Understanding disease transmission in a changing environment: Biotic and abiotic effects

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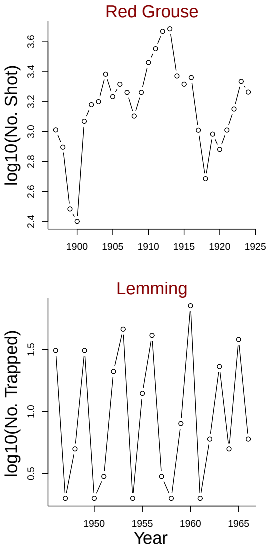
Population Cycles



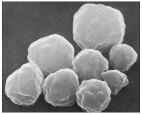
Outline

- Biotic Factors & Disease Transmission
  - Tri-trophic interactions & induced-plant defenses
  - The experimental system – gypsy moth
  - Red oaks – their tannins, gypsy moth, & disease transmission
  - Short-term gypsy moth dynamics (within season)
  - Long-term gypsy moth dynamics (between seasons)
- Abiotic Factors & Disease Transmission
  - Global warming & species interactions
  - The experimental system – fall armyworm
  - Disease transmission under a warmer climate
- Conclusions

Biotic Factors

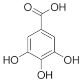
Induced defenses & Baculoviruses – Tri-trophic interactions

Pathogen
Occulsion Bodies



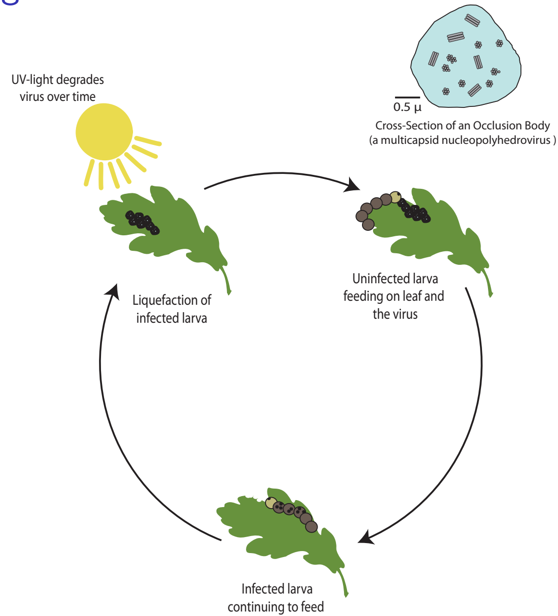
Host/Herbivore
Gypsy moth larva

Primary Producer
Red Oaks (Tannins)



Consumes both leaf and virus at the same time.

Host-Pathogen Interaction



Laboratory vs. Field experiments

Conundrum

- Lab Experiments – as gypsy moth density $\Uparrow$, infection $\Downarrow$.
- Field Experiments – as gypsy moth density $\Uparrow$, infection $\Uparrow$.

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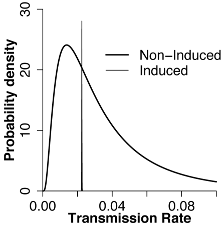
Reconciliation



- **Variability in transmission rate changes with induction.**

Laboratory vs. Field experiments

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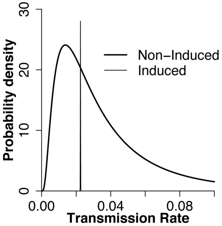
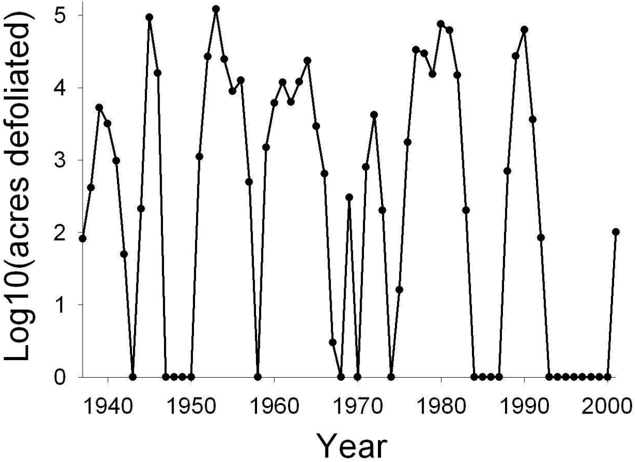


- **Variability in transmission rate changes with induction.**
- Short-term (within-season) dynamics.
- Long-term (between-season) dynamics.

