**Mechanistic Mediation of the Descent into Diapause: The relationship between of stored resources on diapause timing.**

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**MS Thesis Proposal**

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**INTRODUCTION**

**Climate Change**: Of the 137-year history of recorded global surface temperatures, 2016 was the warmest year on record. The National Oceanic and Atmospheric Administration estimates the 2016 average global surface temperature as 1.47°C above the 20th century average (NOAA National Centers for Environmental Information 2017). While debate continues over the exact cause of these changes, the consequences of these changes are shifting ecologies across the globe. Here in the United States, Kirtland warblers, *Dendroica kirtlandii*, are losing habitat as a direct effect of climate change. These ground-nesting birds rely on the combination of sandy soils and jack pine forests to forage and fledgling survival (Schneider and Root 2002). Currently, rising temperatures are pushing jack pine acreages north where the sand is less sandy. and diminishing the habitat of the warbler (Botkin et al. 1991). The climate is changing dramatically and has been doing so over the past four decades (Mac et al. 1998). Historically, climate and seasonal temperature variations are more predictable and organisms gradually flowed into different habitats and occupied new niches over time. In the context of a less predictable climate, organisms are thrown into different ecological spaces where the pressure to survive results in ecological upheaval. These ecological consequences, as a function of dramatic climate fluctuations, must be investigated to fully comprehend the extent of these changes.

Understanding the degree to which these climate fluctuations will affect ecological stability and global food security is central to mitigating the effects of these changes.

**Effects of Climate Changes:** Corn here in the United States is an important economic agricultural commodity. Agriculture output adds $136.7 billion dollars to the nations economy, accounting for 1% of the United States GDP in 2015 (Glaser 2016). For many farmers and consumers,

[ Expected effects of climate change on food security: DOI: 10.1038/ncomms6989]

* Parameter of food security
* Food security projections in the context of climate change
* pest pressure, degree days, crop yield as points

[ Expected effects of climate change on ecological diversity: DOI: 10.1046/j.1365-2486.2002.00451.x]

* Parameter of diversity
* Diversity as a function of reliability of seasons
* Population, location, and gradient of diversirty and specialists

**Ecological Result of Climate Change**

[ How organisms/insects adapt to climate change: doi: 10.1073/pnas.241391498]

* Removal of resources/hosts
  + Seasonally or permenantly
* migration
* “host switching?”
* plasticity

**Insect Diversity:** This effect is becoming more noticeable in regions where temperatures are less variable but extreme. For instance, in Antarctica (Find the Denlinger paper on that small insect losing its habitat). (Obligate lifestyle, specialized physiology, fragile ecosystem) Beyond simply losing acreage of habitable terrain, this species population will eventually decline to an unmaintainable number, making this and other species like it that live on the temperature extremes, causalities of climate change.

Farther away from these temperature margins, the interplay between temperature and organismal diversity is less conspicuous. (Reference the Sinclair paper and the William’s paper, discuss how there are alternatives to the dogma that climate change will diminish insect diversity.)

As environments continue to change and as seasonal temperatures become warmer and less predictable, organism diversity by some measures is declining. Ultra-cold temperature organisms are losing acres of habitat every year as these icy places become warmer. Reciprocally, ultra-hot environments are increasing in size as rainfall becomes more sporadic. These dry, hot places are also losing diversity to desiccation and heat exhaustion. Organisms that exist on these extreme margins have a more difficult time dealing with these biologically fast changes in their environment due to their extremely specialized lifestyle. As a result, some of this extremophile diversity could be lost as climate continues to change.

On the contrary, these environmental shifts do not necessarily spell disaster for all diversity, in fact organism diversity could increase in some environments (Sinclair 2015). This type of survival will depend largely on species genetic traits and phenotype plasticity (Williams et al 2014). **Animals and Climate:** Prior to the industrial revolution of the 19th century annual seasons followed a reliable pattern of high temperatures during the peak of summer and low temperatures during the peak of the winter. Associated with these cyclic temperatures was the waxing of daylight hours leading to the middle of the summer, and the waning of those hours leading to the middle of the winter. Both plants and animals have evolved to live in synchrony with these annually cycles and in many cases organism life histories have become constrained by them. In the Southern ocean, the ultra low temperatures freeze the sea water into a semi solid matrix. The sea ice matrix is crossed by a network of extremely brine filled passages, and within those passages microorganisms thrive (Thomas and Dikemann 2002). These tiny plants and animals have evolved to tolerate the habitat extremes of the free water of the Southern ocean and the semi-solid salty sea ice matrix. In fact these microorganisms living in the sea ice of the Southern Ocean rely on the ultra-low temperatures and predators, like krill, depend on the seasonal melting of the sea ice as a food resource. Such that changes to the pattern of freezing and thawing could potentially have cascading effects on the grazing and life histories of these lynch-pin predators.

