Developing quantitative skills for ecological data: the effects of climate warming on phenological variation and species interactions

Module Adaptation

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Photo Credit: John Harte, Winter and Summer at the Warming Meadow Experiment, Rocky Mountain Biological Laboratory

Module Adaptation Overview

Application of fundamental ecological principles to biological systems requires formulation and testing of ecological hypotheses, followed by evaluation and interpretation of ecological data. Thus, a fundamental objective within general ecology courses is the development of (i) hypothesis testing, (ii) effective data visualization, and (ii) quantitative skills that address and apply core ecological concepts. This adaptation combines the teaching module '*The Biology of Climate Change: The effects of a changing climate on migrating and over-wintering species at a high-elevation field station'* (Wu and Ellwein 2017) with a new dataset from a long-term Warming Meadow Experiment led by John Harte and colleagues monitoring biomass accumulation in shrubs and forbs in response to experimental warming (Harte and Shaw 1995, Price and Waser 1998, Saleska et al. 2002, Harte et al. 2015). The goal of this adaptation is to test hypotheses associated with phenological changes over time and examine the consequences of phenological mis-match between species, while developing skills associated with data visualization and analysis using observational and manipulated field experiments.

This activity is designed to be carried out in a 1.15 hr lecture style course. Students will need access to computers during this activity. While the adaptation is meant primarily to fit within a short period of classroom time and facilitate group learning, the activity may be extended and used as outside-of-classroom homework.

Original modules
This lesson is an adaptation of the teaching module:

Wu, C and A. Ellwein (2017) The Biology of Climate Change: The effects of a changing climate on migrating and over-wintering species at a high-elevation field station. Teaching Issues and Experiments in Ecology 13: http://tiee.esa.org/vol/v13/issues/data_sets/wu/abstract.html

The Rocky Mountain Biological Laboratory (RMBL) in Gothic, Colorado has been host to long-term phenological monitoring efforts associated with identifying the consequences of environmental change to phenological transitions.

New data
This lesson incorporates new data from Dr. John Harte's Warming Meadow experiment at the Rocky Mountain Biological Laboratory (Harte and Shaw 1995, Saleska et al. 2002, Harte et al. 2015; https://www.digitalrmbl.org/for-instructors/wm-teachers-guide/). For over 25 years, Dr. Harte has been artificially warming a subalpine meadow in Gothic, Colorado to evaluate the consequences of climate warming on community composition. Here we use biomass accumulation data from shrubs and forbs in control and heated plots within the Warming Meadow experiment.

The Data Sets
- Inouye_2000_PNAS_Data_sightings.xlsx – Phenological observations used in Inouye et al. (2000) from 1975 to 1999
- RMBL_phenology 2000to2010.xlsx – Updated phenological dataset from 2000 to 2010

- WarmingMeadowExperiment_RMBL.xlsx – Aboveground biomass summary of forbs and shrubs from John Harte's Warming Meadow experiment.

Instructors Notes on Student Instructions

In this section, I lay out the instructor notes for the presentation. The information is designed to be context specific and provide information that may build on previous knowledge gained on hypothesis testing, experimental design, and statistical analysis. The slides are designed to be presented prior to commencing the student activity. Following the presentation, students will need access to a spreadsheet program like Microsoft Excel to participate in the activity.

Instructor's Guide to the Lecture Presentation

Answering ecological questions (Slide 1-3)

This section **introduces ecology as a quantitative science and briefly covers the concepts of hypothesis testing in ecology and provides a workflow for answering ecological questions**. In addition, this section introduces the concept that ecologists evaluate competing hypotheses using a variety of approaches. This may include observational experiments, manipulated experiments, models and more, indicating that no single approach works for addressing ecological questions and that there may be pros and cons associated with different approaches. In addition, instructors may want to introduce minimum requirements for experimental design. This would include replication (replication in space or time), assigning treatments at random and appropriate use of statistical methods to standardize approaches to test hypothesis predictions.

This activity will focus on a long-term observational study and a manipulated field study at the Rocky Mountain Biological station. Instructors may want to highlight potential pros and cons of observational and manipulated experiments and the value of long-term datasets.

