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Chemical Espionage between *P.brassicae* and *T. brassicae*

Problem C

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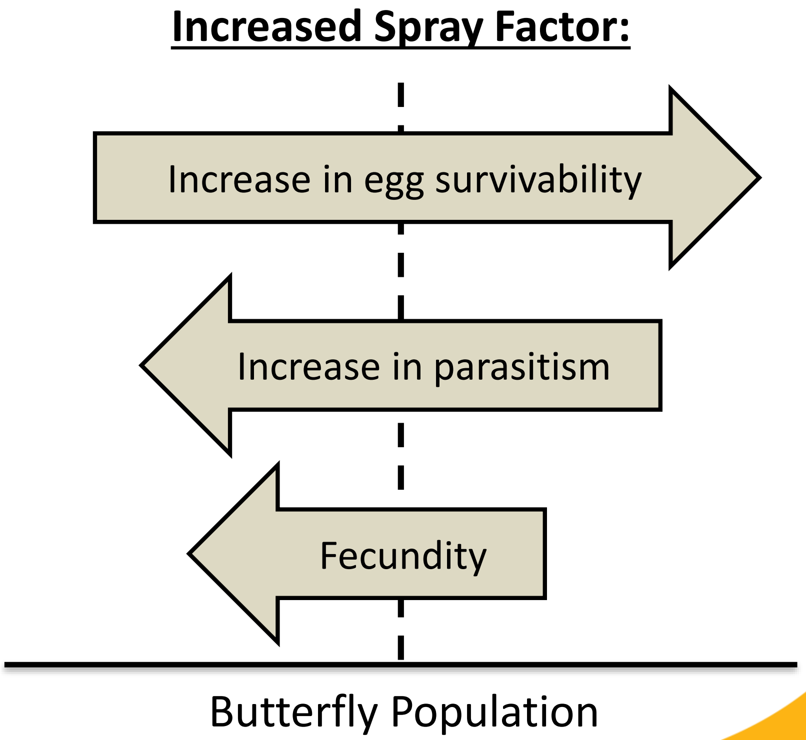
Chemical Biochemical and Environmental Engineering

Background on Butterfly and Wasp Interaction

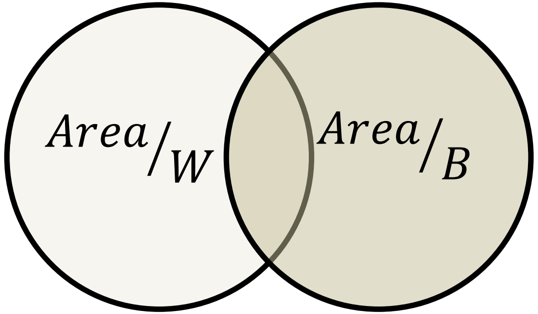
- After mating, male large white cabbage butterflies spray the female with an anti-aphrodisiac (Benzyl Cyanide)
- As such, it is desirable to understand the optimal release of anti-aphrodisiac by the male butterfly



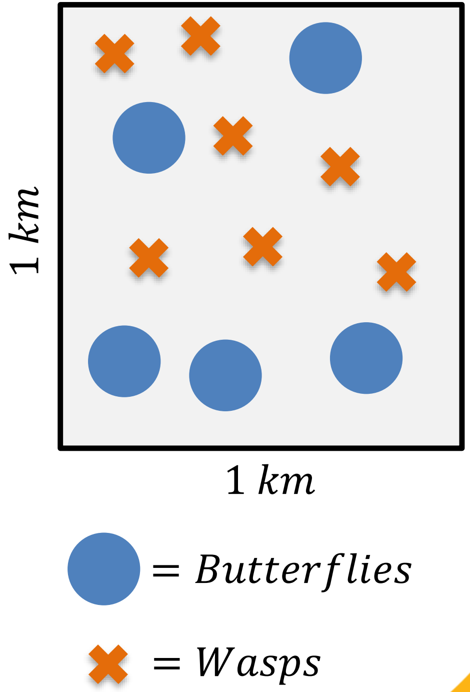
Broader Impact of Butterfly Population

- Finding an appropriate balance of the two species is important
- Butterflies assist in pollination, and are excellent barometers for ecosystem changes
- The caterpillars of the butterflies ravage farmers' fields
- Many farmers have been known to release the wasps into their fields to limit the butterfly population

