Male-killing bacteria and egg cannibalism in ladybugs

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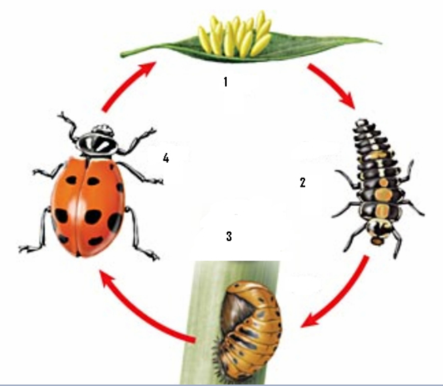
Overview

Introduction

- Some bacteria can be maternally transmitted. (i.e.: *Wolbachia*, *Rickettsia* and *Spiroplasma*).
- The infection is maintained in the population even though it kills male infected individuals in an early life stage, since there is a resource allocation to the females through sibling cannibalism.
- This results in a population with a female-biased sex ratio.

- Ladybugs feed on aphids, however, they also cannibalize on individuals in earlier life stages.



Questions and main points

To propose a model of male-killing infection that incorporates sibling cannibalism:

- Under what conditions can sibling cannibalism explain the persistence of male-killing bacteria?
- How does the aphid population dynamic affect the persistence of infection?

The proportion of infected individuals in the total female population relates to the persistence of infection.

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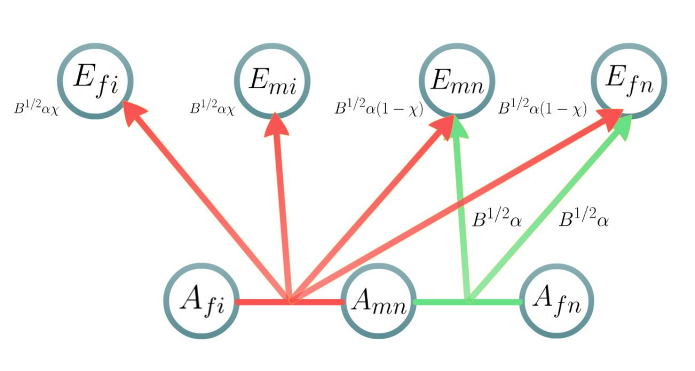
   - The transmition of the bacteria from mother to offspring is imperfect.
   - Infected eggs are laid with a fixed probability of infection.
   - There is no horizontal transmition.

Interactions to consider

Mating



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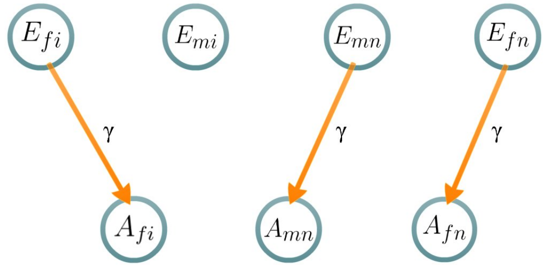
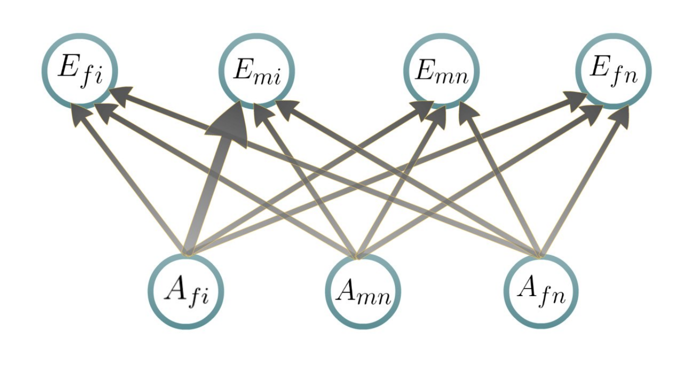
Hatching



Interactions to consider

Cannibalism



Writing the equations

Eggs population (E):

$$\frac{dE_{xy}}{dt} = \begin{pmatrix}\text{eggs}\\ \text{production}\end{pmatrix} - \begin{pmatrix}\text{cannibalism}\\ \text{rate}\end{pmatrix} - \begin{pmatrix}\text{hatching}\\ \text{rate}\end{pmatrix} - \begin{pmatrix}\text{mortality}\\ \text{rate}\end{pmatrix}$$

$$\frac{dE_{fi}}{dt} = \underbrace{B^{1/2}\alpha\chi\frac{(A_{fi}A_{mn})}{A_{fi}+A_{mn}}}_{\substack{\text{eggs}\\ \text{production}}} - \underbrace{CE_{fi}(\omega_i^n A_{fn} + \omega_i^i A_{fi} + \omega_i^n A_{fn})}_{\text{cannibalism}} - \underbrace{\gamma E_{fi}}_{\text{hatching}} - \underbrace{\mu_E E_{fi}}_{\text{mortality}}$$

