

ISSUES : DATA SET

The Effect of Climate Change on Butterfly Phenology

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Strymon melinus (Media retrieved from:
[http://api.idigbio.org/v2/media/
c4ca533b9aff812438198337589626bf](http://api.idigbio.org/v2/media/c4ca533b9aff812438198337589626bf))

THE ECOLOGICAL QUESTION:

What are the effects of climate change on butterfly phenology and how do phenological changes of one species compare to that of an associated species?

ECOLOGICAL CONTENT:

butterfly, climate change, interspecific interactions, natural history collections, phenology

WHAT STUDENTS DO:

Plot and analyze natural history specimen data to identify trends in butterfly phenology, plot temperature data and test for relationships between temperature and phenology, relate their findings to published research

STUDENT-ACTIVE APPROACHES:

Students work in cooperative groups to make predictions, visualize and analyze data, and evaluate primary literature.

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SKILLS:

Using spread sheets, plotting data, analyzing data, interpreting data to address an ecological question, using data to predict interspecific interactions

ASSESSABLE OUTCOMES:

Completed scatterplots, written interpretation of a variety of data sources

SOURCE:

iDigBio portal of natural history collections records for butterfly specimen data

(www.idigbio.org/portal/search)

Environment and Climate Change – Canada for surface air temperature data of British Columbia

(<https://www.ec.gc.ca/dccha-ahccd/default.asp?lang=en&n=1EEECD01-1>)

ACKNOWLEDGEMENTS:

Our sincere thanks to the AIM-UP! project for leading the way in integrating natural history collections in undergraduate education, to QUBES and the DIG Faculty Mentoring Network for providing the infrastructure and constructive discussions about this lesson, to the Biodiversity Literacy in Undergraduate Education (BLUE) network for ongoing dialogue on the topic, and to Central Michigan University for their support of this effort in their biology curriculum.

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OVERVIEW OF THE ECOLOGICAL BACKGROUND

Phenology is the study of the timing of cyclical events in an organism's life cycle, including plants flowering, adult insects eclosing, and birds migrating. The timing of these events is often influenced by climatic variables, in particular temperature and precipitation. As global weather patterns are altered due to climate change, an organism's phenology may change in response. Further, interactions between organisms may be affected to the detriment of one or both species. If, for example, a plant flowers earlier in warmer springs, it is dependent on its insect pollinators emerging at a similarly early pace in order for the plant to be pollinated and effectively reproduce. Likewise, the insect pollinator will ideally eclose at a time when its nectar food source is available.

In the present exercise, students explore natural history collections as a source of phenology data, using the research presented in the article, *Flowering time of butterfly nectar food plants is more sensitive to temperature than the timing of butterfly adult flight* (Kharouba and Vellend 2015) as an entry point. The target audiences include introductory biology and ecology courses. Students use natural history collections data that has been downloaded from the iDigBio portal representing flight dates of butterfly species in British Columbia, Canada. While we encourage educators and students to visit and use the iDigBio data portal, due to the fact that the portal is regularly updated with new data, the data used in this module has been pre-downloaded for the sake of consistency. The species in this dataset are a subset of those used by Kharouba and Vellen and were selected based on the relative abundance of available data. Students are also provided temperature data to assess how temperature has changed over time and how butterfly phenology relates to temperature. Students interpret their graphs and assess how butterfly phenology is changing and whether an ecological mismatch may be possible.

LITERATURE CITED

Kharouba, H.M. and M. Veland M. 2015. Flowering time of butterfly nectar food plants is more sensitive to temperature than the timing of butterfly adult flight. *Journal of Animal Ecology* 88:1311-1321.

DATA SETS

Two data files are included in this activity, [Instructor data.xls](#) and [Student data.xls](#).

STUDENT INSTRUCTIONS

The Effect of Climate Change on Phenology

Learning Objectives

1. Identify trends in long-term climate data.
2. Measure shifts in the timing of life history events using long-term, specimen-based organismal data.
3. Compare trends in climate change and phenology shifts.
4. Predict the effects of phenology shifts on interspecific interactions.
5. Evaluate the advantages and limitations of specimen-based data in addressing specific biodiversity questions.

