Modeling the effects of climate change on the smaller tea tortrix and its natural enemies

Introduction*:* With global temperature projected to rise, it is crucial we understand how major agricultural pests and their natural enemies will respond to implement more effective integrated pest management for the future. Pathogens and parasitoids are common biological control agents, yet there have been few studies exploring how *temperature*, the pacemaker of all ecotherms, could affect the stability of *multi-trophic insect systems*. For instance, increasing temperature can indirectly affect the transmissibility or attack rate of a natural enemy that it competitively excludes another natural enemy species. Alternatively, changes in the pest's physiology, such as the *immune response* and *feeding rate*, can allow the pest to escape from its biological control agents through increased physiological mismatch. The question of how the temperature effects on individual traits will translate into the persistence of natural enemies is complex and will require construction of a mathematical model supported by empirical data collection.

Background: The model pest for this study is the multivoltine lepidopteran, *Adoxophyes honmai*, also known as the smaller tea tortrix. *A. honmai* is a major tea pest in the eastern hemisphere as it causes significant damages to tea crops in its feeding larval stages (5-6 instars). To regulate the tea tortrix population, both parasitoid wasps and baculoviruses are widely used as biological control agents. The baculovirus is transmitted by occlusion bodies (OBs), a crystalline protein matrix that protects the virions. After the OBs are consumed by the host, the virions replicate in the insect's midgut before the host disintegrates and releases the virions back into the environment. *Older larval instars of lepidopterans are more resistant to the baculovirus infection as they have a higher rate of sloughing off infected midgut cells*[1]. For this study, I will use the baculovirus, AdhoGV, which is commonly used to control the smaller tea tortrix population. The other natural enemy, *Ascogaster reticulata*, is a *stage-specific* parasitoid wasp which oviposits in the tea tortrix eggs and emerges from the host's fourth instar. The wasp larva then consumes the host and pupates before emerging as an adult parasitoid.

Changes to the tea tortrix's *immune response* and *feeding rate* can indirectly alter the competitive interactions between the baculovirus and the parasitoid. Evidence suggests a *trade-off between immunity and reproduction*, as mounting a resource-intensive immune response imposes a cost on other components of fitness[2]. At higher temperatures, invertebrates generally have higher fecundity and metabolic rates[3] which can induce *lower immune responses* and *higher feeding rates* in the tea tortrix larvae. These changes can lead to increased susceptibility of the lepidopteran hosts to the baculovirus and can result in higher premature, virus-induced mortality in the parasitized hosts. *The host-parasitoid-pathogen system may become destabilized, thus unraveling critical interactions which underlie the biocontrol of this damaging pest.*

Hypothesis*:* I hypothesize that higher temperatures will change the tea tortrix's ability to escape from both natural enemies. The host larvae containing the larval parasitoids may be more likely to consume and be infected by OBs at higher temperatures due to the host's depressed immune response and increased feeding rate. If the host liquidates before the wasp's emergence, the parasitoid population will be less likely to persist in the system. However, it is also possible that the shortened development time of the tea tortrix can allow it to slough off OB infected midgut cells. Without the presence of young, susceptible hosts, the virus will likely go extinct in the system. To test my hypothesis, I will create a mathematical framework of the host-parasitoid-pathogen system to predict possible outcomes at different temperatures.

Host Trait Experiment: The tea tortrix larvae will be reared at three temperatures: 12°C, 15°C, and 20°C. Haemolymph will be extracted from the 1st to 3rd instar larvae of each temperature system to run a phenoloxidase assay. Phenoloxidase is an important enzyme for cuticular melanization, an immune response which defends the invertebrate from foreign invaders such as viruses. The larvae will then be fed on OB-infected leaves to observe if there is a correlation between phenoloxidase expression and survivorship. To quantify feeding rate, 1st to 3rd instar tea tortrix larvae will be fed a premeasured leaf for twelve hours at different temperatures and the remaining leaf will be weighed to calculate the feeding rate. I will utilize generalized linear regression to observe differences between the temperature systems and to estimate parameters.

