

Exploring the universal ecological responses to climate change in butterflies

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Introduction

In recent decades, ecologists have widely discussed and documented the impact of climate change across a wide range of species and habitats. One of the most visible effects of rising temperatures is the shifting distribution of species and changes in their abundance (Pacifi et al. (2015)). As global temperatures continue to rise, many species are responding by moving to cooler habitats or altering their behaviour and life cycles ((Miller-Rushing and Primack 2008; Diamond et al. 2011)). Alongside these trends the impact of temperature on body sizes have not been thoroughly examined. Invertebrates are of particular interest in this regard, as they make up the vast majority of biodiversity, are found in all types of habitats and are ectothermic (Bickford, Sheridan, and Howard (2011)). This makes them highly susceptible to temperature changes (Ohlberger (2013)). Horne, Hirst and Atkinson (2015) found that species that produce multiple generations per year (multivoltine species) tend to decrease in body size as temperatures rise, particularly at lower latitudes. In contrast, species that produce a single generation per year (univoltine species) exhibit the opposite trend. These patterns are believed to reflect evolutionary adaptations to variation in season length, whereby univoltine species capitalise on a longer growing season by growing larger, while multivoltine species may mature earlier at smaller sizes to maximise the number of generations per year (Horne, Hirst, and Atkinson (2015)). Such adaptations are critical for optimising reproductive success in different environments. This report focuses on the potential impact of climate change on the size of the univoltine Silver-spotted Skipper (*Hesperia comma*) butterflies. These butterflies are found throughout the Northern Hemisphere, and their populations have already shown sensitivity to changes in temperature ((DAVIES et al. 2006; Fenberg et al. 2016)). Thus, we hypothesise that (i) the years with warmer temperatures will lead to larger adult butterflies and (ii) there will be a difference between males and females butterflies.

Analysis

In this report, an analysis was conducted to investigate the impact of climate change on the wing length in univoltine butterflies. The aim was to explore whether there is a significant relationship between the average temperature in June and the size of the butterflies, *Hesperia comma*, in historical museum collections. Forewing length (mm) served as a proxy for body size in this study, representing the distance from the point of wing attachment on the thorax to the apex of each forewing (Figure 1). The sex of each butterfly was also recorded. The average temperatures in June was collected from years ranging between 1880 and 1973, as well as the total annual precipitation (mm) to identify it as a possible covariate.

To explore the relationship between forewing length and various factors, I conducted a multiple linear regression analysis in R (Version 4.3.0). I included three variables in the model: mean temperatures in June, the year of collection and the sex of the specimens as a categorical variable. Prior to conducting the analysis, I ensured that the assumptions necessary for running a linear model were met using the R package *performance*. I repeated this analysis using the year variable as predictors of the average temperature in June. High collinearity was detected in all of the models so the `drop1` R function was used to identify the least significant predictor variable. None of the interaction terms were statistically significant ($p < 0.05$). The R package *GGrally* was used for correlation analysis. It is important to note that even though the predictor variables with high collinearity were removed, it does not necessarily mean that multicollinearity is no longer

biasing the regression model. This is possibly due to lack of data. The MASS package in R showed that the data was not amenable to log transformations.

Results and Discussion

Male and female sizes

I hypothesised that there would be a difference in the sizes of male and female butterfly specimens because of potential sexual dimorphism, where males and females of the same species often exhibit distinct physical characteristics. Female *Hesperia comma* butterflies were an average of 1.23 mm larger than their male counterparts in forewing length [95% CI;1.008, 1.452] with statistical significance (Linear Model: $F_{1,28} = 61.3$, $P < 0.001$, Figure 1).

