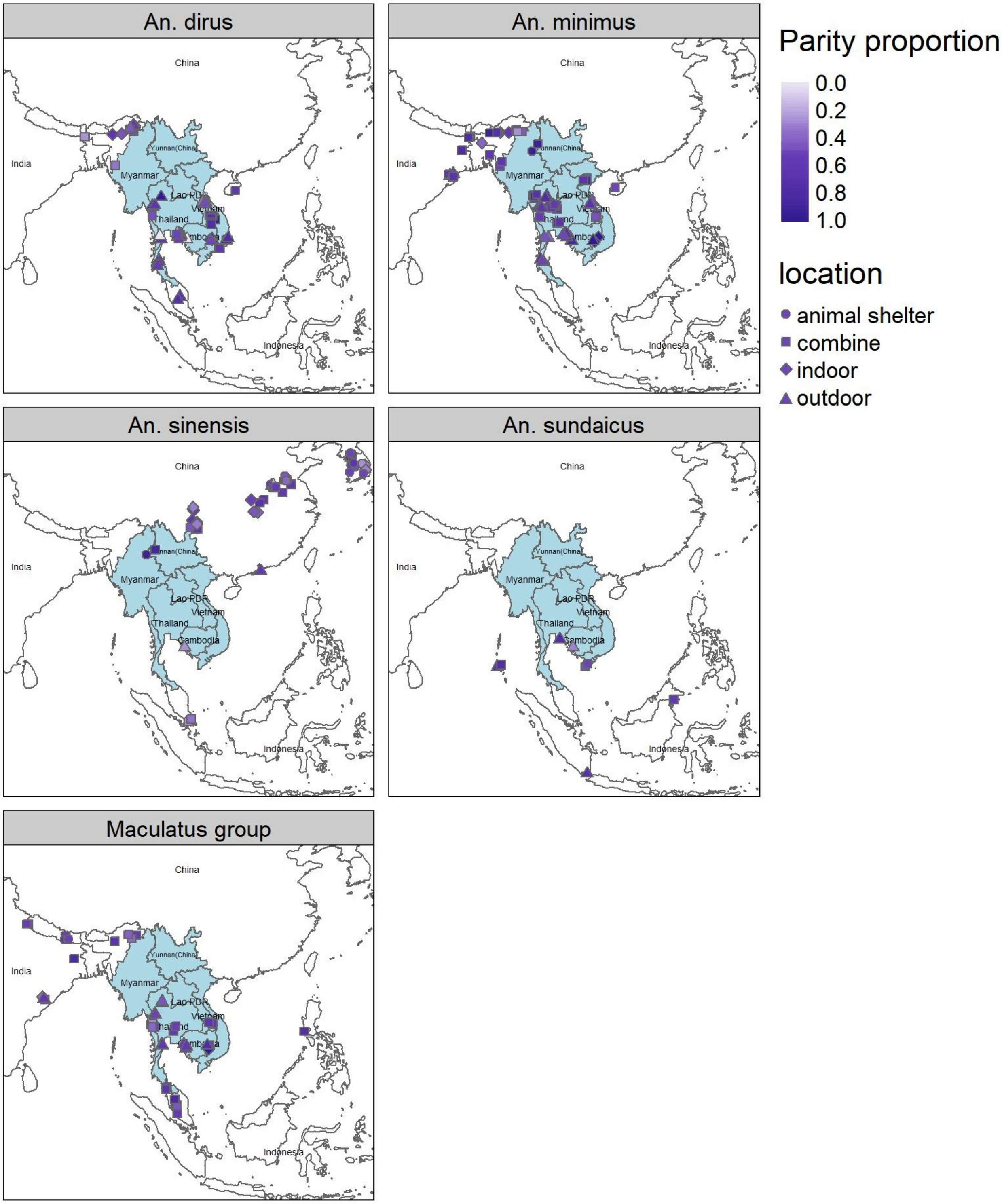

Figure S2: Geographic distribution of parity proportion data points for different species complexes

3 Parity rate logistic regression results

Table S2: Univariate and multivariate regression results for parity proportion.

Variable		OR (univariate)	OR (multivariate)
Species complex	Maculatus group	-	-
	An. dirus	1.72 (1.65–1.79, p<0.001)	1.18 (1.06–1.30, p=0.002)
	An. minimus	1.40 (1.36–1.45, p<0.001)	1.91 (1.70–2.15, p<0.001)
	An. sinensis	1.28 (1.24–1.32, p<0.001)	1.10 (1.02–1.19, p=0.017)
	An. sundaicus	1.37 (1.30–1.45, p<0.001)	1.21 (1.12–1.32, p<0.001)
Insecticide	No	-	-
	Yes	0.87 (0.85–0.89, p<0.001)	0.82 (0.79–0.85, p<0.001)
Season	Dry	-	-
	Rainy	0.86 (0.83–0.89, p<0.001)	0.99 (0.94–1.03, p=0.509)
	Both	0.80 (0.77–0.83, p<0.001)	0.92 (0.87–0.96, p<0.001)
Location	Indoor	-	-
	Animal shelter	1.48 (1.39–1.58, p<0.001)	1.33 (1.20–1.46, p<0.001)
	Combined	1.09 (1.05–1.14, p<0.001)	1.10 (1.04–1.17, p<0.001)
	Outdoor	1.48 (1.42–1.55, p<0.001)	1.24 (1.15–1.32, p<0.001)
Method	Biting (whole night)	-	-
	Biting (half night)	1.13 (1.07–1.19, p<0.001)	0.82(0.77–0.88, p<0.001)
	Combined	0.98 (0.95–1.00, p=0.079)	1.20 (1.13–1.26, p<0.001)
	Light trap	1.30 (1.24–1.37, p<0.001)	1.18 (1.08–1.28, p<0.001)
	Odour trap	1.03 (0.94–1.13, p=0.552)	0.48 (0.17–1.33, p=0.158)
	Resting	0.92 (0.88–0.96, p<0.001)	1.00 (0.94–1.07, p=0.958)
Land use	Herb	-	-
	Cropland	0.82 (0.79–0.85, p<0.001)	1.18 (1.09–1.27, p<0.001)
	Forest	0.81 (0.79–0.84, p<0.001)	1.22 (1.14–1.31, p<0.001)
	Forest/cropland	0.85 (0.81–0.89, p<0.001)	1.17 (1.08–1.26, p<0.001)
	Urban	0.71 (0.63–0.80, p<0.001)	1.16 (0.90–1.49, p=0.258)
Climate	Temperate	-	-
	Cold	1.33 (1.28–1.37, p<0.001)	1.09 (1.03–1.16, p=0.005)
	Tropical	1.21 (1.18–1.25, p<0.001)	1.17 (1.08–1.27, p<0.001)
	An. dirus:tropical		1.57 (1.40–1.77, p<0.001)
	An. minimus:tropical		0.72 (0.64–0.81, p<0.001)
	An. sinensis:tropical		0.36 (0.25–0.51, p<0.001)

4 Sensitivity analysis results

Table S3: Sobol's second order index

Parameters	Index (95% confidence interval)
HBI . parity	0.14 (0.10–0.18)
HBI . sac	0.00 (-0.01–0.01)
HBI . resting duration	0.06 (0.04–0.09)
Parity . sac	0.05 (-0.02–0.14)
Parity . resting duration	0.09 (0.05–0.13)
Sac . resting duration	0.05 (0.02–0.07)