Supplementary materials for "The assembly effect: the connectedness between populations is a double-edged sword for public health interventions"

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Methods

Model structure

The general model structure for a patch can be seen in Figure 1 which is mathematically represented by the set of equations below.

$$\frac{dS_i}{dt} = \mu P_i - \mu_{out} S_i + \omega R_i - \lambda_i S_i + \omega_D S_{Di} - m_i S_i$$

$$\frac{dI_{C_i}}{dt} = \mu_C P_i - \mu_{out} I_{C_i} + p_S(1-\tau)\lambda_i S_i + p_R(1-\tau)\lambda_i R_i + p_R(1-\tau)\lambda_i I_{U_i} + p_R(1-\tau)\lambda_i I_{A_i} - \nu_C I_{C_i} - m_i I_{C_i}$$

$$\frac{dI_{A_i}}{dt} = \mu_A P_i - \mu_{out} I_{A_i} + (1-p_S)\lambda_i S_i + (1-p_R)\lambda_i R_i + (1-p_R)\lambda_i I_{U_i} - p_R\lambda_i I_{A_i} + \nu_C I_{C_i} - \nu_A I_{A_i} + f\nu_T T_i - m_i I_{A_i}$$

$$\frac{dI_{U_i}}{dt} = \mu_U P_i - \mu_{out} I_{U_i} - \lambda_i I_{U_i} - \nu_U I_{U_i} + \nu_A I_{A_i} - m_i I_{U_i}$$

$$\frac{dR_i}{dt} = -\mu_{out} R_i - \omega R_i - \lambda_i R_i + \nu_U I_{U_i} + \omega_D R_{D_i} - m_i R_i$$

$$\frac{dT_i}{dt} = -\mu_{out} T_i + p_S\tau\lambda_i S_i + p_R\tau\lambda_i R_i + p_R\tau\lambda_i I_{U_i} + p_R\tau\lambda_i I_{A_i} - \nu_T T_i + m_i\left(I_{C_i} + I_{A_i} + I_{U_i}\right)$$

$$\frac{dS_{D_i}}{dt} = -\mu_{out} S_{D_i} + \omega R_{D_i} - \omega_D S_{D_i} + m_i S_i$$

$$\frac{dR_{D_i}}{dt} = -\mu_{out} R_{D_i} - \omega R_{D_i} + (1-f)\nu_T T_i - \omega_D R_{D_i} + m_i(R_i)$$

where $P_i = S_i + S_{D_i} + I_{C_i} + I_{A_i} + I_{U_i} + R_i + R_{D_i} + T_i$.

The description and assumed values of the parameters can be found in Table 1.

The two patches are connected through the λ term (see Figure 1 in the main manuscript) which is influenced by the level of connectedness, C, as described by the equation below.

$$\lambda_i = (1 - C)\,\beta_i \left(\frac{I_i}{P_i}\right) + \frac{C}{2}\frac{(\beta_1 + \beta_2)\,(I_1 + I_2)}{(P_1 + P_2)}$$

Where $C \in (0,1)$.

Therefore, when C=0,

$$\lambda_1 = \beta_1 \left(\frac{I_1}{P_1}\right), \lambda_2 = \beta_2 \left(\frac{I_2}{P_2}\right)$$

And when C=1,

$$\lambda_1 = \lambda_2 = \frac{0.5(\beta_1 + \beta_2)(I_1 + I_2)}{P_1 + P2}$$

For brevity, all the sub-compartments of *I* are not shown in the equation. β is the contact rate between mosquito and human, adjusted by the effectiveness and coverage parameters of insecticide treated nets ($\zeta_{ITN}, \kappa_{ITN}$). Coverage and effect of early diagnosis and treatment is modelled through the parameter τ. Mass drug administration (MDA) is modelled for three months during which $m_i = -\frac{\ln(1-\kappa_{m_i})}{3}$. m_i moves individuals from S and R to their respective compartments with active drug, and individuals from I to T (Figure 2).

Model validation

The parameters for the model are calibrated based on the data from Parker et al.[2] In order to do so, we simulated a scenario with the MDA coverages corresponding to the two parts of the village as in [2]. Human biting rate and the size of the patches were assumed to be the same.

In the result of this scenario analysis (Figure 3), the red line indicates that no elimination threshold would be achieved in the part of the village with lower MDA coverage (64%), at all level of connectedness. But because the two patches were from a single village, the connectedness would be close to 100%. At this connectedness

level, both parts of the village will not achieve the elimination threshold. Therefore, the model can explain why there were clinical cases throughout the village 12 months after the completion of the MDA. Table 1 lists of all other model parameter values.

