Regional and State-wide, Long term Climate change and Phenology In Ohio

Introduction

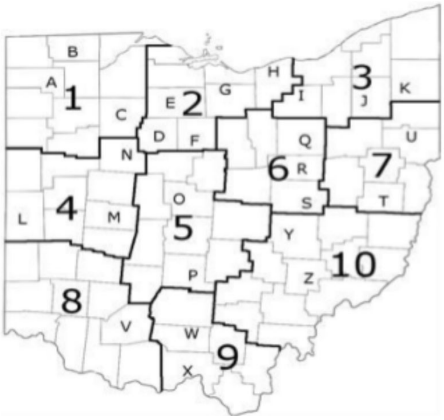
Climate change as a result of anthropogenic greenhouse gas (GHG) emissions isclear in both climatological and biological data. Global temperatures have increased by 0.74°C ± 0.18°C over the past 100 years (1906-2005), although some regions experience locally greater warming (IPCC 2007). Along with this average increase in temperature, extreme weather events including extreme heat have become more common. The ten hottest years on record have all occurred since 1998. Scientists use long-term climate (for example, see Figure 1) and biological datasets to assess past and current rates of warming and the impacts of this warming on key ecosystem functions. These analyses provide crucial information for the prediction of future impacts of warming as we continue to release massive quantities of GHGs into the atmosphere.

One clear biological indicator of climate change is phenology, or the timing of key life events in plants and animals. Phenological events are diverse and include time of flowering, mating, hibernation, and migration among many others. Generally, phenological events are strongly driven by temperature, with warmer temperatures typically resulting in earlier occurrence of springtime migration, insect emergence from dormancy, and reproductive events. Shifts in phenology in the direction predicted by climate change have been observed worldwide, suggesting that climate change is already having profound, geographically broad impacts on ecology (Parmesan & Yohe 2003, Menzel et al. 2006; Rosenzweig et al. 2008). In this lab, you will be analyzing long-term temperature data collected in Ohio by the U.S. Historical Climatology Network (http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn.html) to establish temperature trends in Ohio over the past 115 years. You will then investigate temperature effects on the flowering of six plant species and the arrival and emergence times of two pollinator species to determine biological signals of climate change in Ohio.

Part I. Regional, Long-term Temperature Trends

An important component of climate change studies is the analysis of temperature change over long timescales in the region of interest. For our analysis of Ohio, you will assess temperature change across the entire state as well as at smaller, regional scales. The U.S. Historical Climatology Network (USHCN) has collected temperature and precipitation data at 26 weather stations throughout Ohio since 1895 (Figure 2). The number of USHCN weather stations is limited as USHCN stations are required to have a consistent, non-urban location since 1895; this eliminates urban heat island effects (urbanized areas that are hotter than surrounding rural areas, U.S. EPA) and latitudinal/altitudinal effects. Changes in the location of weather stations can cause apparent increases or decreases in temperature as a result of moving to a generally warmer or cooler location. These possible altitudinal or latitudinal effects are eliminated in the USHCN climate record by requiring consistent station locations since the start of data collection. Using the mean of temperatures recorded at all 26 weather stations in Ohio, we can evaluate statewide trends in temperature since 1895. To assess regional trends in temperature, we can

use the ten climate divisions in Ohio established by the National Oceanic and Atmospheric Administration.



Look at the Excel file with data we have provided. The temperature record for each climate division is given in separate worksheets. Each climate division worksheet includes two columns; "Year" provides the year in which the temperature data were collected, and "Temp (deg C)" provides the spring time temperature for that year in degrees Celsius. These division temperatures were calculated by averaging the temperature records for every USHCN weather
station in that division for the year of interest from February to May (spring temperatures).

You will be assigned a climate division within which to work. Graph the data and answer the following questions:

What are your independent and dependent variables? What type of graph would be useful and why? What statistics would you use to extract the rate of temperature change from that graph? How would you calculate total temperature change over the 115 year period? Plot your data.

Now plot statewide temperature including ONLY yearly spring temperatures from 1990-2009. Does your plot indicate temperature increase or decrease from 1990-2009? What is the rate of temperature change? Based on the long-term, 115-year assessment of temperature change versus the shorter, 20-year assessment, can we accurately assess temperature change using a small subset of the data? Refer to the data in your answer. Why is it inappropriate to use only a subset of the total years to establish a climatic pattern?

Hop on the internet and navigate to VassarStats.net . Follow the link to "correlation/regression" on the left-hand navigation bar. Scroll down and go to the "data import" option. Copy the data from the Excel sheet provided into the appropriate box and click "calculate."

Report the equation, p-value and r-squared.

Record the rate of change (^{o}C/year) and total temperature change (^{o}C) from 1895-2009 below.

Stop here. We will share the results and interpret them together.

Part II. Using our shared data:
Are temperatures changing in your divisions? What about the other divisions? Using the group dataset, how would you describe the overall change in temperature across the state? Is it uniform?

