# Modeling the mitigation of dengue fever, Chikungunya and Zika by infecting mosquitoes with *Wolbachia* bacteria

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# Outlines


1. Mosquito-borne diseases v.s. *Wolbachia*
2. Vertical transmission *Wolbachia* model
3. Numerical simulations of *Wolbachia* mitigation

"Mosquitoes cause more human suffering than any other organism."

– American Mosquito Control Association

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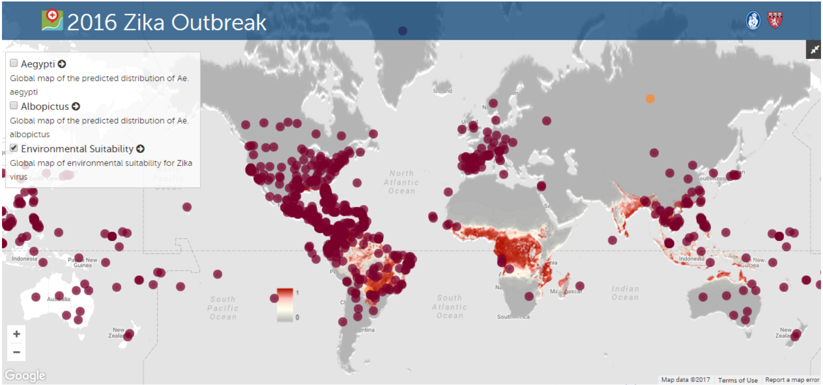

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☹ Eradication failed: lost political importance, no financial support, etc.

☹ The re-infestation of Aedes aegypti keeps happening.

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- a natural parasitic microbe, found in 60% insects, but not in the wild *Aedes aegypti* mosquitoes (reproductive number $< 1$)
- stops the proliferation of harmful viruses inside the mosquito
  $\rightarrow$ reduces the disease transmissions

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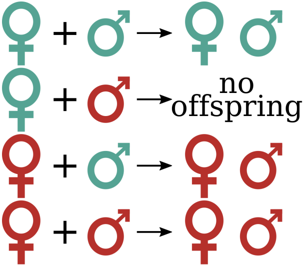
Schematic of the complex vertical transmission mating




uninfected F + uninfected M = uninfected offspring

uninfected F + infected M = no offspring (CI)
cytoplasmic incompatibility

infected F + uninfected M = infected offspring (%)

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Green: uninfected/natural; Red: *Wolbachia*-infected.

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If there is a threshold condition that the *Wolbachia* endemic can take off?

Our approach:

- develop an ODE model to describe the complex transmission cycle
- analyze the critical threshold condition for a sustained *Wolbachia* infected population

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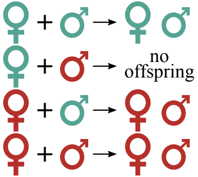
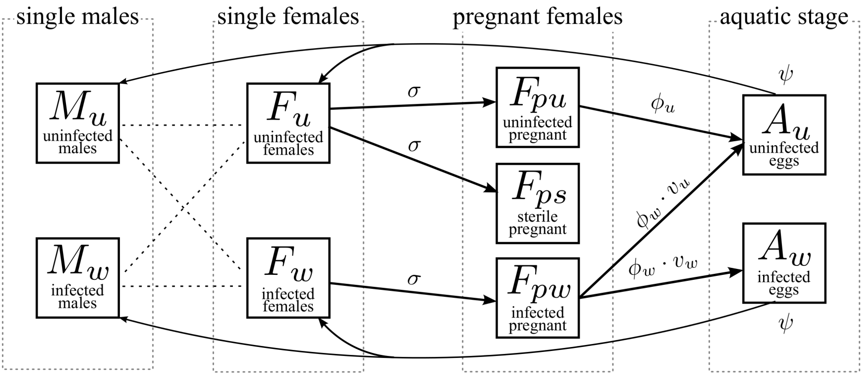
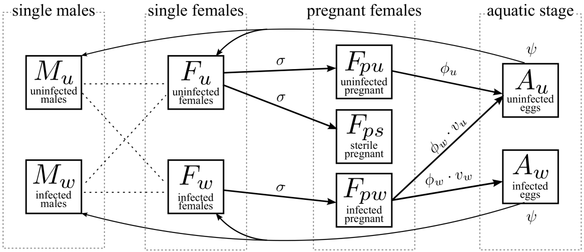
# Our new model captures the complex transmission cycle

by accounting for ...

- heterosexual transmission
- multiple pregnant states for females
- aquatic-life stage with carrying capacity






$\nu_w$: vertical transmission

$\sigma$: mating rate

$\phi_w/\phi_u$: egg laying rates

$\psi$: egg developing rate

single males
$$\begin{cases} \dot{M}_u = b_m\psi A_u - \mu_{mu} M_u \\ \dot{M}_w = b_m\psi A_w - \mu_{mw} M_w \end{cases}$$

single females
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pregnant females
$$\begin{cases} \dot{F}_{pu} = \sigma F_u \dfrac{M_u}{M_u + M_w} - \mu_{fu} F_{pu} \\ \dot{F}_{pw} = \sigma F_w \dfrac{M_u}{M_u + M_w} + \sigma F_w \dfrac{M_w}{M_u + M_w} - \mu_{fw} F_{pw} \end{cases}$$

aquatic stage
$$\begin{cases} \dot{A}_u = (\phi_u F_{pu} + \nu_u \phi_w F_{pw}) \left(1 - \dfrac{A_u + A_w}{K_a}\right) - (\mu_a + \psi) A_u \\ \dot{A}_w = \nu_w \phi_w \left(1 - \dfrac{A_u + A_w}{K_a}\right) F_{pw} - (\mu_a + \psi) A_w \end{cases}$$