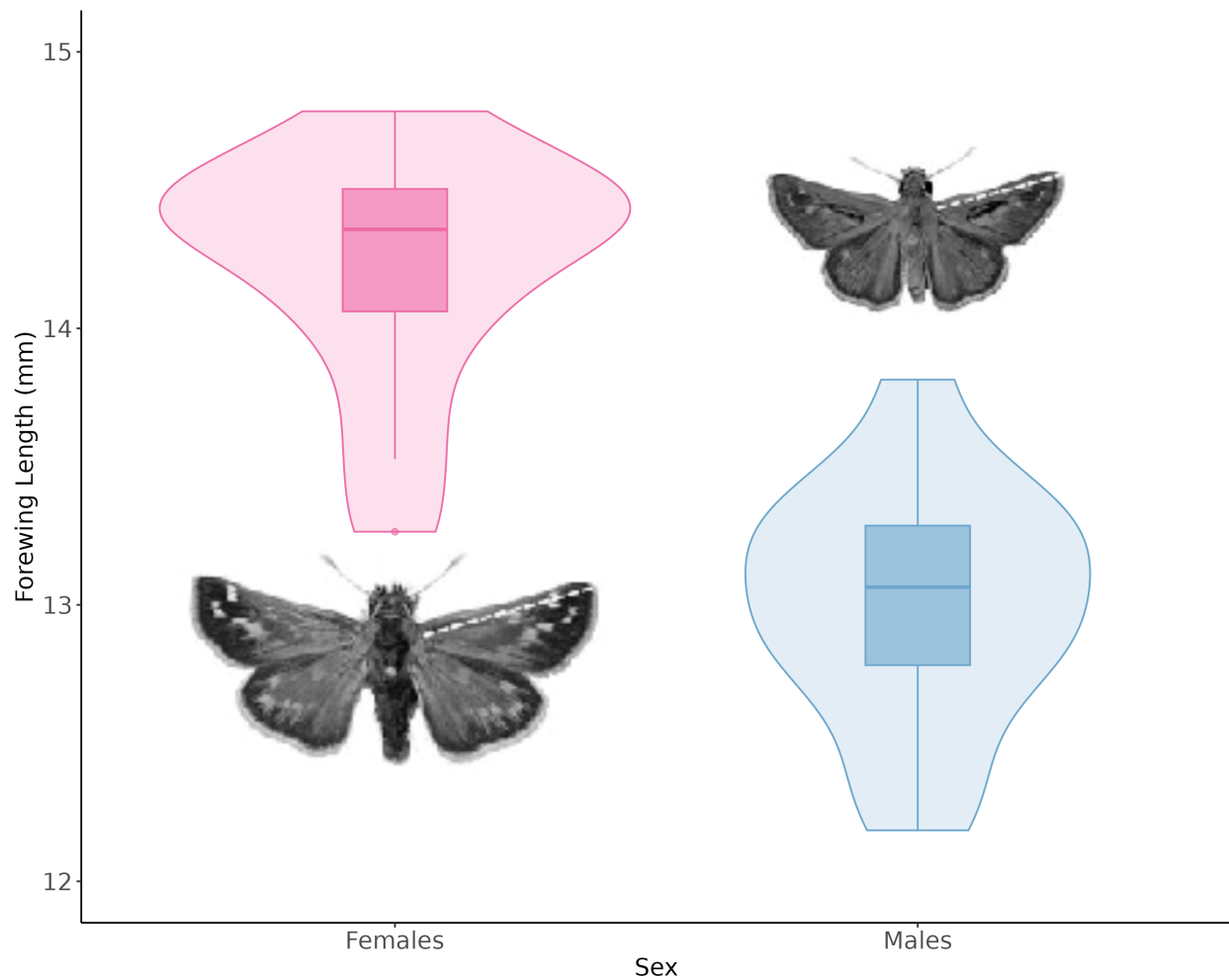


Figure 1. Box and violin plots of male ($n=15$) and female ($n=15$) forewing lengths of *H. comma* specimens. Males have significantly smaller forewing lengths than females. The white dotted lines illustrate specimen forewing lengths.

One possible explanation for this sexual dimorphism in size is the role of fecundity (Blanckenhorn et al. (2007)). In many butterfly species, females carry the responsibility of egg production, requiring more energy and resources for reproduction (Wiklund et al. (1993)). Larger body size in females may provide an advantage in terms of reproductive success by allowing for greater egg production and potentially increasing offspring rates (Bissoondath and Wiklund (1997)).

