NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Can Birds "Keep Up" with Earlier Springs?

by
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Introduction

Before beginning this case study, read the following article:

- Crimmins, T. (2020, March 4). Spring is arriving earlier across the US, and that's not always good news. *The Conversation*. <https://theconversation.com/spring-is-arriving-earlier-across-the-us-and-thats-not-always-good-news-129967>

In Part I of this case study you will read more about phenology and some of the concerns about phenological change, with a particular focus on migratory birds. Please answer the questions at the end of Part I before you move on. In Part II, you will read more about the results of a research project focused on changes in the phenology of plants and migratory birds. After answering the questions at the end of Part II, you will work with data developed as a part of this research project. Parts III and IV are focused on manipulating, analyzing, and interpreting these phenological data. Part V is a concluding section with several final questions.

In working through this case study, you will:

- Explain what phenology is and why it is important for ecological systems.
- Interpret results from a published scientific study.
- Apply and interpret results from linear regression using real world data.
- Hypothesize as to how and why ecological systems might be responding to phenological change.
- Develop research questions related to phenology and phenological change.

Part I – Phenology, the Timing of Seasonal Events

The timing of seasonal ecological events (known as *phenology*) is critical to the functioning of ecosystems. Organisms often need to time important events to coincide with either favorable environmental conditions (e.g., frogs coming to seasonal ponds to breed) or the availability of resources (e.g., caterpillars coming out of diapause to begin feeding on fresh leaves in the spring).

The importance of this timing drives many seasonal dynamics that you may have observed, such as the tendency for animals to give birth to young in spring and early summer in temperate zones. Consumers ideally time their periods of peak resource requirements to overlap with periods of peak resource availability. For example, songbirds can raise more young if their eggs hatch when there are more caterpillars available, as young birds require large amounts of food to survive to adulthood. Since the availability of caterpillars varies throughout the year in temperate environments (peaking in spring to early summer), birds that rely on caterpillars as a food resource tend to nest during this period as well. If a bird nests before or after this optimal window of time (where caterpillar availability is highest), fewer young might survive (Stenseth & Mysterud, 2002).

When these two periods align (peak resource requirements with peak resource availability), it is known as a phenological match. When they are uncoupled in time, resulting in negative consequences (perhaps decreased survival of young), it is known as a phenological mismatch (Figure 1). In response to climate change, the time of year at which these events are occurring is now changing. These changes have been observed across a large number of taxonomic groups (Parmesan & Yohe, 2003) and across trophic levels (e.g., producers, consumers, predators; Thackeray et al., 2016). For example, warming temperatures have generally resulted in earlier spring events. Plants are flowering earlier (Cleland et al., 2007), insects are emerging earlier (Gutiérrez & Wilson, 2021), and birds are breeding earlier (Hurlbert & Liang, 2012) than they did previously. However, not all species are changing their phenology at the same rate. Because of this, events may become increasingly decoupled in time due to climate change (Figure 2).

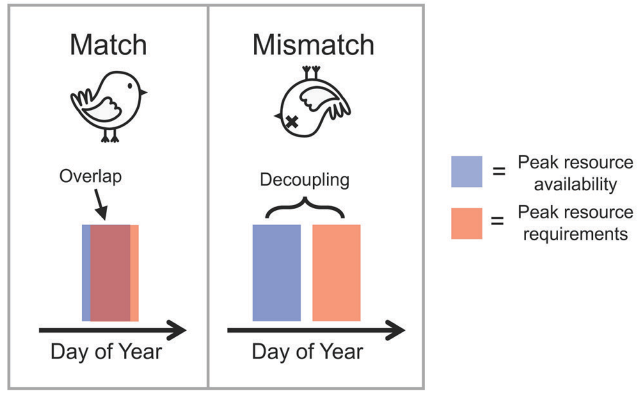

Figure 1. The timing of ecological events is critical to the function of ecosystems. The blue bar represents the period of peak resource availability (e.g., peak caterpillar abundance). The red bar represents the period of peak resource requirements (e.g., when birds are feeding chicks). Any decoupling between these periods may have ecological consequences (e.g., decreased breeding success for birds).