B: Aphids ; α: mating rate; χ:infection rate; γ: hatching rate; μ: mortality rate; ω: cannibalism rate, $\omega_i^i > \omega_i^n$

$$C = \bar{c} - \frac{(\bar{c} - \underline{c})B}{1+B} \qquad (1)$$

Writing the equations

Adult population (A):

$$\frac{dA_{xy}}{dt} = \binom{\text{hatching}}{\text{rate}} - \mu_A A_{xy} A_T$$

$$\mu_A = f(A, B, C)$$

A_T: Total population of adults; B: Aphids population, C: Cannibalism. *V. gr*:

$$\frac{dA_{fi}}{dt} = \underbrace{\gamma E_{fi}}_{hatching} - \mu_A A_{fi} A \lambda \qquad (2)$$

$$\mu_A = \varphi + \frac{1 - \varphi}{\underbrace{1 + \frac{B + C(\sum wE)}{A}}_{feeding}} \qquad (3)$$

φ: natural death constant.
λ: rescale parameter.

Eggs equations

$$\frac{dE_{fi}}{dt} = B^{1/2}\alpha\chi 0{,}9\frac{(A_{fi}A_{mn})}{A_{fi}+A_{mn}} - CE_{fi}(\omega_i^n A_{fn} + \omega_i^i A_{fi} + \omega_i^n A_{fn}) - \gamma E_{fi} - \mu_E E_{fi} \quad (4)$$

$$\frac{dE_{mi}}{dt} = B^{1/2}\alpha\chi 0{,}9\frac{(A_{fi}A_{mn})}{A_{fi}+A_{mn}} - CE_{mi}(\omega_i^n A_{fn} + \omega_i^i A_{fi} + \omega_i^n A_{fn}) - \mu_E E_{mi} \quad (5)$$

$$\begin{aligned}\frac{dE_{fn}}{dt} &= B^{1/2}\alpha\chi\frac{(A_{fn}A_{mn})}{A_{fn}+A_{mn}} + B^{1/2}\alpha(1-\chi)\frac{(A_{fn}A_{mn})}{A_{fn}+A_{mn}} \\ &\quad -CE_{fn}(\omega_n^n A_{fn} + \omega_n^i A_{fi} + \omega_n^n A_{fn}) - \gamma E_{fn} - \mu_E E_{fn}\end{aligned} \quad (6)$$

$$\begin{aligned}\frac{dE_{fn}}{dt} &= B^{1/2}\alpha\chi\frac{(A_{fn}A_{mn})}{A_{fn}+A_{mn}} + B^{1/2}\alpha(1-\chi)\frac{(A_{fn}A_{mn})}{A_{fn}+A_{mn}} \\ &\quad -CE_{fn}(\omega_n^n A_{fn} + \omega_n^i A_{fi} + \omega_n^n A_{fn}) - \gamma\end{aligned} \quad (7)$$

Adults equations

$$\frac{dA_{fi}}{dt} = \gamma E_{fi} - \lambda \mu_A A_{fi} A \qquad (8)$$

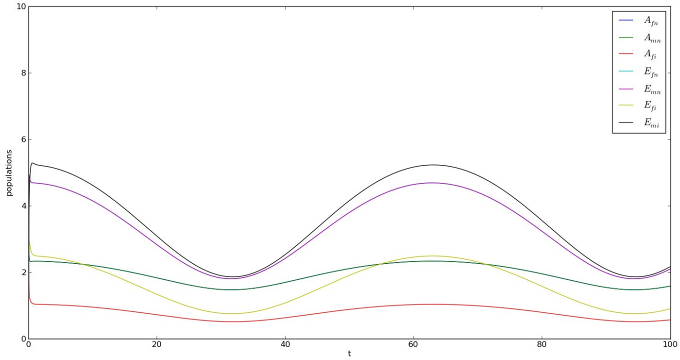
$$\frac{dA_{fn}}{dt} = \gamma E_{fi} - \lambda \mu_A A_{fn} A \qquad (9)$$

