Agent-based modeling to understand the dynamics in a protozoa-bacteria system

Faichal Ayeva[1],

Prof. Diana White[2] and Prof. Jonathan Martin[2]

[1]Department of Electrical Engineering and Business, [2]Department of Mathematics

Clarkson HONORS PROGRAM

Objectives

- Develop an agent-based model (ABM) to study the complex interactions and dynamics of predator-pest systems.
- Here, we model a protozoa (predator)–bacteria (pest) system, as one goal of this project is to compare ABM output with laboratory experiments.
- Protozoa are single cell organisms that feed off bacteria.

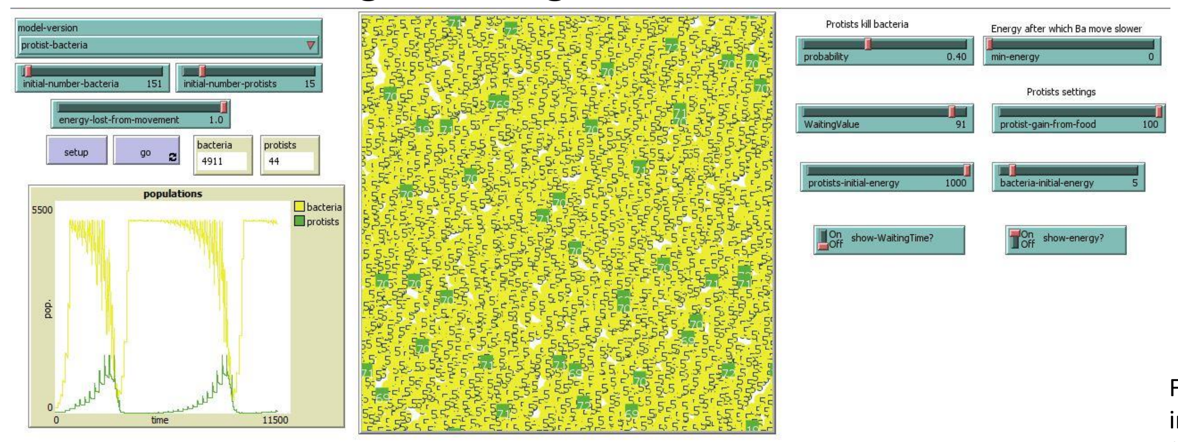

Fig: User interface of NetLogo showing an example of our ABM output. NetLogo is a programming language and integrated development environment for modeling.

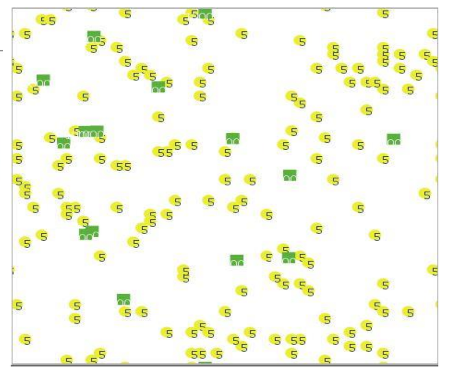

Figure 2: NetLogo "world" showing the initialization stage of our ABM (Protozoa, in green, and the bacteria, in yellow). The world is made up of discrete patches that have coordinates.

Motivation

- We explore complex interactions between predators and pests at the individual level (population models lack this detail - missing important biological detail).
- Not understanding such systems can lead to undesired results, such as the eradication of a native species, or invasion of an unwanted pest species.
- We study a protozoa-bacteria system, with an aim of parameterizing our model using data from experiments (future work).

Sustainability: An eventual goal of this project is to translate our results to large-scale settings, such as those in agriculture (i.e., study the interactions between agricultural pests and potential (predator) bio-control.