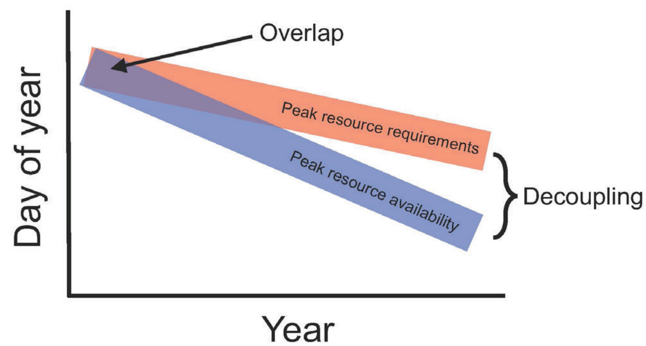

Figure 2. Temporal decoupling may be getting larger over time in response to climate change. The blue bar represents the period of peak resource availability. The red bar represents the period of peak resource requirements. These two periods overlap in earlier years. However, peak resource availability is advancing more rapidly than peak resource requirements, resulting in larger temporal decoupling in later years.

Questions

1. How might phenology be important outside of a predator-prey relationship (such as that illustrated with birds and caterpillars)? Think about interactions both within and among trophic levels and between organisms and the abiotic environment.

2. If you're not familiar with the annual life cycle of North American migratory songbirds, first visit the following webpage hosted by Smithsonian's National Zoo and Conservation Biology Institute:
   - The Full Annual Cycle of Migratory Birds. <https://nationalzoo.si.edu/migratory-birds/full-annual-cycle-migratory-birds>

   Now list some of the specific events that occur on an annual cycle (spring/summer/fall/winter). What kinds of data would be useful to estimate the timing of these specific events? How might these data be collected?

3. Formulate a *research question* focused on any of the specific aspects of phenology you have come up with for Questions 1 or 2, above. What is an example of a study design that could help you answer that question? (Think of locations, time periods, types of organisms, environmental data, etc. that you would need.)

Part II – Changes in Bird Migration Phenology and Green-up

Community (or citizen) science projects, that leverage the expertise of non-professional scientists, can be a valuable resource in trying to understand phenology. Observations from large numbers of project participants allows researchers to understand phenology across large areas. One example of such a project is eBird (Sullivan et al., 2014), which asks users to submit bird observations that they have made to an online platform (eBird.org). These bird observations can be used to determine when birds are migrating and how this changes over time (Hurlbert & Liang, 2012; Mayor et al., 2017).

A study by Youngflesh et al. (2021) published in *Nature Ecology and Evolution* used more than 7 million bird observations from eBird to study spring migration phenology for 56 species of North American birds. These species migrate from their overwintering grounds in North, Central, and South America to more northerly breeding grounds. Youngflesh et al. used these data in conjunction with information on the timing of spring "green-up" (i.e., when leaves start to grow out on deciduous trees and shrubs) in forests, which was derived from satellite imagery (Friedl et al., 2019). Green-up is often used as a metric of spring arrival and is known to be important for key food resources of these birds, namely caterpillars (Cole et al., 2015). They compared interannual fluctuations in bird arrival to fluctuations in green-up to see how well birds were matching any phenological shifts in forest vegetation growth.

The researchers found that bird arrival coarsely matches fluctuations in green-up, though the degree to which this is apparent varied widely across space and among species (Figure 3 illustrates this variation for tree swallow at one location). They calculated measures of phenological sensitivity, defined as the number of days change in arrival per one-day change in green-up, to represent how well bird arrival matched green-up, for any given species in different parts of their breeding range. In general, species had higher sensitivity to green-up in the more northerly portions of their ranges. This may be because birds can adjust the speed at which they are migrating as they move northward, to better match the timing of green-up as they progress in migration to their breeding grounds.

