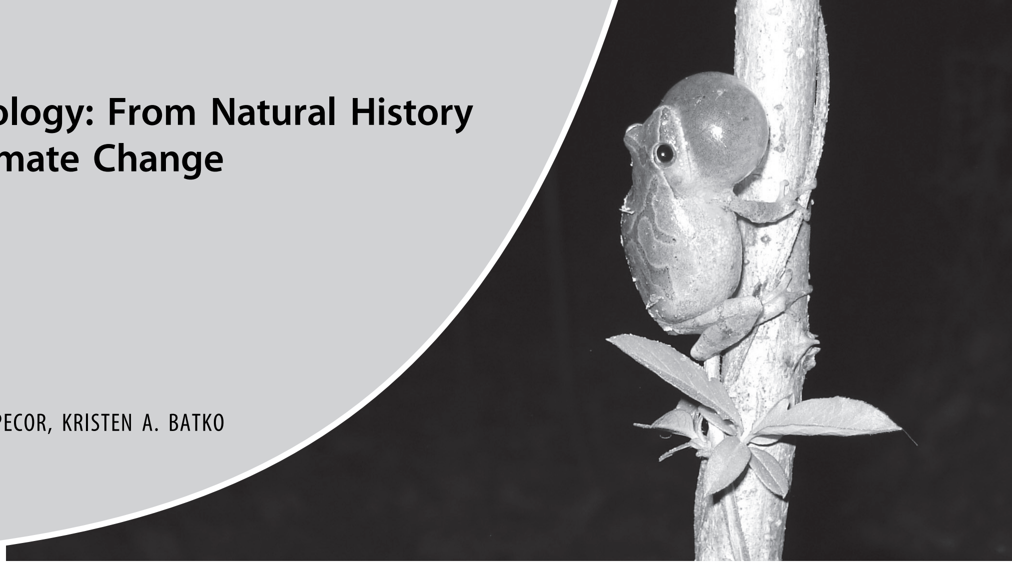
Phenology: From Natural History to Climate Change



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Abstract

Phenology refers to the seasonal changes in activity and abundance observed in both plants and animals. This article highlights two animal groups, aquatic insects and frogs, in which phenology can be observed, using data collected directly and via databases. Effects of climate change on phenological patterns are also discussed.

Key Words: *phenology; insect; frog; climate change; database.*

○ Introduction

As anyone who has tended a garden can attest, plants do not flower in synchrony. Each species has its own window for blooming and setting seeds. This small-scale variation in reproductive timing is an example of phenology, which can be defined as the study of the seasonal patterns of abundance and activity observed in many organisms, including both plants and animals. Phenology is not a new subject, with Robert Marsham considered to have founded the discipline with his publication "Indications of Spring" (Marsham, 1789). In the paper, Marsham noted the date of first occurrence of various spring phenomena, such as the cooing of doves and the appearance of butterflies, for the years 1736–1788.

Moving forward from Marsham's time to the present, there has been and continues to be much interest in phenology, from both laypeople and scientists alike. For example, birders know that some species are only spotted at the feeder during certain months. In attempts to explain these and other phenological patterns, ecologists have put forth several hypotheses, including temporal resource partitioning, tracking of seasonal resources, predator avoidance, facilitation, physiological constraints, and chance (Morin, 2011).

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The consideration of phenological patterns touches on several Next Generation Science Standards (Table 1), and *American Biology Teacher* has recently published two articles that focused upon phenology in plants (Bombaugh et al., 2003; Neil, 2009). In this paper, we describe two projects that could be used by elementary to post-secondary instructors to explore zoological phenology with their students, either independent of or including a consideration of climate change. These projects provide opportunities for hands-on exploration and integration of technology.

○ Project 1: Phenology of Insect Abundance

Insects are the most diverse group of animals and are seemingly unrivaled in their ecological and economic importance. From pollination to disease transmission, insects are major players in human affairs. Phenology is observable in many groups, but aquatic insects are especially good subjects for studies of seasonal changes. Many people are likely more familiar with the phenological patterns of the adult forms of these animals (e.g., black fly season), and the seasonality of the adults reflects the seasonality of the larval stages, which can be easily collected from streams using a variety of techniques.

