Breanna Williams
Kaitlyn Rankin
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The Impact of an Elevation Gradient on Insect Herbivory

Introduction

In the present era of climate change it is necessary to understand how ecosystems could respond to a changing environment. Recent studies have strongly suggested that elevated regions have warmed at a faster rate than lower elevations (Bandopadhyay 2016). Therefore, exploring how communities are distributed and how they could potentially respond to climate change along an elevational gradient, has the potential to enhance our understanding of the ecological factors impacting community structures (Morris et al. 2015). Environmental gradients can be used to improve our understanding of how the abiotic environment, evolution of traits and species interactions affects biodiversity (Moreira et al. 2017). An understanding of the broad scale patterns of insect distribution in relation to all major ecosystems is extremely important.

Insects have the capacity for rapid response to environmental changes, which makes them a useful indicator of ecosystems' health (Schowalter 2011). Plant–insect interactions are central to ecological processes, including trophic interactions, soil nutrient cycling, forest drought tolerance and plant and animal productivity (Altman and Sandra 2015). In some ecosystems, insects and other arthropods represent the dominant pathways of energy and matter flow, and their biomass may exceed that of the vertebrates in their habitat (Showalter 2011). Plants and insects have coexisted for as long as 350 million years and they have developed a series of relationships, but the most common relationship involves insect predation on plants (Gatehouse 2002).

As climate change worsens it is likely to affect insects distributions. A study investigating insect responses to climate change found insects either expand their range to higher elevations or they undergo severe biodiversity loss (Marta et al. 2018). Displacements of populations raises ecological concerns, such as population mismatches between predator and prey, parasitoids and their host insect herbivores, loss of biodiversity or herbivorous insects and their host plants (Rasmann et al. 2011). These factors are predicted to have different responses as elevation increases (Rasman et al. 2011). Therefore, one of the leading factors affecting insect distributions and species richness is elevation.

Generally, there are four main reasons that insect species richness is expected to decline with elevation: reduced habitat area, reduced resource diversity, unfavorable climates, and reduced primary productivity (McCoy 1990). Insect herbivory and species richness is expected to change with elevation due to insects ecological niches (McCoy 1990). As elevation increases, plants and insects must confront different environmental challenges, such as a decrease in temperature, increased UV exposure and different quantity of soil nutrients. These harsh environmental conditions limit the number of species that are able to survive in higher elevations (Khairiyah et al. 2013).

In this study, we tested the hypothesis that the abiotic conditions at higher elevations reduce the suitability of the habitat for insect herbivores. To test this hypothesis we measured the percent of leaf damage from insects as well as soil pH and temperature. We looked at white wood asters, *Eurybia divaricata*, on a single mountain range, Dragon's Tooth. We predicted that the total insect damage to plants and species diversity would decline with elevation. We also expect to see temperature and pH to decline with elevation. Here, we will assess how plant-insect interactions vary along an environmental gradient.

Methods

Study Organism

The focal plant that was chosen is the white wood aster, *Eurybia divaricata.* This plant grows in clumps, blooms in the late summer and thrives until November (Winterrowd 1991). This white wood aster is found mainly in the northeastern region and is a drought resistant plant (Winterrowd 1991). Furthermore, we noticed while examining this plant on our initial field day that there was a higher percentage of insect herbivory on its leaves than the other surrounding plants. We decided to make this our focal plant due to the increased insect herbivory present on the leaves and the abundance of this plant along the mountain range of Dragon's Tooth trail. Dragon's Tooth Trail in Catawba, Virginia offers an elevational gradient as well as an abundance of white wood asters. Mountain ranges along the northeastern region offer one potential solution by providing environmental gradients, such as temperature, area, and habitat, within a limited area, allowing for studies of local biodiversity processes while minimizing confounding factors (Sublett et al. 2019).