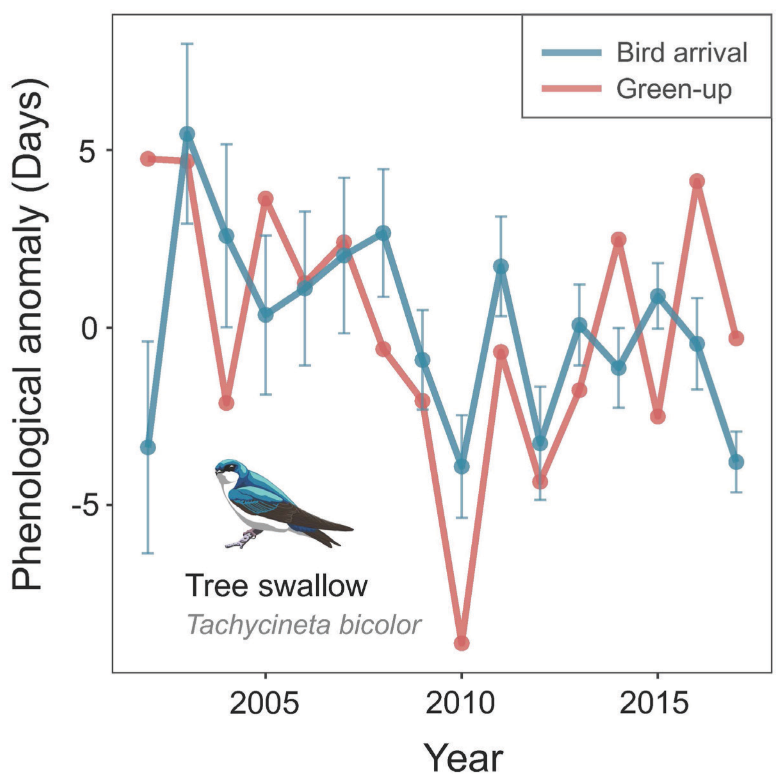

Figure 3. Bird arrival coarsely matches fluctuations in green-up. Variation in green-up (red) and bird arrival (teal) dates over time for a single species (tree swallow), in a single hexagonal grid cell (with an area of 70,000 km^2) located in eastern North America. Error bars for arrival represent the uncertainty in the estimated date of arrival. On the *y*-axis, positive values represent later green-up/bird arrival than average, while negative values represent earlier green-up/bird arrival than average. This phenological anomaly represents how much earlier or later that year's green-up/arrival was compared to the overall mean from 2002–2017. Figure adapted from Youngflesh et al. (2021).

To understand how and why some species might be responding differently to changes in green-up, the researchers also integrated information on species' migratory traits. They combined three traits (migration pace, average arrival date, average overwinter latitude) into a single "trait score" (using principal component analysis) and estimated the relationship between this score and species-level sensitivity to green-up. Results showed that species that migrate more slowly, arrive earlier, and overwinter further north show greater responsiveness to changes in green-up (Figure 4). Birds that overwinter further north may experience conditions more similar to those found at their breeding grounds, compared to species that overwinter further south (and therefore further away from their breeding grounds). That is, birds that overwinter further north could well have better information on which to base the timing of their migration.