Aquatic insects experience their highest diversity during the months of the school year, so they make excellent subjects for school-year-long phenological studies (Figure 1). Collection of insects can be made weekly, biweekly, or monthly in one of several ways. For passive collection, Hester-Dendy samplers or drift nets can be used. For active sampling, Surber samplers or dip nets can be used. See Blocksom and Flotemersch (2005) for a comparison of sampling methods. Once collections are made, insects can either be sorted and identified while alive or preserved in 70 percent ethanol for later identification. In either case, a variety of

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Table 1. Next Generation Science Standards (NGSS Lead States, 2013) that may be addressed by aquatic insect phenology, frog call phenology, and/or climate change impact on phenology. Science and Engineering Practices (SEP) and Crosscutting Concepts (CCC) are integrated with the Disciplinary Core Ideas (DCI) Performance Expectations.

DCI Code	Performance Expectation and Classroom Connection
2-LS4-1	*Make observations of plants and animals to compare the diversity of life in different habitats.* • SEP: Planning and Carrying Out Investigations—design a project to test the diversity of insects and/or frogs in habitats at different latitudes, elevations, etc.
3-LS4-2	*Use evidence to construct an explanation for how the variations in characteristics among individuals of the same species may provide advantages in surviving, finding mates, and reproducing.* • SEP: Engaging in Argument from Evidence—make a claim about the advantages/disadvantages of change in phenology • CCC: Scale, Proportion, and Quantity—number of individuals of a given species exhibiting a certain phenology can vary
3-LS4-4	*Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.* • SEP: Constructing Explanations and Designing Solutions—impact of changes in temperature on animal diversity • CCC: Cause and Effect—temperature and animal diversity
5-ESS3-1	*Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.* • SEP: Obtaining, Evaluating, and Communicating Information—create a presentation proposing solutions to climate change in order to prevent changes in phenology • CCC: Systems and System Models—discuss interaction between climate change and insect and/or frog phenology
MS-LS1-5	*Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.* • SEP: Constructing Explanations and Designing Solutions—describe the temperature effects on phenology and organism development • CCC: Cause and Effect—temperature effect on phenology
MS-LS2-2	*Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.* • SEP: Constructing Explanations and Designing Solutions—explain pattern between climate change and phenology • CCC: Patterns—response to climate change patterns between aquatic insects and/or frogs
MS-ESS3-3 **MS-ESS3-5**	*Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.* *Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.* • SEP: Asking Questions and Defining Problems—explore anthropogenic factors that influence climate change • CCC: Stability and Change—sudden or gradual changes in temperature will have different impacts
HS-ESS3-5	*Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.* • SEP: Analyzing and Interpreting Data—analyze geoscience data about climate change • CCC: Cause and Effect—compare climate change data with phenology data to determine the cause and effect relationship • CCC: Stability and Change—some system changes can be irreversible