In these extreme environments there is a tendancy towards obligate synchrony with the environment.

Temperate climates too have organisms with life histories that are “seasonal obligatory”

Temperate climates also have organisms with life histories that are “seasonally facultative”. Making predictions about these types of environments is important because it could mean [plant growing seasons, pest growing seasons] In more temperate environments….. [diversity, insect ranges, agriculture]

With annual temperatures are becoming more variable, those synchronized life histories are in jeopardy of unraveling. predicting how plants and animals will respond to these changes needs to be investigated further. For centuries, in the more temperate areas of the globe, those temperature drops coincide with the reduction of daylight hours. Plants and animals have evolved over millennia alongside these annual environmental changes and over time those organism’s life histories become dependent upon detecting those changes. Breaking the

**Adaptative Plasticity** [ How plasticity can mitigate effects of climate change: doi: 10.1111/brv.12105, doi:10.1093/icb/icr049, INSECT SEASONAL CYCLES: 195 GENETICS AND EVOLUTION]

* Parameters of plasticity: types and functions
* Buffer to Fluctuations and depleted resources
  + Diapause as an example
* ECB as an example

**ECB as a model** [ Importance of ECB to food security and ecological diversity]

* Agricultural importance [Host-plant diversity of the European corn borer Ostrinia nubilalis: what value for sustainable transgenic insecticidal Bt maize?]
  + Cost to protect
  + Ability to destroy
  + Current range and projections
* Latitudinal distribution [DOI: 10.1111/j.1365-2486.2010.02308.x]
  + Climate seems to have distributed these species. This is a chance to make interesting science
  + Clines are distributed latitudinally and are separated genetically
* Predictive power of model
  + Diapause phenotype and genetic differences

**The European corn borer Model:** As seasonal climates are becoming less predictable so goes our food security. Understanding how to manage unreliable seasons is both difficult and urgent. Predictable seasonal climates and global food security are tenuously bound making a comprehensive approach to dealing with these changes imperative. Farmers and growers must be able to make short-term and long-term decisions about when to control pest populations based upon how the climate affects those populations. Here in the United States, 92 percent of all the corn acreage is planted with a genetically engineered corn crop that expresses *Bacillus thurengensis* (Bt) crystalline protein toxin. Bt toxin was developed agriculturally to assist in managing European corn borer corn pest. pressure manage the that can be done to corn by an infestation of European corn borer. For this technology to be effective, farmers need to predict European corn borer infestations (ERS report 2017). **Diapause and Climate:** Food, mates, water, shelter; these are all resources that organisms must manage to be competitive and survive within their environment, so how is this accomplished? During periods of food abundance one can intuit how managing it can be understood. Simplistically, when available food concentrations are higher than the amount of food required for an organism to survive, they will either consume just enough resources to survive or they will over consume. The dynamics of survival during times of food scarcity is not as simplistic but can be understood in general terms. Overcoming resource decline in most cases leads to different types of dormancy but the intensity, preparation, and duration of that dormancy are all able to be modulated to meet the specific requirements of an organism’s current environment.

Humans experiencing a decline in food resources, become lethargic and slow but when we eat we gradually become less lethargic. This type of dormancy is termed quiescence. Quiescence is a type of dormancy that is an immediate response to changes in the environment. Reductions in food, water, oxygen, temperature can all have direct effects on the immediate developmental state of an organism. A more intense type of dormancy is diapause. Diapause is a form of dormancy that is a genetically based suppression of direct development. This type of dormancy is generally induced prior to the decline in resources and its precipitation stems from environmental cues such as light or temperature. This type of dormancy is a protective response to the reduced availability of resources in the environment and is usually induced before those resources become scarce. The genetic programming that is initiated when diapause is induced normally leads to the acquisition and storage of more resources necessary to survival. survive diapause organisms will that are undergoing this type of dormancy will see a marked increase in the amount of resources they…

For centuries, plants and animals have experienced the global climate in annual cycles. Organisms have evolved in the context of these annual cycles for millennia and as annual temperature fluctuations fall out of synchrony with daylight hours, understanding the consequences of this variability is urgent. What’s more is these organisms have come to depend upon these annual patterns, some more than others. Understanding the extent to which those relationships will be affected by this record setting unpredictability is a challenge that is sure to have broad effects on how we manage agricultural pests and our food security as a nation.

