Abstract

Climate change has been repeatedly linked to phenological shifts across many taxa, but the factors that drive variation in phenological sensitivity remain unclear. For example, relatively little is known about phenological responses in areas that have not exhibited a significant warming pattern, making it difficult to project phenological responses according to future climate scenarios. We used an extensive citizen science dataset to examine changes in the adult flight onset dates of 38 butterfly species with interannual variation in spring temperatures in the Piedmont region of North Carolina, a region that did not experience a warming trend in the 20th century. We also explore whether species traits such as voltinism, overwintering stage, and average adult flight onset dates explain interspecific variation in phenological sensitivity. We found that 35 out of 38 species exhibit an advance in adult flight onset dates with increasing spring temperature. Species that fly later in the year were more sensitive to changes in temperature, and there was a significant interaction between average flight date and voltinism, such that late-flying, multivoltine species tended to be the most sensitive to spring temperature changes. These results point to likely shifts in butterfly arrival date as temperatures are projected to rise in the southeast US, with late-flying, multivoltine species potentially exhibiting the greatest shifts in adult flight onset dates.

Introduction

Mounting evidence indicates that species are undergoing significant changes in seasonal timing and distribution on a global scale in response to climatic change, especially at higher latitudes (Walther et al. 2002, Parmesan and Yohe 2003). These patterns have repercussions for individual fitness, community interactions, and the continued persistence of sensitive species (Møller et al. 2008, Colom et al. 2022). Therefore, as global temperatures rise, it is increasingly crucial to study the consequences of changes in temperature on seasonal timing and biological processes.

Appearance date phenology is an informative measure for examining how species respond to changing temperatures and is consequently used in myriad studies of climate change response (IPCC 2007, Parmesan 2007). Butterflies are a popular model organism for studying changes in phenology because they have predictable and readily observable life events (Roy et al. 2001) and are poikilothermic, making them sensitive to changes in temperature. Additionally, butterflies have long been a popular subject for naturalists and hobbyists, which has allowed for the persistence of long-term datasets of butterfly observations and museum specimens (Thomas 2005, Eskildsen et al. 2015, Prudic et al. 2017). As temperatures increase, adult flight onset dates (hereafter onset dates) has advanced in many butterfly species, as observed in California (Forister and Shapiro 2003), the Mediterranean Basin (Stefanescu et al. 2003), England (Diamond et al. 2011; Roy and Sparks 2000), and Ohio (Diamond et al. 2014).

While there have been multiple studies of changes in butterfly onset dates from around the globe (e.g. Stefanescu et al. 2003, Diamond et al. 2011, Zografou et al. 2021), our understanding of this phenomenon in the southeastern United States is unclear. This region is noteworthy because it has not experienced the same clear upward trend in temperature observed on a global scale. Rather, the southeastern US experienced a slight cooling trend over the 20th century (Portmann et al. 2009), although there was been substantial interannual variation. This designates the southeastern US as a climatically unique region with the potential to shed light on future phenological shifts as temperatures are projected to rise (US Global Change Research Program 2014).

Phenological shifts are variable across taxa as well as across geographic space. Species traits have been shown to play a role in determining phenological sensitivity (Diamond et al. 2011, Karlsson 2014, Kelling et al 2019, Larsen et al. 2021). For example, individuals that overwinter as advanced developmental stages (e.g., as adults) are expected to experience greater shifts with increasing temperatures, because these stages have more reserves to respond to changing conditions (Diamond et al. 2011, Kharouba et al. 2014). However, the strength and direction of the effects of species traits on phenological sensitivity can vary between systems and models (Post et al. 2018). In addition, certain traits, such as whether a species tends to appear earlier and later in the year, have seldom been studied directly (see Karlsson 2014, Kharouba et al. 2014). Given that species with limited phenological sensitivity can experience declines in abundance (Colom et al. 2022), it is crucial to determine how ecologically relevant species traits affect phenological response, and how these factors may vary between geographic areas.