The effect of temperature on forewing length

The multiple linear regression analysis for mean temperature was not a statistically significant ($R^2 = 0.098$, $P = 0.09$) variable for predicting wing length in both males and females combined (Table 1). These results do not change on a log scale transformation. In order to account for the significant role of sex in predicting wing length, I conducted separate linear regression analyses for males and females. Among the variables considered, the mean temperature in June emerged as the sole significant factor for predicting male wing lengths specifically, showing a positive relationship ($R^2 = 0.47$, $P = 0.0048$) (Figure 1). On the other hand, I did not observe any significant relationship between female wing lengths and mean June temperatures ($R^2 = 0.18$, $P = 0.11$). In addition, I found no evidence for an interaction effect of precipitation on forewing length ($F_{1,28} = 0.497$, $P = 0.48$).

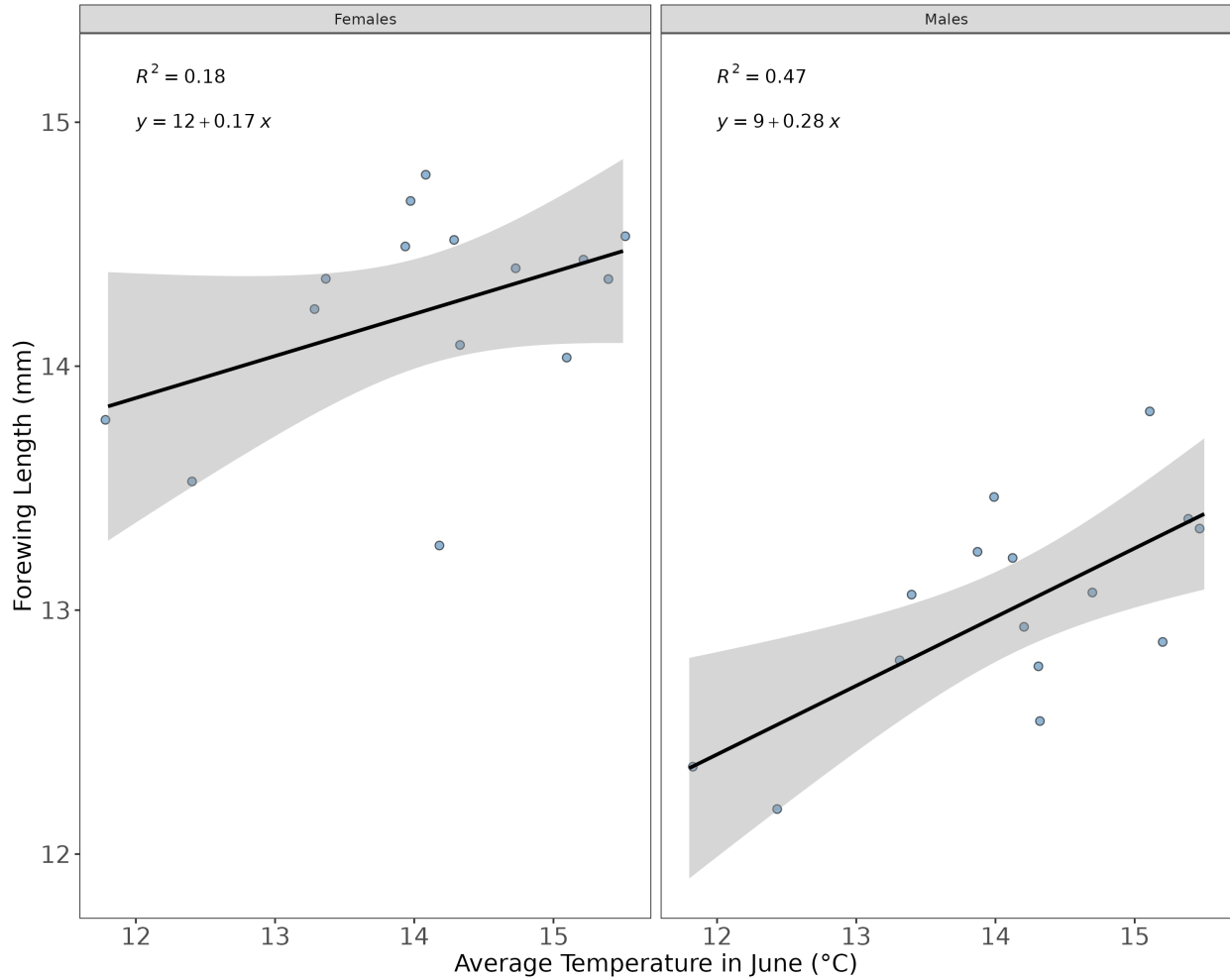


Figure 2. The significant linear regression of male wing lengths and the non-significant regression of female wing lengths vs. June temperature. Each point represents a raw data value ($n=15$ for males; $n=15$ for females, years from 1880 to 1973).