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(within one life cycle)

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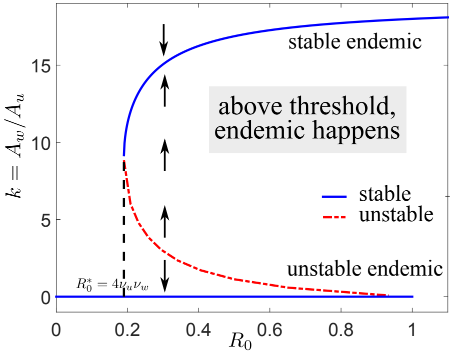
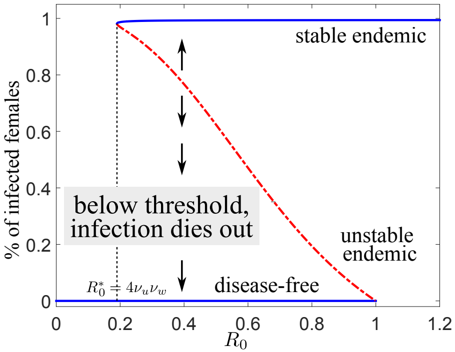
  - There is a critical threshold to maintain *Wolbachia* infection!

# Critical threshold: backward bifurcation




- disease-free equilibrium ($R_0 < 1$): stable
- endemic equilibrium (bifurcated)
  - upper branch ($R_0 > 4\nu_u\nu_w$): stable
  - lower branch ($4\nu_u\nu_w < R_0 < 1$): unstable

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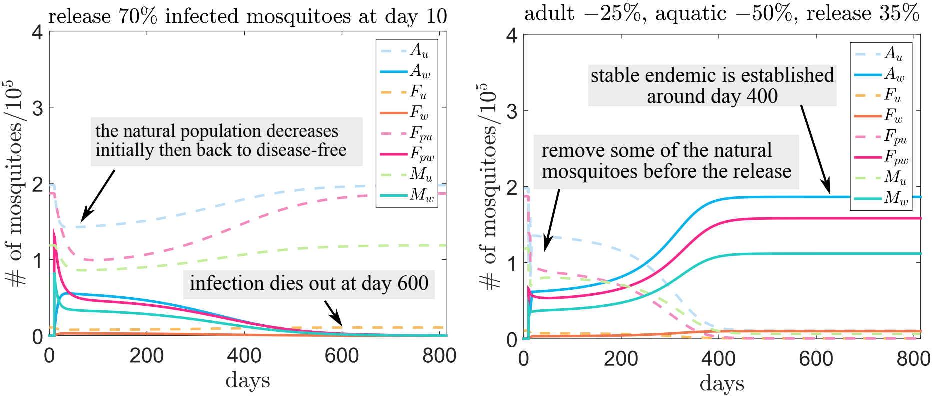


Dashed lines: natural; Solid lines: infected

(The percentage is relative to the initial natural population.)

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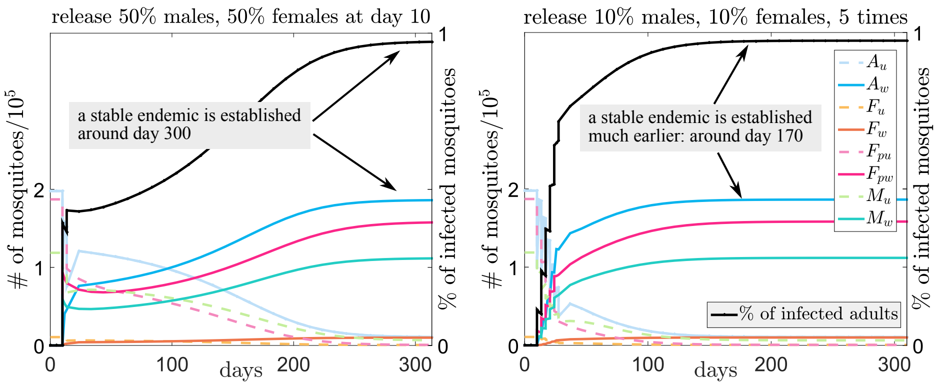


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# Acknowledgment

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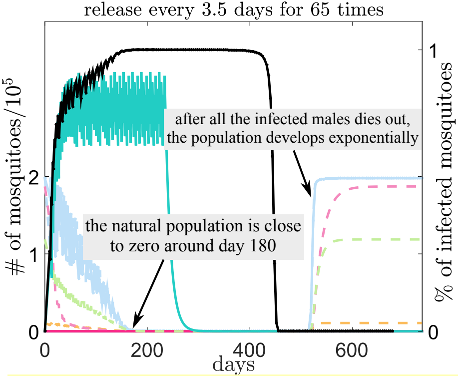
- National Institutes of Health NIGMS/MIDAS Program

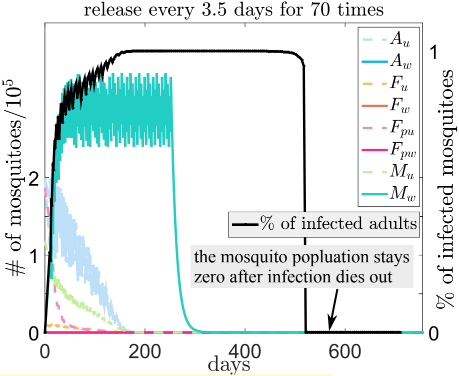
# Thank you!

# Releases of infected males only (to wipe out the population)

♀ + ♂ → no offspring

- requires repetitive releases to wipe out thoroughly
- −25% adult, −50% aquatic, release 80%




Releasing infected males only is not a reliable mitigation strategy

▶ large release quantity ▶ local effect only; the environment is not isolated