In this study, we use a database of butterfly observations collected opportunistically by citizen scientists in Durham, Orange, and Wake Counties of North Carolina to examine the role of spring temperature in affecting onset dates in this region from 1993 to 2020. We also explore how species-specific traits relate to changes in onset dates in North Carolina butterflies, focusing on voltinism, overwintering stage, and average onset dates. We predict that onset dates advance with increasing spring temperatures, reflecting the trend demonstrated by studies in other regions (e.g. Stefanescu et al. 2003, Diamond et al. 2011, Zografou et al. 2021). We also expect that species in this region with high voltinism, advanced overwintering stages, and early average onset dates will exhibit greater phenological sensitivity compared to those with lower voltinism, early overwintering stages, and late appearance dates.

Methods

*Study system*

We used a dataset of opportunistic butterfly observations made by citizen scientists in North Carolina. These data are hosted and maintained by the North Carolina Biodiversity Project and North Carolina State Parks (LeGrand and Howard 2021). The database was launched in 1993 and covers North Carolina’s 177 known butterfly species. It is updated yearly and includes at least 232,779 records from 1899 to 2020. Each entry lists the common name, date, observer name, number of individual butterflies observed, and county.

We selected observations from the North Carolina Triangle region (Durham, Orange, and Wake Counties) since these counties had the highest consistent sampling effort (Fig. S1). In addition, Durham, Orange, and Wake Counties are all within the Piedmont ecoregion and have similar climatic conditions. We selected records collected between 1993 and 2020 because there are few records prior to this interval. Out of these years, we selected species that had least 10 years with at least 10 unique observer dates per year and excluded species that are migratory in the Piedmont ecoregion. We treated *Erynnis horatius* and *E. juvenalis* as a single taxon, *Erynnis* spp., since observers frequently consider time of year to distinguish these very similar species, rendering it impractical to meaningfully interpret any differences in phenology. For the same reason, we also treated *Celastrina ladon* and *Celastrina neglecta* as a single taxon, *Celastrina* spp. We included a total of 38 species or taxa (hereafter referred to as species) in our analysis. (Table S1). We used R (version 4.1.1) for all analyses.

*Adult flight onset date*

Since the first record of appearance is heavily subject to outliers (van Strien et al. 2008), we calculated the adult flight onset date (hereafter “onset date”) as the date on which 10% of records had been collected for each unique species-year. For example, if a butterfly species has 26 records in a given year, then the onset dates would be the date on which the third (the next whole number above 2.6) record occurred (illustrated in Fig. 1). For a given species, we only calculated onset date for years with at least 10 unique observer dates.

We ignored information on abundance and defined a “record” to be each unique combination of observer, date, county, and species in order to limit the outsize influence of survey efforts such as BioBlitzes and North American Butterfly Association butterfly counts (https://www.naba.org) whose large tallies greatly skew perceived onset dates. Thus, a single observer reporting 6 individuals of a given species on a particular date would only count as a single record, whereas two observers who each reported 1 individual from each of the three counties might represent 6 records.

*Spring temperature*

Mean monthly temperature data was obtained from the PRISM Climate Group (Oregon State University). We used the packages ‘raster’ (Hijmans 2022) and ‘rgdal’ (Bivand 2022) to subset spatial temperature data from Durham, Orange, and Wake Counties. For a given year, we defined the spring temperature as the mean monthly temperature for each county averaged over a static 4-month window (March to June) and then averaged across the three counties. We selected this window because spring temperatures strongly dictate the variation in the timing of insect emergence (Forister and Shapiro 2003, Dell et al. 2005).

*Phenological response*

For each species, we used linear regression to model how onset date varied as a function of either spring temperature or year. We omitted highly influential data points from our linear regression models by excluding points where Cook’s distance was greater than four divided by the total number data points for each species (Miles et al. 2017). For each species and predictor (spring temperature or year), we calculated the slope, mean onset date, and the standard deviation of the onset date. The slope of the fitted onset date-temperature relationship is an estimate of phenological sensitivity to changes in spring temperature.

