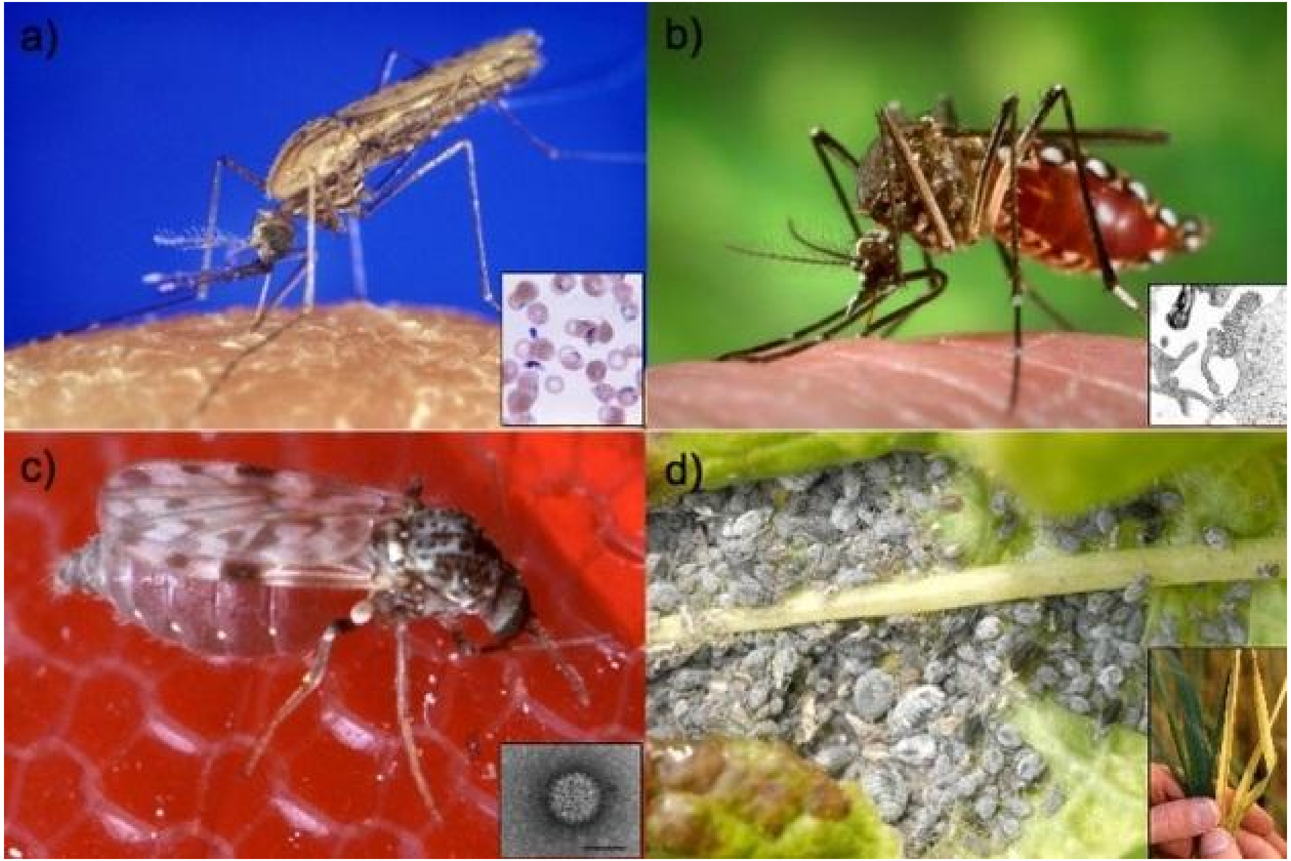
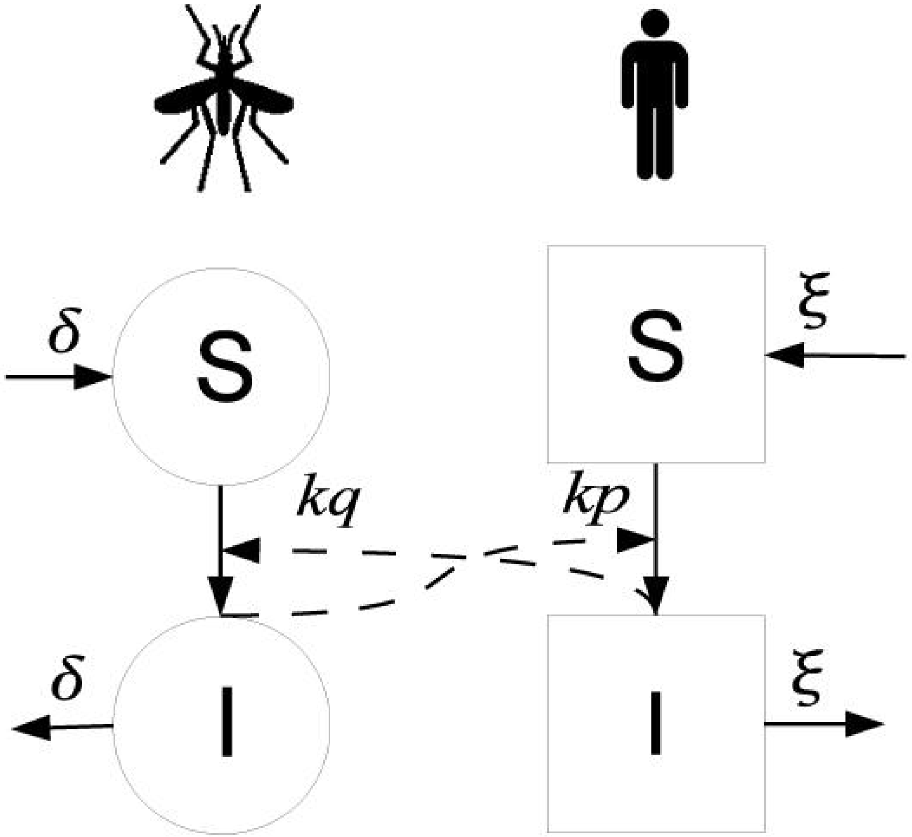
Vector borne disease transmission



