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Climate effects on the flight period of Lycaenid butterflies in Massachusetts

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ABSTRACT

The effect of climate change on the phenology of plants and birds of eastern North America has been well studied in recent years, but insects have received less attention. In this study we investigated whether the response to climate warming of 10 short-lived butterfly species from the Lycaenidae family in Massachusetts is similar to responses seen in other taxonomic groups. We also determined the relative value of museum and citizen science data in ecological and conservation research, and how best to analyze these data. We obtained over 5000 records of butterflies in flight using museum collections (1893–1985) and citizen science data (1986–2009). We analyzed the data using linear regression models with sighting date as the response variable and temperature, precipitation, geographic location, and year as predictors. Temperature in the months during and prior to flight explained more variation in sighting date than the other predictors, with the average advance of flight date being 3.6 days/°C. Statistical tests using the first 20% of observations of flight in a year explained much more variation than tests using all observations. The response of these butterfly species to temperature is similar to plant flowering and bee flight times and is significantly greater than bird arrival times, suggesting the possibility of trophic mismatches. Citizen science data were more abundant and useful than museum data for studying climate change effects on butterflies. Conservation biologists and ecologists will need to develop innovative statistical techniques to deal with the sampling issues associated with citizen science data.

1. Introduction

Shifts in range, abundance, and phenology resulting from climate change have recently been documented at multiple trophic levels in ecosystems around the world (Ahas et al., 2002; Miller-Rushing et al., 2008a; Thackeray et al., 2010). The centuries-old practice of monitoring phenology has realized a renewed place in the tool kit of scientists as a way to measure these changes (Menzel, 2002; Pau et al., 2011). Long-term datasets maintained by individuals, institutions, and governments have been instrumental in allowing researchers to quantify such changes, which have important conservation implications. Evidence is mounting that those species that are able to track temperature changes by shifting their phenology will fare better than those species that are not as flexible (Cleland et al., 2012; Willis et al., 2010).

Despite the prominent role that insects play in ecological food webs, the scarcity of long term datasets on insect phenology, and reduced awareness of those that do exist, compared to those available for birds and plants has led to their being largely underrepresented in phenological research. This missing link has limited the understanding of the community level effects caused by climate change. Here we examine the effect of climate change on butterfly phenology in Massachusetts and compare it to responses observed in plants, birds, and bees. For this study we selected 10 species of butterflies from the Lycaenidae family, including the rare frosted elfin (*Callophrys irus*) (Albanese et al., 2007), and examined the effect of temperature and other factors on the flight dates of these species in Massachusetts.

Butterflies are an ideal group of organisms for investigating insect phenology because they are relatively conspicuous and are of more interest to humans than most other insects because of their size and color, which leads to observations and collections (Sparks and Yates, 1997). Additionally, research has determined that butterflies and other insects respond more quickly to detrimental environmental changes than plants or birds, and there is concern over declines in butterfly populations worldwide (Ellwood et al.,

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2012; Thomas et al., 2004). The United Kingdom supports a well-organized butterfly monitoring scheme that has been in operation since 1976 recording the abundance and phenology of butterflies in the British Isles (Roy and Sparks, 2000). A similar network is in place in Spain and Japan as well (Ellwood et al., 2012; Stefanescu et al., 2003). There are no networks operating with that sort of precision for insect monitoring in the United States, but because people have long enjoyed studying and collecting butterflies, many butterfly specimens dating back to the 19th century are preserved in museums throughout the country. Museum specimens provide important insight into the past and have been useful in studies focusing on other taxonomic groups in determining changes in phenology over time (Bartomeus et al., 2011; Johnson et al., 2011; Primack and Miller-Rushing, 2009).

As collection of natural specimens has fallen out of favor over the past few decades, citizen science groups have picked up where museum collectors have left off (Breed et al., 2012; Scharlemann, 2001). Although some citizen science projects, such as the Christmas Bird Count run by the Audubon Society, go back more than a century, interest in citizen science has exploded over the past decade or so (Silvertown, 2009). Instead of taking physical specimens, many people now "collect" by taking pictures of insects in the field, a practice that has become more common with the advent of digital photography. As with birding, a large population of enthusiastic naturalists who is well educated about butterflies and spends a lot of time observing butterflies in the wild. Citizen science organizations of various sizes and level of professionalism have been founded by butterfly enthusiasts since the 1950s. The North American Butterfly Association (NABA) has chapters across the country and organizes events such as the annual Fourth of July Butterfly Counts. The Massachusetts Butterfly Club (MBC), a chapter of NABA but largely independent club, is an active group of butterfly enthusiasts who maintain records of the butterflies that club members see throughout the growing season.

