Instructor’s Guide

# Exploring Plant Phenology Using Herbarium Specimens

# *Version 2.0*

# Seminar Course

Course Description

Volumes of data on plant diversity are becoming available with the **digitization** of **herbarium specimens**. Images of herbarium specimens provide a rich resource that can be harvested for data on plant form and **phenology**. In this course, students will design and conduct original research that examines the effect of climate on plant phenological events (e.g., flowering) using herbarium specimen data. Students will search for and download herbarium specimen data from the Consortium of California Herbaria online database, CCH2 (cch2.org). Students will use Excel and R code (through RStudio) to visualize, clean, and analyze the data. Each student will present their research as a scientific report, poster, and/or a lightning talk. Students will be guided through the research process through weekly class lectures, activities, and assignments.

Key terms:

* **Digitization**– creation of digital data from once analog-only data; this includes taking pictures of specimens and transcribing label data
* **Herbarium specimen –** dried, pressed plant mounted to archival paper and stored in a natural history collection called an “herbarium”
* **Phenology –** the study of the timing of growth and reproduction; in angiosperms, this includes, flowering and fruiting times

Purpose and Learning Objectives

The goal of this course is to provide an opportunity to learn and practice scientific research skills through developing and conducting original research using herbarium specimen data. By engaging in the research process, students will learn to:

* Read and evaluate scientific literature
* Identify and generate scientific questions and hypotheses
* Design experiments or analyses to describe trends and/or test hypotheses
* Evaluate the limitations of a data sources and design analyses that effectively take these limitations into account
* Gather and vet data from disparate sources
* Use R code (in RStudio) and Microsoft Excel to clean and analyze data
* Produce visualizations of data analyses in RStudio
* Write an academic report or assemble a scientific poster in a clear, concise, scientific tone
* Speak knowledgeably and concisely on conducted research
* Seek, evaluate, and incorporate feedback on work

What’s in the Instructor’s Guide

This document provides guidelines for activities and content for a 10 week version of this course. For each class period, we provide an outline of the lecture topic(s), activities, and the coursework due at class time. Instructors are free and encouraged to edit, augment, and adjust the materials and activities as they see fit.

Class materials that are pre-made and available for use (e.g., assignment instructions, lecture slides) are referred to in **bold and underline**in the content below. A comprehensive list of these materials is provided in the appendix.

No grading scheme is provided. This course can be conducted on a letter-graded or Pass/No Pass system.

Syllabus

For a syllabus, we recommend copying the course description, learning objectives, and course overview into a separate document along with institutionally required text, contact information, etc.

Course Overview

Below is a timeline of the general flow of the course. A more detailed schedule is shown in the table on the next page. Students should have a preliminary research question by week 3 so that they can begin to work with their data in R. The goal is to have an initial cleaned dataset ready by week 5. The instructor will then attach climate data to the students’ specimen datasets (using a provided R code and climate data) so that students can analyze the data and have preliminary results by week 7. Students then have time to adjust and re-run analyses while they are working on the first draft of their poster or paper, due week 9.



To ensure that students are able to successfully complete the project, it is essential that they select a testable question at an appropriate scale. We suggest that the dataset students work with should be about 150-200 specimen records *before* data cleaning. Data cleaning will significantly reduce the size of their starting dataset.

A draft weekly schedule is shown in the following table. This table can be useful for students’ planning purposes; therefore, we recommend including it in the syllabus. Assignments designated in the “Assignment(s) due” column are due **by class time** during the week indicated on the left.

|  |  |  |
| --- | --- | --- |
| Week | In-class topic(s) | Assignment(s) due |
| Week 1 | * **Course introduction and background**
* **Scientific questions**
* **Independent and dependent variables**
* **Reading scientific literature**
 |  |
| Week 2 | * **Displaying phenological data**
* **Response (dependent) variables vs. predictor (independent) variables**
* **Climatic variation**
* **Research questions**
 | * **Assignment 1**: Introductory readings on herbarium specimens, phenology and climate
* Pre-course survey
 |
| Week 3 | * **Methods and assumptions in data analysis**
* **Introduction to modeling in R**
 | * **Assignment 2**: Independent and dependent variables and selecting a study species (see **Protocol 1**)
* Install R Studio on your computer and create new R project (see **Protocol 2**)
 |
| Week 4 | * **R questions and troubleshooting**
* **Data cleaning**
* **Phenoclimate models:**