**OBJECTIVE**

While intuitively it may seem that meeting the additional physiological stress of diapause, organisms should necessarily store more energy when preparing for that stressful time. However, other strategies have been documented (Hahn and Denlinger 2011). “Studies detailing diapause-associated changes in intermediary metabolism and feeding physiology are needed across taxa with different diapause strategies to expand our understanding of the metabolic processes underlying prediapause reserve accumulation. The goal in this area is to under- stand the underlying neurological and endocrine signaling mechanisms that regulate diapause-associated shifts in feeding patterns and intermediary metabolism.” The objective of this study will be to quantify and compare the difference in stored energy between two genotypically different strains of *Ostrinia nubilalis,* the European corn borer. Further, European corn borer (ECB) destined for and ECB avoiding diapause will be compared within each strain. Characterizing the energy stores of ECB destined for diapause, has yet to be capitulated in ECB and is necessary to understanding diapause biology and usefulness as a model system, managing it as an agricultural pest, and predicting its behavior as seasonal climates become less predictable (Denlinger 2008).

I hypothesize that the amount of energy a European corn borer stores in preparation for the additional stress of diapause, is related directly to how it performs during diapause. Specifically, diapause destined individuals preparing for diapause will increase their storage of triglycerides and storage proteins in direct relation to the length of time they will spend in diapause. The ECB strain preparing for a long period of diapause will store more energy than their shorter diapausing and diapause avoiding counterpart. Diapausing ECB may be storing energy in different ratios than diapause avoiders. Higher levels of triglycerides may be used to supplement water and protect against desiccation while higher protein stores could be used to rebuild damaged or depleted enzymes.

European corn borer model is well suited for this type of study. Within the species there are of 2 distinct genotypes that differentially express the diapause phenotype. The univoltine-Z (UZ) genotype expresses a long diapause phenotype, while the bivoltine-E (BE) genotype expresses a shorter diapause phenotype. Further, the expression of the diapause phenotype is facultative. When exposed to a photoperiod of 12h:12h (light hours:dark hours) the diapause phenotype is expressed, photoperiods of 16:8 suppress the diapause phenotype. The strains of ECB persist as inbred siblings, originating from naturally occurring populations genotype can either express or avoid. ECB preparing for a longer period of diapause will store more energy in the form of fats and protein, while ECB preparing for shorter period of diapause should store relatively less energy in the form of fats and proteins. there is a direct relationship between the amount of energy stored when feeding ends and the length of time an individual spends in the diapause state. Such that ECB destined for a longer period of diapause will store more energy than ECB destined for a shorter diapause. Further, the larvae destined for diapause will differentially store more energy than those larvae that are avoiding. To that end I will

Characterizing these metabolic intermediates is intended to approximate the amount of energy an individual has reserved after feeding ends. European corn borer was chosen as the model for these experiments due to their facultative diapause life history strategy, differing genotypes and physiologies, and their different phenotypes. When either strain is exposed to the same photoperiodic and thermal cues in the laboratory, their specific response can be reproducibly observed but the physiological link between genotype and phenotype has not yet been described.

Approximately, $10 billion dollars is spent annually on chemical insecticides to control the damaging effects of insect pests (Pimentel 2005). Corn is an incredibly valuable crop in the United States and protecting it from actively feeding phytophagous insects includes the dynamic use of chemicals and biotechnology.

To control the ephemeral outbreaks of ECB, farmers in the US spend approximately $10 billion dollars on chemical pesticides.

Mitigating the persistent threat to this crop is accomplished through genetically engineered corn seed expressing an insect feeding toxin found in *Bacillus thurgensis* (BT)*.* In 2016, 92% of the corn acreage in the US was planted with BT corn. This type of pest management is a very powerful tool due to its specificity for phytophagous insects. However, the widespread use of this toxin pressurizes competition in the population. Those individuals in that can survive the toxic effects are given a mating advantage over its less advantaged, or dead, peers. Combined with the ability of ECB to produce one or two large generations a year, resistance across populations can be quickly amplified.

Investigating the physiological requirements of this tenuous life history decision will expose diapause phenology to being controlled. Strategies that can precisely affect the progression of the ECB through diapause could be valuable. Perturbing the corn borers ability to survive diapause by effecting how it allocates resources could be used as an added layer of pest management.