*Species traits*

To examine whether species traits explain variation in phenological sensitivity, we considered the mean onset date, overwintering stage, and voltinism of each species as predictors in our models. Mean onset date was included as a continuous estimate of whether each species appears earlier or later in the year (Table 1). We treated the overwintering stage as a factor (larvae, pupae, or adults) and when geographically variable, used the overwintering stage specific to the southeast US, especially the Piedmont region of NC. We treated voltinism as a continuous factor and again used values that were specific to the Piedmont region of NC. In cases where a species had variable voltinism, we selected the average value. For example, if a species was reported to have 3-4 generations per year, we assigned a value of 3.5. Voltinism and overwintering stage were referenced chiefly from LeGrand and Howard 2022, but other sources include Butterflies and Moths of North America (https://www.butterfliesandmoths.org) and University of Florida Department of Entomology and Nematology (https://www.entnemdept.ufl.edu/) (see Table S1).

We fit a series of linear mixed effects models wherein mean onset date, voltinism, and their interactions were the fixed effects and phenological sensitivity was the response variable. We ran separate models for both spring temperature and year. In all models, we inversely weighted the values by the standard deviation of the onset date (Table 1) so that species with extremely variable onset date had less influence in the model, since these are likely to be less biologically relevant. If the model was significant, we compared the base model with a separate model that included overwintering stage as a factor. Linear mixed effects models were run using the package ‘lme4’ (v.1.1.27.1, Bates et al. 2017) and summarized using the ‘Anova’ function within the package ‘car’ (v.3.0.11, Fox and Weisberg 2011). We then compared simple (without overwintering stage) and complex models (with overwintering stage) using an ANOVA.

**Results**

*Phenological response*

Of the 38 focal species, 35 exhibited earlier appearances in years with warmer springs, with 12 species exhibiting strong (*p* < 0.05) negative slopes (Table 1; Fig. 2a). The median response was for a species to appear 4.7 days earlier for every 1℃ increase in average spring temperature, with some species shifting up to 27 days/℃ (Table 1). In contrast, there was no consistent relationship between onset date and year (p value here).

*Species traits*

Phenological sensitivity was greater for species with later mean onset date (F1,34 = 6.28, p = 0.02; Figure 1G), such that species that appear later in the year tended to have more negative slopes compared to species that appear earlier in the year. There was also an interaction between voltinism and mean onset date (F1,34 = 5.84, p = 0.02), such that the relationship between phenological sensitivity and mean first appearance was stronger among species with higher voltinism compared to those that only have a single brood per year (Fig 3). The model that included the interaction between voltinism and mean onset date was a better fit than the model with voltinism alone (ANOVA, p < 0.01). Adding overwintering stage did not improve the model fit (ANOVA, p = 0.91).

**Discussion**

The observed relationship between onset date and spring temperatures in the Piedmont region of North Carolina is consistent with trends demonstrated by previous studies using long-term butterfly data (Diamond et al. 2011; Roy and Sparks 2000, Forister and Shapiro 2003, Stefanescu et al. 2003), and with a well-established trend of the influence of rising temperatures on the phenology of ecothermic species (Forister and Shapiro 2003, Parmesan et al. 2007). Butterflies are highly sensitive to changes in temperature (Pollard et al. 2005), and spring climatic conditions play a role in determining the development rate of early overwintering stages, as well as the ability for adults to be active (Dell et al. 2005). Though other climatic variables such as winter temperatures (Forister and Shapiro 2003) and precipitation (Crossley et al. 2021) may also play a role in this system, the observed results confirm that butterflies in the Piedmont region of NC shift the timing of adult flight onset in response to year-to-year variation in spring temperature in a manner consistent with phenological responses observed in regions with more consistent temperature trends.