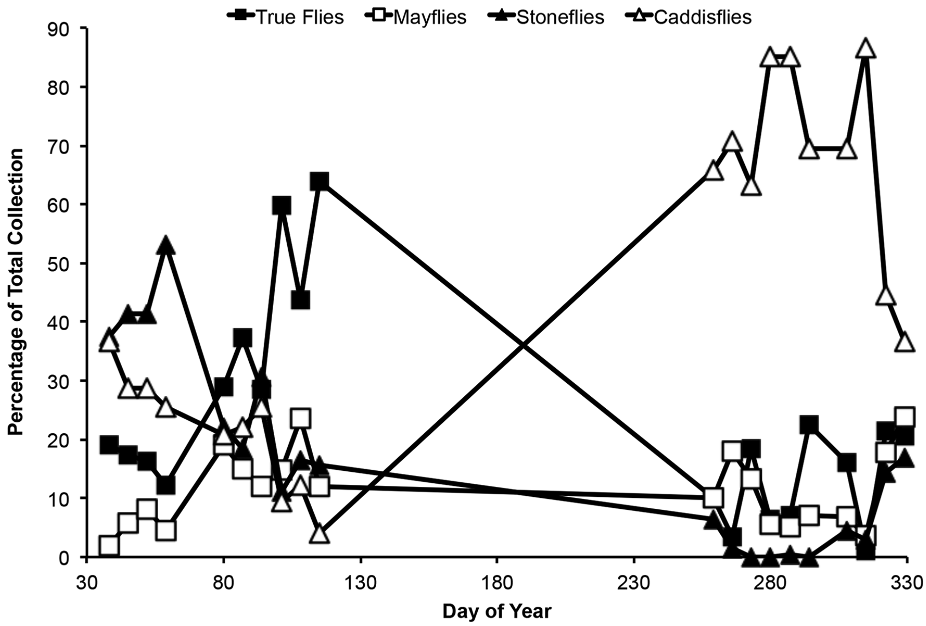

Figure 1. Percentage of total collection represented by the four most abundant insect groups collected from Moores Creek in Mercer County, New Jersey, during 2013.

resources are available for identification, including online keys (e.g., Stroud, 2015) and printed texts (e.g., Merritt et al., 2008), and whereas identification to genus or species can be challenging, identification to order is relatively straightforward.

○ Project 2: Phenology of Frog Calls

Another group well-suited for the study of phenology is frogs. Frogs are of general interest to many people, and although observation of actual individuals can be challenging and time intensive, observation of their calls is relatively easy. Further, extensive printed and digital resources are available with regard to call identification and calling periods. For situations in which it is possible for students to visit field sites, calls can be recorded with a cell phone, tablet, or other device, and then identified later via comparison to recorded calls of individuals of known species. The United States Geological Survey (2015) hosts one of many free, accessible databases of frog calls, and the frogs that might be found in a given area could be determined using a field guide (e.g., Peterson or Audubon guide) or by visiting the website of the state Department of Natural Resources or equivalent agency (e.g., Gessner & Stiles, 2001). In addition to a species list, these resources often provide months of the year when calling occurs and descriptions of call characteristics for each species that can help with identification.

An advantage to studying frogs relative to insects is that a phenological project can be undertaken even if students cannot visit field sites. The resources described above can be used to familiarize the students with species and their calls, and data can be collected via means other than field recordings. State and/or local agencies such as the Department of Natural Resources may have records of calling patterns, and there are publicly accessible databases that can be mined for data. For example, the FrogWatch USA (http://frogwatch.fieldscope.org/v3/) and North American Amphibian Monitoring Program (https://www.pwrc.usgs.gov/naamp/) databases include information on calling dates, calling intensity, and other details for species and habitats nationwide. The data can be sorted, viewed, and downloaded in a variety of ways; analogous to field collection, one way is to select a year and a site and view records of calling by month (Figure 2). In addition, the use of databases allows other types of data collection. For example, students could select habitats at different latitudes and/or longitudes and compare phenological patterns, or select data on a single species of frog and compare calling patterns across space and time (Figure 3).

○ Phenology and Climate Change

One of the patterns of interest, for both insects and frogs, is the change in their phenology as a consequence of climate change. As global mean temperatures rise, the timing of insect life cycles and amphibian reproduction are affected, as are the compositions of their respective communities. Changes in insect phenology have pest management and public health impacts (Nietschke et al., 2007; Hodgson et al., 2011), whereas the changes in frog phenology are somewhat more academic (Gibbs & Breisch, 2001), but each group is nonetheless being affected. The general trend is for events that occurred later in years past to occur earlier in present times as temperatures increase. For example, the first reported calls for some species of frogs moved up by over a week between the early 1900s and the 1990s in New York state (Gibbs & Breisch, 2001). In comparing mean temperatures between these two time periods, there were significant increases for some (but not all) winter and spring months. Similar patterns between increasing temperatures and earlier breeding dates for frogs have been noted in several other studies (Todd et al., 2011; Klaus & Lougheed, 2013; Benard, 2015; Green, 2016). Although most easily accessible databases do not go back over a hundred years, they do provide

