SCUDEM IV: Problem C - Chemical Espionage

Coe College

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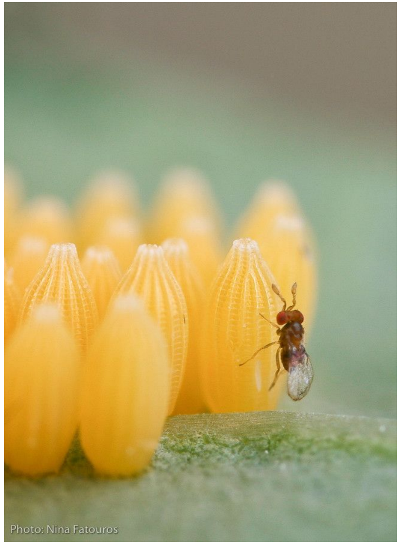
Background

- ➢ Large White Cabbage Butterflies (Pieris brassicae) use chemical signals in their mating process
- ➢ Parasitic Wasps pick up on the male's anti-aphrodisiac chemical signals and insert their eggs into the butterfly's eggs
- ➢ More anti-aphrodisiac means…
  - For butterflies:
    - More fertilized eggs
    - More time to find safe space for eggs
    - Less actually hatched eggs
  - For wasps:
    - More larvae

Problem

- How does the interaction between the butterflies and wasps affect their populations?
- What is the best balance for this system?
- What is likely to happen in the long run?



Model

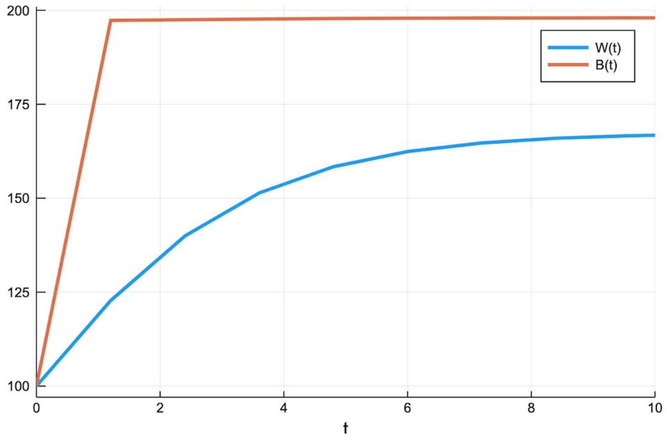
$$\frac{dW}{dt} = W\left(\gamma \cdot \phi \cdot e_b \cdot e_w\right)\left(L_w - W\right) - W \cdot D_w$$

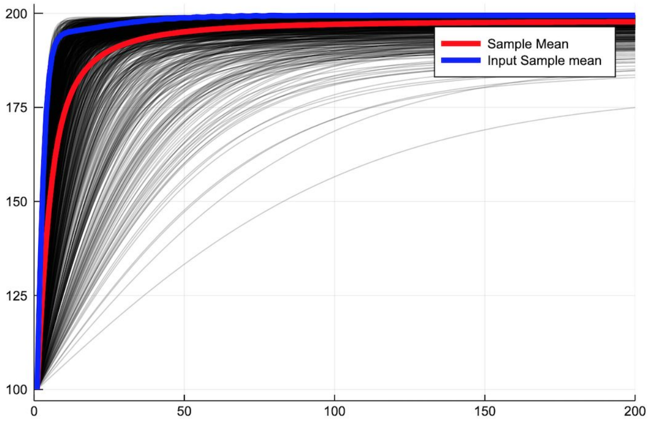
$$\frac{dB}{dt} = -W\left(\gamma \cdot \phi \cdot e_b\right) + B\left(\gamma \cdot e_b\right)\left(L_b - B\right) - B \cdot D_b$$

- Assumptions:
  - Equal number of male and female butterflies
  - Butterflies reproduce continuously
  - All wasps are female
  - Each wasp inserts 20-60 wasp larvae per egg
  - If the wasps detects the anti-aphrodisiac, it will infect the butterfly eggs
  - Wasps only rely on butterfly eggs to reproduce, no other prey
  - There is a carrying capacity *L* for each population

- Parameters:
  - B butterfly population
  - W wasp population
  - γ interaction between male and female butterflies
  - Φ interaction between wasps and anti-aphrodisiac
  - e_b, e_w number of butterfly and wasp eggs, respectively
  - D_b, D_w death rate of populations
  - L_b, L_w carrying capacity of populations

