Modeling the transmission of *Wolbachia* in mosquitoes for controlling mosquito-borne diseases

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Outlines

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

– American Mosquito Control Association

- dengue fever, chikungunya: high fever, muscle and joint pains, may be life-threatening
- Zika virus: no or only mild symptoms; infection during pregnancy can cause birth defect of brain

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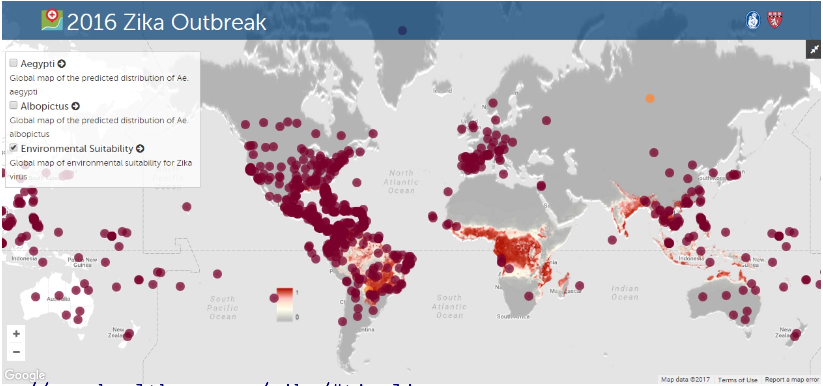

http://www.healthmap.org/zika/#timeline

Aedes aegypti – primary vector for the transmission

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mitigation approaches:

- remove breeding habitats
  - water tank/scrap tires
- introduce natural predators
  - fish to control larvae
- spraying of insecticide (most used)
  - financial cost can be prohibitively high
  - logistically difficult in urban/remote areas
  - evolution of resistance

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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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$\Downarrow$

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create a *Wolbachia* epidemic in the mosquito population

- a natural parasitic microbe, found in 60% insects, but not in the wild *Aedes aegypti* mosquitoes (reproductive number < 1)
- stops the proliferation of dengue/chikungunya/Zika viruses inside the mosquitoes $\rightarrow$ reduces the disease transmission to human

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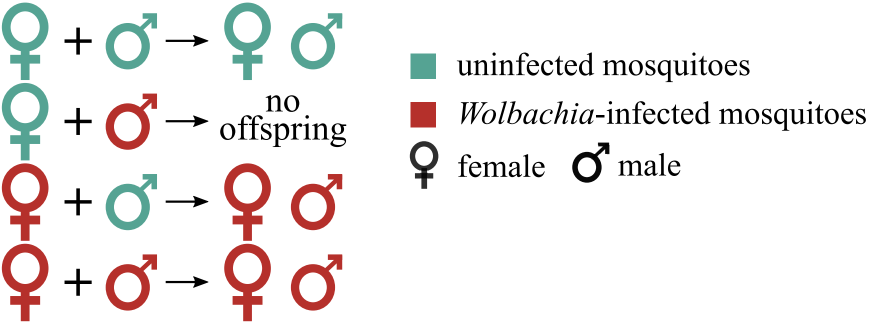
Schematic of the complex maternal transmission mating



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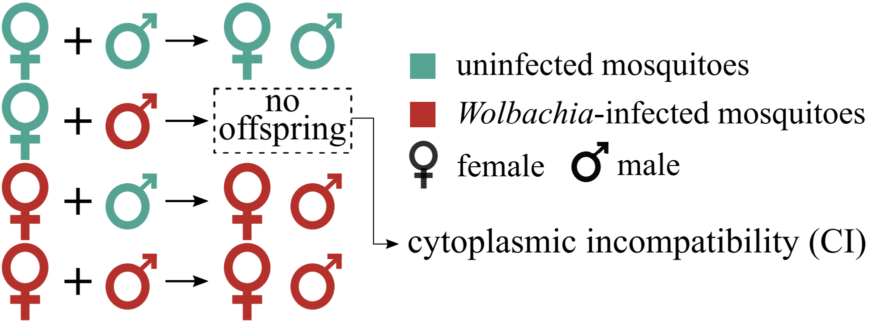

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☹ female lifespan $\downarrow$
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If there is a tipping point, beyond which the infection could take off?