**Linear model design and analysis (demo in RStudio)** | * **Assignment 3**: Prepare and perform simple analyses in R using sample data set of herbarium data for *Nemophila menziesii*
 |
| Week 5 | * **Designing and writing a scientific paper or poster**
 | * **Assignment 4**: Apply R code to clean your data and submit your cleaned dataset to the instructor for combination with climate data
* Read **Turbek et al. 2016**
 |
| Week 6 | * **Open Discussion: Your questions, your models**
 | * **Assignment 5**: Prepare your research questions and possible linear models for workshopping next week
* **Annotated bibliography** draft with at least 3 sources
 |
| Week 7 | * **Describing results**
* **Designing additional analyses**
 | * Preliminary results with cleaned data
* Introduction section of poster
 |
| Week 8 | * **Interpreting results (discussion and conclusion)**
 | * Methods and results sections of poster
 |
| Week 9 | * **Giving and receiving feedback**
 | * Draft of final poster
 |
| Week 10 | * **Poster presentations**
 | * **Final poster**
* Final **annotated bibliography** (8 sources)
* Post-course survey
 |

### Week 1

#### **Topics**

* **Course introduction and background**
* **Scientific questions**
* **Independent and dependent variables**
* **Reading scientific literature**

#### **Materials**

* Syllabus
* **Week 1 lecture slides**
* **List of important resource links**
* **Assignment 1: Course Introduction Readings**
* Course Assessment (see Instructor Preparation)

#### **Instructor preparation**

* Prepare a syllabus that includes the course overview, your contact information, other required text, etc.
* Prepare to have students tour the herbarium or have physical herbarium specimens on hand to display, if possible
* Set up the pre-course survey as a Google Form or using another survey tool. Suggested questions are provided in the **Course Assessment** file, but instructors are encouraged to customize the assessment according to learning objectives or core competencies of your course/institution. Students will fill out the same survey before the course as a pre-course survey, then at the close of the course in a post-course survey.

#### **Coursework due at class time**

* None

#### **Coursework due next class**

* **Assignment 1: Class Introduction Readings**
* Pre-course survey

#### **Class overview**

1. Introductions/icebreaker
2. Discuss logistics of the course including syllabus, purpose, and format, emphasizing the fact that the project is largely self-guided and will result in a research poster.
3. If the course is online, describe videoconferencing logistics. Discuss course website and where to find assignments.
4. Guided by the course slides, discuss the following topics. Some notes are provided below and in the course slides.
	1. Phenology
		1. The study of the timing of life history events (e.g., flowering, fruiting, leafing out, migration, hibernation)
		2. For angiosperms, this can include germination of seeds, appearance of flower buds, appearance of vegetative buds, fruit maturity, seed dispersal, leaf fall, etc.
		3. We can measure phenological variables such as onset of phenological phase, termination of phenological phase, and duration of phenological phase
		4. Phenological events can depend on temperature, taxon/phylogeny, disturbance, light availability, genetics, elevation, latitude
		5. The phenological timing of one population/taxon may affect the fitness of another population/taxon.
	2. Herbarium specimens
		1. Herbarium specimens are plants that have been picked/cut, pressed, dried, and mounted onto archival specimens.
		2. Herbarium specimens are collected by botanists, ecologists, graduate students, land managers, and many others.
		3. Herbarium specimens are a treasure trove of information. Each specimen may include data about date, location, habitat, collector, collector number, scientific name, additional notes about color or morphology...
		4. If possible, give a tour of an herbarium or bring/show physical herbarium specimens as examples
	3. Using herbarium specimens to study phenology
		1. We can use herbarium specimens to study phenology because they represent the phenological status of a specific taxon at a specific place and time.
5. Discuss scientific questions, emphasizing that they are testable and have defined variables. Explain examples of testable questions in phenological research.
6. Describe **Assignment 1: Course Introduction Readings**
7. Remind students to fill out the Pre-course survey. We recommend setting up this assessment as an anonymous Google form. Suggested assessment questions are provided in the **Course Assessment** document.