Record key information (equation, p-value, r-squared, total change in temperature, annual change in temperature) from the other groups in the table below that is similar to the division map you encountered earlier.
TIP: Shade in divisions with the most rapidly warming temperatures in the warmest colors, then work your way to cool colors to represent those with the slowest or cooling trends to more easily visualize the trends.

1.	2.		3.
4.	5.	6.	7.
8.	9.		10.

Below is a graph of the "temperature anomaly" for the whole state over the same period.

How is this information different from what you calculated? Why is it important to consider a larger geographic region?

Part III. Biological Indicators of Climate Change: Flowering Time

Flowering time is a crucial phenological event for plants as it can strongly impact reproductive success (Calinger et al. 2013). Previous research has shown significant advancement of flowering with temperature increase (called phenological responsiveness, days flowering shifted/ºC), although species vary in the degree to which they shift flowering with temperature change. Since flowering time can have substantial fitness effects, climate change may alter species performance as climate warms, causing some species to decrease in abundance. You will analyze data on Ohio flowering times and assess impacts of temperature increase on species diversity. Click on the worksheet labeled "Flowering data." This worksheet provides data on the dates of flowering for six plant species collected throughout Ohio as well as temperature data and additional descriptive data (Calinger et al. 2013). Look at the column headings: Species, Common Name, County, Year, Division, Temperature, and DOY. Species and Common Name specify the plant species of interest. Each row represents an individual observation for a given species. County and Division provide information on the county of observation and the NOAA Climate Division in which that county is found. Year simply indicates the year in which the observation was made. Flowering dates are given in the "DOY" column. DOY stands for "day of year" and is the numeric day of year (day 1=Jan.1, Dec. 31=365, and so on) that the plant was flowering. Each flowering date is paired with a temperature specific to the individual plant's location, year, and season of observation. This temperature (ºC) is given in the Temperature column.

Again, use the VassarStats.net website to fill in a statistical evaluation of the dataset. Use the following table to record these data:

Species	Flowering shift (days/oC)	r-squared	p-value
Carduus nutans			
Castilleja coccinea			
Cornus florida			
Clematis virginiana			
Aquilegia canadensis			
Cypripedium acaule			

Do all species exhibit identical shifts in flowering time with an increase in temperature, or do some species advance/delay flowering more than others as temperature increases? Use specific species as examples in your answer.

Part IV. Biological Indicators of Climate Change:
Butterfly Emergence and Hummingbird Arrival

Along with shifts in the timing of plant phenological events, scientists have observed significant shifts in the timing of animal phenological events such as migration, insect emergence, and mating associated with temperature increase (Cotton 2003). Like flowering time in plants, the timing of these phenological events has direct impacts on reproductive success in animals. Further, changes in the timing of phenological events in plants and animals may disrupt important plant-animal interactions such as pollination. These disruptions of interactions as a result of shifting phenology are called trophic mismatches. For example, in pollination mutualisms, the pollinator benefits from pollen and nectar food resources and the plant benefits by being pollinated and increasing its reproductive success. Under average climate conditions, without climate change associated warming, flowering time in the plant and arrival time of the pollinator (based on migration or insect emergence date) are cued to coincide. However, if the plant or pollinator responds more strongly to climate warming and shifts their phenology more than their mutualistic partner, this relationship will be disrupted. This trophic mismatch results in decreased pollination and reproduction for the plant and a loss of important floral food resources for the pollinator.

Using data provided below, you will be assessing the effects of warming on shifts in arrival time of the migratory ruby throated hummingbird, *Archilochus colubris* and emergence from overwintering of the Spring Azure butterfly, *Celastrina ladon* (data from Ledneva et al. 2004). Both of these species occur in Ohio although this data was collected in Massachusetts. For this study, we will assume that the responses of both the ruby throated hummingbird and the Spring Azure butterfly are uniform throughout their ranges. You will also discuss whether we have evidence for trophic mismatches based on your findings.

Species	Arrival Time Change (days/°C)
Celastrina ladon (adults)	0.55
Archilochus colubris	-1.40

Based on the data given above for arrival time change, describe the pattern of shifting arrival/emergence time phenology for each pollinator species.

Archilochus colubris uses *Aquilegia canadensis* (columbine) flowers as a nectar food resource, and, in turn, is an important pollinator of this plant (Bertin 1982). *Celastrina ladon* caterpillars feed on *Cornus florida* (flowering dogwood) flowers (University of Florida IFAS Extension), although this interaction is not mutualistic as the dogwood receives no benefit. Given your knowledge of flowering shifts with temperature in *A. canadensis* and *C. florida* as well as arrival time shifts with temperature in *A. colubris* and *C. ladon*, speculate on what effects climate warming might have on survival and reproduction in these species. How would species interactions change with a 1ºC temperature increase? With a 3ºC temperature increase?

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Modified from:

Kellen M. Calinger. April 2014, posting date. Investigating the footprint of climate change on phenology and ecological interactions in north-central North America. Teaching Issues and Experiments in Ecology, Vol. 10: Practice #1 [online].

http://tiee.esa.org/vol/v10/issues/datasets/calinger/abstract.html