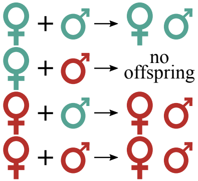
- develop an ODE model to describe the complex transmission cycle
- analyze the threshold condition for having a stable endemic *Wolbachia*

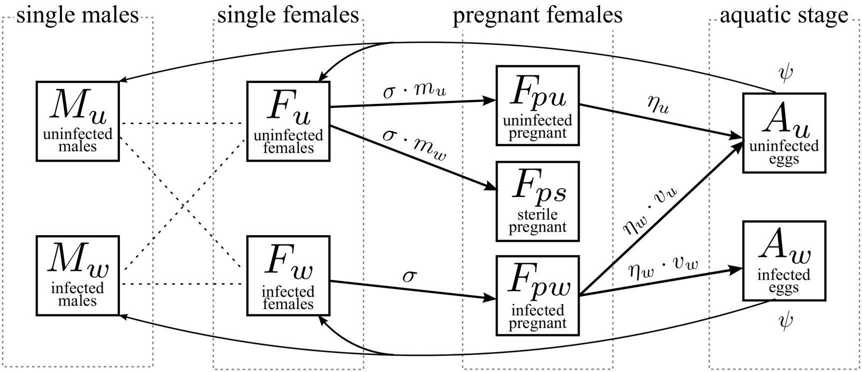
Outlines

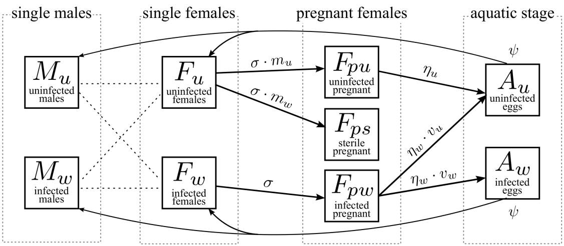
Our new model captures the complex transmission cycle

by accounting for ...

- two-sex transmission
- multi-stage for female life cycle
- carrying capacity for aquatic stage







σ: mating rate

m_w: prop. infected males

η_w/η_u: egg laying rates

v_w: maternal transmission

ψ: 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
$$\begin{cases} \dot{F}_u = b_f\psi A_u - (\sigma + \mu_{fu}) F_u \\ \dot{F}_w = b_f\psi A_w - (\sigma + \mu_{fw}) F_w \end{cases}$$

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

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

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In epidemiology, the basic reproductive number $\mathbb{R}_0$ of an infection

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By *next generation matrix* approach ... (messy calculations) ...

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(within one life cycle)

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  - *infection dies out?*

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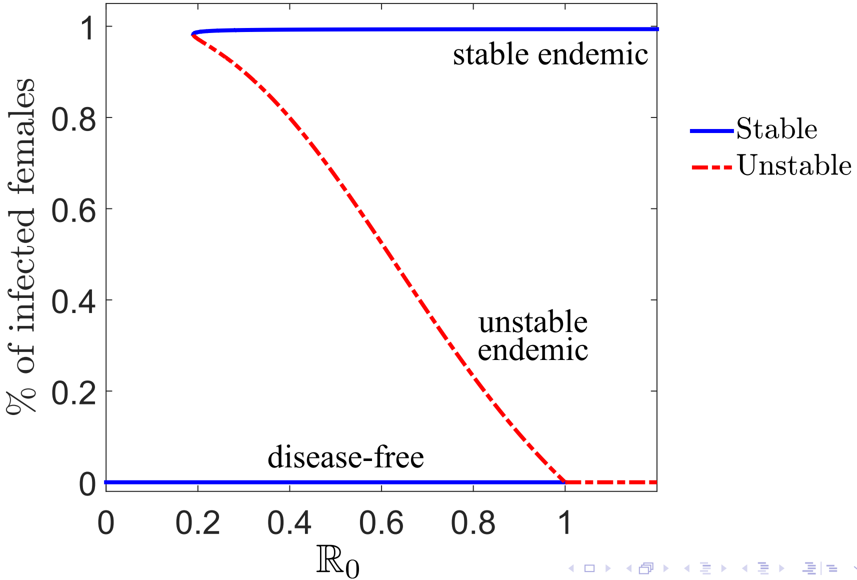
- $\mathbb{R}_0 < 1$ ("new infected<new uninfected")
  - *infection dies out? Not necessarily!*
  - There is a critical threshold for *Wolbachia* infection to spread out.