Figures

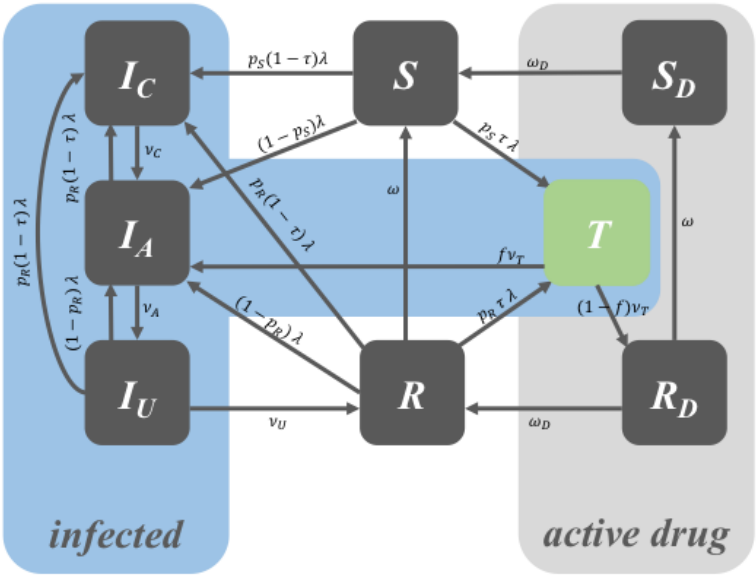


Figure 1: General structure of the compartmental model. Reproduced from our previous manuscript Tun et al. 2017

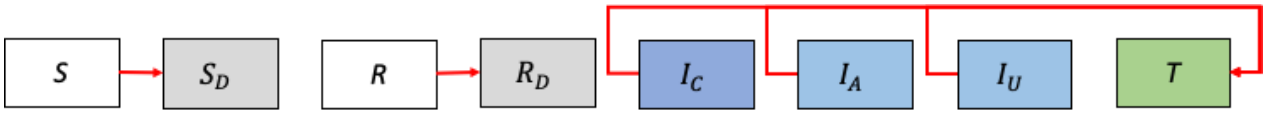


Figure 2: Consequence of MDA, revised from Tun et al 2017

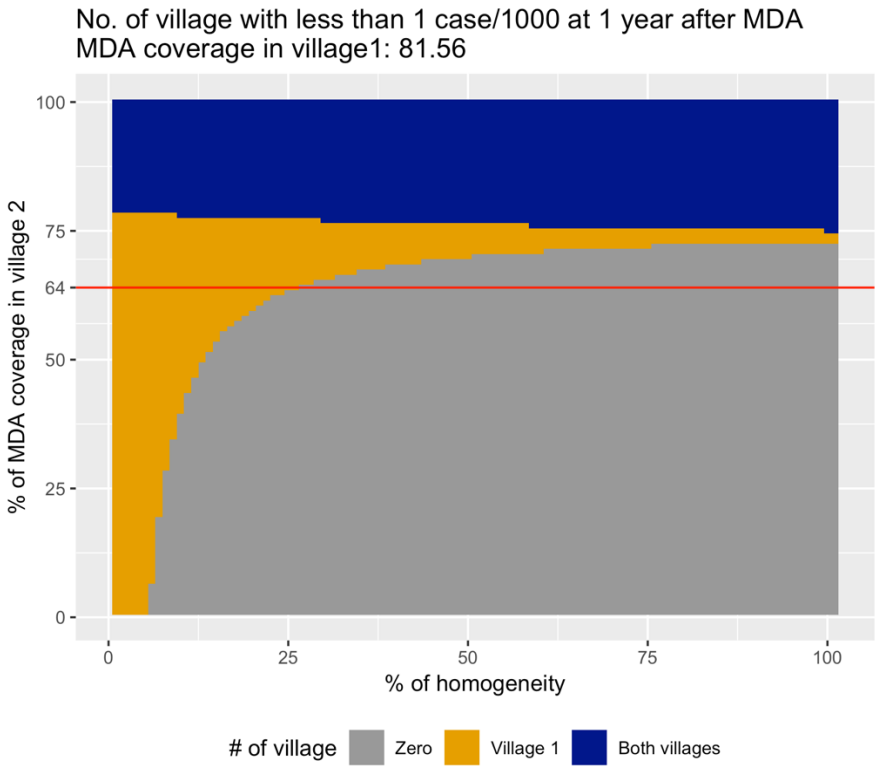
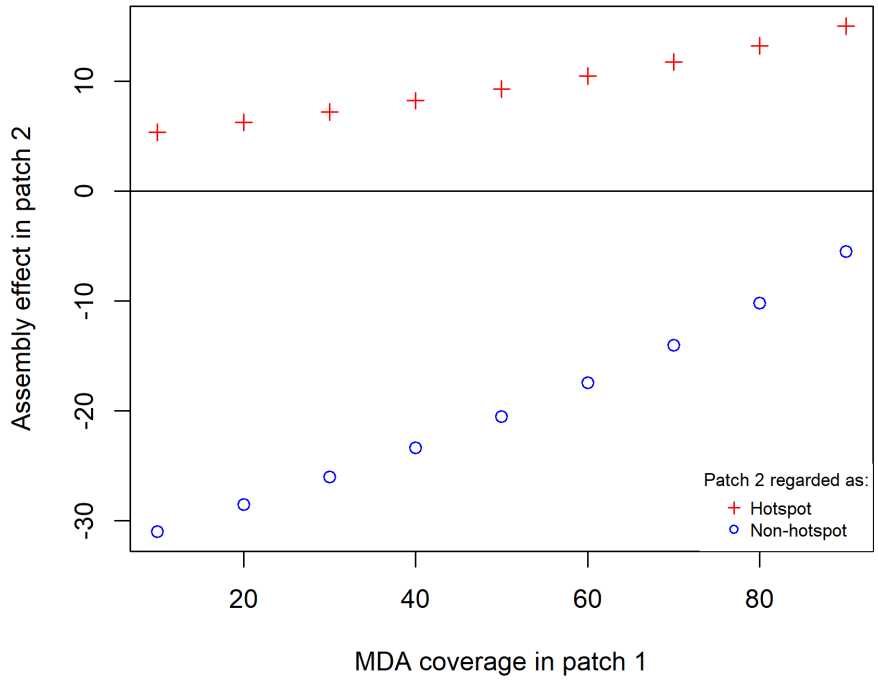