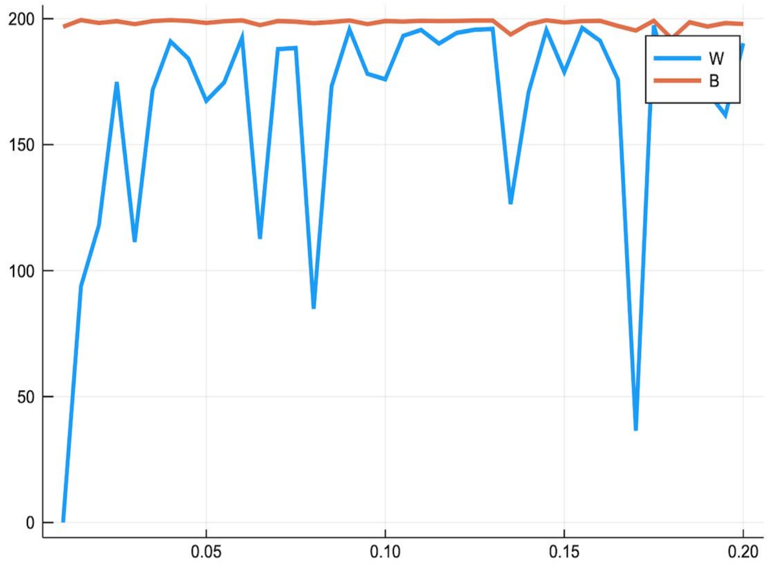
Results





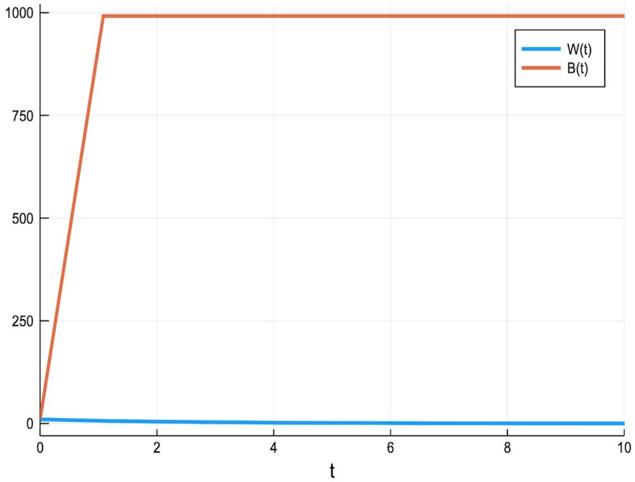
- ➢ The graph on the left is an example of one possible output
- ➢ The graph on the right is a simulation of the example output 1000 times and how the results may vary

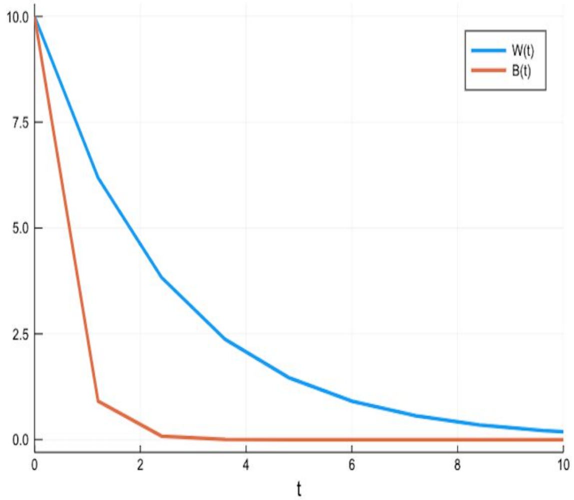
Results Part 2



- One parameter variation, resampling one parameter: interaction between Wasps and Scent

Example Outcomes





- Left Graph displays where only butterflies survive
  - Interaction between wasps and scent is weak
- Right Graph Displays when both die
  - Butterflies die due to low interaction between males and females and wasps die due to no butterflies

Additional Issue

- Suppose you are asked to add an animal that is a predator of both the butterflies and the wasps, a bird for example. How would you change your model to accommodate this new situation.

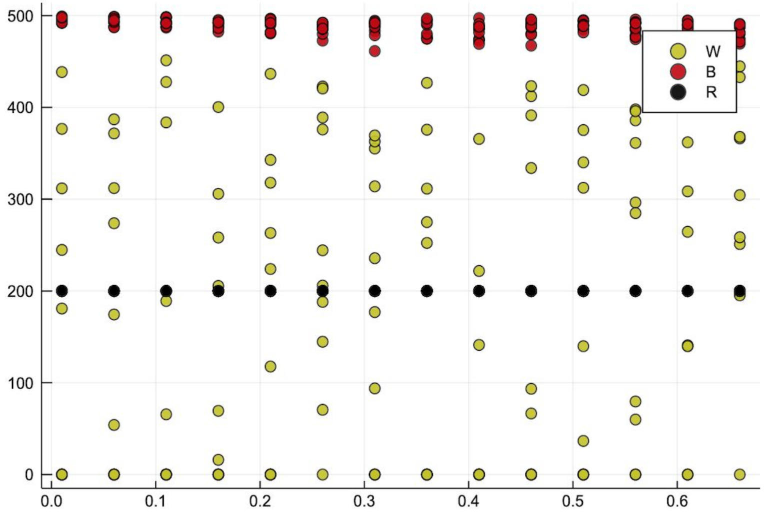
$$\frac{dW}{dt} = W\left(\gamma \cdot \phi \cdot e_b \cdot e_w\right)\left(L_w - W\right) - W \cdot D_w - \left(\alpha \cdot W\right)$$