Study Site

Our study covered Dragon's Tooth Trail in Catawba, Virginia, 37°22'44.5″N 80°09'22.1″W. There is an elevational gain of 1,320 ft along a 4.1 mile highly trafficked trail. This site was chosen because of its close proximity to Virginia Tech and its abundance of white wood asters along an elevation gradient. Dragon's Tooth is located in Jefferson National Forest, Southwest Virginia and in 1995 this forest combined with the George Washington National Forest (Satterthwaite 1993). These forests are wide spread covering almost 8.1 million acres with primarily Appalachian hardwood and mixed pine-hardwood forest types (Satterthwaite 1993).

Study Design

To test if insects herbivory decreases as elevation increases, we conducted an observational study where we chose five sites along the elevational gradient of Dragon's Tooth trail. We chose our sites by evenly spacing them along the trails elevation gain. Five sites were established along the trail at the following elevations: 1720 ft (Site 1), 2200 ft (Site 2), 2620 ft (Site 3), 3039 ft (Site 4) and 3462 (Site 5). At each site, clumps of five individual white wood aster plants were chosen.

Temperature and the time of day were taken at each site. In the field, each leaf on each individual plant was assessed for insect herbivory damage using the iPhone app LeafByte (Getman-Pickering et al. 2019). The average number of leaves per plant was four with a range of between 2-5 leaves. Only one person measured the leaves on the plants to control for discrepancy between app users. We measured a total of 25 white wood asters and the average score was recorded for the amount of leaf damage on all plants. Then, the focal plant was shaken a total of 25 seconds over a beat sheet to capture any insects that were present. Insects that were present were put into 80% ethanol in the field and brought back to be identified (Knopf 2000). Our focal plant grows in clumps therefore soil samples were taken at the base of the plants at each elevation. Giving a total of 5 soil samples. The samples were then put in containers to be brought back to the lab from each site to be analyzed for pH, nitrogen, phosphorus and potassium levels using the Rapid Soil Kits (Luster Leaf products, patent #347,188). We let the soil samples sit for 24 hours at room temperature before analyzing the P, N and K, following kit instructions.

Data Analysis

In order to test our hypothesis we tested elevations effect on leaf damage. Leaf damage was averaged across the leaves on the plants. All analyses were conducted using statistical software R (version 3.6.1) with the following packages installed: ggplot2, dplyr, betareg, multcomp, and RColorBrewer. We used a beta regression to examine how our response variable, which was the average proportion leaf damage per plant, changes with our predictor variable, which was elevation. Elevation was treated as a categorical variable for our model. We followed our model with a post-hoc comparison among all pairwise combinations of elevations using a Tukey test. We used the package multcomp in R for this test. We used a linear model to test the effect of elevation on pH.

Results

Our findings from our linear model suggested that there was a significant difference in insect herbivory along an elevation gradient ($z = 3.50$, $P = 0.00046$). We found the mid-elevation site to be significantly different ($p < 0.013$ for all comparisons) from all the other sites. There was a high percentage of leaf damage at the mid elevation of 2620 ft. The second-highest percent of leaf damage was found at the highest elevation site of 3463 ft (*Figure 1)*.