Introduction

Phenology is the study of the timing of cyclical events in an organism's life cycle, such as the flowering of plants, emergence of worker bees from the hive, or the migration of birds. The timing of critical life stages can be triggered by external environmental clues such as seasonal temperature change, photoperiod, or precipitation. As global weather patterns alter or fluctuate due to climate change, an organism's phenology may shift in response to a change in triggers. If species that interact closely respond to triggers that are no longer synced, the interaction may be disrupted. This is known as an ecological mismatch and can impact organisms across trophic levels (Winder and Schindler 2004, Both et al. 2006). For example, warmer spring temperatures often result in earlier emergence dates for temperature sensitive insects. If the plant nectar source is triggered by day length, the flowering time may not change in sync with the pollinator flight. If the emergence dates of their insect pollinators are not triggered by the same cue as the plant nectar source, the pollinator may not have food to fuel reproduction and the plants can lose a pollinator that is an important component of their reproductive success (e.g., Robbirt et al. 2014).

To address the impacts of climate change on phenology we need to examine long-term historical patterns and trends in both the environmental conditions and phenologies of the species of interest. We need current and historical data on when and where species occur, the timing of phenological events (e.g. emergence, flowering dates, peak flight), and key environmental variables that can initiate phenological transitions (e.g. temperature, precipitation). This means we need long-term data for both the organisms we study and the ecosystems they occupy. No problem! We are in the data rich era of science. Environmental data and data from natural history collections, professional scientists, and long-

term weather stations provide the information that is necessary to investigate phenological changes.

Natural history collections data are based on a physical specimen that was collected by a scientist, carefully preserved, and stored in a museum, university, or research collection space, much like books in a library. These collections serve as warehouses for all kinds of biological data such as phenology, taxonomy, evolution, and ecology of the species (e.g., Robbirt et al. 2011, Jacquemyn et al. 2015). Each specimen has information beyond the physical object itself. A specimen contains valuable metadata (e.g., collection date, location, habitat, images) and is accessible for repeatable, iterative, and expanded observations when physical verification is needed, new questions arise, or new investigative techniques are developed. For example, recent technological advances allow researchers to use specimens to study past biological phenomena such as molecular variation, historical environmental conditions, presence of environmental toxins, and host parasite assemblages; topics or approaches that were generally not imagined when the original specimen was collected. Natural history collections provide a source of biodiversity data that is unequalled in temporal, geographic, and taxonomic complexity and unique in its ability to allow researchers to verify and expand the data by returning to the physical specimens on which they are based. Further, these data can be combined with other data sources to inform research questions. For example, climate data can provide information on historic temperature and precipitation, citizen science observations can provide contemporary species occurrence information, and genetic data can provide information about evolutionary history.

Here, we'll be using the earliest collection date each year of butterfly specimens as a proxy for phenology. That is, the date that the adult butterfly was collected signifies a date that the butterfly was in flight. The relatively short lifespan of butterflies allows us to use their collection date to study how their phenology may have changed over time and relative to abiotic variables such as temperature. Today we'll use data from an online natural history collections database, iDigBio. This database provides us the opportunity to peek into the past, in this case as far back as the 1930s, to see the species, dates, and localities of butterflies that were collected. Butterfly phenology research conducted by Kharouba and Veland (2015) using specimens collected in British Columbia, Canada, provide the inspiration for this activity.

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In-Lab Assignment

In their research, one of Kharouba and Velland's investigations is into the effect of climate change on butterfly phenology in British Columbia, Canada. Here, we will take a slightly simplified version of their analysis to address the butterfly's response to temperature.

Using the data provided, complete the following activities and answer the related questions:

1. In this lab, you'll be working in the Excel spreadsheet, Student_data.xls. This file contains weather data and butterfly phenology data.
 - a. Data from how many weather stations are compiled in the Temp Data?

 - b. How many butterfly species are in the Butterfly Data?

 - c. Understanding the details of the data, where they come from, and what they represent is a critical part of data management. What is the term for these "data about data"?

2. Create a scatterplot of average annual temperature vs. year for British Columbia. Add a trend line. Based on the trend line, how has annual temperature changed over time in British Columbia?