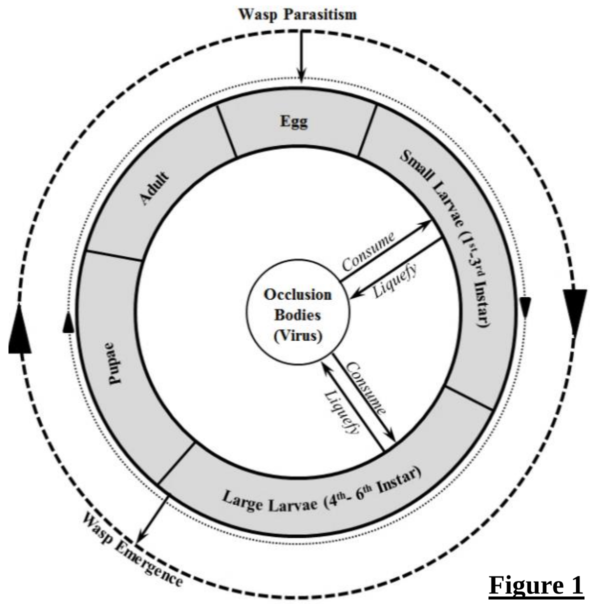

Figure 1

Modeling: Figure 1 is a simplified graphical representation of the mathematical model I will create. *Unlike previous multi-trophic models, all parameters such as development rate, feeding rate, immune response, and parasitoid functional response will be linked to temperature and determined experimentally*. I will use *delayed differential equations* to capture temperature-dependent development delays of both the tea tortrix and parasitoid. The transmission of the baculovirus in the system will be modeled using the SEIR (Susceptible-Exposed-Infected-Removed) model. The virus transmission will be dependent on both the *feeding rate* and the *immune response* of the tea tortrix which will vary with temperature and the larval instar. The number of larval parasitoids is dependent on the successful oviposition of adult wasps which will be modeled as a Type II functional response with the attack rate and handling time linked to temperature. This ensures that even with increasing host egg density, the oviposition rate will be limited by the wasp's handling time. *I expect that at higher temperatures, the model will predict extinction of both natural enemies because of temperature-dependent changes to system stability*. As this model utilizes delay differential equations, it can realistically capture life cycles with distinct stages and be applicable to other important insect pests.

Parameterization: Tea tortrix egg masses will be placed in the three temperatures (12°C, 15°C, and 20°C) with tea as the plant food source. Fourteen female adult *A. reticulata* will be released into the system. After the tea tortrix eggs hatch, I will randomly place AdhoGV infected cadavers on the tea leaves to mimic the natural spread of baculoviruses in the field[3]. Each week, I will record the number of surviving larvae at different instars, infected larval cadavers, wasp pupae, and the surviving adult parasitoids. I will have multiple replicates which will run until both enemies are extinct or long-term persistence is established. *I will then fit the model I have constructed to the experimental data and verify with maximum likelihood analysis.*

Broader Impact: This study will help inform policymakers in agriculture and forestry sectors on implementing the effects of temperature to prepare for resilient production systems with increasing demands and increasing environmental variability. I plan to work with the Rainforest Alliance to inform tea farmers on how to adapt pest management techniques to climate change. Finally, I will recruit undergraduates from underrepresented groups as this project provides a unique opportunity to be exposed to both mathematical and experimental biology.

[1] K. Hoover, M. Grove, S. Su, Biol.Control. 25 (2002) 92-98 **[2]** P. Schmid-Hempel, Ann. Rev. Entomol. 50 (2005) 529-551**[3]** M.O'Connor, Ecology. 90 (2009) 338-339 **[4]** B. Elderd, J. Reilly, J.Anim.Ecol. 83 (2014), 838-849