Visualizing ecological datasets (Slide 4-8)

This section introduces the **concept of independent and dependent variables in data visualization** and aims to identify the types of data that are used in different ecological experiments. This section uses the long-term observational study and experimental manipulation as an example. A particular goal in this section is to distinguish between continuous and categorical variables

Identifying the appropriate statistical test (Slide 9)

Once students are confident identifying the type of ecological variables they are evaluating (continuous or categorical) the goal in this section is to **identify the appropriate statistical test to test the probability that a hypothesis is supported**. In this section, instructors will want to briefly describe the differences between correlation and regression, t-test and ANOVA and the use of chi-squared tests in hypothesis testing. The brief summary indicates an assumption that students are familiar with these terms already and have some working knowledge of these

statistical tests prior to this lecture. If this is not the case, instructors may wish to spend additional classroom time supplementing the current offering on statistical tests.

Introduction to Inouye et al. 2000 (Slide 10-12)

This section is designed to **introduce students to the Inouye et al. experiment** and work with them in a first example. Students will have read Inouye et al. 2000 prior to class so the goal in this section is to work through a first example with students answering questions associated with analysis of phenological changes in the Yellow Marmot between 1976-1999. Throughout the course of this analysis the class will focus on the Yellow Marmot evaluating (i) the rate of change in timing of first marmot sighting between 1976-1999, (ii) how the rate of change in timing compares with that of Spring Beauty, a potential food source of the Yellow Marmot, and (iii) relating change in biomass accumulation of herbs and forbs in John Harte's experimental warming manipulation to future food availability for the marmot. This section can be used to again reiterate **briefly the importance and value of long-term observations and long-term experimental manipulations.**

Tips for constructing graphs in Excel (Slide 13)

This slide presents guidance for the duration of the activity; it includes quick tips to remind students where they might access additional information on the use of graphing in Excel (via an HHMI biointeractive spreadsheet link) and points out important questions to consider during hypothesis testing, data visualization and appropriate statistical approaches.

Skills developed:

- Development of hypotheses and data interpretation
- Using spreadsheets to organize and effectively visualize ecological datasets
- Identifying appropriate statistical tests for data interpretation
- Understanding the impacts of climate variation on species and how changes may impact species interactions in complex ways

Assessable Outcomes:

- Short answer questions datasheet associated with pre-class reading and analysis of datasets
- Data reconstruction and development of new means to visualize data
- Hypothesis development

Sources

Armitage, K. B. 2003. Observations on plant choice by foraging Yellow-Bellied Marmots. Oecologia Montana. 12: 25-28.

Harte, J. and R. Shaw. 1995. Shifting dominance within a montane vegetation community: results form a climate-warming experiment. Science. 267: 876-880.

Harte, J., Saleska, S. R., and C. Levy. 2015. Convergent ecosystem responses to 23-year ambient and manipulated warming link advancing snowmelt and shrub encroachment to transient and long-term climate-soil carbon feedback. Global Change Biology. 21: 2349-2356.

Inouye, D.W., barr, b., Armitage, K. B. and B. D. Inouye. 2000. Climate change is affecting altitudinal migrants and hibernating species. PNAS. 97: 1630-1633.

Price, M. V. and N. M. Waser. 1998. Effects of experimental warming on plant reproductive phenology in a subalpine meadow. Ecology. 79: 1261-1271.

Saleska, S. R., Shaw, M. R., Fischer, M. L., Dunne, J. A., Still, C. J., Holman, M. L., and J. Harte. 2002. Plant community composition mediates both large transient decline and predicted long-term recovery of soil carbon under climate warming. Global Biogeochemical Cycles. 16: 1055

Effects of rapid climate change on phenological transitions
(Adapted from Wu et al. 2017, TIEE):

Your task is to analyze data from a long-term investigation of climate variables and phenological transitions that have been collected at the Rocky Mountain Biological Laboratory (RMBL) in Gothic Colorado for several decades. Data has been collected by long-term resident billy barr for decades where he has monitored weather conditions, animal sightings and appearance of plant species following snow melt. Your goal in this analysis is to evaluate some of the long-term observed trends in phenology for different species as they relate to changes in climate conditions and to predict how these changes might influence phenological changes in the future.