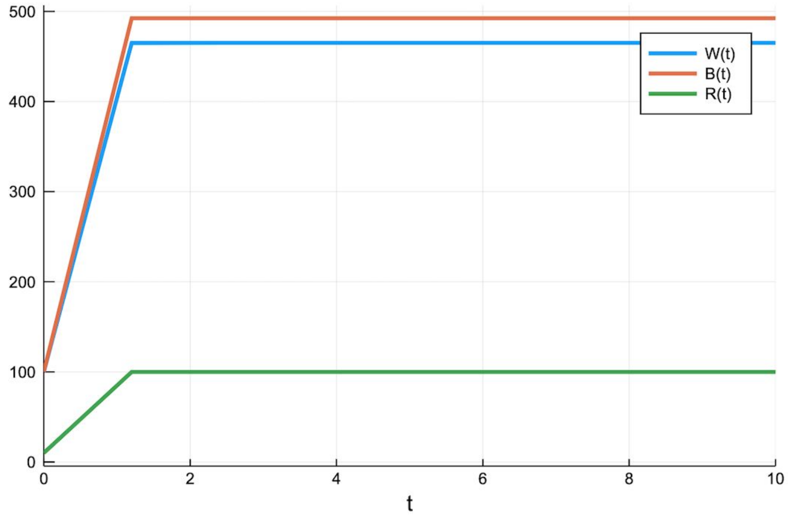
$$\frac{dB}{dt} = -W\left(\gamma \cdot \phi \cdot e_b\right) + B\left(\gamma \cdot e_b\right)\left(L_b - B\right) - B \cdot D_b - \left(\beta \cdot B\right)$$

$$\frac{dR}{dt} = R \cdot \left(\alpha \cdot W + \beta \cdot B\right) \cdot r\left(L_r - R\right) - R \cdot D_r$$

- Additional Parameters:
  - R bird population
  - α portion of wasp population eaten
  - β portion of butterfly population eaten
  - r growth rate of birds
  - L_r carrying capacity of birds
  - D_r death rate of birds

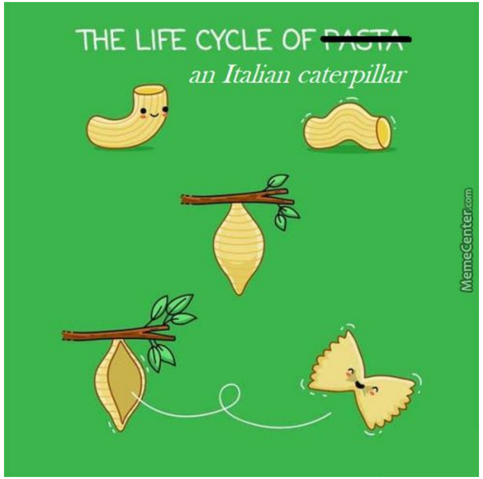
Butterflies, Birds and Wasps





- ➢ Left Graph: Simulation of Equilibrium points with differences in the number of butterflies the birds eat
- ➢ Right Graph: One example of Equilibrium over time

Looking Forward



- Adding other factors: some plants where the butterflies lay eggs give off the anti-aphrodisiacs to attract wasps to kill the butterfly larvae so the plant does not get eaten
- Adjusting the model to account for differences between summer and winter mating as well as incorporating certain mating aspects such as major mating seasons
  - This may cause a cyclic pattern from these mating seasons which would be interesting to see

Questions?

Thank you!

References

[1] “Chemical espionage on species-specific butterfly anti-aphrodisiacs by hitchhiking Trichogramma wasps, “ Martinus E. Huigens, Jozef B. Woelke, Foteini G. Pashalidou, T. Bukovinszky, Hans M. Smid, and Nina E. Fatouros. Behavioral Ecology. Volume 21, Issue 3, May-June 2010, Pages 470–478, 11 February 2010. https://doi.org/10.1093/beheco/arq007