ABM Rules

Protozoa (P)

- **Move** ⟶ (to random open patch and lose 1 unit of energy)
- **Reproduce** (divide every 4 hours)
- **Die** (when energy = 0)
- **Kill/Eat** Bacteria (when **Waiting Time** [1] is 0 and gain prescribed amount of **Energy**)
- One per patch

Bacteria (B)

- **Move** (randomly one step – movement does not depend on patch structure)
- **Reproduce** (divide every 2 hours)
- **Die** (when eaten by the protozoa)
- An unlimited amount of bacteria can be on the same patch

Note: Different prescribed carrying capacity for both (each species population does not grow past its carrying capacity – max population to which each grow)

[1] **Waiting Time** (time until protozoa eats again)

ABM Illustration

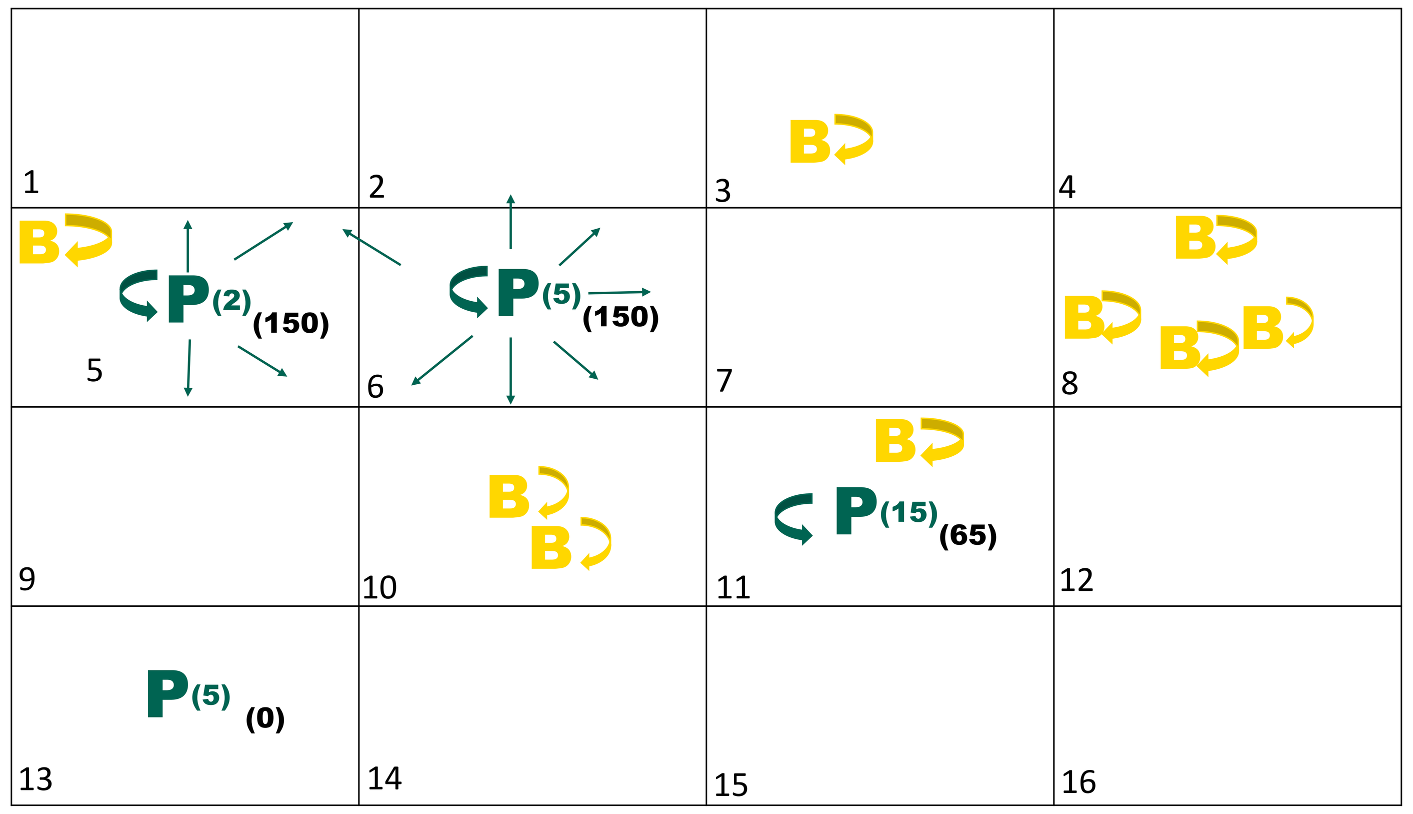

Fig: Protozoa and bacteria randomly placed on the NetLogo world's patches. The subscripts on the protozoa represent the amount of **Energy** protozoa have. The superscripts represent their **Waiting Time**. The straight arrows represent the patch that a protozoa can move to at each time step.