Gypsy moth long-term dynamics



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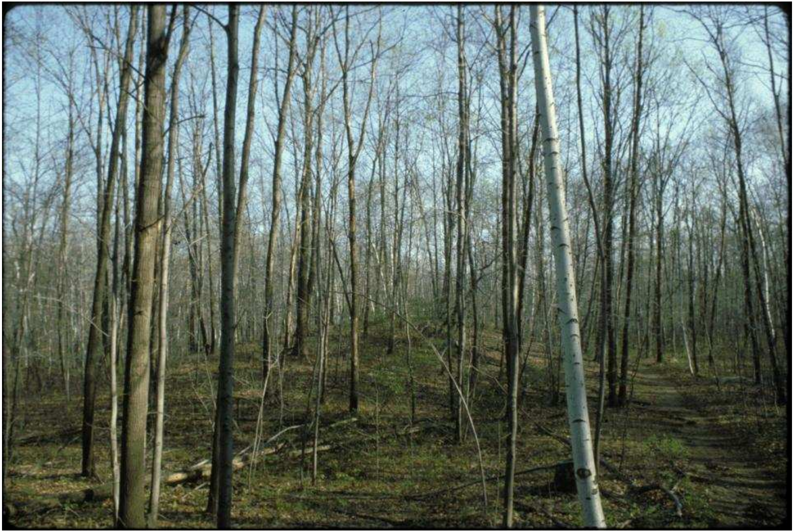
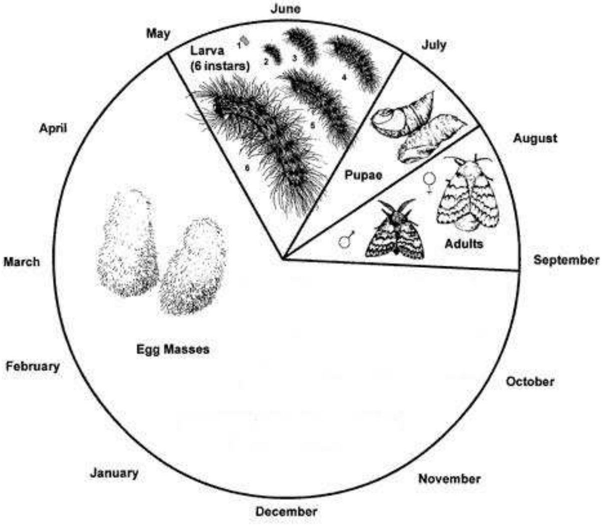


Gypsy moth life cycle



The Experiments - Induction

- Stimulate tannin induction
- Jasmonic acid/control solution

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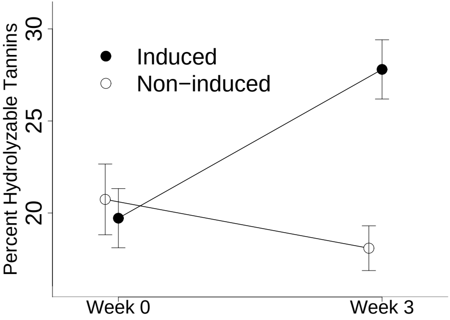
- Stimulate tannin induction
- Jasmonic acid/control solution
- 72 branches on 16 red oak trees
  - 8 control trees
  - 8 experimental trees w/ non-induced and induced branches
- Sprayed every other day for 3 weeks
  - Collect leaf samples prior to spraying and at 3 weeks
- Coincides with 3rd instar of gypsy moth

The Experiments - Induction

Within Season
Same level as natural defoliation



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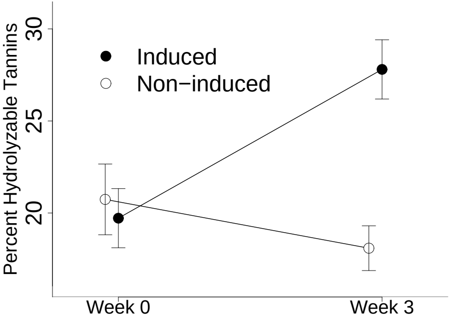
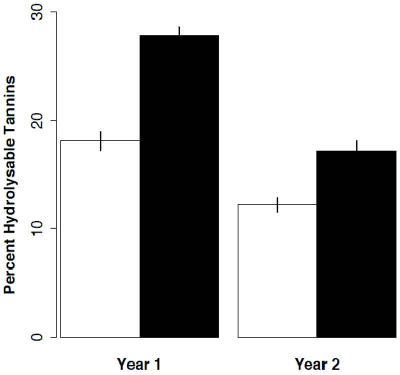


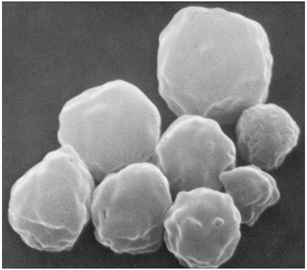
Between Seasons



The Experiments - Lab

Dose-Response Experiments

- Feed leaf disk with varying amounts of virus
- Need to eat all of the leaf disk - full dose of virus & tannins
- Place on individual diet cups
- Rear for 3 weeks
- Record mortality & cause



The Experiments - Field

- Infect 1st Instars
  - 0, 10, and 40 infected 1st instars
  - 40 red oak (*Quercus rubra*) leaves
- Healthy 3rd Instars

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Fitting Models to Data - within seasons

Dose-Response Experiments (Laboratory Results)

Treatment	$\log_{10} LD_{50}$ (95% CI)
Non-induced	3.04 (2.24, 3.84)
Induced	3.89 (3.77, 4.03)

Lab Experiments – as gypsy moth density $\Uparrow$, *infection* $\Downarrow$.