Four examples of the vectors and the pathogens causing vector borne diseases

A. *Anopheles gambiae*, the vector of *Plasmodium falciparum*
B. *Aedes aegypti*, the yellow fever mosquito, which transmits the dengue viruses
C. *Culicoides sonorensis*, which transmits bluetongue viruses
D. *Rhopalosiphum padi*, the oat aphid, the vector of the barley yellow dwarf virus, which causes stunting with yellow color in wheat

Magori, K. & Drake, J. M. (2013) The population dynamics of Vector borne diseases. *Nature Education Knowledge* 4(4):14



Magori, K. & Drake, J. M. (2013) The population dynamics of Vector borne diseases. *Nature Education Knowledge* 4(4):14

Ross MacDonald Model

$$\frac{dI_H}{dt} = kpI_V \frac{N_H - I_H}{N_H} - \xi I_H$$

$$\frac{dI_V}{dt} = kq(N_V - I_V)\frac{I_H}{N_H} - \delta I_V$$

State variables
I_H: Infected hosts
I_V: Infected vectors

Parameters
N_H: Host population size
N_V: Vector population size
k: Biting rate
p: Infection probability (V→H)
q: Infection probability (H→V)
ξ: Host recovery rate
δ:Vector mortality rate

Is this density-dependent or frequency-dependent transmission?

Basic reproduction number

Invasion criterion: $R_0>1$

$$R_0 = k^2 \frac{pq}{\delta\xi} \frac{N_V}{N_H}$$

Questions:

1. Why is k squared?
2. Why are p and q multiplied?

Entomological threshold

Rearranging the expression for R_0

$$R_0 = k^2 \frac{pq}{\delta\xi} \frac{N_V}{N_H}$$

we have

$$\frac{N_V}{N_H} > \frac{\xi\delta}{k^2 pq}$$

How would you interpret this inequality?