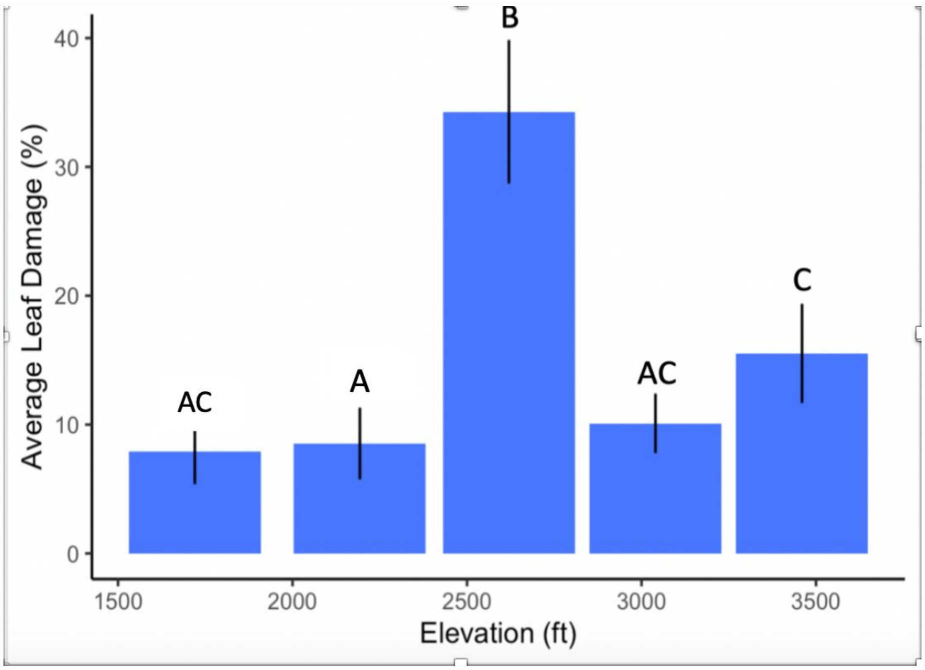

Figure 1. Bar plot showing the average per plant and SE computed across all plants(+/- SE) of leaf damage per elevation (p=0.0699). The bars that share a letter are not statistically different from one another.

Our findings from the rapid soil kit (P, K & pH) are shown in (*Table1)*. The pH showed an increase at the middle elevations. Elevation was found to not have an effect on soil pH (t = -0.79, p=0.49, df=3) (*Figure 2*). The temperature was also found to not be affected by elevation (t = -0.65, p=0.56, df=3), ranging from 55.5-58.4 °C. As elevation increased, temperature decreased along Dragon Tooth's hike. Our mid-elevation site had the warmest temperature than the other sites. Only two individual insects from two different species were observed when we used the beater sheets, a leaf-footed bug in the family *Coreidae* at 1770 ft, and a leafhopper in the family *Cicadellidae* at 2193 ft. We did not run any statistical tests on the insects found.

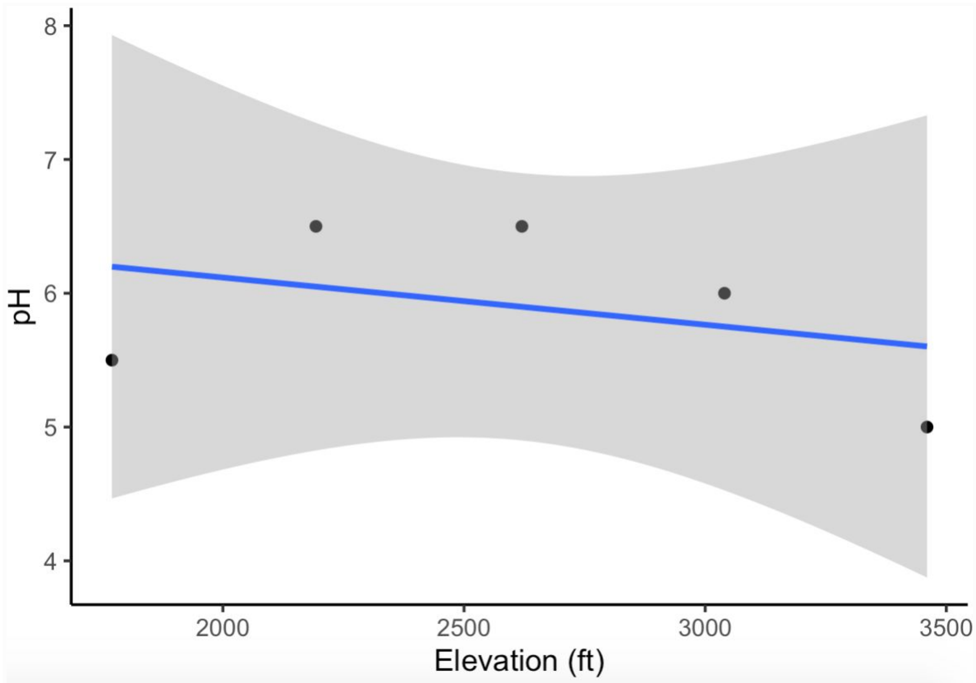

Figure 2. Scatterplot showing no relationship between elevation and soil pH.