$$\frac{dA_{mn}}{dt} = \gamma E_{fi} - \lambda \mu_A A_{mn} A \qquad (10)$$

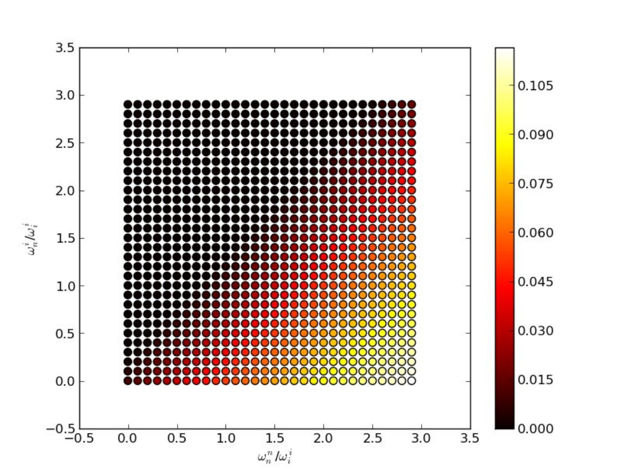
$$\mu_A = \varphi + \frac{1 - \varphi}{1 + \underbrace{\frac{B + C(\sum wE)}{A}}_{feeding}} \qquad (11)$$

φ: natural death constant.

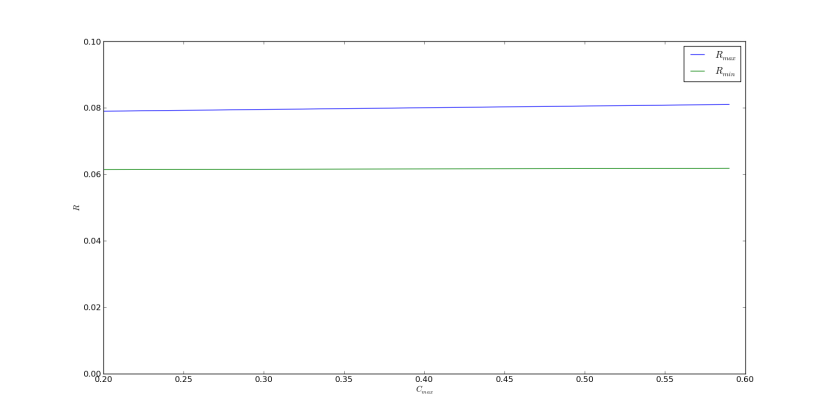
Population Dynamics



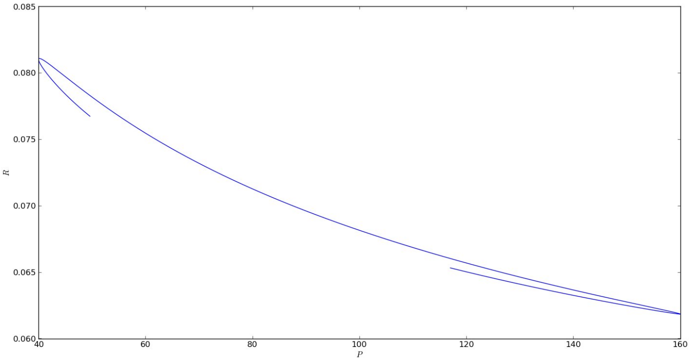
Effect of preferential cannibalism



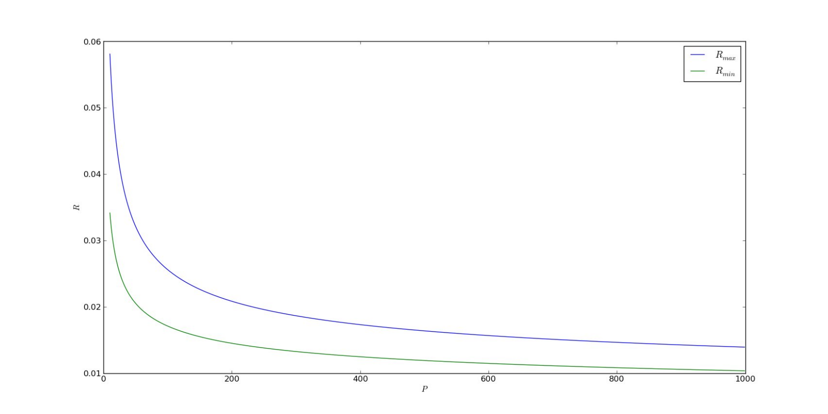
Effect of voracity in cannibalism



Aphid's impact (Momentaneous)



Aphid's impact (Long-term)



Conclusions

- If infected females were lower in fitness than non-infected they would go extinct. However, they do not.
- Cannibalism can explain the maintenance of infection, even without horizontal transmition...provided there is preferential access to the "dead" eggs.
- A higher amount of aphids means a lower prevalence of infection.

References

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