### Week 2

#### **Topics**

* **Displaying phenological data**
* **Response (dependent) variables vs. predictor (independent) variables**
* **Climatic variation**
* **Research questions**

#### **Materials**

* **Week 2 lecture slides**
* **Week 2 breakout challenge** (optional)
* **Assignment 2: Dependent and Independent Variables and Selecting your Study Species**
* **Annotated bibliography assignment**
* **Protocol 1: Using CCH2 to download herbarium specimen data**
* **Protocol 2: Installing and Setting Up RStudio**

#### **Coursework due at class time**

* **Assignment 1: Class Introduction Readings**
* Pre-course survey

#### **Coursework due next class**

* **Assignment 2**: Independent and dependent variables and selecting a study species (see **Protocol 1**)
* Install R Studio on your computer and create new R project (see **Protocol 2**)

#### **Class overview**

1. Use the **week 2 lecture slides** to explain:
	1. How phenological data are presented and analyzed
	2. What the general predictor and response (i.e., independent and dependent) variables can be in such research
	3. The source of climate data, PRISM
	4. Potential questions for phenological research projects
2. **Week 2 breakout challenge** (optional) to help students practice selecting a species and coming up with phenological questions about that species. Give student groups 25 minutes to conduct this activity, then re-join as a class to discuss and critique the results.
3. Describe the upcoming assignments:
	1. **Assignment 2**: students will explore independent versus dependent variables and choose a study species for their research project. They will use **Protocol 1** to help them download specimen-based data from the data portal, CCH2
	2. Students should use **Protocol 2** to set up RStudio on their computers.
	3. **Annotated bibliography**: students will turn in a draft of the annotated bibliography assignment consisting of a minimum of three sources by week 6. The remaining five sources (for a total of eight) will be due at the end of the course (week 10).

### Week 3

#### **Topics**

* **Methods and assumptions in data analysis**
* **Introduction to modeling in R**

#### **Instructor preparation**

* Open the R markdown file (.Rmd) from Assignment 3 and ensure that all code is functional. Clear the R environment. Get familiar with the general workings of the code.

#### **Materials**

* **Week 3 lecture slides**
* **Assignment 3: Getting Familiar with R and Linear Regression**

#### **Coursework due at class time**

* **Assignment 2: Dependent and Independent Variables and Selecting your Study Species** (will require reference to **Protocol 1**)
* RStudio downloaded and new project created **(Protocol 2)**

#### **Coursework due next class**

* **Assignment 3: Getting Familiar with R and Linear Regression**

#### **Class overview**

1. Ask for and answer any questions from last week’s assignment
2. Use **week 3 lecture slides** to explain linear regression and how it is done in R (to slide 17)
3. Open the R code from **Assignment 3** and describe the general functioning and use of RStudio, including:
	1. What is the environment?
	2. What is the console?
	3. What are objects (and how can they be viewed in the environment)?
4. Use the R code from **Assignment 3** and **week 3 lecture slides** to demonstrate how phenological models are created and analyzed in R. Explain basic rules of functions and how to interpret the output of the model function (slides 18-36).
5. Assign **Assignment 3**. If necessary, set up extra office hours to help students who had trouble with Protocol 2.

### Week 4

#### **Topics**

* **R questions and troubleshooting**
* **Data cleaning**
* **Phenoclimate models: Linear model design and analysis (demo in RStudio)**

#### **Instructor preparation**

* Get familiar with **Coding Demo – Phenoclimatic Modeling in R** and make sure it all works on your computer so you don’t need to de-bug in the middle of class. If you run into too many problems, you can instead walk through the **PDF RMarkdown of Coding Demo**.