Elevation (ft)	pH	Phosphorus	Potassium	Temperature (C)
1770	5.5	P1 Deficient	K3 Sufficient	55.5
2193	6.5	P2 Adequate	K3 Sufficient	58.4
2620	6.5	P1 Deficient	K3 Sufficient	58
3040	6.0	P4 Sufficient	K4 Surplus	56.5
3460	5.0	P3 Sufficient	K3 Sufficient	54.5

Table 1. Table showing the measurements of pH, phosphorus and potassium at each elevation using the scale found in the Rapid Soil Kits.

Discussion

Insect herbivory damage along an elevation gradient has received attention by ecologists in the past couple of years due to the importance of understanding how ecosystems will react to a changing climate (Birkemo et al. 2016). Furthermore, forested ecosystems are expected to be sensitive to the changing climate which is why studying them is necessary (Birkemo et al. 2016). Higher elevations are becoming increasingly impacted by the changing of temperatures and evaluating insect-plant relationships can improve understanding of possible responses due to temperature change (Song et al. 2019). We predicted that as elevation increased insect herbivory, pH and temperature would decrease.

Our hypothesis was not supported by our results. Contrary to our expectations, we found the highest insect herbivory to be at the mid-elevation site. A possible explanation for insect herbivory being highest in the mid elevation is that it provides a suitable environment for insect survival (Descombes 2017). The mid elevation is protected from extreme conditions that the lowest elevation and the highest elevation are subject to (McCoy 1990). We noticed that in the mid elevation sites there was a lot more shaded areas, which is the preferred habitat of white wood asters (Winterrowd 1991). Temperature at our mid-elevation site was the warmest which could have led to higher insect herbivory (Altmann and Carlos 2015). Although, a factor to take into account is that temperature was measured throughout the day so the mid elevation being the warmest temperature could have been dependent on the time of day. Also, there could be a specific insect species that is well-adapted and abundant at the mid-elevation site that is responsible for the high rates of herbivory found at that elevation.

Previous studies on this subject have turned up mixed results. A recent study supported increased insect herbivory damage in the high elevations (Kooyers 2017). But, we found similar results to a study which found a higher rate of insect herbivore damage and plant defense mechanisms at their mid-elevation site (Song et al. 2019). They reasoned that they found higher herbivory at their mid-site because species richness and herbivory have been widely reported in a number of studies from different countries (Song et al. 2019). This study was conducted over a much larger elevational gain than ones from other studies as well as the one we measured. It was concluded that their findings was a cause from having such a larger elevation gain than previous studies (Song et al. 2019).

However, possible limitations of our study could be user error within the LeafByte app. Another huge factor to consider is that it was very dry this year. Many plants that were not as drought resistant as the white wood aster had died causing more insect herbivory on the only remaining source of food being our focal plant. The soil testing was very broad and could have been done with more quantitative methods which was a limitation for our data. We would recommend that future studies measure insect damage earlier in the season and that they investigate higher elevation gains. On our first field day it was raining which could have affected insect prevalence on the focal plant. Then on the second day we went out it was very cold, which could also be a reason why we did not find many insects. Further research is needed on this topic to provide concrete evidence that insect herbivory is strongest in mid-elevations. With climate change becoming an increasing threat there is a need to understand how natural populations of insects will respond to a changing environment. Understanding these relationships and interactions can help ecologists with conserving natural populations.

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