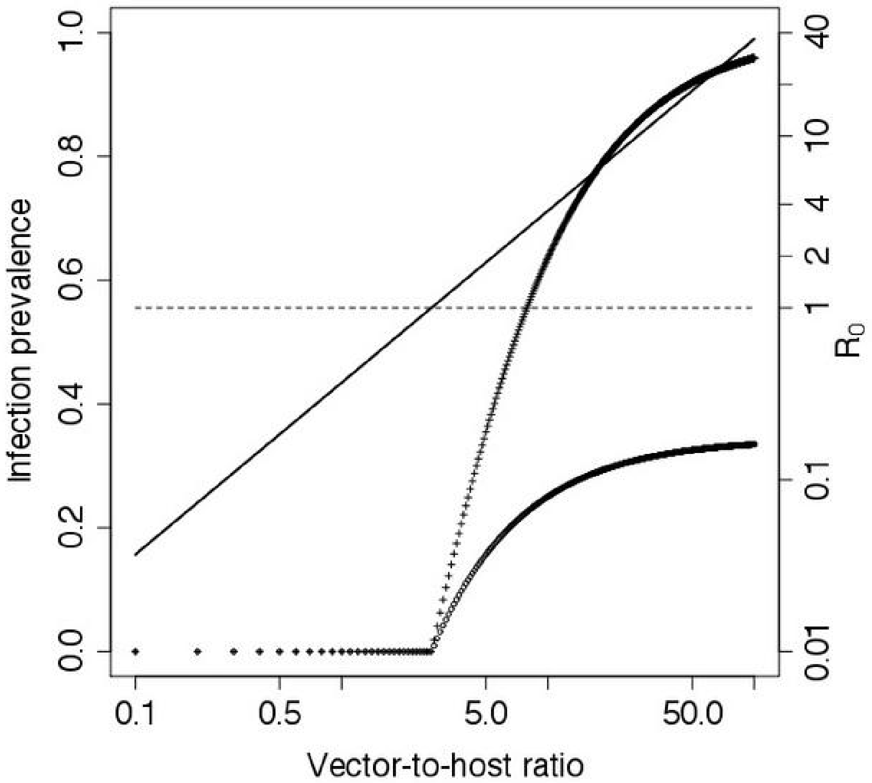
Stationary solution

Figure

- Symbol “+” are infected hosts
- What else can you figure out about this figure?

Assignment (15 minutes)

1. Find a partner
2. Find the endemic equilibrium
3. Solve the equations and verify the equilibrium



Endemic equilibrium

$$\overset{*}{I_V} = \frac{k^2 pqN_V - \delta\xi N_H}{k^2 pq + \delta kp}$$

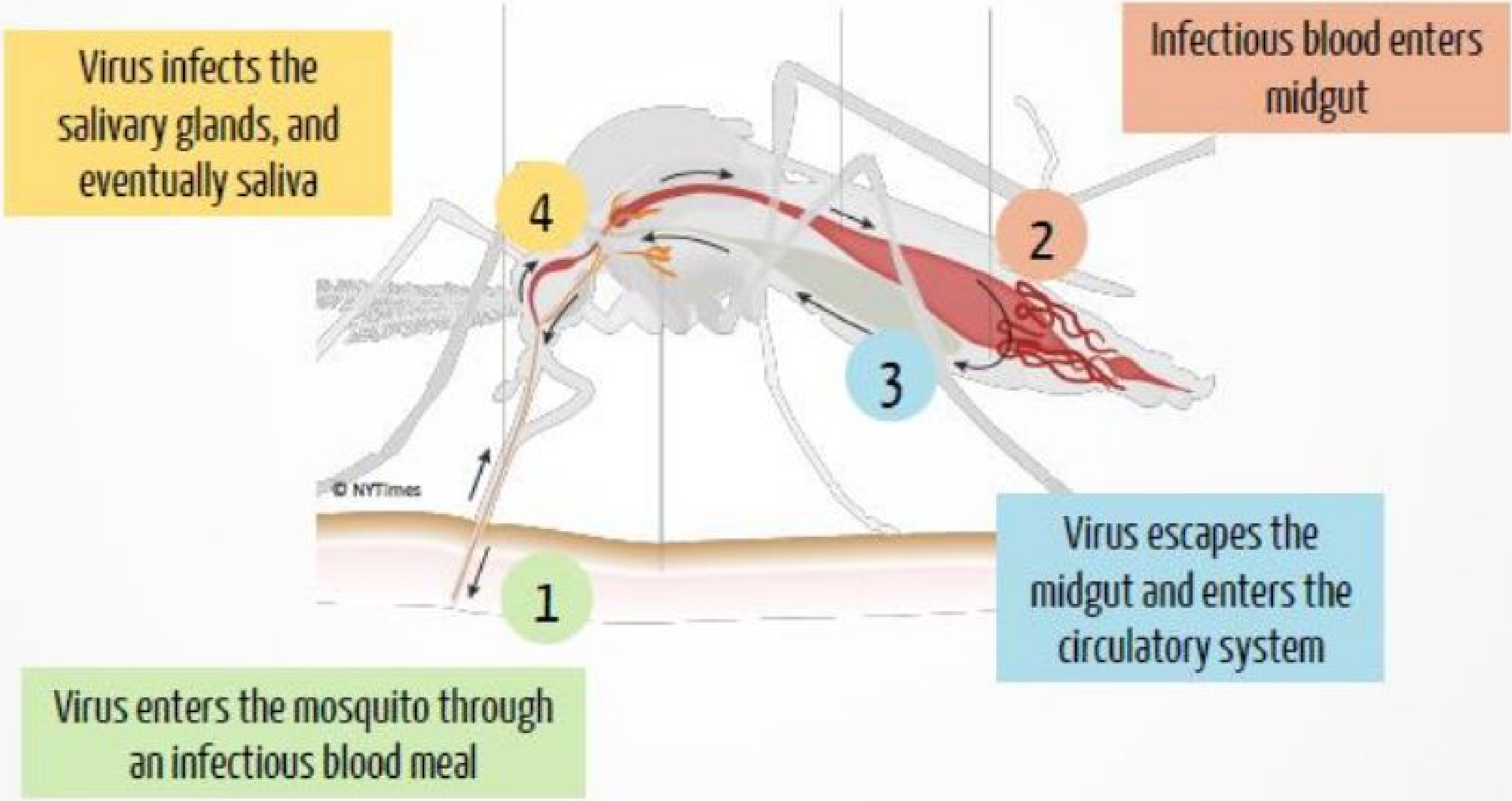
$$\overset{*}{I_H} = \frac{k^2 pqN_V - \delta\xi N_H}{k^2 pq \dfrac{N_V}{N_H} + \xi kp}$$