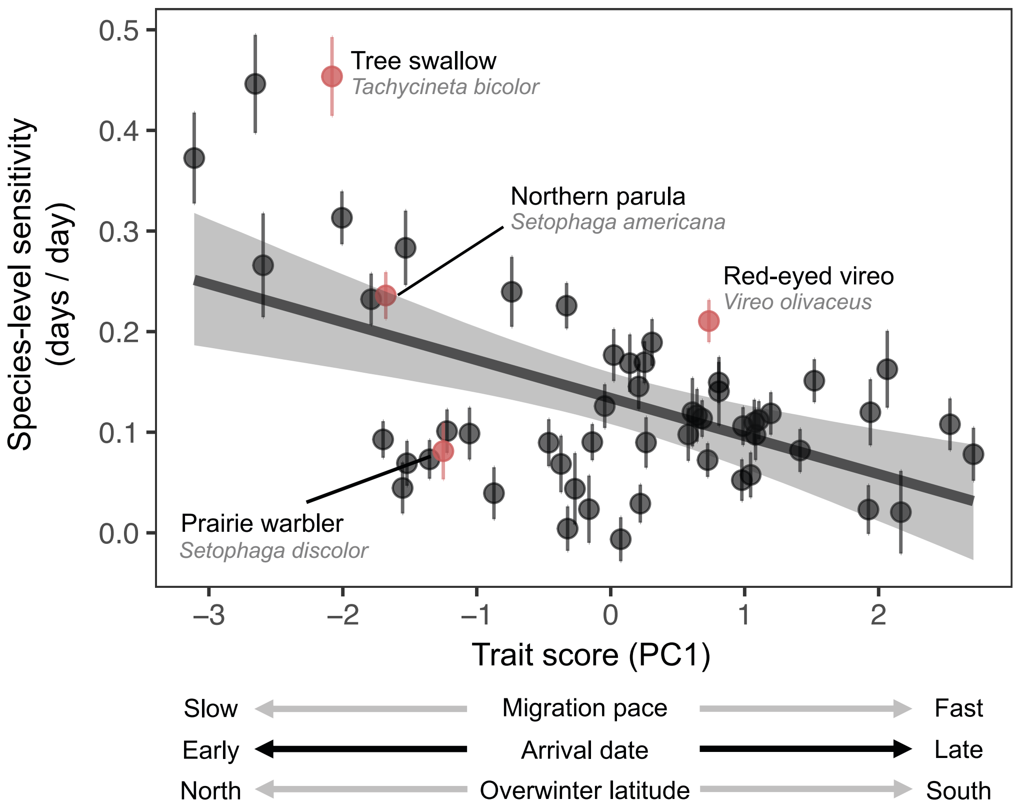

Figure 4. Migratory traits explain why some species may be more sensitive to changes in green-up than others. The sensitivity (the *y*-axis) of each bird species to green-up (i.e., how many days arrival changes for every one-day change in green-up) is plotted as a function of their combined migratory "trait score" (the *x*-axis). Since migration pace, arrival date, and overwinter latitude were correlated, the authors created a single value that represents these three traits using a method known as principal component analysis. Negative trait scores indicate that a given species (e.g., tree swallow) migrates more slowly, arrives earlier, and overwinters further north, compared to other species. Each point in the plot represents one species. The thick black line represents the linear regression fit, while the shaded band represents the uncertainty in the linear regression fit. Figure adapted from Youngflesh et al. (2021).

These findings indicate that as green-up continues to advance (i.e., occurs earlier in the year) over time in response to climate change (Allstadt et al., 2015), some birds may be better able to match these changes than others. Importantly however, even the most sensitive bird species were not perfectly matching changes in green-up. That is, these birds will likely continue to become increasingly decoupled with green-up over time, because green-up is changing more rapidly than bird migration phenology is changing (Mayor et al., 2017).

Questions

1. What other factors might influence a species' sensitivity to changes in green-up? Would you expect species with generalist vs. specialist diets to respond differently? Think also about the "cues" species might use to initiate breeding and their overall breeding strategy.

2. Would you necessarily expect species that respond more strongly to changes in green-up to suffer fewer consequences of being decoupled with green-up? Why or why not? Are there other factors that were not considered in this study?

3. North American birds have declined by 30% over the last five decades (Rosenberg et al., 2019). Results from Youngflesh et al. (2021) suggest that some birds are responding to changes in green-up more than others. How can this information be used in trying to understand how natural systems respond to climate change? How can this information be used for conservation-based management?

Part III – Working with Green-up and Migratory Bird Data

Data, maps, and figures from the Youngflesh et al. (2021) study are available on the interactive website Migratory Sensitivity: <https://migratory-sensitivity.shinyapps.io/MigSen-app/>

In this section you will be asked to explore and examine the data in more detail, and answer questions based on the information presented on the *Green-up* and *Bird Arrival* "tabs" of the site. You are, of course, also welcome to explore the data on your own! The site was created as a Shiny App using RShiny. If the web link is unavailable for any reason, the app can be produced locally (on your laptop or desktop computer) by downloading the code at <https://doi.org/10.5281/zenodo.4938371> and following the instructions in the README file.

Navigate to the *Introduction* tab on the Migratory Sensitivity website; read the page including the section at the bottom, "How to use this website." Then navigate to the *Green-up* tab. This tab shows the date when spring "green-up" occurred, by year, across eastern North America. Green-up is a measure of when plants begin to "green up" in the spring (as produced by the new, light-green vegetation that emerges at this time of year), and is a commonly used indicator of spring arrival. Move the slider in the upper left to see how vegetation phenology varies from year to year and changes through time.

Questions

1. What is the fundamental pattern in green-up dates, moving from S to N? What do you think explains this pattern?

2. Is there a noticeable trend over time? (*Hint:* to help answer this, pause at earlier years like 2002–2004, then compare to recent years like 2015–2017.) What is that trend, if any?

