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Data-Driven Mathematical Models for HLB: Testing Interventions in a Virtual World

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"Asian citrus psyllid D. citri adult" by Florida Department of Agriculture - Jeffrey Weston Lotz. Licensed under Public Domain via Wikimedia Commons

Non-Technical Summary

Determining the best way to intervene during a disease epidemic, such as HLB, can be challenging. Mathematical models are one way to test the possible impacts of a wide array of interventions comparatively cheaply and inexpensively. We show how this can work in practice, including what kinds of data are needed for effective model development, and how interventions can be tested. This approach can be combined with current field and laboratory studies to develop interventions that better control HLB.

Background

• **Controlling the spread of Huanglongbing** (HLB) requires better understanding of the bacteria/psyllid (i.e. vector)/tree system and the abiotic factors that impact spread to citrus.

• Although empirical work has helped to elucidate details of many of components of the HLB pathosystem, **mathematical models can provide insights into the cost effectiveness** of many possible combinations of viable interventions more quickly and effectively than large-scale field manipulations.

• In addition to guiding intervention strategies, **models can provide feedback on data collection** and experimental efforts, and sensitivity analyses can tell us which variables likely have the biggest effects on outcomes, such as citrus yields and HLB burdens, and which contribute the most to uncertainty in outcomes.

• **Here we present a preliminary mathematical model on the spread of HLB in time that incorporates some known details of the psyllid life-cycle, and transmission propensities, the impact of temperature, and the costs and benefits of two types of interventions.**

Goals and Hypotheses

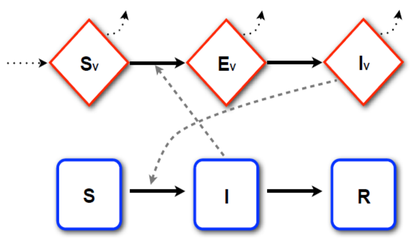
Goal: Develop a validated model describing the development of the HLB epidemic across spatial scales -- from individual trees, to groves, to farms, to regions – to 1) test the relative cost effectiveness of current and future control strategies (see below) and prioritize these for implementation and testing in the field, and 2) identify novel optimal adaptive control strategies for HLB.

Hypothesis: The cost and benefits of intervention strategies for HLB depend on: 1) the time scale of interest (short term or long term strategies), 2) environmental factors (temperature, humidity, light, wind), 3) vector traits (dispersal ability, mortality, reproduction, resistance to controls) which depend on environment, 4) host traits (age, susceptibility, stress), and 5) spatial patterns (spacing of trees, barriers to insect dispersal).

Methods

We extend an established model for the spread of a vector borne disease (j,l) for HLB. We incorporate temperature dependence in three parameters, and use literature estimates (where available) for others. We also consider two types of simple interventions – insecticide and antibiotic application.

Transmission Model

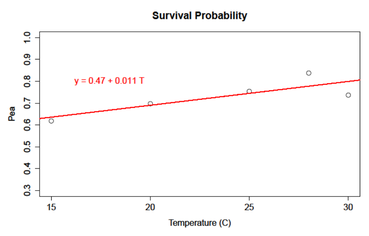


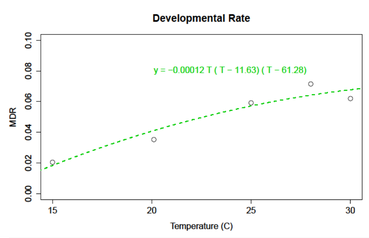
Graphical representation of model for HLB transmission. Red diamond = psyllids, blue squares = trees. S/E/I/R = Susceptible/Exposed/Infected/Recovered. Solid lines indicate individuals moving between compartments, dashed lines the route of infection, and dotted lines demographic processes in the vectors.

System Parameters

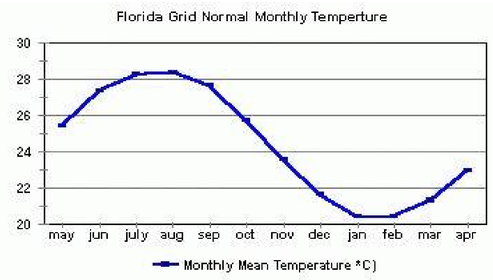
Table 1. Data needed for baseline model. Component parameters of R_0 for the baseline model, their definitions, sources in the literature for data, and whether they are recorded for temperature, humidity, or both simultaneously (T/H/B). For the initial model we group nymphal and adult psyllids together as the infectious vectors.