Entomological inoculation rate

- Number of infective bites per person per unit time - usually measured according to landing rate and prevalence

$$EIR = N_V k(I_V/N_V) = kI_V$$

Vector competence



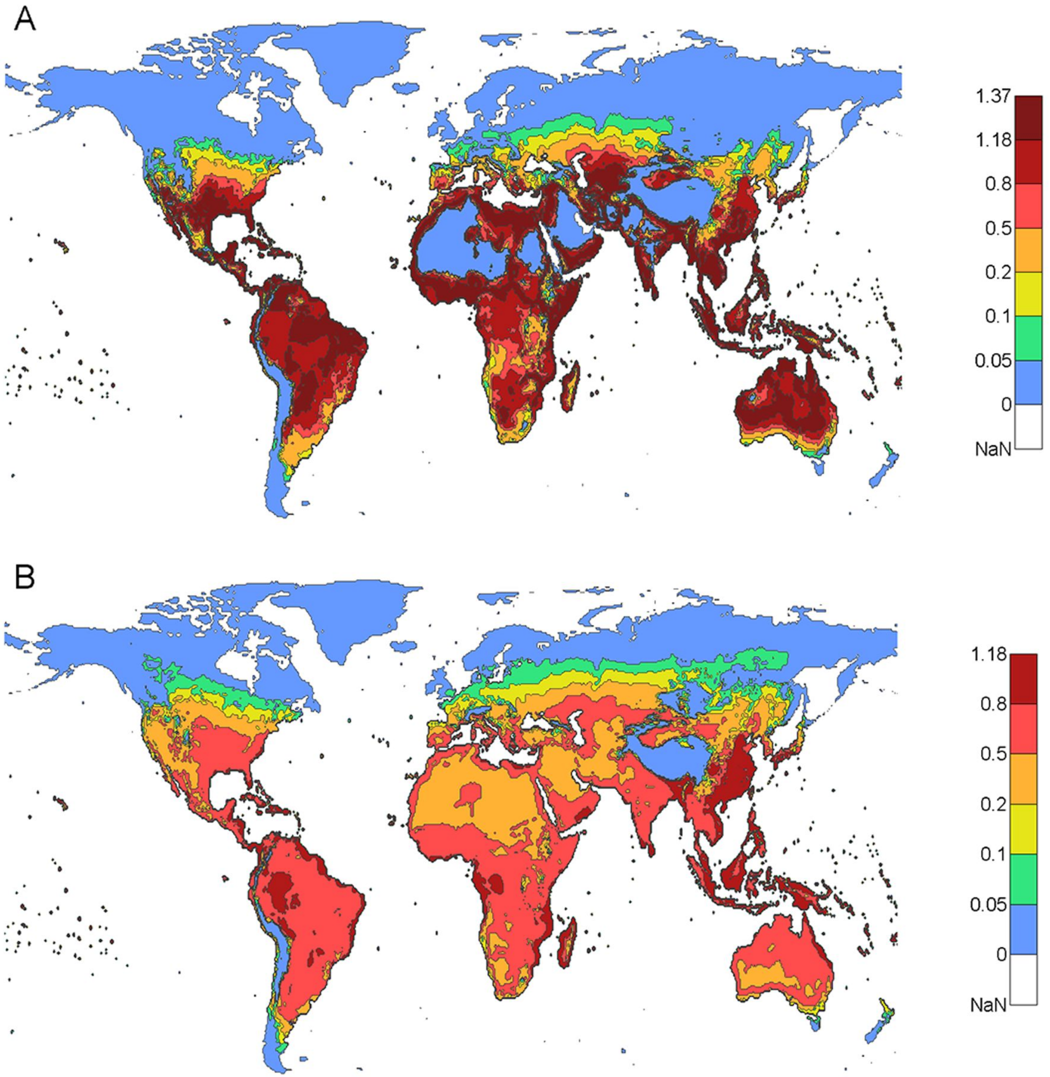
Vectorial capacity

- The rate at which a vector population generates new inoculations from a currently infectious case
- Vectorial capacity is the product of many components
- Vector longevity is a key component
- Usually calculated “relative” to the mosquito-human ratio and accounting for the extrinsic incubation period (time lag between mosquito infection and transmission)