Download the green-up data and read the data into *R* or Excel. Your instructor may provide .csv files for you to use. The README files included with the data explain what each of the fields corresponds to. Be sure to read this to properly understand the data.

3. With the downloaded data, for each cell calculate the standard deviation in green-up dates across years. What is the minimum standard deviation value? The maximum? Why might some cells (different locations) have more variable green-up dates from year to year than others?

Next, navigate to the *Bird Arrival* tab. This tab shows an estimate of the spring arrival of each bird species in the study, in eastern North America for each year. Results can be displayed over the species' breeding range, migratory range, or both, and from estimates from two different models. Your instructor may ask you to use just one set of estimates, or to look at both. The two different models are:

- GAM model estimates, obtained from Generalized Additive Models fit to observations from eBird.
- IAR model estimates, which use the GAM model estimates to spatially smooth arrival dates for each year (as arrival dates are likely to be similar for neighboring cells).

In this section, we are going to use tree swallow *(Tachycineta bicolor)* as a focal species. However, your instructor may give you another species to use, or give you the option of choosing your own species for this task. Select your focal species (e.g., tree swallow) from the drop-down menu. To start, select the "GAM model" and "Breeding and migratory range" options, and slide to the most recent year (2017).

4. What pattern across the species' range do you notice in Estimated Arrival dates?

5. Change the displayed species distribution to just breeding range, then just migratory range. Is there part of the study area where your species is migratory, but not breeding? What part(s) of North America is that in?

6. With either "Breeding" or "Breeding and migratory" range selected, click on the "play" button or move the slider to see how spring arrival dates have (or have not) changed over time. Do you notice any changes from one year to the next? (Look for slight changes in color.)

7. Is there any noticeable trend in arrival dates over time (there may or may not be)? If so, what is that trend?

Download the IAR model data for that species and read the data into *R* or Excel. Your instructor may provide .csv files for you to use.

8. With the downloaded data (data_arrival.csv), for each cell (Figure 5, next page), count the number of years where "valid_GAM" is "TRUE" (the authors consider these cells to be the most robust estimates of bird migration phenology). Why do you think there are more data for some cells than for others? Calculate the mean arrival date for each cell (remember to only use values where "valid_GAM" is "TRUE"). Plot the mean arrival date for each cell against cell latitude. Does arrival date vary across latitude (use Figure 5 to see where specific cells are located across eastern North America)? If so, how?

9. Using the arrival data from the previous question (data_arrival.csv), what is the earliest arrival date (cell mean) for this species (convert Ordinal Date to a calendar date either manually or programmatically, rounding to the nearest whole number, and ignoring leap years)? The latest?

Download IAR model data for a second species, for instance red-eyed vireo (make sure there is some overlap in their breeding ranges of this species and the previous species that you used), and read into *R* or Excel. Your instructor may provide .csv files for you to use.

10. With both sets of IAR model data (data_arrival.csv for two different species), calculate the mean arrival date, for each cell for each of your species. Compare the arrival dates between these two species for cells where they co-occur (or occur near one another, using Figure 5 as a guide). Is one species always earlier or later than the other? Why might different species arrive (on average) at a different time than others?