Table 1. Parameter estimates for the candidate models for using June temperatures to predict wing lengths of combined individuals (males and females), and run separately for males and females. A p value less than 0.05 is statistically significant.

	Estimate	Standard Error	Statistic	P Value
Combined	0.23	0.13	1.74	0.09
Males	0.28	0.08	3.40	0.004

	Estimate	Standard Error	Statistic	P Value
Females	0.17	0.10	1.70	0.11

In parallel with Fenberg et al., (2016), they observed a 2.20% increase in male *H. comma* wing length per °C while female wing length exhibited a smaller increase of 0.90% female wing length (although their regression for females was also not significant) (Fenberg et al. (2016)). This finding reinforces the notion that male wing sizes are more responsive to changes in June temperature compared to female wing sizes.

Climate change

Between 1880 and 1973, the multiple linear regression analysis shows that the mean June temperature did not have a significant increase over time ($R^2 = 0.04$; $P = 0.201$). Figure 3 shows an incredibly weak positive correlation between the two variables.

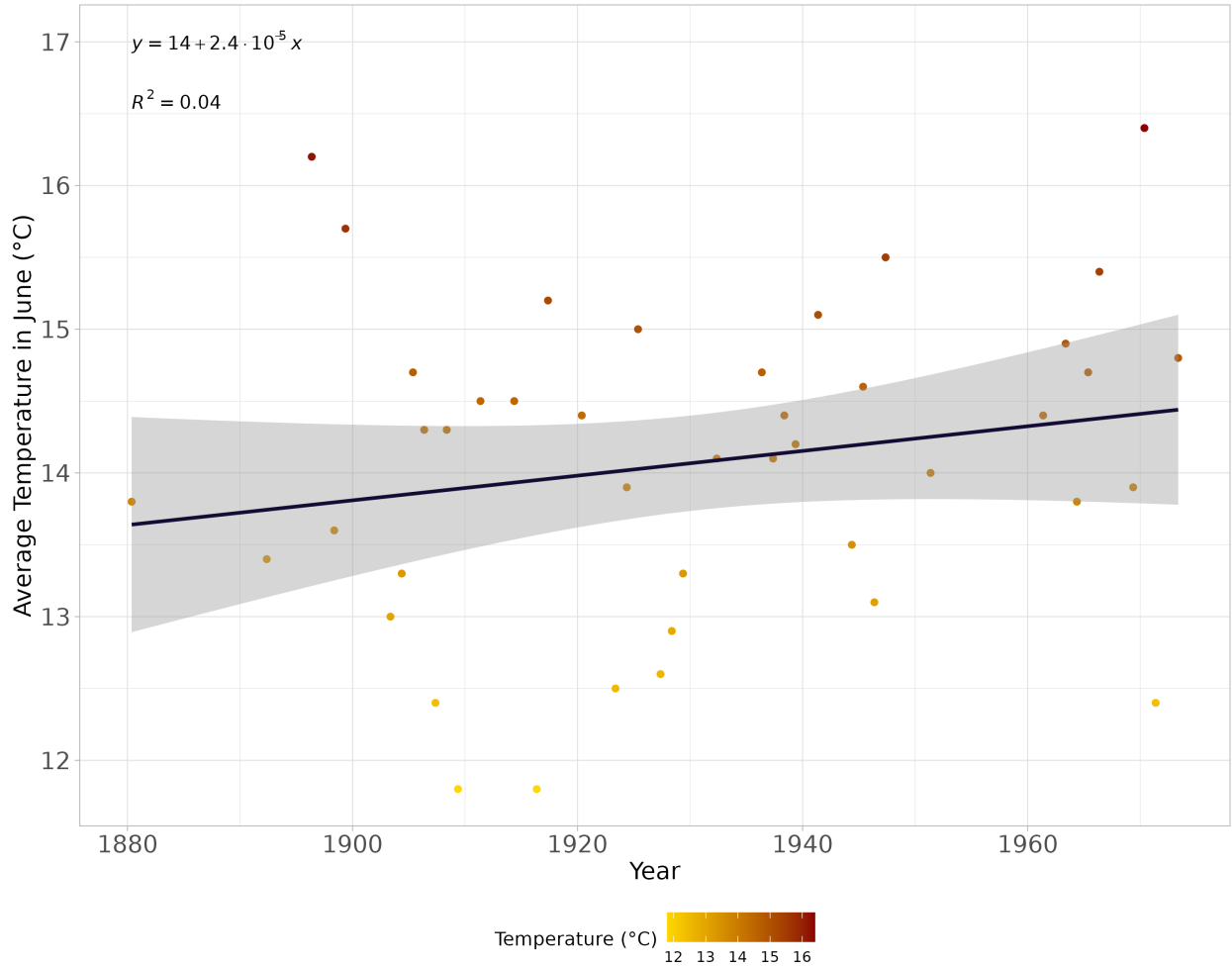


Figure 3. The non-significant linear regression of mean June temperatures over time. The data points indicate the measured temperature values at different time intervals ($n=30$, years from 1880 to 1973).

These findings suggest that the temperature in the studied region shows no significant fluctuations that can be attributed to climate change. It warrants further investigation to determine what other factors may be influencing the ecological consequences on butterfly phenology in the area, considering that the collinearities in my analysis were very high.

Conclusion

In this study, we explored the potential impact of climate change on the wing length of univoltine butterflies, specifically *Hesperia comma*. Our results revealed sexual dimorphism in wing size, with female butterflies being significantly larger than males. This size difference is likely attributed to the role of fecundity, as larger body size in females can provide advantages in terms of reproductive success and egg production.

Although we hypothesized that the average temperature in June would be a significant predictor of wing length, our multiple linear regression analysis did not yield statistically significant results. This suggests that, within the studied period, there were no significant fluctuations in temperature that can be attributed to climate change. However, it is important to acknowledge the limitations of our data and analysis. The collinearity detected among predictor variables and the lack