$$V_c = k^2 pqe^{-\delta\theta}/\delta$$

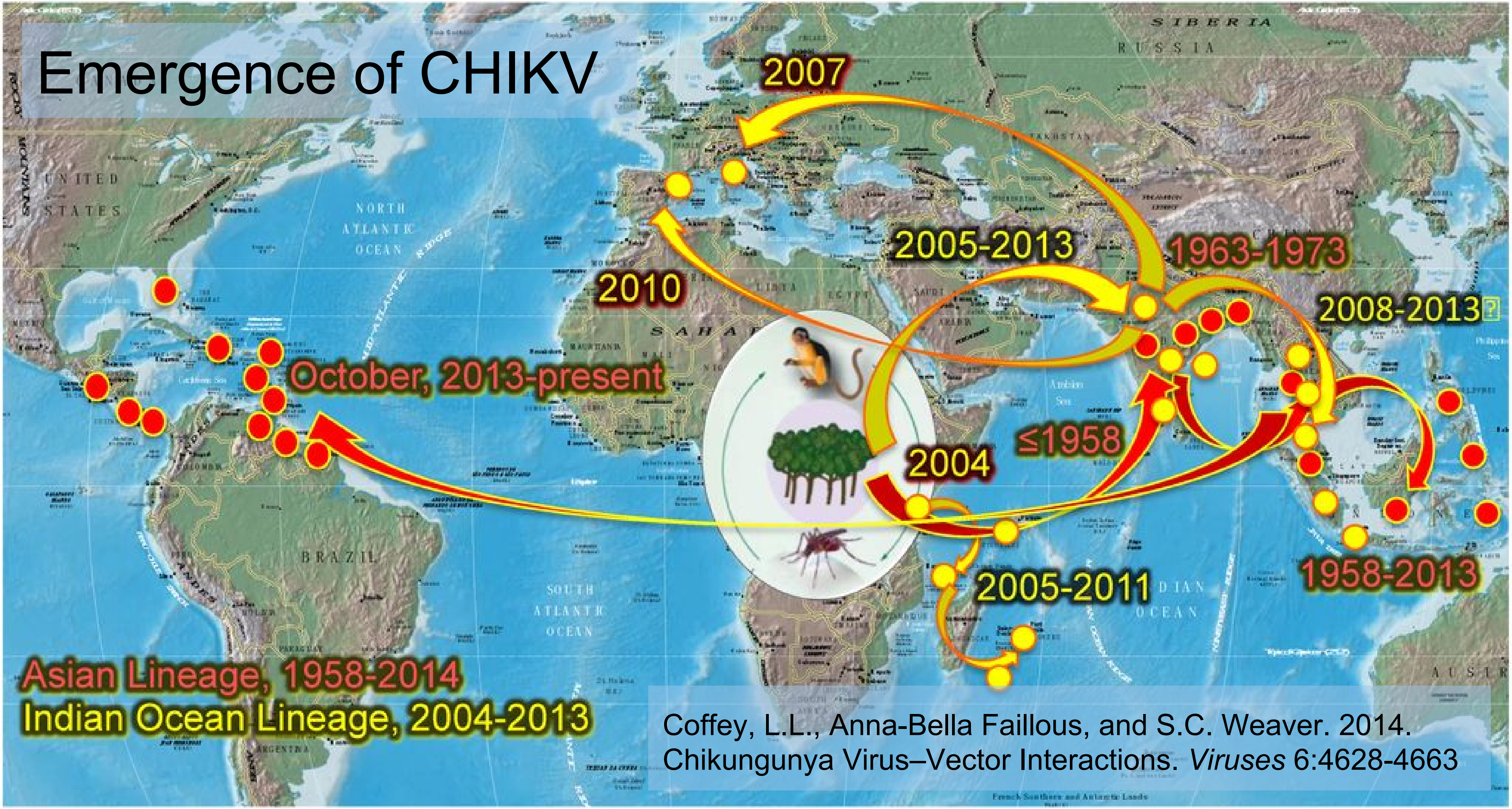
Mapping vectorial capacity for Dengue

The effect of diurnal temperature range on global dengue epidemic potential A) Using only average monthly temperature. B) Using average monthly temperature and diurnal temperature range.