Instructions

Data sets: You will need to download data sets from Blackboard to use for this assignment: (1) Inouye_2000_PNAS_Data_sightings.xlsx and (2) RMBL_phenology_2000to2010 and (3) WarmingMeadowExperiment_RMBL.xlsx

Part I: In-class Activity - Re-creating Inouye et al.'s Data:

To familiarize yourself with managing large spreadsheets you have been provided the raw data used by Inouye and his colleagues for their 2000 study (Inouye_2000_PNAS_Data_sightings.xlsx). This dataset includes a number of climate variables (C-), data on hibernating animals (H-), migratory animals (M-) and plants (P-). Our goal is to re-create the relationship depicted in Figure 4 of Inouye et al. - the date of the first sighting of a marmot at RMBL from 1976 to 1999.

(1) How many days has the first sight of marmots changed between 1976 and 1999?

(2) What is the rate of change in timing since the first sighting? What type of statistical analysis would you want to do to calculate a rate?

(3) What is the independent variable in this figure? Dependent variable?

Part II: Expanding the dataset - how are these trends changing in recent decades?

For this analysis you will retrieve the data from the most recent decade: 'RMBL_phenology_2000to2010.xlsx'. This file contains the same records for the previous file, but for a different timeframe. Your goal will be to compare rates of change in first yellow bellied marmot sighting between 1976 and 1999 (previous dataset) with those rates observed between 2000 and 2010 (new dataset).

1) How many days has the first sight of marmots changed between 2000 and 2010?

(2) What is the rate of change in timing since the first sighting? How has the rate changed between the 1976 to1999 timeframe to the 1976 to 2010 timeframe? (note: you will have to merge data)

(3) Early in the spring when marmots first emerge from hibernation they are known to feed on Spring Beauty (*Claytonia).* When has Spring Beauty sightings changed between 1976 and 2010? How does it compare with the emergence of the marmot? What might be the consequences of different rates of phenological change across these species?

(4) billy barr's dataset currently includes observations from ~40 years. Do you consider this a long-term data set? What considerations do you think are necessary for extrapolating from long (or not-so-long)-term datasets?

Part III: Do phenological transitions in one species impact another? How is food availability for herbivorous species changing in response to climate change?

Yellow-bellied marmots are generalist herbivores that have been observed to eat a range of different plant species; included grasses and forbs (Armitage 2003). Researchers have been interested to know how warming temperatures might impact subalpine meadows and thus influence food availability for marmots and other herbivores. In a long-term Warming Meadow Experiment John Harte and his colleagues have been monitoring biomass accumulation in shrubs in forbs in response to climate warming (Saleska et al. 2002). His team has suspended heaters within a subalpine meadow at RMBL allowing long-term observation of biotic and abiotic shifts in response to warming. Using data from 'WarmingMeadowExperiment_RMBL.xlsx' compare biomass production of forbs and shrubs in response to varying temperature treatments and answer the following questions:

(1) Develop a hypothesis for examining the impact warming may have on shrubs and forbs. Do you expect shrubs and forbs to respond in a similar manner? Why or why not? How would you test your hypothesis?

(2) Compare the mean biomass accumulation under control and treatment conditions in forbs. What are your independent and dependent variable? What statistical test would you do to compare means? Justify your answer graphically with a figure (**to be handed in along with the assignment**).

(3) Building upon the previous analysis compare mean biomass accumulation between shrubs and forbs under control and warming conditions What is the independent and dependent variable in your figure? Justify the statistical test you chose to evaluate mean differences across groups.

(4) If you want to compare the accumulation of biomass over time in response to different treatments how might that change your visualization of the data? What type of variables would be on x-axis and y-axis? Justify your answer graphically with a figure (**to be handed in along with the assignment**).

(5) Do you see the same patterns between forbs and shrubs? Why or why not? How might this impact food availability for marmots in the future? What is a phenological mis-match?

Tips for constructing graphs in Excel

- Check out: https://www.hhmi.org/biointeractive/spreadsheet-data-analysis-tutorials
- Calculating a rate requires a trendline, which can be added to graphs in excel with a right click. NOTE: don't forget the units of your rate! You can even click 'Display equation on chart' for the type of trendline (linear for us!) you use. The slope of the trendline is the rate of change.

References

Armitage, K. B. 2003. Observations on plant choice by foraging Yellow-Bellied Marmots. Oecologia Montana. 12: 25-28.

Harte, J. and R. Shaw. 1995. Shifting dominance within a montane vegetation community: results form a climate-warming experiment. Science. 267: 876-880.

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Wu, C. and A. Ellwein. 2017. The biology of climate change: the effects of a changing climate on migrating and over-wintering species at a high-elevation field station. Teaching Issues and Experiments in Ecology. 13: 1-20