Critical threshold: bifurcation analysis



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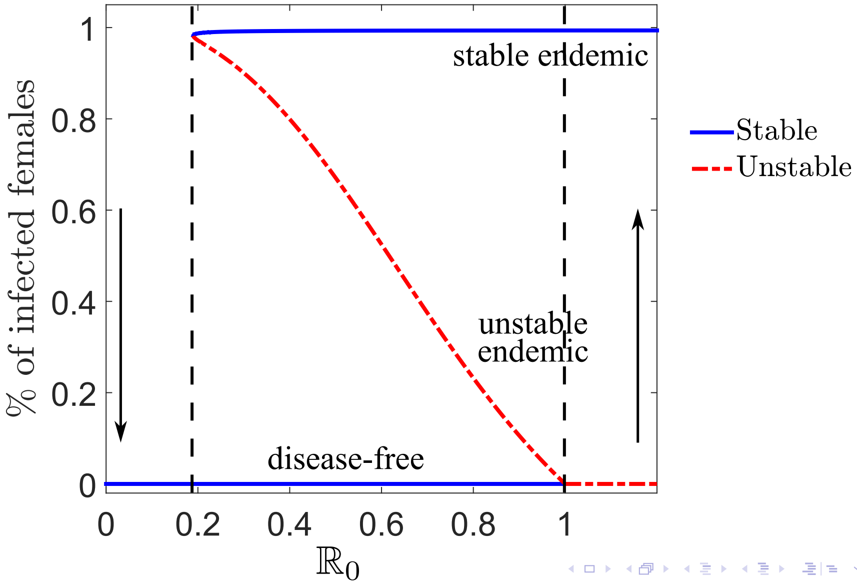

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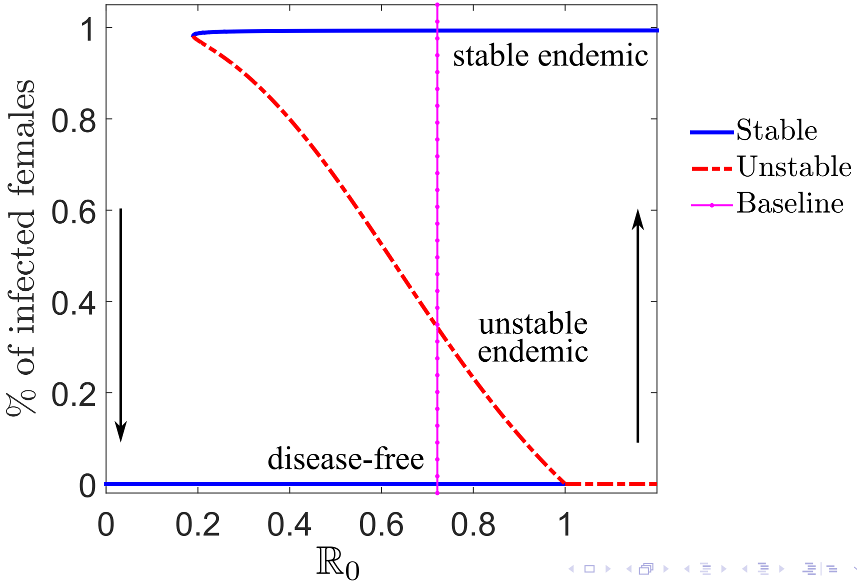