We observed that species with high voltinism were more sensitive to spring temperatures, but the reason for this trend is not immediately clear. It is noteworthy that this trend is not consistent across all studies examining the role of traits on phenological response, with mixed results concerning the strength and direction of votinism on phenological sensitivity (Kharouba et al. 2014, Larsen et al. 2021, Zougrafou et al. 2021). Zougrafou et al. (2021) observed that species with high voltinism were more sensitive to changes in temperature, and reason that this is because species with high voltinism may be highly responsive to climatic variability (Roy David et al. 2015), which is reflected in their greater ability to vary the number of generations in a given year (Tobin et al. 2008, Altermatt et al. 2010). Voltinism has been shown to vary with climatic warming (Tobin et al. 2008, Altermatt et al. 2010), which points to the fact that voltinism is apparently both a trait that varies between species, as well as a plastic life history strategy that varies across years and geographic areas. In order to understand why species with high voltinism exhibited greater phenological sensitivity in our system, it may be necessary to disentangle the proximate explanations for how voltinism varies with temperature. In other words, are high-voltinism species more sensitive to temperature, or do species that are more sensitive to temperature tend to exhibit high voltinism? Voltinism may indeed reflect phenological relationships or underlying traits that are otherwise not considered in our models.

In contrast to findings from previous studies (Hassall et al. 2007, Diamond et al. 2011, Kharouba et al. 2014, Brooks et al. 2017), we observed that late-flying species were more sensitive to changes in temperature. One possible explanation is that late-flying species may be experiencing spring temperatures during a prolonged developmental window (i.e. during the larval or pupal stage), which in turn may dramatically affect their emergence time. However, our models were not improved by the addition of overwintering stage, which is a more direct way of including developmental stage in our models. Previous studies have observed a significant effect of overwintering stage on phenological sensitivity (Diamond et al. 2011, Larsen et al. 2022). Larsen et al. (2022) found that butterflies that overwinter in the egg stage in the eastern US showed the highest sensitivity towards changing spring climates. However, none of our focal species overwinter as eggs in this region, which may have contributed to the lack of a significant effect from overwintering stage. It is also worth pointing out that we utilized a static temperature window (March - June) and therefore, late- and early-flying species are at different stages prior to their emergence during this focal window. It is possible that this window may reflect a key developmental period for our late-flying species that is highly impacted by temperature, but which may be also somewhat decoupled from overwintering stage.

We found that most of our species exhibited a negative correlation between onset date and spring temperatures, sometimes quite dramatically. Though the southeastern US did not exhibit a consistent warming trend in the 20th century, average temperatures are projected to climb (US Global Change Research Program 2014). This analysis therefore points to the potential for continued changes in first appearance as temperatures continue to warm. This could have repercussions for survival at both the individual and species level (reviewed in Parmesan 2006, Møller et al. 2008). The southeastern US is also projected to have more frequent or intense periods of drought (Ingram et al. 2013), which we did not include in our analyses. For a more cohesive model of predicting phenological change in butterflies, additional analyses should account for climatic variables such as precipitation and photoperiod in addition to temperature.

As temperatures rise in the southeastern US, future studies should continue to track insect phenologies to determine if they align with projections, taking care to account for other confounding global change factors such as urbanization (Diamond et al. 2014). It remains unclear whether the predicted changes in this study will have a detrimental effect on butterfly populations in North Carolina. In addition, the ramifications of changes in butterfly populations for interacting species such as host plants and predators in the southeast US remains poorly known. Large, consistent citizen science datasets like the one used in this study represent an opportunity to track the abundances and phenologies of organisms as climate change accelerates.