of data for certain periods may have impacted the robustness of our regression model. Additionally, the limited sample size and the historical nature of the museum collections may have introduced bias and limitations in interpreting our findings. It is important to note that previous studies have found that increasing temperatures will affect univoltine species in other ways, such as early adult emergence and range expansion (Kharouba et al. (2013); Brooks et al. (2014); Fenberg et al. (2016)).

To further investigate the relationship between climate change and butterfly phenology, it would be beneficial to expand the study with a larger sample size and include more recent data. Long-term monitoring of butterfly populations, along with comprehensive climate data, can provide valuable insights into the ecological responses of butterflies to ongoing climate change. Additionally, incorporating other factors such as habitat fragmentation, land-use changes, and resource availability would contribute to a more comprehensive understanding of the ecological implications of climate change on butterfly species. Fenberg et al. (2016), investigated a similar hypothesis but with a much larger sample size which yielded far more statistically significant results and answers (Fenberg et al. (2016)).

Our study highlights the importance of considering sexual dimorphism and reproductive strategies when examining the effects of climate change on butterfly populations. The observed sexual differences in wing size may have implications for mate selection, resource allocation, and population dynamics. Understanding how these size differences influence butterfly behavior, fitness, and ecological interactions is crucial for predicting the adaptive responses of species to changing environmental conditions (DAVIES et al. (2006)).

To conclude, these findings suggest that the studied population of *Hesperia comma* butterflies exhibits sexual dimorphism in wing size, with females being larger than males. However, the lack of a significant relationship between wing length and temperature indicates the absence of notable temperature fluctuations in the studied region during the analyzed period. The limitations of our study underscore the need for further research incorporating larger sample sizes, more recent data, and a comprehensive assessment of environmental factors to elucidate the ecological consequences of climate change on butterfly phenology. This knowledge is vital for effective conservation strategies and understanding the broader impacts of climate change on global biodiversity.

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