- Patch 11: if the assigned **Kill Probability** is satisfied, and the protozoa gains a prescribed amount of **Energy** and **Max Waiting Time (e.g. 15).**
- Patch 13: since Energy = 0.
- Patch 8: Many B can be located within a single patch (and located anywhere).
- Patch 6: Only 1 protozoa per patch.

Possible outcomes for varying Waiting Time

(I) Both Species Die

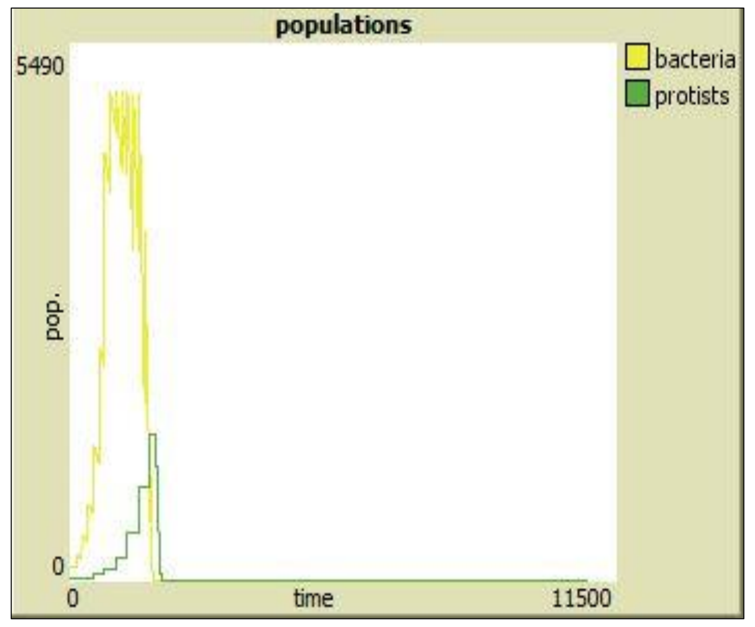

Fig: bacteria grow and protozoa begin to eat. Not enough bacteria to sustain population.

(III) Protozoa Die & Bacteria Survive

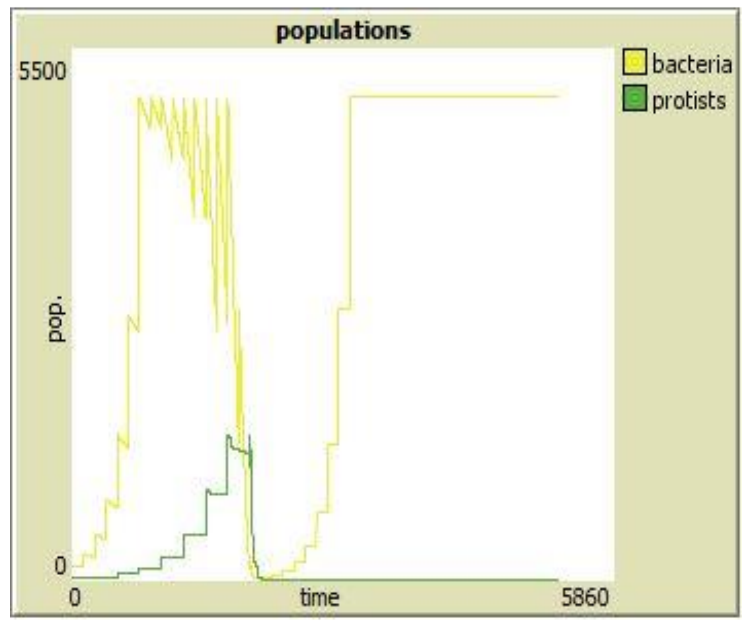

Fig: bacteria grow and protozoa begin to eat. Here, protozoa lose energy faster than they can grow/eat. Bacteria reach their carrying capacity.