#### **Materials**

* **Week 4 lecture slides**
* **Phenoclimatic Models in R** (R code and data)
* **PDF RMarkdown of Phenoclimatic Models in R**
* **Assignment 4: Preparing Your Dataset for Analysis**
* **Turbek et al. 2016**

#### **Coursework due at class time**

* **Assignment 3: Getting Familiar with R and Linear Regression**

#### **Coursework due next class**

* **Assignment 4: Preparing Your Dataset for Analysis**
* Read **Turbek et al. 2016**

#### **Class overview**

1. Ask for and answer questions on the previous week’s assignment.
2. Discuss the purpose of data cleaning using **week 4 lecture slides**.
3. Explain **Assignment 4** (due next class), in which students will clean their data.
4. Introduce the remainder of class: you will be demoing the code that the students will ultimately use to conduct their own analyses. Example research questions and how to answer them are provided in the **Phenoclimatic Models in R code**, along with example data. Students may not necessarily do every step that you demo in their own analyses, but they will want to take careful note of which elements of the code they may want to use in order to answer their research questions.
	1. Advise students to think about how they might answer their own questions using the code you will demo.
	2. Students may choose to run through the code on their own computers during class; however, this might require some troubleshooting on how to open the folder, access data, install packages, etc. Therefore, we recommend that if you want students to walk through the code during class, announce this ahead of time and require them to come to class with the code loaded and libraries installed. Otherwise, you will lose valuable class time debugging individuals’ RStudio sessions. This should be done outside of class.
5. Open the Rmd file from the **Phenoclimatic Models in R** folder in RStudio and walk through it with the students in class. This may take longer than the allotted class time, depending on the level of detail you discuss. The part of the demo that is not covered in this class can be finished in week 5.

### Week 5

#### **Topics**

* **Designing and writing a scientific paper or poster**

#### **Materials**

* **(Phenoclimatic Models in R)** if not finished from week 4 class time
* **Week 5 lecture slides**
* **Week 5 Breakout Challenge** (optional)
* **Assignment 5: Research Questions Proposal**
* **Final Poster/Paper Assignment Instructions**

#### **Coursework due at class time**

* **Assignment 4: Preparing Your Dataset for Analysis**
* Read **Turbek et al. 2016**

#### **Coursework due next class**

* **Assignment 5: Research Questions Proposal**
* **Annotated bibliography draft (3 sources)**

#### **Class overview**

1. Ask for and answer questions on the previous week’s assignment.
2. Finish **Coding Demo of Phenoclimatic Modeling in R**, if necessary.
3. Discuss the format and development of a scientific paper or poster (depending on what you are assigning as the final project) and provide them with the **Final Poster/Paper Assignment Instructions**. Show examples of scientific papers/posters, describe what is good about them, and point out what could be improved (2 example posters provided in the **week 5 lecture slides**). If the students will create a poster, consider having a mock poster session in which you demonstrate presenting a poster.
4. Discuss the **Turbek et al. 2016** paper and how it relates to a good scientific poster: framing the narrative, editing, past tense, etc.
5. *(Optional*) Have students break out into groups for **week 5 breakout challenge**: writing hypotheses and predictions. Have them send their hypotheses and predictions to you, then re-convene to discuss.

**Follow-up from Assignment 4**. In Assignment 4, students will clean their dataset and send it to the instructor. The instructor or TA will then use the **Instructor Code: Merging PRISM data with student CCH2 datasets** to attach climate data to each student’s specimen data file. This step is performed by the instructor rather than the student due to the complicated nature of the code. In beta-testing of this course, we found that the time spent by the instructors and the TAs helping to debug the climate-association code was much greater than the time it would take for the instructors to do it themselves.

Associating climate data with students’ specimen data requires downloading and accessing normal and monthly PRISM climate data, found in the Data folder of the Instructor Code folder. Please refer to the written instructions and the instructional video for a walk-through of using this code.

### Week 6

#### **Topics**

* **Open discussion: your questions, your models**

#### **Instructor preparation**

* Associate climate data to all students’ specimen data and return to students soon after week 5 class time so they will have enough time to start working on their analyses. See “Follow-up from Assignment 4” text from previous week for more information about this process. Students’ preliminary analyses (models and graphs) will be due Week 7.
* If possible, read students’ assignment 5 submissions ahead of time to prioritize errors or misunderstandings that should be discussed during class. Some examples of common issues include:
	+ Vague questions that do not clearly delineate variables being tested
	+ Claiming to test variables that are not addressed by herbarium data (e.g., date of first flowering, flowering duration)
	+ Scope of question does not match the scope of the data (e.g., the question purports to look at flowering “across the range of the species”, while the data only include flowering data across the state of California)

#### **Coursework due at class time**

* **Assignment 5: Research Questions Proposal**
* **Annotated bibliography draft (3 sources)**

#### **Coursework due next class**

* **Preliminary results (model outputs) from cleaned data (using pieces of Phenoclimatic Models in R code)**
* **Draft of introduction section of poster**

#### **Materials**

* **Week 6 breakout challenge instructions and to do list**
* **Week 6 breakout challenge posters**
* If possible, make slides of some assignment 5 submissions for workshopping during class.