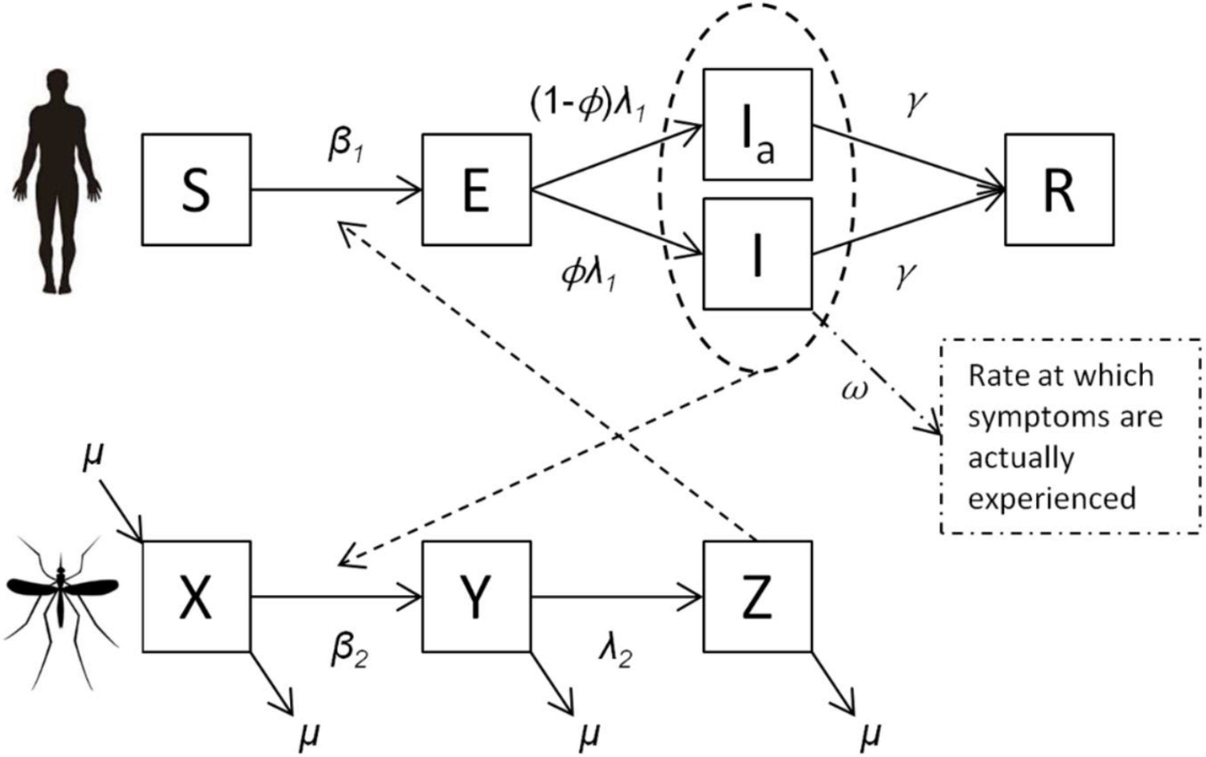
Liu-Helmersson J, Stenlund H, Wilder-Smith A, Rocklöv J (2014) Vectorial Capacity of Aedes aegypti: Effects of Temperature and Implications for Global Dengue Epidemic Potential. PLoS ONE 9(3): e89783.

Emergence of CHIKV



Coffey, L.L., Anna-Bella Faillous, and S.C. Weaver. 2014. Chikungunya Virus–Vector Interactions. *Viruses* 6:4628-4663

Epidemic in Réunion Islands



$$\frac{dS}{dt} = -\beta_1 SZ$$

$$\frac{dE}{dt} = \beta_1 SZ - \lambda_1 E$$

$$\frac{dI}{dt} = \phi\lambda_1 E - \gamma I$$

$$\frac{dI_a}{dt} = (1-\phi)\lambda_1 E - \gamma I_a$$

$$\frac{dR}{dt} = \gamma(I + I_a)$$

$$\frac{dX}{dt} = \mu - \beta_2 X(I + I_a) - \mu X$$

$$\frac{dY}{dt} = \beta_2 X(I + I_a) - \lambda_2 Y - \mu Y$$

$$\frac{dZ}{dt} = \lambda_2 Y - \mu Z$$

Yakob L., Clements A.C.A. 2013. A mathematical model of chikungunya dynamics and control: The major epidemic on Réunion island. *PLOS ONE* 8:e57448.