**PROPOSED METHODOLOGY**

**Origin and Husbandry of European Corn Corer.** The univoltine (UZ) and bivoltine (BE) strains of European corn borer (ECB) were provided courtesy of (\_\_\_\_). These laboratory reared colonies were established in the year (\_\_) as larvae. These laboratory colonies will be continuously reared at 26C and a day cycle regimen of 16 hours of light and 8 hours of dark. These larvae have been sibling mated since their capture in (\_\_) and throughout the course of these experiments. To compare the differences in energy storage between diapause destined and diapause avoiding larvae, newly hatched larvae from each colony will be reared at 23 C and under two different lighting treatments. Larvae reared at 23 C with 12 hours of light and 12 hours of dark will diapause and larvae reared at 23 C with 16 hours of light and 8 hours of dark will avoid diapause (\_). Those diapause destined larvae from UZ and BE colonies will be labeled UZ12 and BE12 respectively. Those UZ and BE colony larvae reared under diapause avoiding conditions will be labeled UZ16 and BE16 respectively. Under these conditions larvae will be reared gregariously from hatching, through the 4th instar.

**Sampling Wandering Larvae.** Wandering larvae will be sampled using a modified version of the framework put forth in the 1982 study by Gelman and Hayes. For the purposes of this experiment, the wandering stage of ECB will be determined developmentally as the stage when the larvae stop feeding, the contents of their gut is cleared, and they search for refuge in preparation for either diapause or pupation. Feeding caseation, gut clearing, and seeking refuge will each be used as proxies for the beginning of the wondering stage. A 5th instar larva will be individually placed into an arena with food and allowed to eat ad libitum for 5 consecutive days. Starting on the 5th day, the burrowing larva will still be provided with food ad libitum, but every 24 hours it will be separated from the food source and placed at the opposite end of the arena. Feeding cessation will be determined by the larva not returning to the food source, or the larva not eating the food source. Gut clearing will be determined when frass production is replaced by the production of liquid from the anus or there are no anal exudates. Seeking refuge will be determined by the larva walking around the arena or the larva producing a sealed silken gallery. Any combination of these behaviors will be categorized as “wandering”. (Gelman and Hayes 1982). Once the developmental stage is determined to be wandering, each larval sample will be weighed, hemolymph will be extracted for protein analysis, and the larva will then be freeze dried for lipid analysis. Larvae samples will be analyzed in cohorts of 9 for protein and lipid analysis.

**Protein Extraction and Quantification:** The larvae in the proteins group will be extracted in groups of 7. Collecting the lymph fluid will be done through a small incision into the cuticle at the tip pf the prologs (Gelman and Woods 1983). Lymph fluid will be dotted onto stretched Parafilm wax where it is collected using a pipette tip. Lymph will be collected into a microcentrifuge tubes held on ice to reduce oxidation of the lymph. Each tube will contain 200µl of 1x PBS to simulate biological conditions and 3µL of Halt™ Protease and Phosphatase Inhibitor Cocktail to inhibit proteolytic enzymes. Protein quantification will be accomplished using the Bradford protein assay. Dilutions from each sample will be made into 1:1, 1:2, and 1:10 solutions This colorimetric assay is based upon mechanics of the protein in solution binding to the dye. As the dye and protein interact, there is a shift in the color of the dye from its unbound color of reddish brown, to blue, a color which deepens as more protein interacts with the dye.

**Protein Separation**

**Protein Identification:**

**Triglyceride Extraction and Derivatization.** The larvae that were previously bled will serve as samples for the triglyceride analysis. Before beginning the triglyceride analysis, each larva will be lyophilized until they lose no more than 1% of their body weight in a 24 hour period. To analyze triglyceride content, larvae will be separated into cohorts. A cohort will consist of two larvae from each of the four treatment groups (UZ16, BE16, UZ12, and BE12) and six null samples. The null samples will serve to characterize the background effects of the extraction method. The extraction method used will be a modification of the 1957 study performed by Folch and Sloane Stanley. The modified method allows for the partitioning of less polar lipid molecules and more polar water soluble molecules. The layer containing the less polar lipid molecules will be decanted, the solvent removed and gravimetrically weighed providing a measure of total lipid extracted from the insect. The total lipids extracted from each sample will be processed further to separate triglycerides out of the mixture of total lipids. Using a Florisil SPE column, the total lipid extract will be washed through the column. The Flourisil solid phase extraction column interacts more strongly with polar molecules while allowing less polar molecules to flow through the matrix of the column. Once triglycerides have been separated, they will be weighed to determine the total triglyceride content of each sample.