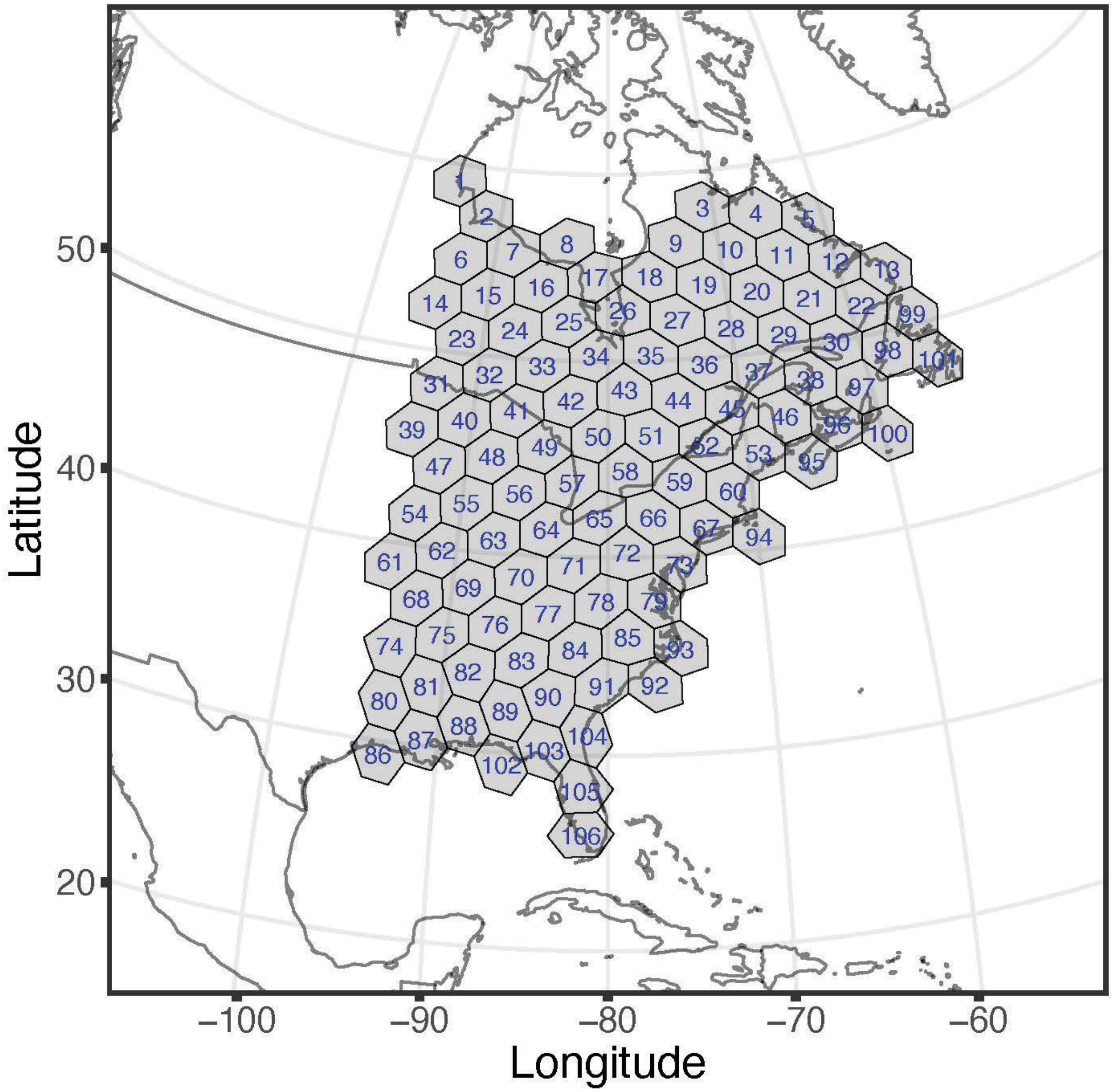

Figure 5. Cells over the study area used by Youngflesh et al. (2021). The numbers within each cell correspond to the numbers in the data downloaded from the web application/in the .csv files.

Part IV – Advanced Work with Phenology Data

In this section you will continue to examine data on the interactive web site Migratory Sensitivity: <https://migratory-sensitivity.shinyapps.io/MigSen-app/>. Navigate to the *Sensitivity Across Latitude* tab. Select tree swallow (or the initial species you have chosen to focus on) to start. As the page says, sensitivity is defined as the magnitude of change in bird arrival (in days) for every one-day change in green-up.

Before reading further, do the units (days/day) on the map and the *y*-axis of the figure make sense to you? It might help to consider a single cell to start. From the color map legend can you estimate the value of sensitivity, for that species in a single cell? Can you explain what that means to a classmate?

Here is some additional explanation. For a given cell and a given species, sensitivity is calculated as the slope of a linear regression, with arrival date as the response variable and green-up as the predictor variable. For example (Figure 6), in cell 64 for Tree Swallow, from 2002–2017 the arrival date (on the *y*-axis) advances approximately 0.37 days for every one advancement in green-up (on the *x*-axis). This represents the sensitivity of tree swallow to green-up in that cell. A value of less than one indicates that bird migration phenology is not keeping pace with the rate of change in the arrival of spring. Note that the values for each cell, across the entire range of a given species, are the data points that go into the plot on the right of the *Sensitivity Across Latitude* tab.