Literature Cited:

- Both, C., S. Bouwhuis, C.M. Lessels, and M.E. Visser. 2006. Climate change and population declines in a long-distance migratory bird. *Nature* 441:81-83.
- Jacquemyn, H. and M.J. Hutchings. 2015. Biological flora of the British Isles: *Ophrys sphegodes*. *Journal of Ecology* 103:1680-1696.
- Kharouba, H.M. and M. Veland. 2015. Flowering time of butterfly nectar food plants is more sensitive to temperature than the timing of butterfly adult flight. *Journal of Animal Ecology* 88:1311-1321.
- Robbirt, K.M., D.L. Roberts, M.J. Hutchings, and A.J. Davy. 2014. Potential disruption of pollination in a sexually deceptive orchid by climatic change. *Current Biology* 24:2485-2489.
- Robbirt, K.M., A.J. Davy, M.J. Hutchings, and D.L. Roberts. 2011. Validation of biological collections as a source of phenological data for use in climate change studies: a case study with the orchid *Ophrys sphegodes*. *Journal of Ecology* 99:235-241.
- Winder, M. and D.E. Schindler. 2004. Climate change uncouples trophic interactions in an aquatic ecosystem. *Ecology* 85:2100-2016.

NOTES TO FACULTY

*Instructor resources and answers and provided in orange type.

The Effect of Climate Change on Phenology

Learning Objectives

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Notes: This module is intended as an introduction to phenology, natural history collections data, and basic statistical analysis. The target audiences include introductory biology and ecology courses. The Kharouba and Veland paper, on which this activity is based, serves as a pre-class reading assignment. We recommend that the instructor review the article with the class before starting the

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activity. The article goes into detail, particularly with regard to analysis, beyond what this activity will cover. As such, it is not necessary for students to have a complete and in-depth understanding of all the statistical methods; a basic understanding will suffice. Assessment is in the form of completed scatterplots and written interpretation of analyses and results.

For additional background information and media related to natural history collections, you may find it helpful to show YouTube videos of collections tours, interviews with curators, and footage of collections field work. We recommend the videos on the ScienceLIVE channel, which can be viewed here:

<https://www.youtube.com/user/MountainErb>.

The module may be expanded for higher level courses or to provide a more student-centered or place-based activity by having students visit the iDigBio portal and downloading data from species of their choice or local examples of plant and insect species. Be advised that data downloaded directly from the portal include a multitude of fields that are not directly relevant to this activity. Cleaning and manipulating data directly from the iDigBio portal will take a fair amount of time and may not fit into the time or subject material of a typical introductory biology course.

As a small extension, after the activity you may choose to discuss the trend towards later butterfly flight dates over time even though butterfly flight dates are earlier in warmer years and temperature is increasing over time. Kharouba and Velland came to similar results and describe the reasoning for this as such:

“Phenological trends over time do not necessarily indicate responsiveness of phenology to temperature as they are dependent on the degree and pattern of temperature change (Table 3; Cook et al. 2008; Kharouba et al. 2014) and the time frame of available data (Table 3; Ba-deck et al. 2004; Diez et al. 2012; Iler et al. 2013). They can also be influenced by changing population sizes (Miller-Rushing, Inouye & Primack 2008) and habitat type (Altermatt 2012).” For the purposes of this module, we kept in these analyses as they are basic to the research questions. The statistical findings and explanation may be beyond what an instructor would like to incorporate into their lesson though, so we leave that as optional material.

Introduction

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precipitation. As global weather patterns alter or fluctuate due to climate change, an organism's phenology may shift in response to a change in triggers. If species that interact closely respond to triggers that are no longer synced, the interaction may be disrupted. This is known as an ecological mismatch and can impact organisms across trophic levels (Winder and Schindler 2004, Both et al. 2006). For example, warmer spring temperatures often result in earlier emergence dates for temperature sensitive insects. If the plant nectar source is triggered by day length, the flowering time may not change in sync with the pollinator flight. If the emergence dates of their insect pollinators are not triggered by the same cue as the plant nectar source, the pollinator may not have food to fuel reproduction and the plants can lose a pollinator that is an important component of their reproductive success (e.g., Robbirt et al. 2014).