Encounter Factor of Butterflies and Wasps



$$P(W \cap B) = P(W)\ x\ P(B)$$



$$P_{encounter} = \frac{A_e}{A_c/Butterfly}\,\frac{A_e}{A_c/Wasp} = \left(\frac{A_e}{A_c}\right)^2 [Wasp][Butterfly]$$

$A_c = assumed\ control\ area$

$A_e = encounter\ range$

Governing Equations – Butterfly & Wasp Population

Encounter Rate

$$E_f = P_{enc.} * P_W * P_{BF}$$

Butterfly Population

$$\frac{dP_{BF}}{dt} = B_R P_{BF}\left[-K_f E_f S_f + S_f\left(Su_v - Fe_f\right)\right] - \frac{P_{BF}}{L_{Bf}}$$

Wasp Population

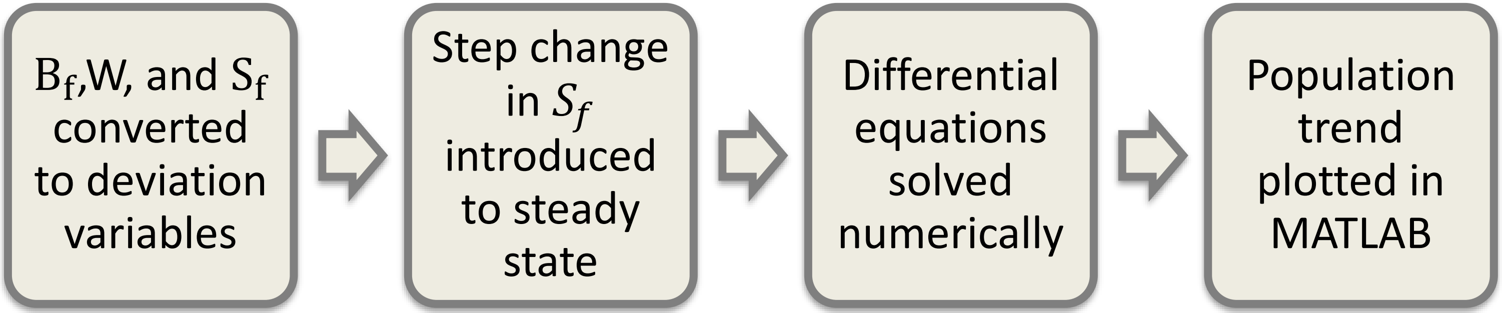
$$\frac{dP_W}{dt} = B_R P_{BF} K_f E_f S_f E_w - \frac{P_W}{L_W}$$

P_{BF} = Butterfly population
P_W = Wasp population
$P_{enc.}$ = Encounter Probability
L_{Bf} = Butterfly life span
L_W = Wasp life span