Fitting Models to Data - within seasons

Dose-Response Experiments (Laboratory Results)

Treatment	$\log_{10}LD_{50}$ (95% CI)	CV (95% CI)
Non-induced	3.04 (2.24, 3.84)	0.204 (0.173, 0.235)
Induced	3.89 (3.77, 4.03)	0.058 (0.038, 0.079)

Within Season Models

Standard Model

$$\begin{aligned} \text{Susceptible} \quad \frac{dS}{dt} &= -\nu SP \\ \text{Latent} \quad \frac{dE_1}{dt} &= \nu SP - m\delta E_1 \\ \frac{dE_i}{dt} &= m\delta E_{i-1} - m\delta E_i, \;\; i = 2, \dots m \\ \text{Pathogen} \quad \frac{dP}{dt} &= m\delta E_m - \mu P \end{aligned}$$

Within Season Models

Heterogenous Model

$$
\begin{aligned}
\text{Susceptible} \quad \frac{dS}{dt} &= -\bar{\nu} S P \left[\frac{S(t)}{S(0)} \right]^{C^2} \\
\text{Latent} \quad \frac{dE_1}{dt} &= \bar{\nu} S P \left[\frac{S(t)}{S(0)} \right]^{C^2} - m\delta E_1 \\
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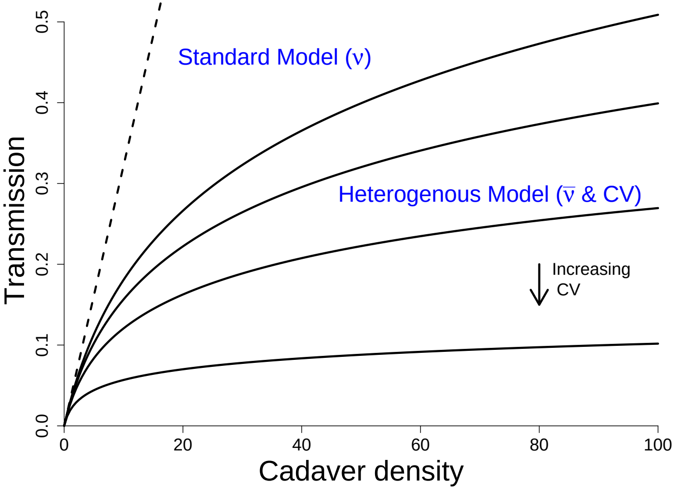
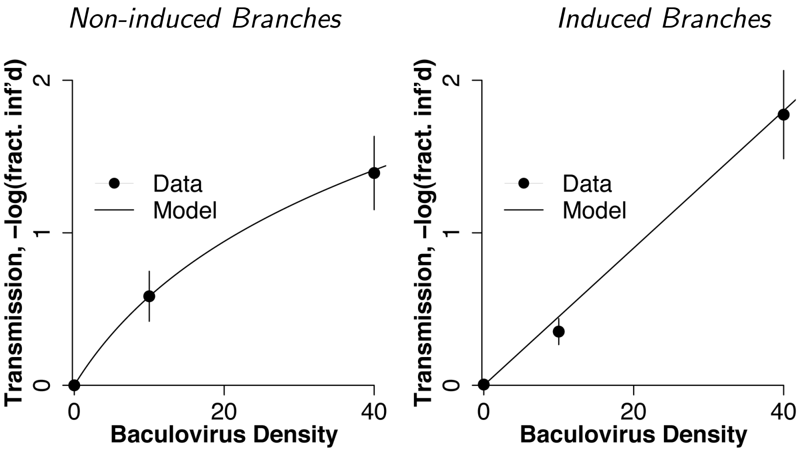
Within Season Models



Fitting Models to Data - within seasons

Transmission Experiments (Field Results)



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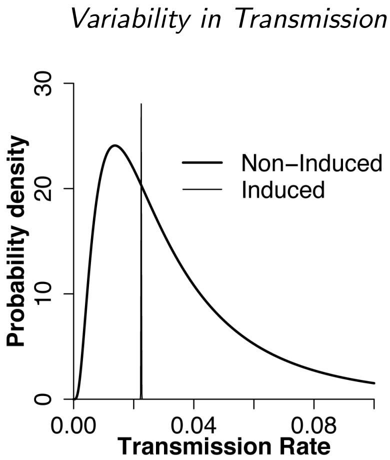

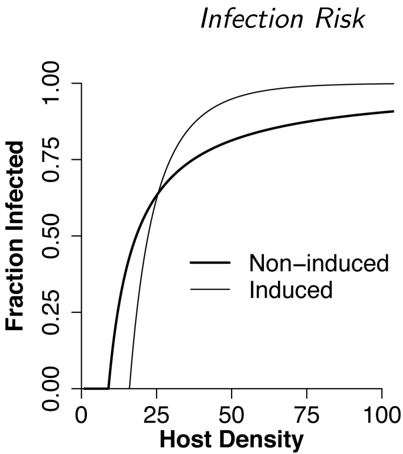

Field Experiments – as gypsy moth density ⇑, infection ⇑.