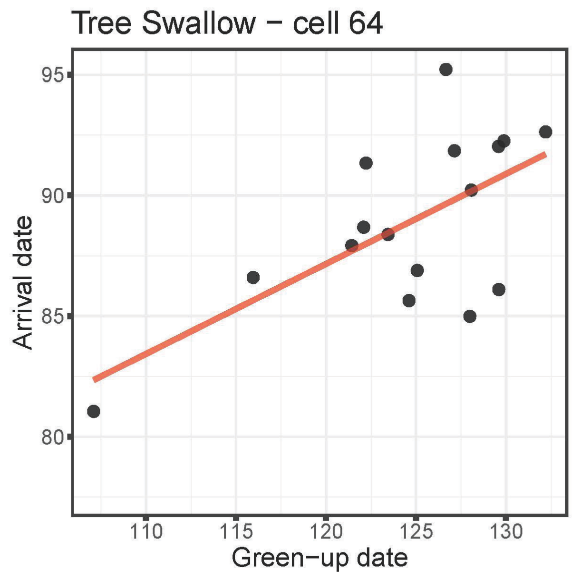

Figure 6. Arrival date as a function of green-up for tree swallow. Each point represents the estimated arrival date for a single year in a single cell (number 64). The red line represents the linear regression model fit.

Questions

1. Using the data you downloaded (or were provided) from the *Bird Arrival* and *Green-up* tabs, choose a cell with at least 10 years of data and regress arrival date on green-up (remember to read the README to make sure you understand the data). Plot the data and the results from the regression.

2. Download the data for your species of interest from the *Sensitivity Across Latitude* tab and read into *R* or Excel. Your instructor may provide .csv files for you to use. Each cell now only has one value in these data. What is the interpretation of the "beta_mean" field in the data? (*Hint:* use the "read_me_sensi.txt" file.) Regress sensitivity on latitude. Plot the data and the results from the regression.

3. Why do you think most species show greater sensitivity to green-up at higher latitudes? Why do you think some species show the opposite pattern?

Now navigate to the *Migratory Traits* tab. This plot is an interactive version of Figure 4 in Part II, above. Each point represents one species. These species-level sensitivity estimates are derived from cell-level estimates of sensitivity. Pick the species that you have been using and see where it shows up on this plot. Download the data and read into *R* or Excel. Your instructor may provide .csv files for you to use.

4. Why might some species fall well above/below the regression line? Why do you think the three migratory traits considered by Youngflesh et al. (migration pace, arrival date, and overwinter latitude) are correlated?

5. Calculate mean sensitivity across all species. What does this say about how these birds are responding to changes in green-up?

6. Plot a histogram of the uncertainties for the sensitivity estimates for these species. (*Hint:* look at "read_me_trait.txt" to understand what each field in the data represents.) Why might sensitivity estimates for some species have higher uncertainty than others? (*Hint:* think about how these species-level estimates are calculated.)

The last tab on the web site is *Interannual Variation*. Your instructor may have specific questions for you to answer from this tab. If you want to explore it on your own, start with the same species you used previously (e.g., tree swallow) and select one of the cells with both bird arrival and green-up data (e.g., 65). What do you see?

Part V – Conclusion

In working through this case study, you have learned about the importance of phenology and how phenological events are changing over time. You have had an opportunity to explore results of a published scientific study and analyzed real-world data on the timing of spring arrival and spring migration for North American birds. Reflect on how the analytical exercises you worked through connect to what you learned about the timing of seasonal events in ecological systems and how the findings presented in Youngflesh et al. (2021) might apply to ecosystems more broadly. Using what you have learned over the course of this case study, answer the concluding questions below.

Questions

1. After reading Youngflesh et al. (2021) and working with the data used in this study, what might you have done differently to answer the primary scientific questions of interest? How do you think this study advances our understanding of phenological mismatch and what pieces of information do you think are still missing?

2. What opportunities do you think are ripe for exploration in phenology research that might build on this work? Frame this in terms of a research question (or questions) and provide an example study design that might help you address this question. How might the necessary data be collected and analyzed? Think about other types of data not considered here and the approaches (including the use of new technologies) that might be used to collect these. How might other sources of data be integrated with the approach used by Youngflesh et al. (2021) to more fully explore the ecological consequences of phenological change?

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