Parameter	Definition	Existing Sources	T/H/B
α	1/residence time	none	-
D_V	vector development rate	a, b, c	T
p_{EA}	egg to nymph/adult survival	a, b, c	B
F	fecundity (eggs/female/day)	a, c	T
μ	vector mortality rate	a, b, c	T
bc	vector competence	d, e	T
τ_{EI}	extrinsic incubation period	none	-
D_P	Parasite development rate	f,g, h, i	T

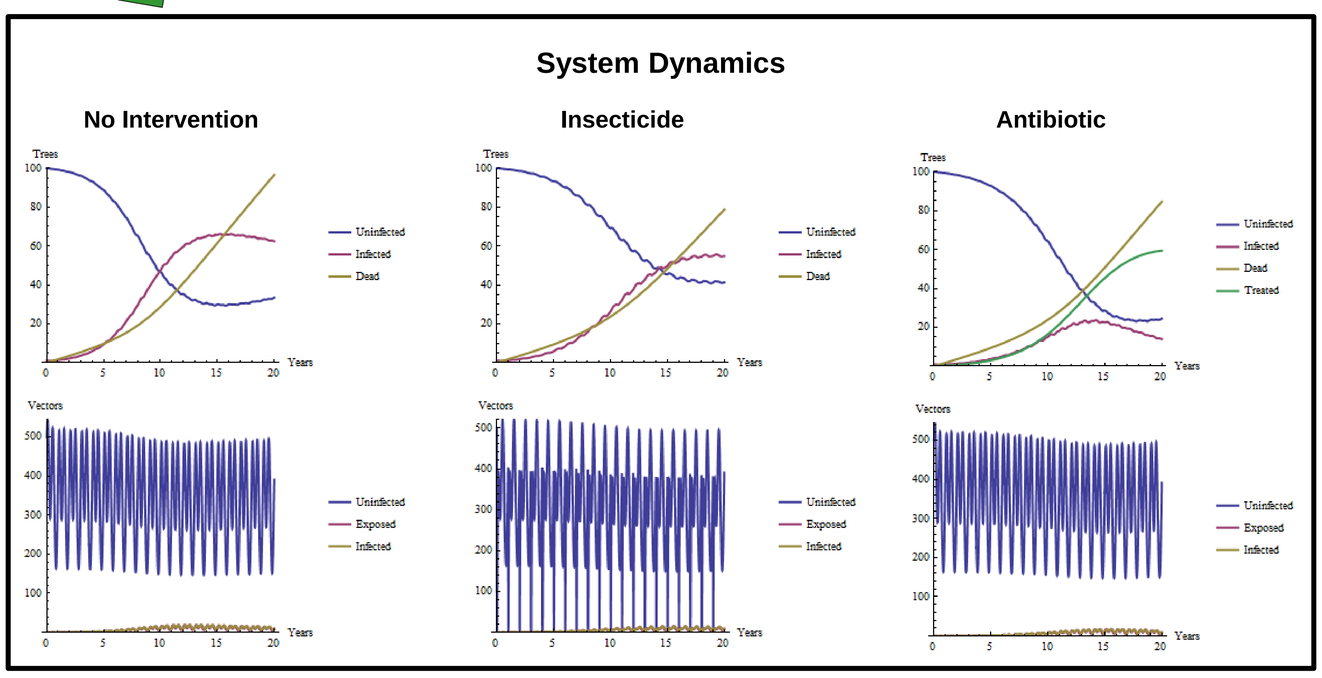




Environmental Forcing



System Dynamics



Interventions

Physical approaches
1) rates, placement, and timing of different types of insecticides
2) rogueing infected trees
3) increased tree spacing
4) repellents (e.g. metalized polyethylene mulch, horticultural oils)
5) nutrient amendments

Biotic approaches
6) sterile or resistant psyllids (theoretical)
7) biocontrol agents (e.g. predatory mites, entomopathogens, parasitoids)
8) resistant citrus genotypes
9) intercropping
10) integrated pest management approaches

Explore dynamics and try out interventions yourself!
Interactive simulations are available online:

http://leah.johnson-gramacy.com/HLB.html

Examples of Costs

Of Intervention
1) pesticide/antibiotic and applications
2) rogueing infected trees

Of HLB
1) decreased yields
2) decreased fruit quality
3) Increased tree mortality

Conclusions

- Simple models allow exploration of the influence of various factors, such as environment and control strategies on the dynamics of disease.
- The relative costs of various interventions can be compared as a straight-forward extension of the disease model
- In order to build models that are useful to stakeholders for planning controls more complete data on the bacteria/psyllid/tree system are needed, as are realistic costs and estimates of treatment effectiveness.
- Feedback and suggestions on possible interventions to test, as well as details of the biology of the system that are of interest to stakeholders are always welcome – tell us what you want to see!

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