Between Seasons Model

$$
\begin{array}{lrcl}
\text{Host} & N_{T+1} & = & \lambda N_T(1 - i(N_T, Z_T, D_T)) \left(1 - \frac{2abN_T}{(b^2 + N_T^2)}\right) \\
\text{Cadavers} & Z_{T+1} & = & \phi N_T \; i(N_T, Z_T, D_T) + \gamma Z_T \\
\text{Tannins} & D_{T+1} & = & \alpha N_T \frac{D_T}{\beta + D_T}
\end{array}
$$

Fitting Models to Data - between seasons

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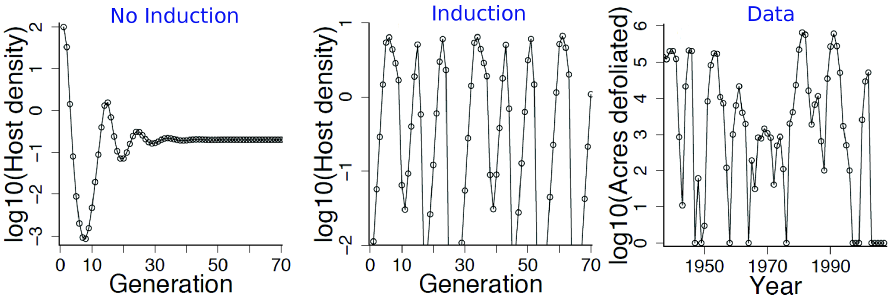

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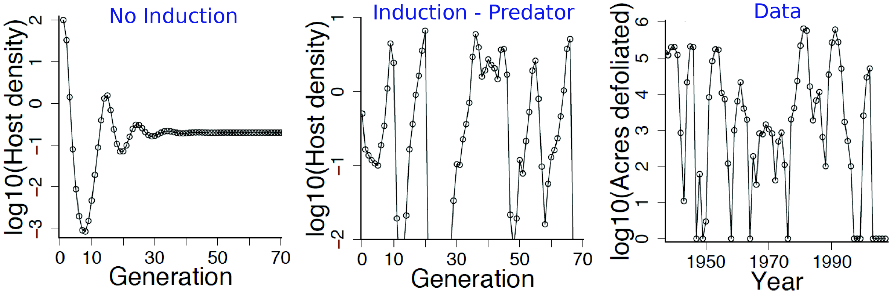
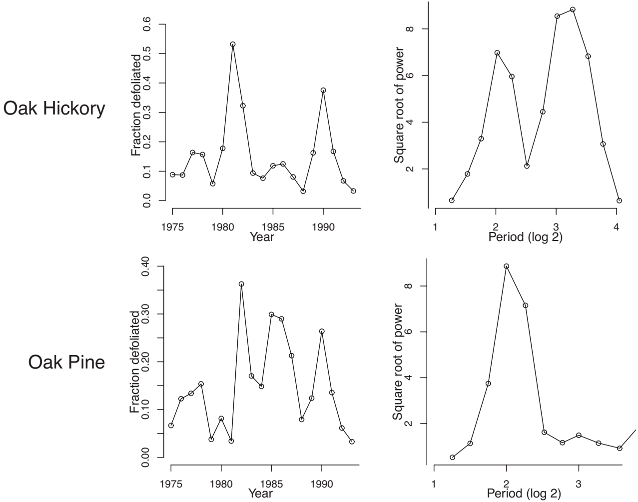
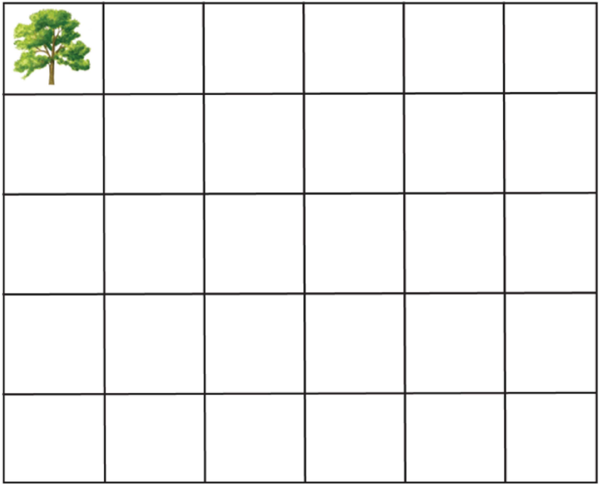


Defoliation



The Spatial Model

- Grid of forest cells
- Strongly or weakly induced trees
- Seed population
- Ballooning or car