(II) Coexistence (both survive)

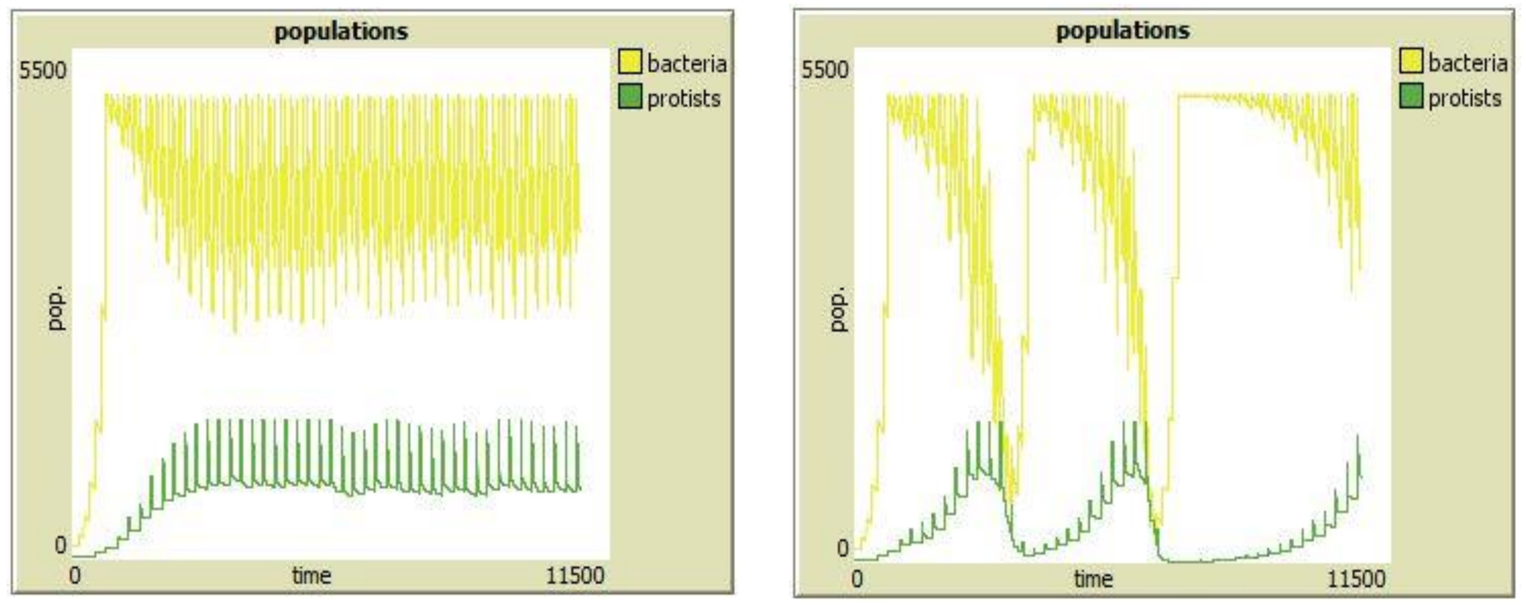

Fig: Here, we see the case of coexistence. (left) Both population oscillate about a mean value. (right) populations cycle.

Note: Our model is able to describe the 4 possible outcome exhibited in other predator-pest models (the 4 mentioned above)