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**Table 1.** Summary of slopes, r-squared values, and p-values from linear regression models of onset date vs. spring temperature in NC Triangle butterfly species, in addition to the mean and standard deviation (SD) of onset date for each species.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **species** | **slope** | **R-squared** | **p-value** | **mean onset date** | **SD onset date** |
| *Abaeis nicippe* | 4.095 | 0.007 | 0.681 | 102.240 | 32.289 |
| *Ancyloxypha numitor* | -8.473 | 0.090 | 0.198 | 148.400 | 20.990 |
| *Anthocharis midea* | -6.432 | 0.627 | <0.001 | 72.409 | 5.492 |
| *Asterocampa celtis* | -8.058 | 0.372 | 0.003 | 140.571 | 9.610 |
| *Atalopedes campestris* | -25.277 | 0.378 | 0.001 | 168.370 | 29.155 |
| *Battus philenor* | 0.815 | 0.002 | 0.870 | 106.368 | 12.615 |
| *Calycopis cecrops* | -2.057 | 0.002 | 0.854 | 129.304 | 38.078 |
| *Celastrina spp* | -1.947 | 0.020 | 0.494 | 82.346 | 9.082 |
| *Colias eurytheme* | -4.547 | 0.027 | 0.414 | 98.926 | 19.977 |
| *Cupido comyntas* | -4.910 | 0.118 | 0.086 | 108.615 | 9.761 |
| *Cyllopsis gemma* | -4.765 | 0.086 | 0.222 | 99.263 | 9.955 |
| *Epargyreus clarus* | -0.896 | 0.002 | 0.829 | 124.077 | 13.380 |
| *Erynnis spp* | -4.697 | 0.183 | 0.033 | 86.800 | 7.200 |
| *Euphyes vestris* | -7.891 | 0.184 | 0.059 | 149.950 | 13.473 |
| *Eurytides marcellus* | 0.949 | 0.007 | 0.742 | 92.118 | 8.313 |
| *Hermeuptychia sosybius* | -6.020 | 0.152 | 0.045 | 114.963 | 10.512 |
| *Lerema accius* | -5.993 | 0.025 | 0.450 | 199.480 | 24.575 |
| *Lethe anthedon* | -11.086 | 0.387 | 0.023 | 148.615 | 13.586 |
| *Lethe appalachia* | -4.065 | 0.046 | 0.505 | 141.750 | 14.710 |
| *Libytheana carinenta* | -0.454 | 0.000 | 0.965 | 88.364 | 32.669 |
| *Limenitis archippus* | -3.054 | 0.012 | 0.624 | 141.500 | 19.966 |
| *Limenitis arthemis astyanax* | -2.749 | 0.040 | 0.326 | 131.346 | 9.907 |
| *Megisto cymela* | -3.386 | 0.311 | 0.025 | 137.063 | 4.106 |
| *Papilio glaucus* | -2.871 | 0.040 | 0.309 | 90.857 | 10.334 |
| *Papilio polyxenes* | -3.134 | 0.042 | 0.348 | 100.304 | 10.403 |
| *Papilio troilus* | -2.148 | 0.010 | 0.630 | 110.192 | 13.908 |
| *Phyciodes tharos* | -7.315 | 0.189 | 0.030 | 115.760 | 11.084 |
| *Pieris rapae* | -10.055 | 0.097 | 0.122 | 98.385 | 22.716 |
| *Polites origenes* | -0.937 | 0.003 | 0.818 | 146.895 | 10.619 |
| *Polygonia comma* | -2.296 | 0.011 | 0.650 | 72.429 | 14.379 |
| *Polygonia interrogationis* | -5.632 | 0.064 | 0.211 | 75.346 | 15.302 |
| *Pompeius verna* | -5.485 | 0.263 | 0.017 | 143.952 | 8.182 |
| *Pyrgus communis* | -27.286 | 0.197 | 0.030 | 138.292 | 44.396 |
| *Speyeria cybele* | -8.521 | 0.326 | 0.033 | 145.571 | 9.419 |
| *Strymon melinus* | -16.468 | 0.123 | 0.085 | 146.880 | 29.789 |
| *Thorybes bathyllus* | -2.935 | 0.048 | 0.473 | 132.692 | 9.286 |
| *Vanessa virginiensis* | -5.346 | 0.055 | 0.258 | 114.200 | 15.335 |
| *Wallengrenia otho* | -7.943 | 0.533 | 0.001 | 151.125 | 8.709 |