To address the impacts of climate change on phenology we need to examine long-term historical patterns and trends in both the environmental conditions and phenologies of the species of interest. We need current and historical data on when and where species occur, the timing of phenological events (e.g. emergence, flowering dates, peak flight), and key environmental variables that can initiate phenological transitions (e.g. temperature, precipitation). This means we need long-term data for both the organisms we study and the ecosystems they occupy. No problem! We are in the data rich era of science. Environmental data and data from natural history collections, professional scientists, and long-term weather stations provide the information that is necessary to investigate phenological changes.

Natural history collections data are based on a specimen that was collected, carefully preserved, and stored in a museum, university, or research collection space. These collections serve as a reference for the phenology, taxonomy, evolution, and ecology of the species (e.g., Robbirt et al. 2011, Jacquemyn et al. 2015). Each specimen contains valuable metadata (e.g., collection date, location, habitat, images) and is accessible for repeatable, iterative, and expanded observations when physical verification is needed, new questions arise, or new investigative techniques are developed. The archived specimen can provide information such as molecular variation, historical environmental conditions, presence of environmental toxins, and host parasite assemblages. Natural history collections provide a source of biodiversity data that is unparalleled in temporal, geographic, and taxonomic complexity and unique in its ability to allow researchers to verify and expand the data by returning to the physical specimens on which they are based.

Here, we'll be using the collection date of butterfly specimens as a proxy for phenology. That is, the date that the adult butterfly was collected signifies a date

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that the butterfly was in flight. Many butterfly species are only alive as adults for a matter of weeks. (Monarchs are a notable exception to this.) The short lifespan of butterflies allows us to use their collection date to study how their phenology may have changed over time and relative to abiotic variables such as temperature. Today we'll use data from an online natural history collections database, iDigBio. This database provides us the opportunity to peek into the past, in this case as far back as the 1930s, to see the species, dates, and localities of butterflies that were collected. Butterfly phenology research conducted by Kharouba and Veland (2015) using specimens collected in British Columbia, Canada, provide the inspiration for this activity.

Additional resources and videos for understanding natural history collections, their value in research, and how to use collections in education, can be found here:

<http://aimup.unm.edu/nat-history-collections/index.html>

<https://www.lessonsinfescience.org/museum-collections-1>

<http://biodiversityliteracy.com/>

Pre-Lab Assignment

In our next lab, we'll be investigating the effects of climate change on phenology. In preparation, please read this article, which was the inspiration for the lab exercise, and answer the questions below.

Kharouba, H.M. and M. Veland. 2015. Flowering time of butterfly nectar food plants is more sensitive to temperature than the timing of butterfly adult flight. *Journal of Animal Ecology* 88:1311-1321.

1. What are the three objectives the authors stated in their introduction?

From page 1312, "We had three objectives:

- (i) to compare the phenological sensitivity to temperature of adult butterflies and plants used as nectar sources,
- (ii) to determine whether this sensitivity differed across space and time for these taxa and
- (iii) to compare recent temporal shifts in phenology between butterflies and their nectar plants."

2. What are the three main sources of data used in this study?

1- Natural history collections data for butterfly phenology from the

Canadian National Collection of Butterflies data base, the Spencer Entomological Collection, and the personal and professional collections of Canadian butterfly experts.

- 2- Natural history collections data for plant phenology from the University of British Columbia herbarium.
- 3- Temperature data from the National Climate Data and Information Archive

3. Starting on page 1314, the authors discuss the limitations of collections based data as opposed to direct field observation. What were the limitations? How could the use of natural history collections based data affect the study?

Limitations: Most locations only had one specimen per year per species so it could not be determined what part of the life cycle the single specimen represented; geographic and temporal biases, though these were assumed to be random; a limited number of records for all species.

These could affect the study: by limiting the analyses that are possible and the conclusions that can be drawn with a limited and potentially biased dataset; if the data are highly biased, the results may be skewed towards a certain region, time period, or phenological state; and with a limited number of records, each record holds weight that may or may not be representative of the larger population of the species.