Results from Varying Waiting Time continued

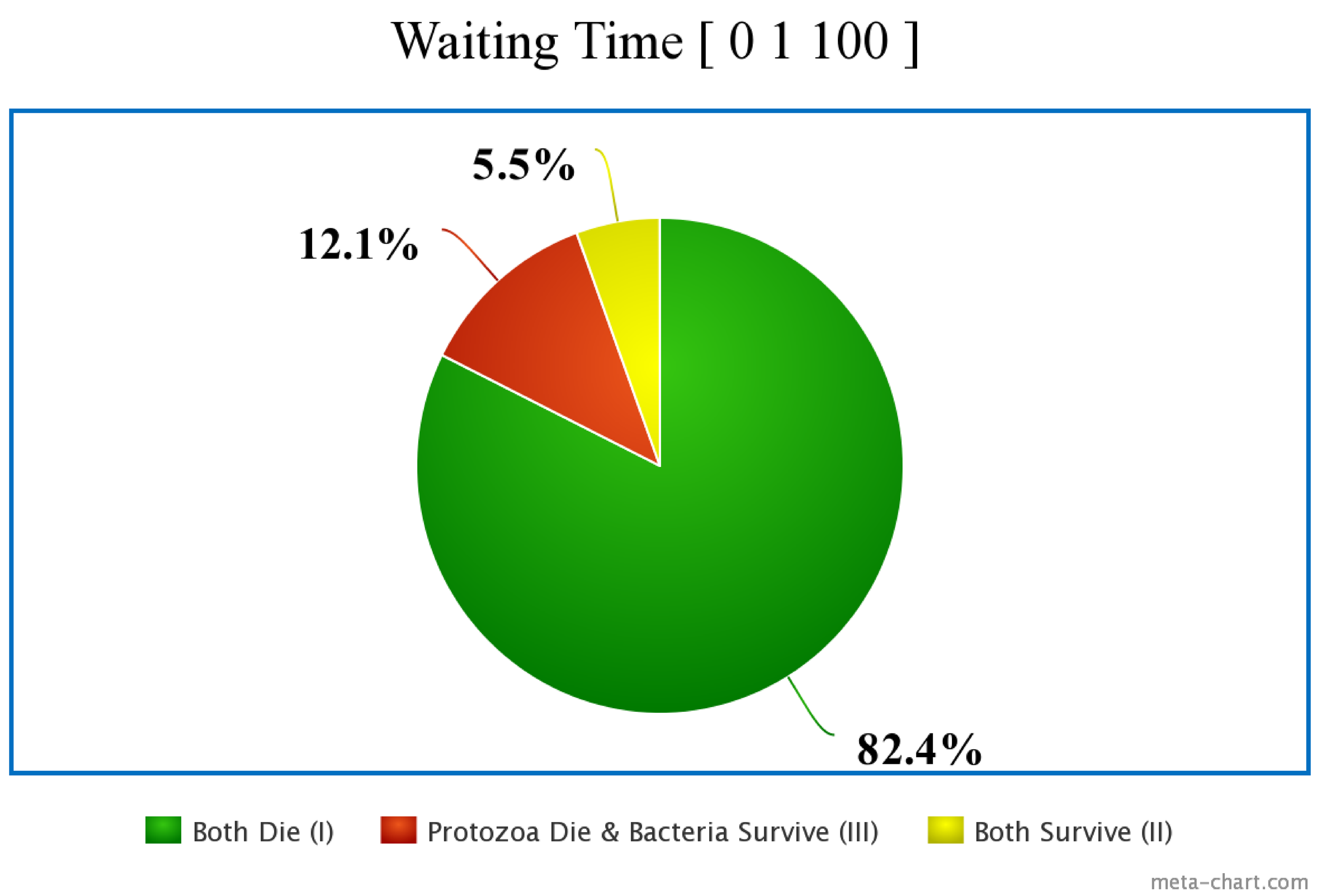

Fig: In this experiment, we kept all variables constant expect the **Waiting Time**. We ran 1010 runs (10 runs for each Waiting Time value from 0 to 100 with an increment of 1). This Pie chart illustrates the percentage at which each outcome is observed.

Conclusion and Future work

- Through variation of model parameters (e.g., **Waiting Time**) we describe the 4 outcomes observed in other predator-pest systems.
- Next, we will parameterize our model by comparison to laboratory experiments; refine our model as needed (work to be completed with the Bailey Lab at Clarkson University).
- Run multiple simulations (varying other parameters such as **Kill Probability** and **Energy**) to better understand the dynamics of our model.

Acknowledgements

- Honors program for the opportunity to do research, the financial support, and guidance.
- Prof White, Prof Martin for their invaluable guidance, friendly advice, and their interest in this project.
- Corning for their financial support and opportunity to do research.

Contact information

Faichal Ayeva: ayevafi@clarkason.edu

Prof. Diana White: dtwhite@Clarkson.edu

Prof. Jonathan Martin: jmarti@Clarkson.edu

References

[1] Bale, J. S., Van Lenteren, J. C., & Bigler, F. (2008, February 27). Biological control and sustainable food production. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2610108/

[2] Thorne, Bailey, M., A., Peirce, M., S., & Bryan C. (2007, June 18). Combining experiments with multi-cell agent-based modeling to study biological tissue patterning. Retrieved from https://academic.oup.com/bib/article/8/4/245/221203