Parameters

New parameters

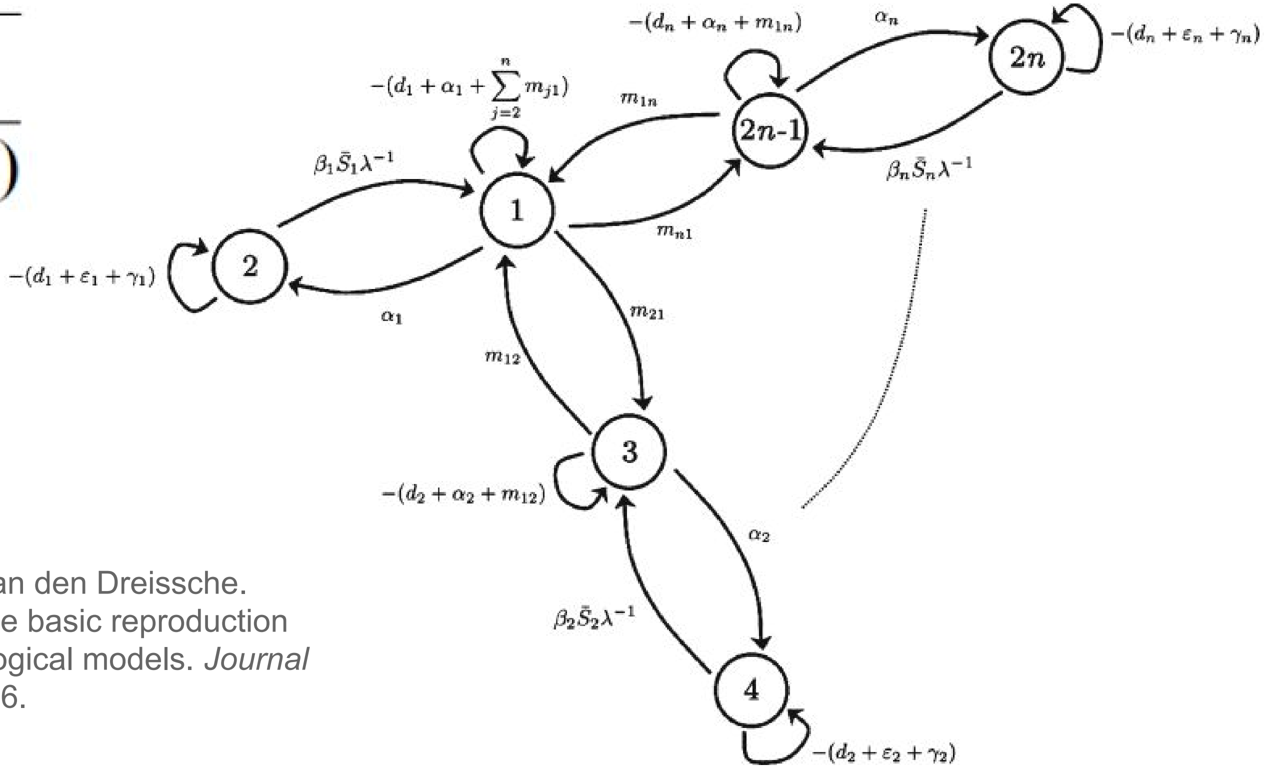
Table 1. The parameters and variables (with units) of the Chikungunya model.

Symbol	Definition (units)
S	Susceptible hosts (proportion)
E	Exposed hosts (proportion)
I	Symptomatically infectious hosts (proportion)
I_a	Asymptomatically infectious hosts (proportion)
R	Recovered hosts (proportion)
X	Susceptible mosquitoes (proportion)
Y	Exposed mosquitoes (proportion)
Z	Infectious mosquitoes (proportion)
β_1	Mosquito-to-human transmission (number of mosquito bites per human per day allowing for imperfect pathogen transmission)
β_2	Human-to-mosquito transmission (per day bite rate also allowing for imperfect pathogen transmission)
ϕ	Hosts that develop symptoms (proportion)
$1/\lambda_1$	Host latent period (from 'infected' to 'infectious', days)
$1/\lambda_2$	Mosquito latent period (from 'infected' to 'infectious', days)
γ	Host recovery rate (per day)
$1/\omega$	Host pre-patent period (from 'infected' to symptoms development, days)
$1/\mu$	Mosquito life span (days)

doi:10.1371/journal.pone.0057448.t001

R_0 from the Next Generation Method

$$R_0 = \sqrt{\frac{\beta_1 \beta_2 \lambda_2}{\gamma \mu (\mu + \lambda_2)}}$$



De Camino-Beck, M. Lewis, and P. van den Dreissche. 2009. A graph-theoretic method for the basic reproduction number in continuous time epidemiological models. *Journal of Mathematical Biology* 59(4):503-516.

Type reproduction number

In this case the TRN is the square of the basic reproduction number

Questions:

- When would this not be true?
- What is the invasion threshold for the TRN?