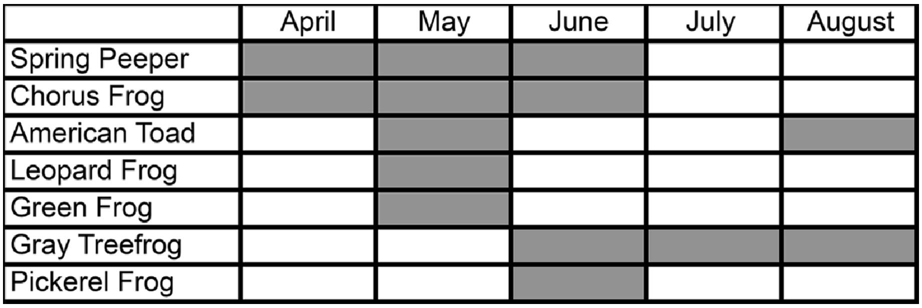

Figure 2. Presence (shaded) and absence (non-shaded) of various frog species during calling surveys of Bear Ridge in New York state during 2015. Data were collected from the Frog Watch USA database.

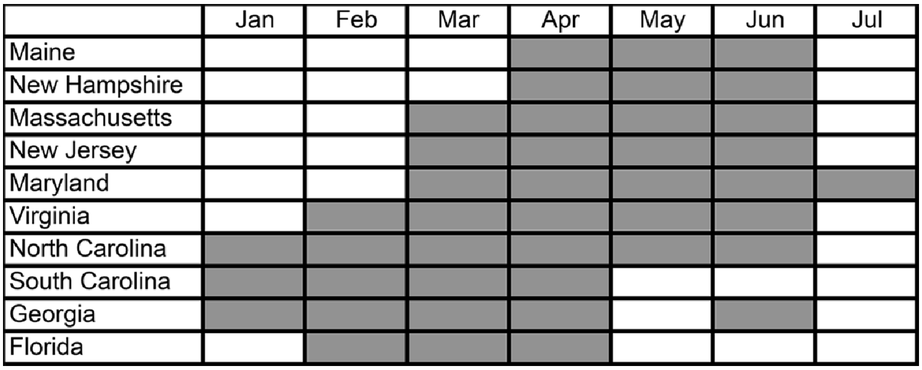

Figure 3. Presence (shaded) and absence (non-shaded) of calling by spring peepers (*Pseudacris crucifer*) in states along the Atlantic coast during 2010. Data were collected from the North American Amphibian Monitoring Project database.

data going back to late 1990s and early 2000s, and studies have shown changes in phenology over the past 30-40 years (Todd et al., 2011; Klaus & Lougheed, 2013). Also, teachers who use these projects in multiple years can show relationships between temperature and activity patterns.

○ Data Analysis and Presentation

The extent to which the data are analyzed and presented will depend upon the scope of the project within a given curriculum and the grade level of the students, but we offer a few possibilities. The simplest presentation is a consideration of patterns from a particular site. In this kind of presentation, insect data have an advantage over frog call data in the sense that relative abundances can be considered rather than simply recording presence or absence (Figures 1 & 2). In earlier grades, gross comparisons of relative abundances across seasons might be the extent of analysis, whereas students in more advanced grades could be asked to describe and contrast diversity quantitatively at different points in time using such tools as the Simpson Index and/or the Shannon Index (Magurran, 2004). As noted earlier, it is also possible to contrast patterns between sites separated in space and/or time and to illustrate the activity patterns of a single species across latitudes (Figure 3). Again, visual inspection and qualitative description of the data might be appropriate in some cases, whereas a statistical approach (e.g., testing for a correlation between date of first calling for a frog species and latitude) might be better in others.

○ Acknowledgments

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