Factors

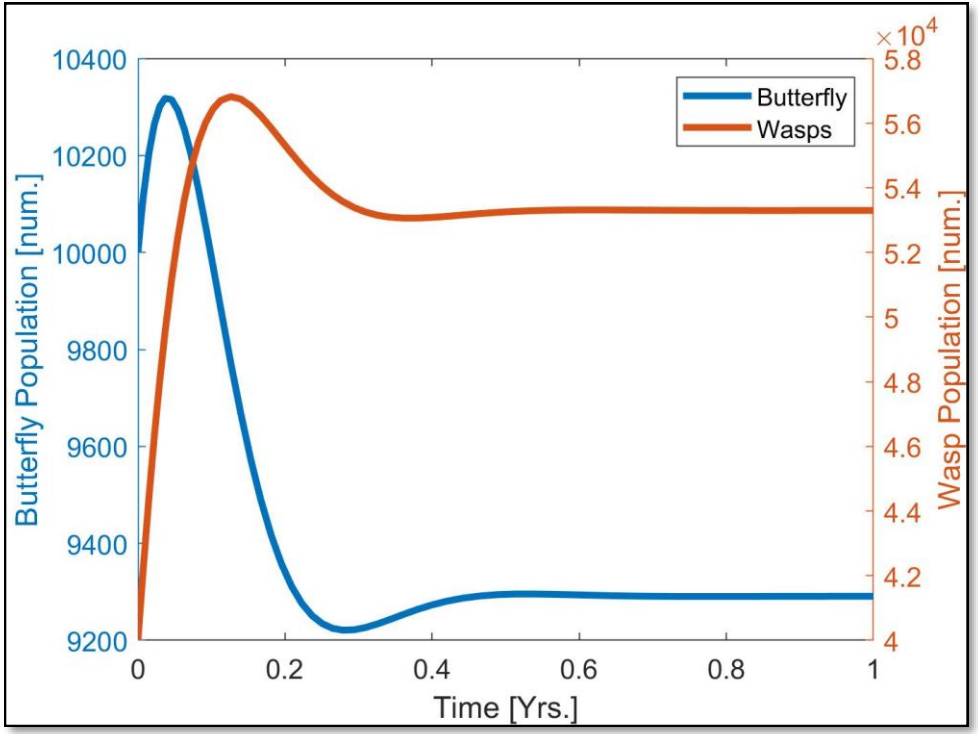
B_R = Butterfly Birth
E_f = Encounter
K_f = Kill
S_f = Spray
Su_v = Survivability
Fe_f = Fecundity

Solution Strategy for Governing Equations



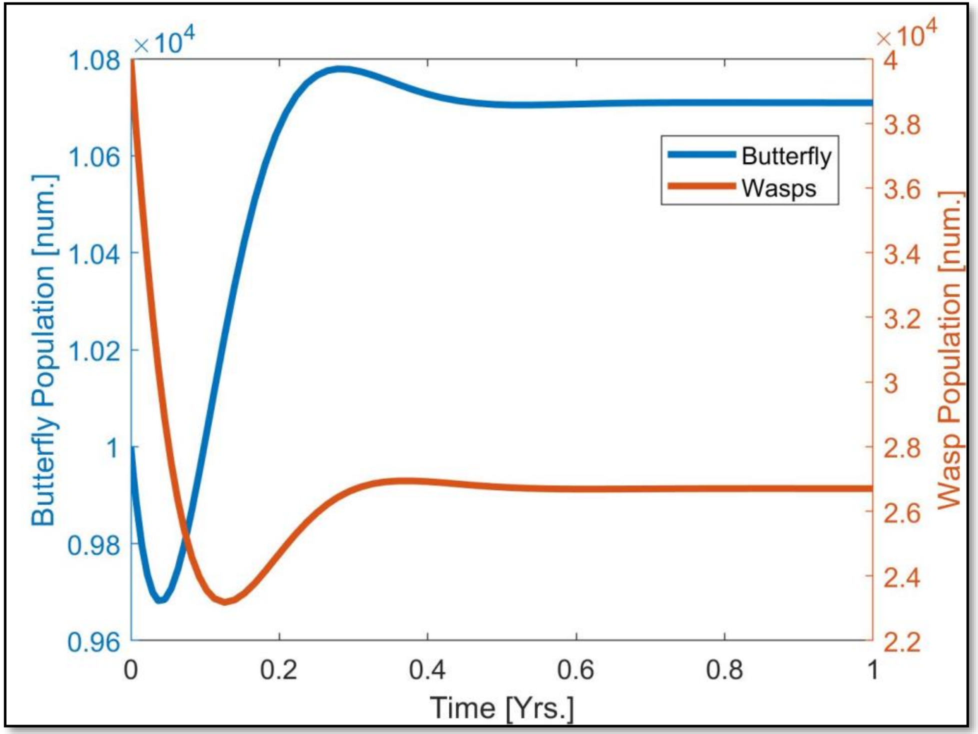
- Step change introduced in the form of percent change in spray rate
- Numerical Solver: ode45 in MATLAB

