**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 and bivoltine strains of European corn borer we provided courtesy of (\_\_\_\_). The laboratory reared colonies were established in the year (\_\_) as larvae. These larvae have been sibling mated to over the course of (\_\_) and throughout the course of these experiments. Three environmental regimens implemented to accommodate the different requirements of each of the phenotypes. The cohort of individuals, from both strains, used to perpetuate the colony were reared using 16 hours of light and 8 hours of dark at a temperature of 26° C. Those that are to be used as sampling for the duration of these experiments, these colonies were maintained under stable hour light, temperature, and humidity regimens

**Preparing Wandering Larvae.** Sampling larvae when they have produced the ultimate amounts of both triglycerides and proteins will be crucial to accurately characterizing the differences in life history choice. For the purposes of these experiments that ultimate developmental period, the “wandering” stage, will be the point at which samples will be taken from the cohort of larvae. Because there are no other diagnostic characters that indicate a larva will be considered in the “wandering” when all the contents of the gut are cleared (Gelman and Hayes 1982). Staging proper wandering samples will be done using individual rearing arenas. Larvae will be separated into individual arenas around the time of their 5th instar molt and given food over the next few days. Once the larvae reach day 5, they are observed for wandering approximately every 8 hours. During these observations, the arena will be cleared of frass, when the arena no longer needs to be cleared will indicate the start of the wandering stage.

Wandering larvae will be divided into two groups; triglyceride analysis or protein analysis. Those larvae destined for protein analysis will be bled through a small incision where approximately 10-12µL of hemolymph will be extracted and stored for protein analysis. Those larvae destined for triglyceride analysis will be lyophilized for approximately 36-48 hours and stored for triglyceride analysis.

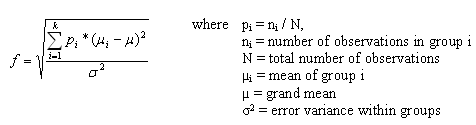
## Sample size will be determined using the power analysis formula. (<http://www.statmethods.net/stats/power.html)> NOVA

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.

**Triglyceride Extraction and Derivatization.** The larvae in the triglyceride group will be sampled in cohorts of 16 using polypropylene microtubes, eight samples with larvae and eight samples without larvae. Larvae from each treatment group (UZ16, BE16, UZ12, and BE12) will be paired with samples without larvae, blanks. These blanks will be treated in the same way as the larva samples and function to describe the background effect of the extraction method and associated materials. To monitor the efficiency of the extraction and derivatization methodology, (\_Tri-Mix?\_) will serve the function of a spike standard. Half of the larvae and half of the blanks will receive the spike, while the other larvae and blanks will not. Each larva will be lyophilized until they lose no more than 1% of their body weight in a 24 hour period. These dry larvae will be weighed, and a modified version of the Folch method will be used to extract the total lipid content from each sample (Folch et al. 1957). To reduce the effects of oxidative damage, the remainder of the triglyceride extraction will be performed on ice and a solution of 0.5mg/ml of BHT (butylated hydroxytoluene) will be prepared fresh before each extraction. Each sample will be mechanically homogenized for 30 seconds using media grinding beads (1.1-1.4mm Zirmil.2) added to each tube and a Precellys®24 bead beater. BHT in methanol will be added to the tubes, again homogenized for 30 seconds, then hexane will be added to the tubes and the tubes will be homogenized for a third and final time for 30 seconds. After grinding the sample, the next step will be to separate the lipid containing fraction from the rest of the insect matrix. Separating the phases requires the sample be centrifuged at 4°C for 5 minutes, the organic fraction containing lipids is collected, the samples will then be re-suspended in organic solvent and placed on a table shaker for 15 minutes. The process of centrifugation and table shaking will be repeated three times. After the organic layers have all been pooled, the pooled fractions will then be dried using a 0.9% solution of NaCl and that aqueous layer will be removed and the dry pooled fractions will be dried under a stream of N2 to remove the organic solvent from the lipids. Those “dry” lipids will be weighed. The pooled fraction of lipids extracted represents the total lipid content from the insect. To remove some of these additional classes of lipids the pooled, dried lipid fractions will be re-suspended in 4mL of organic solvent and passed through a SPE (solid phase extraction) cartridge. This cartridge will capture the non-target lipids and allowing triglycerides to pass through the matrix and be collected. Once non-target lipids have been removed from the solution, dried under N2 and weighed, the triglycerides will be converted into a FAME (fatty acid methyl esters). To accomplish this conversion, the dried target lipid solution will be subjected to base-catylized derivitization using a rapid method of methylation (cite Ishakara paper). Following the method detailed in the Ishakara et al., dried samples will be solubilized in exactly 1mL of HPLC grade hexanes and vortexed to ensure lipids are evenly distributed throughout the solution. The solution will then be augmented by the addition of 200mL of methanolic KOH for every 1mL of hexanes used to solubilize the lipids. This mixture will be heated at 55?C for 2 minutes using a hotplate, then the samples are to be vortexed for 2?minutes. The samples will be allowed to rest on ice for 5 minutes, then the hexane layer containing the methylated lipids is removed and stored while the methanol layer is discarded.

**Triglyceride Analysis and Experiment Efficiency:** Derivatized triglycerides will be injected onto a gas chromatography instrument coupled with a flame ionization detector. Samples injected onto this instruments column are separated along their polarity gradient, allowed to travel the length of the 30 meter column where at the end, each analyte will be ignited and the intensity of the ignition will be This instrument will take the sample of derivatized triglycerides and identify their relative abundance. Testing the efficiency of the derivatization techniques will be accomplished in three ways. (Blanks to illustrate background of experimental design, standard matrix to determine technique percent recovery, spiked standard matrix against which to calibrate the concentration of my results)

**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:**

**Data Analysis:**

Lyophilizing of larvae:

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