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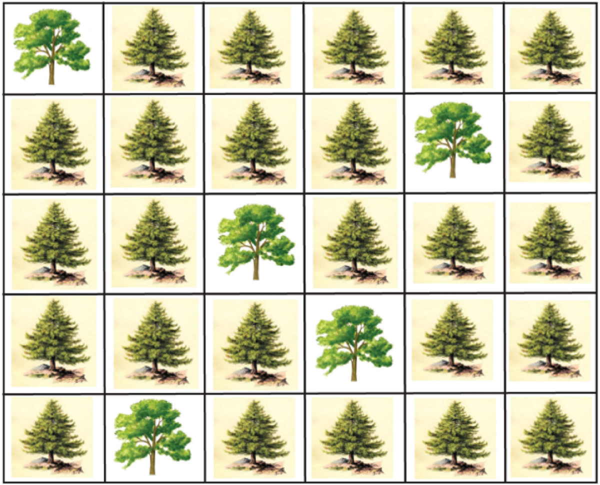
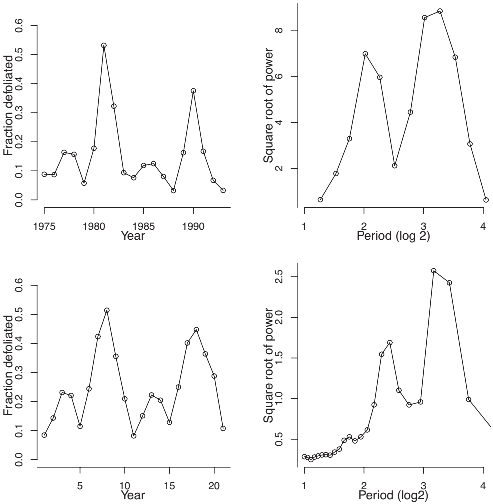
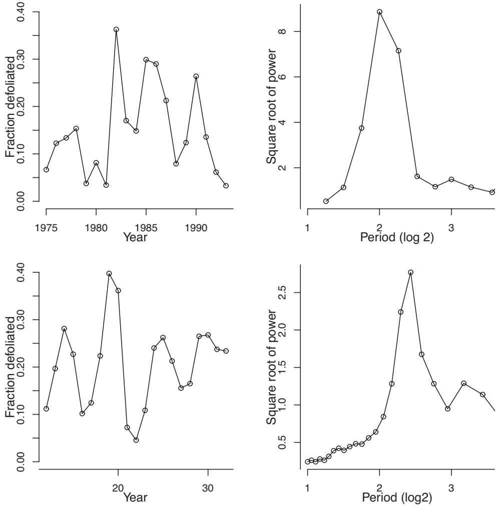


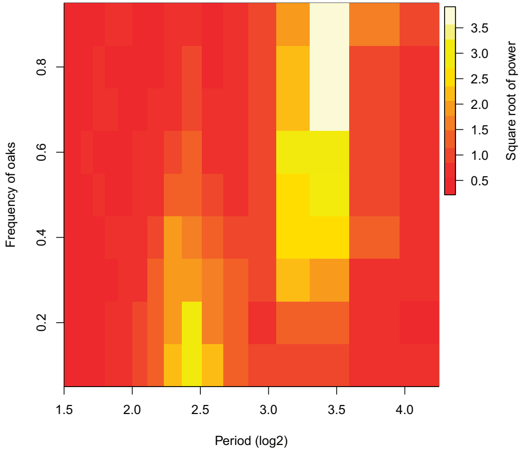
Oak Hickory Forest



Oak Pine Forest

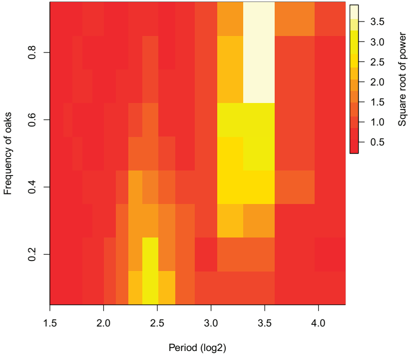


Forest Composition and Outbreak Cycles



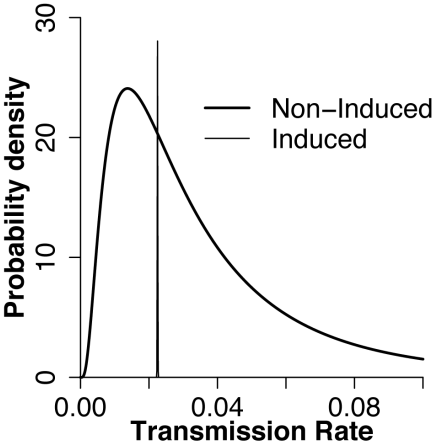
Biotic Factors Conclusions

- Influence top-down & bottom-up important for other systems
- Forest diversity affects population cycles
- Influence use of baculoviruses as bioinsecticides



Biotic Factors Conclusions

- Influence top-down & bottom-up important for other systems
- Forest diversity affects population cycles
- Influence use of baculoviruses as bioinsecticides
- Induction decreases variability in transmission rate
- Interaction between tannins & OB in mid-gut
- Occurs in both lab & field



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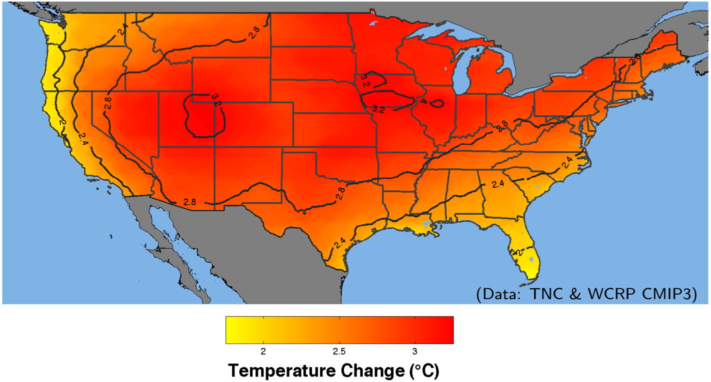
Abiotic Factors – Global Warming