Model fit

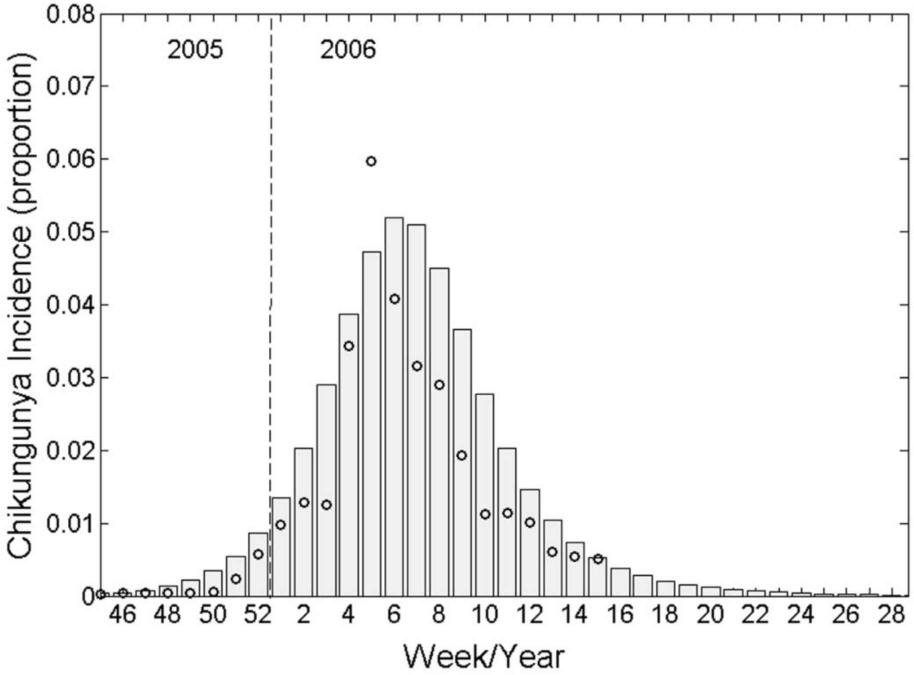


Figure 2. Mathematical model output (bars) fitted to weekly Chikungunya incidence data (circles) collected during the 2005–6 epidemic on Réunion island, Indian Ocean.
doi:10.1371/journal.pone.0057448.g002

Control

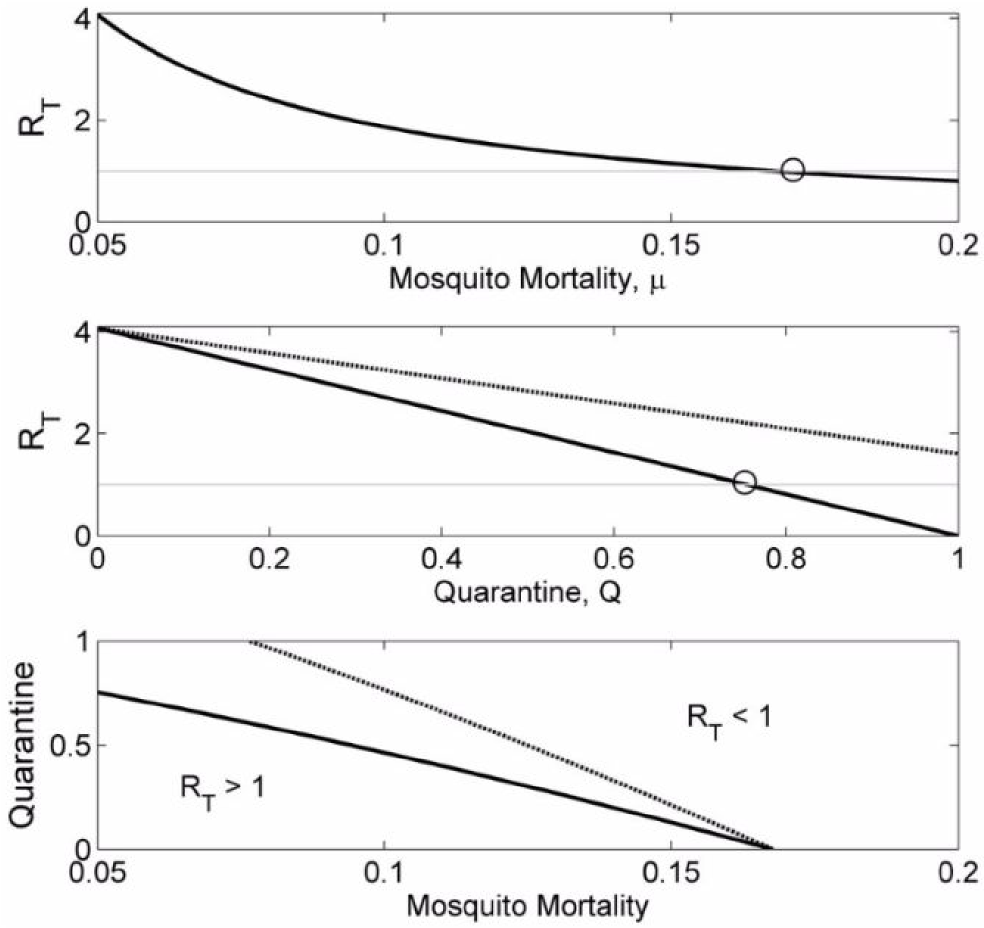
Vector control

Type 1 Quarantine

- Quarantine upon infection

Type 2 Quarantine

- Quarantine upon illness



Key concepts

Transmission by vector implicates two species in the persistence of the virus

New concepts: entomological inoculation rate, type reproduction number, vectorial capacity

Obtaining numerically accurate models may require additional model complexities, but the concepts are the same

Control actions can target either or both species