Diagram

Description automatically generated

**Figure 1.** Methods for determining phenological sensitivity using A) two example focal species, American snout (*Libytheana carinenta*), and red-spotted purple (*Limenitis arthemis astyanax*). Respective values for each species are indicated with orange and light blue symbols, respectively. B) Histograms of records by julian date collected for both species in 2015 and 1996, respectively. Vertical dashed lines indicate calculate onset date for each species, or the julian date on which 10% of records for that year were collected. C) Regression plots of onset date versus temperature, with the calculated onset date indicated with a large, colored point. D) Phenological sensitivity vs. mean appearance date plot, with onset date vs. temperature slopes marked large, colored point.

Chart, diagram

Description automatically generated

**Figure 2.** Violin plots illustrating the distribution of temperature slope values by species traits. Red lines indicate the mean value. A) Distribution of onset date versus temperature slopes. B) Distribution of onset date versus temperature slopes by voltinism. The slopes for species with 3.5 and 5 voltinism are not displayed because there is a single value for each. C) Distribution of onset date date versus temperature slopes by overwintering stage. D) Distribution of average onset date by overwintering stage.

Chart, scatter chart

Description automatically generated

**Figure 3.** Onset date vs. temperature slope plotted against mean onset date. Regression lines correspond to each voltinism value, which is treated as a factor for clarity in this figure. Circles, triangles, and squares indicate species that overwinter as adults, larvae, and pupae, respectively. Grey shaded areas indicate the confidence interval of the regression model.