Ensembled average of A2 emissions scenario
Projection for 2050

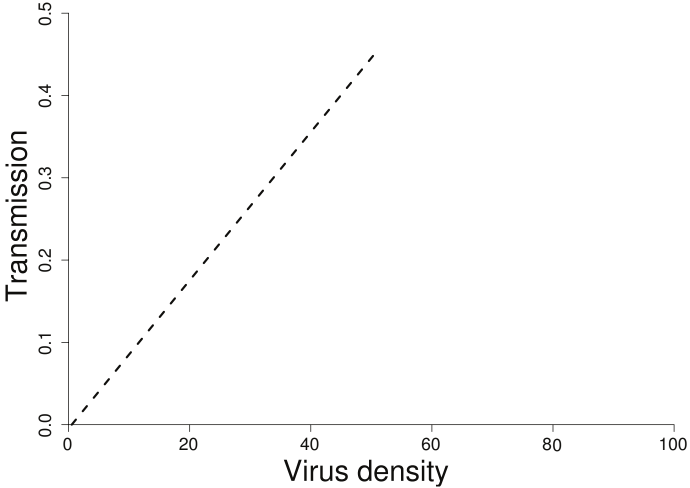


- Shift in species ranges.
- Emerging importance of species interactions.

Species Interactions & Global Warming

- Weak interactions typified by generalists
- Strong interactions typified by specialists
  - Plant–Pollinator
  - Predator–Prey
  - Host–Pathogen

Disease Models



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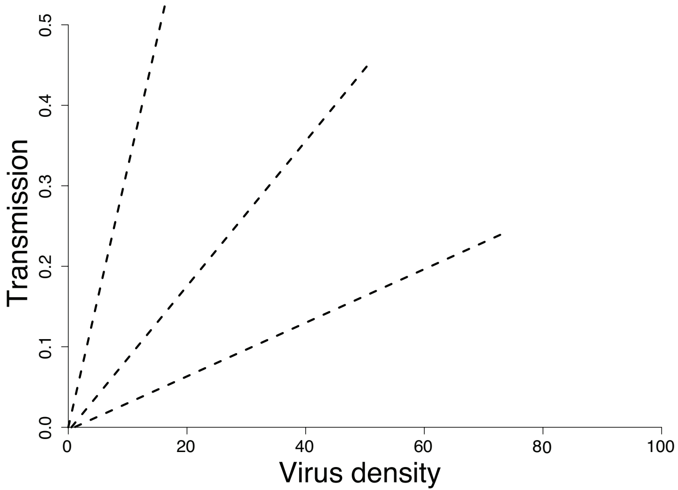

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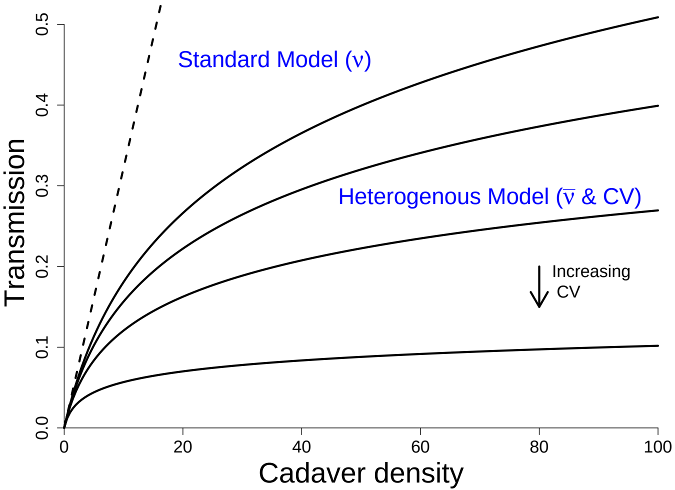


Host-Pathogen interactions: The fall armyworm

- The fall armyworm
  - Six larval instars
  - Multivoltine

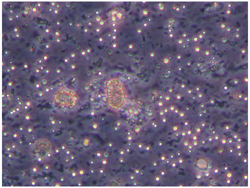
Fall armyworm

Host-Pathogen interactions: The fall armyworm

- The fall armyworm
  - Six larval instars
  - Multivoltine
- Baculovirus
  - SfNPV
  - Species-specific
  - Occlusion bodies with multiple virions