#### **Class overview**

This class is largely a time to discuss any remaining issues or questions that students have about their research questions, and its format is flexible according to the students’ needs. We recommend having students share their questions (or you can post questions anonymously from their assignment 5) and discussing the strengths and weaknesses of them as a class. You may alternatively/additionally choose to meet with students 1-on-1 to discuss potential improvements.

To solidify the discussion from last week, you may choose to use the **Week 6 breakout challenge**, in which students evaluate example research posters. This could be a good activity for students to work on while you meet with students individually to discuss their questions.

### Week 7

#### **Topics**

* **Describing results**
* **Designing additional analyses**

#### **Instructor Preparation**

* Examine students’ posters so far and determine whether there are any common errors or potential improvements. Some commonly overlooked elements include:
	+ Acknowledging/citing the herbaria from which the data came
	+ Reporting the number of specimens used in the dataset and what proportion of the original (pre-cleaning) dataset this represents
	+ Within reason, reporting all the statistical tests that were conducted (even if some were not significant)
* Some elements to look out for in the students’ introductions include:
	+ Wordiness/length
	+ Citing sources (Did they cite any sources? Did they do so correctly?)
	+ Providing sufficient background knowledge such that someone unfamiliar with herbarium specimens and phenology could understand the project
	+ Including the questions in the introduction
	+ Including relevant figures

#### **Materials**

* **Week 7 lecture slides** + any comments on students’ posters so far

#### **Coursework due at class time**

* **Preliminary results (model outputs) from cleaned data (using pieces of Phenoclimatic Models in R code)**
* **Draft of introduction section of poster**

#### **Coursework due next class**

* **Draft of methods and results sections of poster**

#### **Class overview**

1. Ask for and answer any questions that came up from last week’s assignments.
2. Address any common issues you see with students’ posters so far.
3. Discuss how to describe and present scientific results using the **week 7 lecture slides**.
4. Ask for and answer questions about students’ preliminary analyses. This can take place in a group workshop or 1-on-1 format.

### Week 8

#### **Topics**

* **Interpreting results (discussion and conclusion)**

#### **Instructor preparation**

* Examine students’ posters so far and determine whether there are any common errors or potential improvements to their methods and results. Some common problems include:
	+ Describing results using definite words like “prove”
	+ Interpreting the meaning of results in the results section
	+ Including too many details in the methods section
	+ Wordiness/length
	+ Poor choice or aesthetic appearance of figures

#### **Materials**

* **Week 8 lecture slides**
* **Discussion and conclusions checklist**

#### **Coursework due at class time**

* **Draft of methods and results sections of poster**

#### **Coursework due next class**

* **Finished draft of poster (electronically, such that it can be presented to a peer and receive feedback)**

#### **Class overview**

* Use the mini-lecture **week 8 lecture slides** to discuss the purpose of the discussion and conclusions sections of a scientific paper/poster. Provide the **discussion/conclusions checklist** for their reference.
* We recommend using the remaining time for workshopping and answering questions

### Week 9

#### **Topics**

* **Giving and receiving constructive feedback**

#### **Materials**

* **Week 9 lecture slides**
* **Peer review worksheet**

#### **Coursework due at class time**

* **Finished draft of poster (electronically, such that it can be presented to a peer and receive feedback)**

#### **Coursework due next class**

* **Final poster**
* **Post-course survey**
* **Annotated bibliography** (minimum of 8 sources)

#### **Class overview**

1. Use the **week 9 lecture slides** to discuss the idea of peer review and frame giving and receiving feedback as a necessary and helpful process.
2. Pair up students and have them read and analyze their partner’s poster according to the questions in the **Peer Review Worksheet**. Make sure to allot enough time for reviewing the posters (10-15 minutes), then announce that it is time to have students share their peer review with their partner (5-10 minutes).
3. Pair up students with new partners and have them read and analyze their new partner’s poster using a **Peer Review Worksheet**.
4. Bring the group back together. As a group, have students give examples of useful feedback that they received about their posters.