Results – 50% Increase In Spray Rate



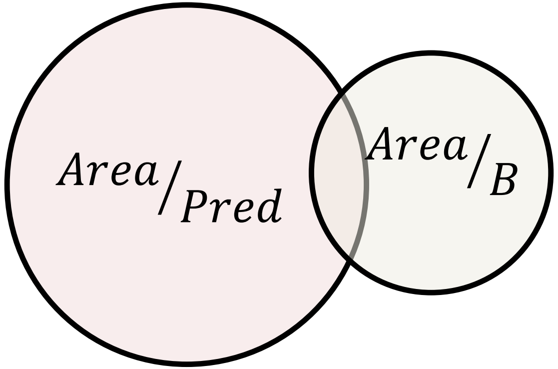
- Introduce a 50% step increase in anaphrodisiac spraying
- Steady rise in wasp population
- Initial rise in butterfly population, transitioning to a steady state decrease

Results – 50% Decrease In Spray Rate



- Introduce a 50% step decrease in anaphrodisiac spraying
- Steady fall in wasp population
- Initial fall in butterfly population, transitioning to steady state increase

Additional Issue: Predator & Butterfly/Wasp Interaction



- Predator population assumed constant
- A_k is the assumed kill area

$$P(Pred \cap B) = P(Pred)\ x\ P(B)$$

$$P_{encounter} = \frac{A_k}{A_c/_{Butterfly}} \frac{A_k}{A_c/_{Predator}} = \left(\frac{A_k}{A_c}\right)^2 [Predator][Butterfly]$$

$$A_c = assumed\ control\ area$$
$$A_e = kill\ area$$

Model Adaptation: Predator & Butterfly/Wasp Interaction

Butterfly Population

$$\frac{dP_{BF}}{dt} = \ldots - \left(\frac{A_k}{A_c}\right)^2 P_{BF} P_{pred}$$

Wasp Population

$$\frac{dP_W}{dt} = \ldots - \left(\frac{A_k}{A_c}\right)^2 P_W P_{pred}$$

P_{BF} = Butterfly population
P_W = Wasp population
P_{pred} = Predator population
$P_{enc.}$ = Encounter Probability
L_{Bf} = Butterfly life span
L_W = Wasp life span

Factors

B_R = Butterfly Birth
E_f = Encounter
K_f = Kill
S_f = Spray
Su_v = Survivability
Fe_f = Fecundity

Model Conclusions – Don’t Spray!

- Optimal anaphrodisiac spraying is a balance between the increase in survival rate against the increase in parasitizing
- Butterflies should spray less anaphrodisiac to increase population
- The introduction of predators dampens the magnitude of the rise and fall in the butterfly and wasp population

References

[1] “Anti-aphrodisiac Compounds of Male Butterflies Increase the Risk of Egg Parasitoid Attack by Inducing Plant Synomone Production,” Fatouros, Nina E., et al. Journal of Chemical Ecology. Volume 35, Issue 11, Nov 2009, Pages 1373-1381, 1 December 2009. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2797620/

[2] “Butterfly anti-aphrodisiac lures parasitic wasps.” Fatouros, N., Huigens, M., van Loon, J. *et al*. *Nature* Volume 433, Issue 704, 17 February 2005. https://www.nature.com/articles/433704a#citeas.

[3] “Chemical espionage on species-specific butterfly anti-aphrodisiacs by hitchhiking Trichogramma wasps,” Fatouros, Nina. E, et al. Behavioral Ecology. Volume 21, Issue 3, May-June 2010, Pages 470–478, 11 February 2010. https://doi.org/10.1093/beheco/arq007

[4] “Egg size-number trade-off and a decline in oviposition site choice quality: female Pararge aegeria butterflies pay a cost of having males present at oviposition.” Gibbs, M et al. *Journal of insect science (Online)* Volume 5, Issue 39, 6 Dec. 2005. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC161524