Fall armyworm

Virus



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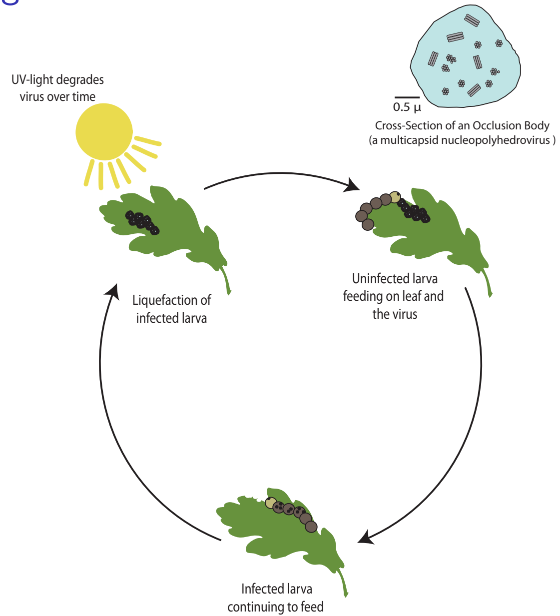
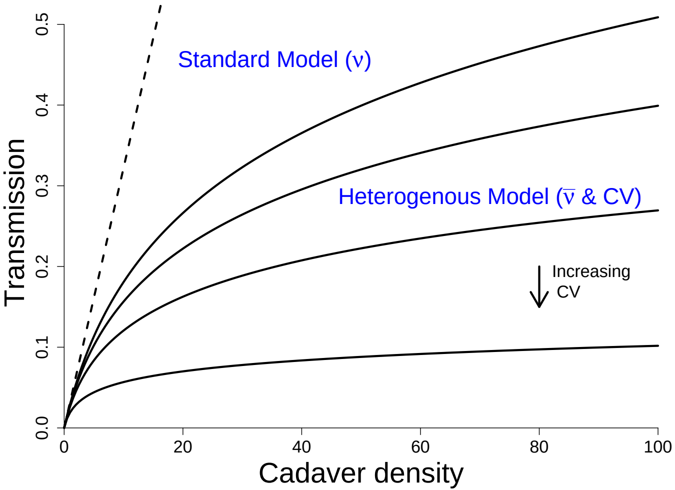


Short-term dynamics & Long-term consequences



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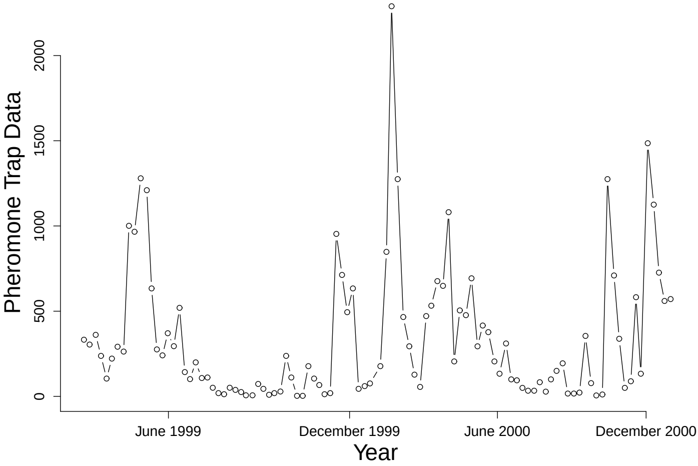

Field Experiment

- Control or 4-sided
  - Open-top chambers
- iButtons in selected plots
- 5 tri-foliate soybean leaves (*Glycine max*)
- Infect 1st instars
  - 0, 15, 30, and 60

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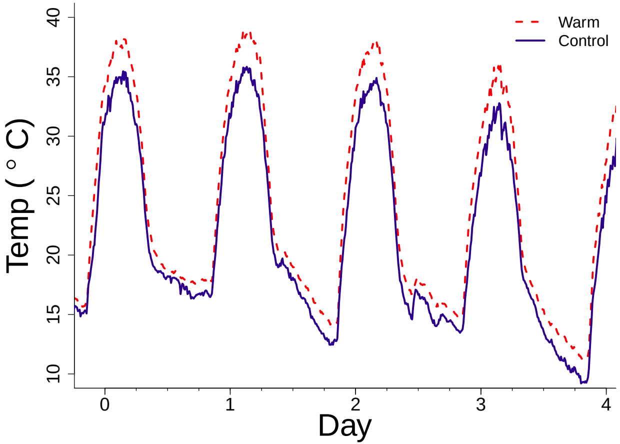
- Healthy 4th Instars
- Feed for two to four days
- Place on individual diet cups
- Rear until pupation or death
- Conducted three times
  - October 2010, July 2011, September 2011