### Week 10

#### **Topics**

* **Poster presentations**

#### **Coursework due at class time**

* **Final poster**
* **Post-course survey**
* **Annotated bibliography** (minimum of 8 sources)

#### **Class timeline**

* The format of this class could be one of the following:
	+ Poster session (in person): students set up their posters in a classroom or hallway; half the class stands by their poster for half of the class time while the other half mills around and hears about the other students’ research, then the groups of students switch halfway through the class time
	+ Lightning poster presentations: each student takes a turn presenting their poster in 5 minutes; you can either have them bring a paper poster or you can project (or share your screen of) the image of the poster for the class
	+ Lightning talks: have the students prepare 2-5 slides ahead of time and speak for no more than 5 minutes each on the results of their analyses; because all the students will have similar methods, stress the dissemination of results and conclusions rather than explaining methodology

Appendix: List of Course Materials

Assignments

* Assignment 1: Course Introduction Readings
* Assignment 2: Independent and Dependent Variables and Selecting your Study Species
* Assignment 3: Getting Familiar with R and Linear Regression
* Assignment 4: Preparing Your Dataset and Questions
* Assignment 5: Research Questions Proposal
* Annotated Bibliography Assignment
* Peer Review Form
* Final Poster / Final Report Assignment Instructions
* Course assessment (pdf of suggested questions)

Guides/Protocols

* Protocol 1: Using the CCH2 data portal
* Protocol 2: Preparing to use RStudio
* (*for instructor use only*) Protocol 3: Using Instructor’s Code to Merge PRISM data into Students’ CCH2 datasets
* (*for instructor use only*) Video tutorial for Using Instructor’s Code to Merge PRISM data into Students’ CCH2 datasets: <https://youtu.be/-2dXPVdjB8M>
* Discussion and conclusions checklist
* List of Important resources

Slides and In-class Activities

* Week 1 lecture slides: Introductions, Logistics, and Background
* Week 1 breakout challenge: Shared interests
* Week 2 lecture slides: Research Questions, Species Selection, and the CCH2 Website
* Week 2 breakout challenge: Mockup of research question and study species
* Week 3 lecture slides: Data Analysis in R
* Week 4 lecture slides: Data cleaning
* Week 5 lecture slides: Creating a research poster / research report
* Week 5 breakout challenge: Hypotheses and predictions
* Week 6 lecture slides (to do list only)
* Week 6 breakout challenge: Evaluate a poster
* Week 7 lecture slides: Results
* Week 8 lecture slides: Discussion and conclusions
* Week 9 lecture slides: Giving and receiving feedback

R Scripts and datasets

* Assignment 3 code and *Nemophila* specimen datasets (file names: nemoPhenoClim, NemophilaMeasurementOrFact, NemophilaOccurrences). In *Assignments* folder.
* Week 4 Coding Demo – Phenoclimatic Modeling in R.
* Assignment 4 code. In *Assignments* folder.
* Instructor Code: Merging PRISM data with student CCH2 datasets
	+ See Protocol 3 and video tutorial (<https://youtu.be/-2dXPVdjB8M>)

Required Reading

* Haggerty B, Hove A, Mazer S. A primer on herbarium-based phenological research. https://www.usanpn.org/files/shared/A%20primer%20on%20herbarium-based%20phenological%20research.pdf
* Turbek SP, Chock TM, Donahue K, Havrilla CA, Oliverio AM, Polutchko SK, Shoemaker LG, Vimercati L. . Scientific writing made easy: A step-by-step guide to undergraduate writing in the biological sciences. Bulletin of the Ecological Society of America 97(4):417-426. https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/bes2.1258
* Willis CG, Ellwood ER, Primack RB, Davis CC, Pearson KD, Gallinat AS, Yost JM, Nelson G, Mazer SJ, Rossington [Love] NL, Sparks TH, Soltis PS. Old plants, new tricks: Phenological research using herbarium specimens. Trends in Ecology and Evolution 32(7):531-546. https://www.researchgate.net/publication/316591008\_Old\_Plants\_New\_Tricks\_Phenological\_Research\_Using\_Herbarium\_Specimens