Figure 3: Result of the model calibration based on Parker et al. 2019



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81 *Figure 4: Assembly effects between a hotspot and a non-hotspot. The non-hotspot has 25% lower pre-intervention incidence*

82 *compared to the hotspot.*

Tables

#	Name	Description	Value	Unit	Reference
1	ζ_{ITN}	Effectiveness of ITN (insecticide treated nets), proportion of new infections averted due to ownership of ITN	0.30	proportion	[3]
2	κ_{ITN}	Coverage of ITN	0.70	proportion	-
3	κ_{MSAT}	Coverage of MSAT to prevent case importation from other areas	0.90	proportion	-
4	μ	Birth/death rate	1/69	/year	[4]
5	μ_A	Rate of importation of asymptomatic patent cases from other areas	1	/year/1000	-
6	μ_C	Rate of importation of clinical cases from other areas	1	/year/1000	-
7	μ_{out}	Death rate + emigration rates for malaria cases	-	-	-
8	μ_U	Rate of importation of asymptomatic non-patent cases from other areas	1	/year/1000	-
9	ν_A	Rate of transition from asymptomatic patent state (IA) to asymptomatic non-patent state (IU)	365/60	/year	[5]
10	ν_C	Rate of relief from clinical symptoms in absence of treatment	365/3	/year	[6]
11	ν_U	Rate of transition from asymptomatic non-patent state (IU) to recovered state (R)	365/100	/year	[7]
12	ν_T	Recovery rate after treatment with anti-malarial drug	365/14	/year	[8]
13	ξ_A	Sensitivity of the detecting an asymptomatic, patent (microscopically detectable) case with MSAT	0.87	proportion	-
14	ξ_C	Sensitivity of the detecting a Clinical case with MSAT	0.99	proportion	-
15	ξ_U	Sensitivity of the detecting an asymptomatic, non-patent (microscopically undetectable) case with MSAT	0.44	proportion	[9]

16	ρ_A	Relative infectivity of super-microscopic asymptomatic infections compared with clinical infections	0.55	proportion	[10]
17	ρ_U	Relative infectivity of sub-microscopic asymptomatic infections compared with clinical infections	0.17	proportion	[10]
18	ω	Rate of immunity loss	½	/year	-
19	ω_D	Rate of loss of protection by anti-malarial drug	365/30	/year	-
20	p_R	Proportion of all immune new infections that are clinical	0.20	proportion	[11]
21	p_S	Proportion of all non-immune new infections that are clinical	0.90	proportion	[5]
22	f	Proportion of failed treatment	0.05-0.30	proportion	-

Table 1: Parameter values and descriptions

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