The derivatization, in theory, will convert the triglyceride molecules into fatty acid methyl esters. To accomplish this conversion, the extracted triglycerides will be subjected to a base-catylized esterification reaction (AOCS, Cyber lipid, Christie, Ichikara, bumble bee paper, unpublished work J. Beck lab). Esterification of triglycerides under basic conditions produces the fatty acid methyl ester and a molecule of glycerol. To capture the efficiency of the extraction and derivatization method, (\_) will be used as a spike-in standard. Three of the six null samples will receive a known amount of the spike-in standard. By comparing the weight of the spike-in at the start of the extraction process after and passing through the SPE column recovery of the extraction method will be quantified. Knowing the weight of the triglyceride after it passes through the SPE column the theoretical yield amount of the triglyceride can be compared to the actual amount derivatized triglyceride to determine percent yield.

**Triglyceride Identification and Quantification:** Using an Agilent 7980B gas-liquid chromatographer coupled with flame ionization detection (GC-FID), derivatized triglycerides will be identified and quantified. GC-FID will provide a method to compare the extracted esterified triglycerides to a standard mixture of esterified fatty acids. To characterize the compounds in the esterified triglyceride extract, the compounds in the mixture will be separated on a 30-meter capillary column lined with a highly polar liquid substrate, DB-WAX. The amount of time each compound spends interacting with the substrate will be recorded as its retention time and the intensity of the ionization detected will be recorded as its abundance. This process will be repeated using the standard mixture of esterified lipids of known concentration and identity. The measured retention times and abundance of the compounds in the sample extract will be compared to the retention times and abundance of the compounds in the standard mixture. Comparisons of retention time and abundance will be used to estimate the identity and the concentration of the esterified triglycerides in the extract respectively.

**Data Analysis:**

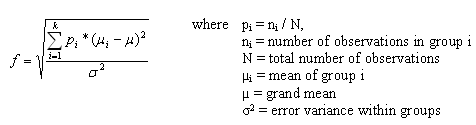
Sample size will be determined using the power analysis formula. (http://www.statmethods.net/stats/power.html) NOVA

For a one-way analysis of variance use

**pwr.anova.test(k = , n = , f = , sig.level = , power = )**

where k is the number of groups and n is the common sample size in each group.

For a one-way ANOVA effect size is measured by f where

  
Cohen suggests that f values of 0.1, 0.25, and 0.4 represent small, medium, and large effect sizes respectively.

**REFERENCES:**

Introduction:

1. NOAA National Centers for Environmental Information,. 2017. State of the Climate, Global Analysis for Annual 2016.
2. Mac, M. J., P. A. Opler, C. E. Puckett Haecker, and P. D. Doran. 1998. Status and trends of the nation’s biological resources. Vol. 1. U.S. Department of the Interior, U.S. Geological Survey, Reston, Va. 1-436 pp.
3. Botkin, D., D. Woodby, and R. Nisbet. 1991. Kirtland's warbler habitats: A possible early indicator of climatic warming. Biological Conservation. 56: 63-78.
4. Schneider, S., and T. Root. 2002. Wildlife responses to climate change, 1st ed. Island Press, Washington.

Objective

1. Pimentel, D. 2005. ‘Environmental and Economic Costs of the Application of Pesticides Primarily in the United States’. Environment, Development and Sustainability. 7: 229-252.
2. Hyde, J., M. Martin, P. Preckel, and C. Edwards. 1999. The Economics of Bt Corn: Valuing Protection from the European Corn Borer. Applied Economic Perspectives and Policy. 21: 442-454.
3. Wechsler, S. J. 2017.United States Department of Agriculture Economic Research Service,. Recent Trends in GE Adoption.
4. Glaser, L., 2016. United States Department of Agriculture Economic Research Service,. What is agriculture’s share of the overall U.S. economy.
5. DENLINGER, D. 2008. Why study diapause?. Entomological Research. 38: 1-9.

Husbandry and sampling

1. Gelman, D. and D. Hayes. 1982. Methods and Markers for Synchronizing Maturation of Fifth-Stage Larvae and Pupae of the European Corn Borer, Ostrinia nubilalis (Lepidoptera: Pyralidae). Annals of the Entomological Society of America. 75: 485-493.

Lymph collection

1. Gelman, D. and C. Woods. 1983. Haemolymph ecdysteroid titers of diapause- and nondiapause-bound fifth instars and pupae of the European corn borer, Ostrinia nubilalis (Hübner). Comparative Biochemistry and Physiology Part A: Physiology. 76: 367-375.

Extraction and Derivatization

1. Folch, J., M. Lees, and G. Stanley. 1957. A SIMPLE METHOD FOR THE ISOLATION AND PURIFICATION OF TOTAL LIPIDES FROM ANIMAL TISSUES. Journal of Biological Chemistry. 226: 497-509.