Temperature Differences



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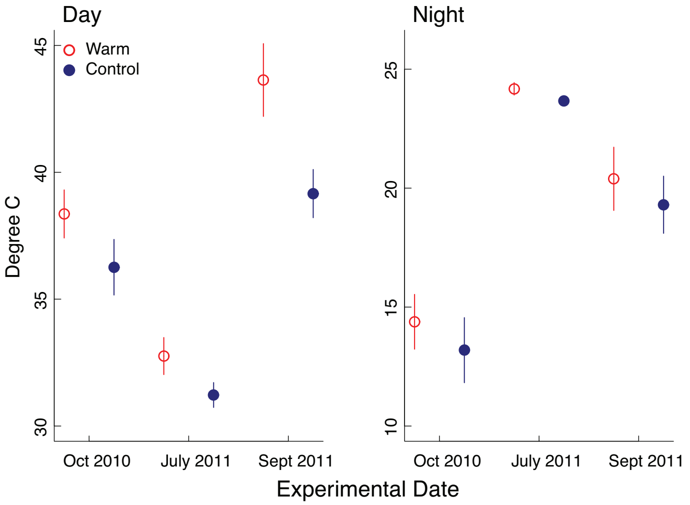
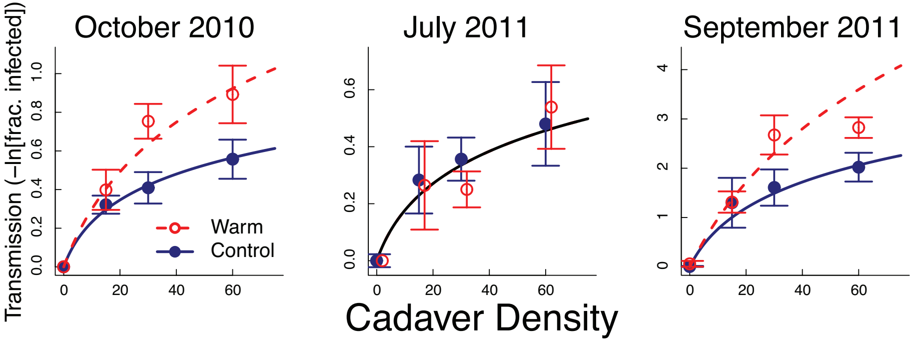


Field Experimental Results



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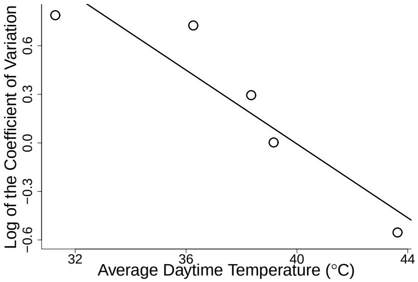

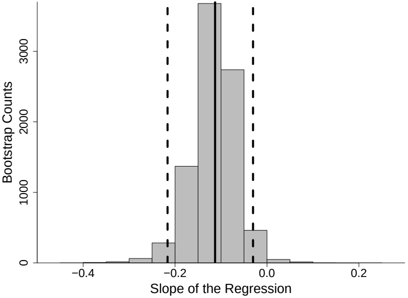

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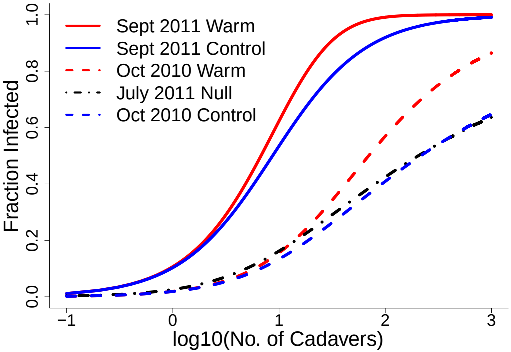
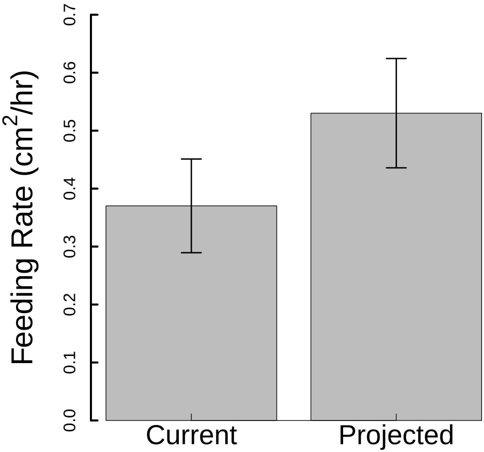


Lab Experiment - Feeding Rates



Abiotic Conclusions

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- Effects of other climatic factors
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- Importance of considering tightly-linked species interactions

Conclusions

- Disease Transmission
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  - Plant Defenses
  - Changes in Temperature

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    - Plant Defenses
    - Changes in Temperature
- Deconstructing the mechanisms
- Future Work
    - Climate Change
        - Long-term dynamics
    - Plant defenses
        - Fall armyworm and Soybean

Acknowledgments

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- Kyle McCauley, Maynard Milks, William Vial, and Jennie Kluse

Within Season Dynamics Solution

$$\text{Standard} \quad \frac{dS}{dt} = -\nu S P_0$$

$$\Downarrow$$

$$-ln\left(\frac{S(T)}{S(0)}\right) = \nu S P_0 T$$

$$\text{Heterogeneous} \quad \frac{dS}{dt} = -\bar{\nu} S P \left[\frac{S(t)}{S(0)}\right]^{C^2}$$

$$\Downarrow$$

$$-ln\left(\frac{S(T)}{S(0)}\right) = \frac{1}{C^2} ln(1 + \bar{\nu} C^2 S P_0 T)$$

Expt'l outcome Expt'l treatment

Note: As $K \to \infty$, the heterogeneous model becomes the standard model