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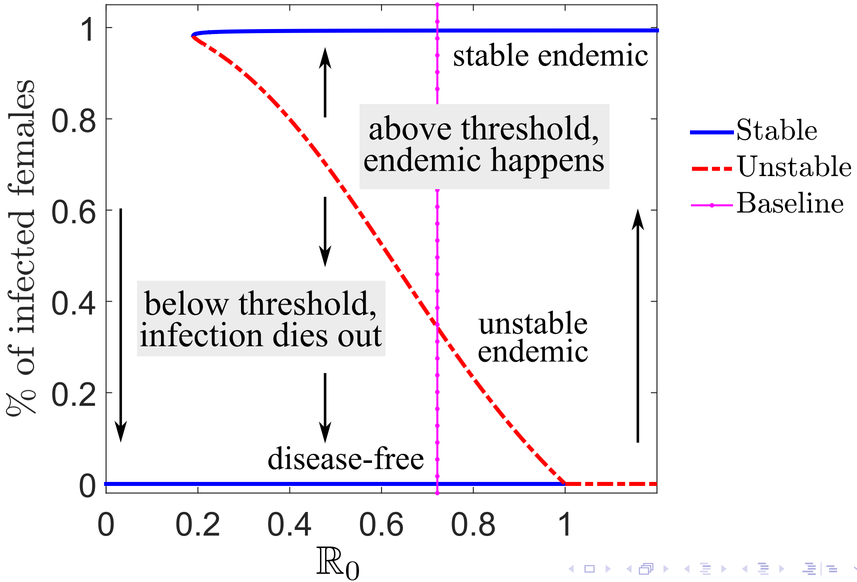
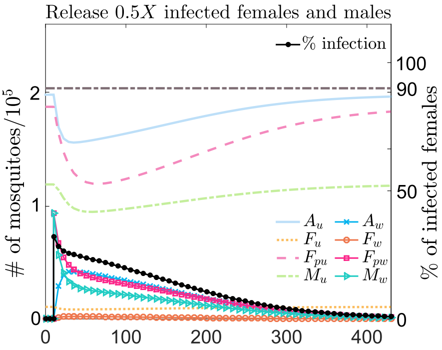
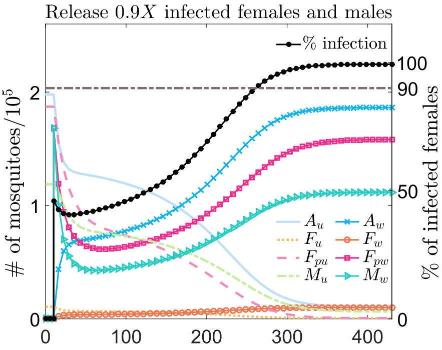


Outlines

Threshold condition for *Wolbachia* transmission



Not enough infected population are released ⇒ infection dies out



Stable endemic *Wolbachia* is established (90% around day 261)

(X = number of natural pregnant female mosquitoes at disease-free state)

Integrated mosquito control with pre-release mitigation

1. Remove some of the natural population before releases
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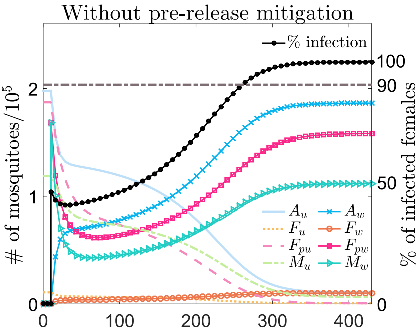

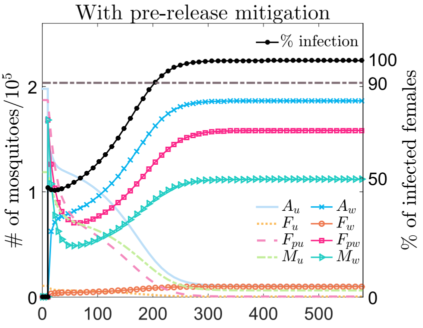

Without pre-release mitigation,
90% infection $\sim$ day 261

Without pre-release mitigation,
90% infection $\sim$ day 203

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Comparison using different pre-release mitigations

Approach	Target	$T_{90\% \text{ in F}}$
None	N/A	261
Residual spraying	Adults	**52**
Larval control	Aquatic-stage	203
Sticky ovitrap	Pregnant females	105
Acoustic attraction	Males	215

residual spraying $>$ sticky trap $>$ larval control $\approx$ acoustic attraction

Acknowledgment

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Thank you!

Sensitivity Analysis