Team: Josh Marrs, Reagan McClellan, Jesus Hernandez
Instructor/Coach: Kambiz Shahroudi
School: Central New Mexico Community College

# Team Executive Summary (Problem C)

Our team concluded that the best way to find the solution to **Problem C: Chemical Espionage** was to use a model that would find a balance of pheromones that keeps the butterfly population in equilibrium with its environment's carrying capacity and wasps for as long as possible. This required us to find a model that measures the change in population of the butterflies over time, with respect to butterfly pheromones and wasps in the environment. We decided to use the three following equations in our model, in order of greatest weight over the outcome: the equation for the amount butterfly eggs, the equation for wasp eggs, and equation of the rate of pheromone decay. As a result of our model we found that **overtime, in the long run, wasp eggs will overtake butterfly eggs, and the population of both butterflies and wasps will decrease to zero.**

We set up our model and equations using the following methods:

We researched what factors might be able to affect the system of the butterflies and wasps, then decided to declare the following variables and constants for our equations:

| **Variables** | **Description** | | **Constants** | **Description** |
|---|---|---|---|---|
| $\frac{dE}{dt}$ | Change of butterfly eggs over time | | M | Rearing period = $\frac{1}{5}$ (5-day cycle) |
| $E$ | Number of butterfly eggs | | $E_{ave}$ | Average butterfly eggs laid per cycle = $\frac{40}{3}$ |
| F | Number of female butterflies | | D | Morality rate = 0.15 |
| $S_1, S_1$ | Success rate of wasp parasitism | | A | Amount of butterflies that make it to adulthood = $\frac{1}{40}$ |
| $W_{i1}, W_{i2}$ | Wasp interest rates | | $E_w$ | Average butterfly eggs parasitized by wasps = 6.5 |
| $\frac{dW_1}{dt}, \frac{dW_2}{dt}$ | Change of wasp eggs over time | | | |
| $B$ | Number of adult wasps | | | |
| P | Number of wasp eggs laid per interaction | | | |
| r | Ratio of butterfly eggs over total eggs | | | |
| $W_1$ | Total wasp population of type 1 wasp | | | |
| $W_2$ | Total wasp population of type 2 wasp | | | |
| $\frac{dR}{dt}$ | Rate of pheromone decay | | | |

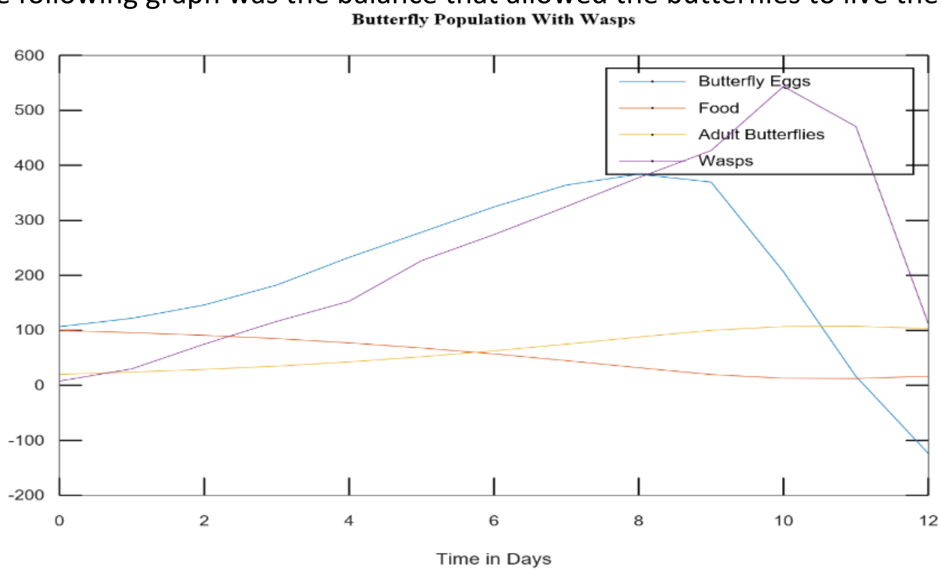
With these variables and constants, we formed the three equations of our model:

1. $\frac{dE}{dt} = F(ME_{ave}) - DE - AE - W_{i1}W_1W_{r1}S_1 - W_{i2}W_2W_rS_2$ (butterfly eggs)
2. $\frac{dW_1}{dt} = SBE_wrPW_{i1}W_{r1} - \frac{1}{2}W_1 = \frac{dW_2}{dt} = SBE_wrPW_{i2}W_{r2} - \frac{1}{2}W_2$ (wasp eggs)
3. $\frac{dR}{dt} = kR$ (pheromone rate)

After forming these equations, we did some research to find reliable values to input as our constants. Inputting the new values into our equations gave us the following:

1. $\frac{dE}{dt} = F(\frac{1}{5})(\frac{40}{3}) - (0.15)E - \left(\frac{1}{40}\right)E - W_{i1}W_1W_{r1}S_1 - W_{i2}W_2W_rS_2$ (butterfly eggs)
2. $\frac{dW_1}{dt} = SB(6.5)rPW_{i1}W_{r1} - \frac{1}{2}W_1 = \frac{dW_2}{dt} = SB(6.5)rPW_{i2}W_{r2} - \frac{1}{2}W_2$ (wasp eggs)
3. $\frac{dR}{dt} = kR$ (pheromone rate)

We then used graphing software to combine and plot our equations. Next, we tried to find the maximum amount of time butterflies could live before they either consumed the capacity of the environment or were overtaken by the wasps. We tried different inputs for the variables in our equations, until we found the balance that would allow them to last the longest. We determined that this balance would be the answer to **Problem C**, and **in the long run the outcome of this balance was that the wasps overtook the butterflies, and both populations fell to zero.** According to our model, the following graph was the balance that allowed the butterflies to live the longest:




We obtained general information and values for our constants from the following websites and Internet sources:
http://www.animalplace.net/invertibrates/cabbage-white-butterfly-facts-characteristics-habitat-and-more
https://www.evergreengrowers.com/trichogramma-brassicae-3759.html
https://link.springer.com/article/10.1007%2FBF00299686
https://web.stanford.edu/~jhj1/teachingdocs/Jones-dynamics2006.pdf
https://en.wikipedia.org/wiki/Cauliflower
https://www.evergreengrowers.com/trichogramma-brassicae-3759.html
https://www.arbico-organics.com/product/moth-egg-parasites-trichogramma-minutum/pest-solver-guide-caterpillars moths?msclkid=3205ab36142c10759528f6f6f935f4cd&utm_source=bing&utm_medium=cpc&utm_campaign=Caterpillars%20%26%20Moth%20Control&utm_term=trichogramma&utm_content=Trichogramma%20Wasps%20Caterpillar%20Control
https://edepot.wur.nl/120979
https://www.reference.com/pets-animals/butterflies-reproduce-f291f3be9c5cc24f
https://www.theatlantic.com/science/archive/2017/06/butterfly-cabbage-white-vagina-dentata/530889/
https://scialert.net/fulltext/?doi=ajps.2004.391.393
https://academic.oup.com/jinsectscience/article/19/4/10/5535715
https://bugsforgrowers.com/products/egg-parasite-trichogramma-brassicae
https://en.wikipedia.org/wiki/Trichogramma
https://academic.oup.com/beheco/article/21/3/470/219121
https://link.springer.com/article/10.1007/s10886-011-9935-2
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1691801/pdf/15315890.pdf
https://www.wildlifenatural.com/Pieris-brassicae/
http://www.yourarticlelibrary.com/zoology/cabbage-butterfly-pieris-brassicae-distribution-in-india-life-cycle-and-control/23965s
https://www.academia.edu/11962948/Evaluation_of_Efficiency_of_Trichogramma_evanescens_Reared_on_Different_Factitious_Hosts_to_Control_Helicoverpa_armigera
ipm.ucanr.edu/PMG/NE/trichogramma_spp.html
https://www.appliedbio-nomics.com/wp-content/uploads/270-trichogramma.pdf