Case Teaching Notes

for

"Can Birds 'Keep Up' with Earlier Springs?"

by

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Introduction / Background

Phenology, the timing of seasonal ecological events, has changed substantially in response to climate change (Parmesan & Yohe, 2003). As the timing of these events changes over time, there is concern that ecological interactions are becoming increasingly mismatched in time. This may refer to interactions across (consumer-resource interactions) or within (competition) trophic levels, or even between an organism and the abiotic environment. These mismatches may have substantial implications for the function of ecological systems, by way of population (Møller et al., 2008) and coexistence dynamics (Rudolf, 2019). Migratory birds and plants represent widely studied taxa where phenology can be characterized at scale. For birds, this can be accomplished using large-scale information collected as a part of programs such as eBird. For plants, this can be accomplished using satellite-based sensors, which quite literally use the color of the landscape as an indicator of spring arrival.

The material presented here is broken down into five sections. Part I provides a general background on phenology and its importance for ecosystem function. Part II provides an overview of a study on the phenology of migratory birds by Youngflesh et al. (2021). The authors look at how sensitive North American birds are to changes in vegetation phenology, and how that varies across space, and among species. Part III provides an opportunity for students to work with data from the Youngflesh et al. (2021) study, with exercises geared towards data analyses and interpretation. Part IV includes additional instructions and questions on more advanced topics, again using data and results from Youngflesh et al. (2021). Part V is the concluding section and ties case study concepts together. There are several open-ended questions for students to answer to facilitate a synthesis of information.

This case study is designed for upper-division undergraduate or graduate courses in ecology, environmental science, climate change, or even some organismal courses, such as botany, zoology, or ornithology. The data-centric exercises in Parts III and IV could be adapted or built upon for courses with a quantitative focus. Questions that ask students to analyze data could be excluded entirely, if the instructor prefers a more concept-centric exercise or to fit into the time window allocated for the exercise.

Learning Objectives

Students who successfully complete this case study will:

- Explain what phenology is and why it is important for ecological systems.
- Interpret results presented in the focal scientific study.
- Apply and interpret results from linear regression using real world data from the focal scientific study.
- Hypothesize as to how and why ecological systems might be responding to phenological change.
- Develop one or more research questions related to the specific aspects of phenology covered in the case study.

Classroom Management

Students should work through each section of the case study before moving on to the next section, as the material builds upon itself. The material presented should be sufficient to cover several shorter class periods or one to two longer class periods. The case may be particularly well suited for course "lab sessions." Alternatively, students could work through Part I on their own, and then work individually or in small groups on Parts II–V in class. Part IV is an extension of what students have worked on in Part III; of course, the time it takes to complete these two sections may vary substantially, depending on whether students analyze the data, and how proficient students are with data analysis (in Excel or *R*). If some sections or questions are skipped, it is recommended that students still complete Part V, which is designed to challenge students to think about what might be missing from our understanding of phenological mismatch.

Questions presented in this case study are intended to stimulate thinking and discussion among students. There are many acceptable answers to many of these questions, particularly for Parts I, II, and V. Solutions provided (which include *R* code; see the answer key) are not comprehensive, but represent some potential answers to these questions. It may be helpful to split the classroom into small groups to work through questions together, as different perspectives may stimulate discussion.

Parts III and IV make use of an online, interactive application: <https://migratory-sensitivity.shinyapps.io/MigSen-app/>. This is used to explore and download the data necessary for Part III. If you have trouble using this app, it can be produced locally (i.e., on one's laptop or desktop computer) using the archived code on Zenodo at <https://zenodo.org/record/4938371>. There is a README file on Zenodo that explains how to create the application. Be sure all packages loaded at the top of *app.R* are installed on your computer if this route is taken. There are also data files (in .csv format) included with this case study (see Supplemental Materials), if that is preferred over having students download data from the application. There are data folders for greenup, tree swallow arrival, red-eyed vireo arrival, tree swallow sensitivity, and species-level sensitivity coupled with species-level traits. These folders are identical to those downloaded from the web application. Each of these folders has an associated .csv and README file. The README files explain the included data. We recommend that students read the README files associated with each of the data files. Referring to README files is an important part of the data analysis process (when using existing data) so this is an excellent skill for students to practice. Alternatively, the instructor could communicate this information to students. Files in .csv format can be opened in Excel and converted to .xls format if desired.

The end of Part IV directs the students to explore the *Interannual Variation* tab on the web application. This open-ended exploration by students presents an opportunity for the instructor to pose additional questions to students. The application shows how the timing of bird arrival and green-up varies across time for a single species in a single cell. Bird arrival estimates are not available for every cell/species. Cells at mid latitudes are generally more likely to have estimates for more years. From these plots, students can more easily visualize how bird arrival fluctuates "in synchrony" with changes in green-up.

This case study also contains links to two web-based articles. One posted on the website for *The Conversation* ("Spring is arriving earlier across the US, and that's not always good news") in the Introduction, and one posted on the Smithsonian National Zoo's website ("The Full Annual Cycle of Migratory Birds") in the Questions section for Part I. We have also provided copies as Supplemental Materials (an .html file which can be opened in a web browser for *The Conversation* article, and a .pdf file for the Smithsonian National Zoo page) if the links to these articles change in the future or are unavailable for any reason.

Blocks of Analysis

Phenological Mismatch

The ecological theory that is the basis of this case study is the Cushing match-mismatch hypothesis (Cushing, 1969), which is ably summarized by Kharouba and Wolkovic (2020) as "… the consumer should temporally match the peak of its most energetically demanding period with the peak of resource availability, and any change to the relative timing of the interaction will result in a mismatch."

Although Cushing was writing about recruitment in fish stocks, the terms *match* and *mismatch* have been used in a variety of ecosystems and contexts including consumer-resource and mutualistic interactions. Some authors, ourselves included, have used the term *phenological asynchrony* to refer to differences in the timing of phenological events, while reserving *mismatch* for situations where changes in the timing of phenological events (i.e., phenological shifts) result in fitness consequences for the population of consumers. We do not include or define the term *asynchrony* in this case study, but rather focus on *match* and *mismatch*, e.g., in Part I and Figure 1 of the case study handout (where the decoupling or mismatch is associated with a consequence such as "decreased breeding success for birds"). For a deeper discussion of the different terms and definitions used in phenological research, instructors are encouraged to incorporate review articles such as Kharouba and Wolkovic (2020), Rudolph (2019), or Visser and Gienapp (2019) into their classes.

Principal Component Analysis

Instructors should also consider to what extent their students have familiarity with principal component analysis (PCA) or other multivariate methods to reduce the dimensionality of a dataset, given the "trait score" used and defined in Part II, Figure 4. In our tests of this case study a number of students wanted additional explanation of this score, i.e., the *x*-axis in Figure 4. We had time for brief, impromptu explanations of how to interpret the trait score, but of course not for detailed instructions on PCA; see Joliffe and Cadima (2016) for a recent review. We recommend emphasizing the directional arrows below the trait score axis for interpretation, i.e., that species with higher (more positive) trait scores are associated with faster migration pace, later spring arrival dates, and overwintering ranges further to the south.

Using R *to Answer Case Questions*

Finally, we did not provide instructions for students interested in learning *R* since that is beyond the scope of a single case study. *R* is freely available statistical computing and graphing software available for download: https://www.r-project.org/. Many resources are available for learning *R*, including *R for Data Science* by Wickham and Grolemund (https://r4ds.had.co.nz/).

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