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- c. Understanding the details of the data, where they come from, and what they represent is a critical part of data management. What is the term for these “data about data”?

Metadata

2. Create a scatterplot of average annual temperature vs. year for British Columbia. Add a trend line. Based on the trend line, how has annual temperature changed over time in British Columbia?

(scatterplot shown in [Instructor data.xls](#))

Since 1900, the temperature has risen in British Columbia at a rate of $0.008^{\circ}\text{C}/\text{year}$, which equals $0.08^{\circ}\text{C}/\text{decade}$, $0.8^{\circ}\text{C}/\text{century}$, $p < 0.001$.

Natural history collections are rich repositories of biodiversity data. We can use information from specimen labels to compile data about phenology. Specifically, the date that a butterfly specimen was collected represents a day during which the butterfly was in flight. Create a scatterplot of butterfly flight date vs. year. Add a trend line. Based on your graph, how has the phenology of these butterflies shifted over time?

(scatterplot shown in [Instructor data.xls](#))

Butterfly flight is trending towards slightly later over time, at a rate of $0.12 \text{ days}/\text{year}$, $p = 0.31$.

3. How does your estimate of **phenological shift** from Question 3 compare to the estimate from Kharouba and Velland that is provided in Table 1 of their article? Why is this?

Kharouba and Velland calculated a shift of $0.0095 \text{ days}/\text{year}$. Our data show a stronger relationship/greater slope.

Kharouba and Velland were using different specimens and therefore different flight dates from the collections from which they pulled their butterfly data.

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Collections data are inherently variable, and limited specimens can highlight this fact.

4. Create a scatterplot of butterfly flight date vs. mean spring temperature and add a trendline. Repeat with mean summer temperature instead of spring. Based on your graphs, how does the phenology of butterflies relate to temperatures in each season?

(scatterplot shown in [Instructor_data.xls](#))

Butterfly phenology is negatively correlated with temperature. In warmer springs, butterfly phenology is earlier (-7.93 days/°C in the spring and -12.92 days/°C in the summer). The R^2 values are comparable for both seasons, ($R^2 = 0.06$ in spring and $R^2 = 0.08$ in summer), and the relationship is significant for both season ($p=0.04$ in spring and $p=0.02$ in summer).

5. Is the change in temperature the cause of the changes in phenology? Why or why not?

We can say that temperature and phenology are correlated, but we cannot say that temperature is the cause of changes in phenology. Temperature is variable that is describing some of the shifts in phenology, though there are many other variables that we haven't accounted for that are also responsible for changes in phenology. Correlation does not prove causation.

6. Kharouba and Velland found that plants are more sensitive to temperature than butterflies. Using the figure and values you derived in Question 5 as a reference, describe how a plot of the phenology of temperature-sensitive plants vs. temperature would compare to your butterfly plot.

The plot of a temperature-sensitive plants vs. temperature would have a steeper slope and be more highly correlated.

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7. How would you recognize if an ecological mismatch was possible between butterflies and their host plants? Describe how this would look when plotted.

The potential for an ecological mismatch would be apparent when the slopes of the butterfly flight date vs. temperature plot and the plant phenology vs. temperature plot were markedly different. Their trendlines would diverge or possibly go in different directions.

8. During which periods of time were there the greatest numbers of collected specimens? When were there the least? How might this impact the analysis?

(scatterplot shown in [Instructor_data.xls](#))

The greatest number were collected between 1930-1940, 1950-1960, and since 2000. Few were collected during the mid-1900s.

This could impact the analysis by not providing the full picture of how butterflies respond to temperature during various warmer and cooler periods over time. Knowing that phenology is highly variable from year to year, and that collections data can vary in availability, means that we have a good sense of the relationship between phenology and temp through collections data, but that it's not a complete picture.

With few options for historic phenology data, even with these issues of temporal bias, natural history collections provide some of the best data for phenology research.

9. As a follow-up to the previous question, what other types of data could provide you with additional information on butterfly flight times, particularly in recent years?

Observational data of butterflies from citizen scientists, other researcher studies, or amateur groups of butterfly enthusiasts could also be helpful here.

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