To determine how butterfly flight times respond to variation in temperature and precipitation, we combined historic records from museums and contemporary observation records from the MBC. We hypothesized that butterflies would be responding to climatic variation in Massachusetts and that spring emerging species would show a stronger response than summer emergents, comparable to what is seen in plants (Miller-Rushing and Primack, 2008). To test this hypothesis we selected members of the Lycaenidae family from two genera, one of spring emergers (*Callophrys*, elfins) and one of summer emergers (*Satyrium*, hairstreaks). Species were also selected based on their recognizability by experienced observers. Their relatively short flight period (less than 2 months) and their univoltine habit make them ideal model species for ecological and conservation research investigating whether their time of emergence is affected by temperature or precipitation. An important secondary goal of this research was to determine the relative value of museum specimens and citizen science observations in phenological research, and any special sampling issues involved in analyzing these types of data.

2. Materials and methods

We investigated the effect of climate on the flight times of 10 butterfly species from the family Lycaenidae, five species in the genus *Callophrys* (elfins) and five in the genus *Satyrium* (hairstreaks; Table 1). Elfins, which overwinter as pupae, fly earlier in the spring while hairstreaks overwinter as eggs and emerge as adults to fly in the summer. Most of our study species are common, although the frosted elfin, which occupies sandplain habitats, is listed as being of special concern in Massachusetts (Albanese et al., 2007).

The sighting and collection records included in the study cover the period 1895–2009. Records were included only if they were collected in Massachusetts and if the labels specified both the location of collection at the town or county level and the collection date. Historic data (pre-1986) were obtained by visiting museum collections (see Acknowledgements for list of sources) and transcribing data from specimen labels, through online databases or emailed information of label data from museum collections and from records kept by individuals in field notebooks. Contemporary data (1986–2009) were obtained from the records of the Massachusetts Butterfly Atlas (http://www.massaudubon.org/butterfly-atlas/) and the Massachusetts Butterfly Club (http://www.massbutterflies.org). Records from the Massachusetts Butterfly Atlas are based on either voucher specimens or photographs, while MBC records are based on photographs or reported sightings from experienced club members. Throughout the rest of the paper data from the Massachusetts Butterfly Atlas and the MBC will be grouped together and all referred to as MBC data. Duplicate sightings or specimens reported or collected on the same day at the same location were removed from the database. In total we obtained 5096 sighting records, 86% of which were from the MBC.

The mean sighting date of elfins was May 11 (DOY 131), while the range of sighting dates of all elfins for all years was April 3–July 4. The mean sighting date of hairstreaks was July 14 (DOY 195), with a range of June 6–September 11 (Table 1).

Temperature and precipitation records were obtained from the National Climatic Data Center (NCDC; http://www.ncdc.noaa.gov). In order to get statewide averages of precipitation and temperature we combined records from three weather stations spaced across the state and located in Amherst, Plymouth, and Milton, Massachusetts. There is considerable variation in climate within Massachusetts related to elevation and proximity to the coast. To account for the geographical variation and resulting climatic differences in Massachusetts we used the six hardiness zones as designated by the United States Department of Agriculture (USDA; http://planthardiness.ars.usda.gov/PHZMWeb/). Each sighting or collection record was assigned to its corresponding hardiness zone. The hardiness zones are based on the average annual minimum temperature that an area experiences. For analysis the hardiness zones were numbered such that code numbers increased with increasing minimum temperatures. For example, hardiness zone 7a (minimum -15 to -17 °C), which was assigned a value of 7.0, has milder winters than zone 4b (minimum -32 to -29 °C), which was assigned the value 4.5.

For each species we used a linear regression model incorporating four continuous predictor variables with the date of sighting as the dependent variable. We included all of the records collected for each species in our analysis rather than using only the mean or median. It is possible that there may be a bias toward more collections and sightings at the beginning of a particular season, as people are eager to get their first collections and sightings early in the flight season. There may also be an opposing bias to collect individuals throughout the season, especially the last flying individuals late in the season. To account for these potential biases and to provide a more precise index of first flight times in the season, we repeated the analysis for each species using only the first 20% of the sightings recorded. Using a percentage of the records rather than a specific number of records for each species helps to avoid bias of different samples sizes. In these first sighting models we used data only from years in which there were at least five observations. Because the number of observations for pre-MBC years was generally small, we used only MBC data in our first 20% sighting models. We deliberately selected species with short flying times as adults to minimize the effects of sampling bias and to increase the chances of detecting the effects of climate change.