**Supplemental Table 1.** Summary of species and species traits included in analysis.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Species** | **Family** | **Voltinism** | **Overwintering stage** | **Reference** |
| *Abaeis nicippe* | Pieridae | 3 | adults | LeGrand and Howard 2022, Florida Museum 2021 |
| *Ancyloxypha numitor* | Hesperiidae | 3 | larvae | LeGrand and Howard 2022 |
| *Anthocharis midea* | Pieridae | 1 | pupae | LeGrand and Howard 2022, BAMONA 2022 |
| *Asterocampa celtis* | Nymphalidae | 2 | larvae | LeGrand and Howard 2022, Hall and Butler 2021 |
| *Atalopedes campestris* | Hesperiidae | 3 | larvae | LeGrand and Howard 2022, NABA North Jersey Chapter 2017 |
| *Battus philenor* | Papilionidae | 3 | pupae | LeGrand and Howard 2022, Illinois Department of Natural Resources 2017 |
| *Calycopis cecrops* | Lycaenidae | 2 | larvae | LeGrand and Howard 2022, Hall and Butler 2019 |
| *Celastrina* spp. | Lycaenidae | 3 | pupae | LeGrand and Howard 2022, BAMONA 2022, Alabama Butterfly Atlas 2022 |
| *Colias eurytheme* | Pieridae | 4.5 | pupae | LeGrand and Howard 2022, BAMONA 2022 |
| *Cupido comyntas* | Lycaenidae | 4.5 | larvae | LeGrand and Howard 2022, BAMONA 2022 |
| *Cyllopsis gemma* | Nymphalidae | 3 | larvae | LeGrand and Howard 2022, BAMONA 2022 |
| *Epargyreus clarus* | Hesperiidae | 2 | pupae | LeGrand and Howard 2022, Hall 2008 |
| *Erynnis* spp. | Hesperiidae | 3 | larvae | LeGrand and Howard 2022, BAMONA 2022 |
| *Euphyes vestris* | Hesperiidae | 2 | larvae | LeGrand and Howard 2022, BAMONA 2022 |
| *Eurytides marcellus* | Papilionidae | 3 | pupae | LeGrand and Howard 2022, Hall and Butler 2020 |
| *Hermeuptychia sosybius* | Nymphalidae | 3 | larvae | LeGrand and Howard 2022, Tan and Lucky 2016 |
| *Lerema accius* | Hesperiidae | 1 | pupae | LeGrand and Howard 2022, Burgess 2018 |
| *Lethe anthedon* | Nymphalidae | 2 | larvae | LeGrand and Howard 2022, Alabama Butterfly Atlas 2022 |
| *Lethe appalachia* | Nymphalidae | 2 | larvae | LeGrand and Howard 2022, Alabama Butterfly Atlas 2022 |
| *Libytheana carinenta* | Nymphalidae | 2 | adults | LeGrand and Howard 2022, Hall and Butler 2021 |
| *Limenitis archippus* | Nymphalidae | 3 | larvae | LeGrand and Howard 2022, Wisconsin Pollinators |
| *Limenitis arthemis astyanax* | Nymphalidae | 3 | larvae | LeGrand and Howard 2022, Hall and Butler 2019 |
| *Megisto cymela* | Nymphalidae | 1 | larvae | LeGrand and Howard 2022, BAMONA 2022 |
| *Papilio glaucus* | Papilionidae | 2 | pupae | LeGrand and Howard 2022, BAMONA 2022. Note name change |
| *Papilio polyxenes* | Papilionidae | 3 | pupae | LeGrand and Howard 2022, BAMONA 2022 |
| *Papilio troilus* | Papilionidae | 2 | pupae | LeGrand and Howard 2022, BAMONA 2022 |
| *Phyciodes tharos* | Nymphalidae | 4.5 | larvae | LeGrand and Howard 2022, Alabama Butterfly Atlas 2022 |
| *Pieris rapae* | Pieridae | 5 | pupae | LeGrand and Howard 2022, BAMONA 2022 |
| *Polites origenes* | Hesperiidae | 2 | larvae | LeGrand and Howard 2022, BAMONA 2022 |
| *Polygonia comma* | Nymphalidae | 2 | adults | LeGrand and Howard 2022 |
| *Polygonia interrogationis* | Nymphalidae | 2 | adults | LeGrand and Howard 2022 |
| *Pompeius verna* | Hesperiidae | 2 | larvae | LeGrand and Howard 2022, Alabama Butterfly Atlas 2022. |
| *Pyrgus communis* | Hesperiidae | 3 | larvae | LeGrand and Howard 2022, BAMONA 2022. Note possible name change |
| *Speyeria cybele* | Nymphalidae | 1 | larvae | LeGrand and Howard 2022, Alabama Butterfly Atlas 2022. Note possible name change |
| *Strymon melinus* | Lycaenidae | 3 | pupae | LeGrand and Howard 2022, BAMONA 2022 |
| *Thorybes bathyllus* | Hesperiidae | 2 | larvae | LeGrand and Howard 2022, BAMONA 2022. Note possible name change |
| *Vanessa virginiensis* | Nymphalidae | 3.5 | adults | LeGrand and Howard 2022, Hall 2021 |
| *Wallengrenia otho* | Hesperiidae | 2 | larvae | LeGrand and Howard 2022, Burgess 2018. Note name change |

Chart

Description automatically generated

**Supplemental Figure 1.** A) A map of North Carolina counties, with NC Counties indicated in light green and Triangle counties (Durham, Orange, Wake) indicated in purple. B) Non-cumulative number of Triangle butterfly observations records per year and yearly fluctuations in mean temperature from March to June between 1993 and 2020. Map compiled using ArcGIS Version 10.6.1. County shapefile obtained from the US Census Bureau. Temperature data obtained from PRISM Climate Group (Oregon State University 2022).