Phenology Lecture #1:
Introduction to Phenology, the Science of the Seasons
Slide Notes

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Slide 1: overview of phenology and intro to the lecture
This lecture series presents an introduction to phenology science and climate change. The goal of Lecture 1 is to provide a basic introduction to phenology and how this scientific discipline can be applied to evaluate the effects of climate change on natural systems. Lectures 2 and 3 in this series build upon this lecture. Lecture 2 describes coordinated phenology monitoring efforts in the United States. Lecture 3 presents an overview of current questions being addressed by phenological researchers and uses a series of peer-reviewed case studies to introduce this ongoing research.

Note to instructors: More phenology educational materials and activities are available online**,** including lesson plans for advanced undergraduate or graduate seminars; lesson plans for undergraduate laboratory activities; and phenological activities for use in informal educational settings. To learn more and to download materials, visit the Education section of the California Phenology Project website (www.usanpn.org/cpp/education) or the USA National Phenology Network (www.usanpn.org/education).

Slide 2: global concern about climate change
In recent years, citizens and national governments worldwide have become increasingly worried about climate change. A variety of problems, including: catastrophic weather disturbances (tornados, hurricanes), famine, biodiversity losses, and wildfires have been attributed to global climate change.

Possible Question to Ask Students:
- Can anyone think of other climate-mediated problems that affect the human population?

Slide 3: global concern about climate change
Government bodies worldwide have acknowledged that climate change poses a serious threat to our collective well-being. This slide presents a recent quote from John Ashton, United Kingdom Ambassador on Climate Change to the United Nations.

Slide 4: scientific interest in climate change has increased in recent decades
A recent search using the terms "Climate Change" on the library database, Web of Science found that over 83,000 **peer-reviewed** articles have been published between 1904 and 2011.

Note to teachers:
Depending on the student audience, it may be helpful here to describe what peer-reviewed journal articles are and what the peer-review process entails.

Slide 5: scientific interest in climate change has increased in recent decades
As this figure shows, most of these articles have been published in recent years **and** the number of articles published each year continues to grow.

Slide 6: use of historical photos
Historical photos provide evidence of recent climate change. These two photos depict the Main Rongbuk Glacier and the north face of Mount Everest, as photographed from Tibet in 1921 (left) by George L. Mallory and in 2007 (right) by David Breashears. Glaciers are enormous bodies of ice that last year-round in many high elevation and polar regions of the world. Glaciers form in cold places when snow accumulates much more rapidly than it melts. Situated at an elevation of 16,600 to 21,200 feet, this glacier experienced an average vertical ice loss of 330 feet between 1921 and 2007. Mallory and his climbing partner, Andrew Irvine, disappeared high on the northern slopes of Everest in 1924 during an attempt to be the first to summit the mountain (Mallory photo courtesy of Royal Geographical Society).

Note to teachers: The mountaineer, photographer, and filmmaker, David Breashears, compared historic and contemporary photos for an art exhibit titled "Rivers of Ice: Vanishing Glaciers of the Greater Himalaya". The exhibit and details about it can be found online at: http://sites.asiasociety.org/riversofice/. This website contains extensive material (images, film footage of photographic expeditions, an interactive map, and an interview with Breashears) that you may find interesting and that students may want to explore outside of class.

Slides 7-9: use of historical photos
Large amounts of ice from this glacier (and others) have been lost in the Himalayas in the past decades. The arrows in this set of slides and the ice climber in Slides 8 and 9 provide an idea of this glacier's massive size.

Slide 10: use of historical photos
Glacier loss has also been documented in the United States. These photos were taken at *similar times of the year* the Sierra Nevada in California.

Slides 11: intro to phenology
Phenology is the study of the seasonal biological events that can be observed in plants, animals, and microbes. We all have an intuitive sense of phenology (e.g., wildflower blooms, deciduous leaf color change in the fall, and seasonal bird migrations). Phenology is the scientific quantification of these events.

Slide 12: intro to phenology
This scientific discipline, which dates back hundreds of years, can provide us with valuable information regarding the effects of climate change on the Earth's biological systems.

Slide 13: phenology and its role in human societies

Why study phenology? There are numerous phenological processes that influence our daily lives. For example, the frequency and intensity of wildfires is often determined by how much plant growth is present during a given time of the year. Seasonal timing also affects how rapidly pests (such as the pine bark beetle, which is currently decimating montane pine forests in the Rocky Mountains and elsewhere) and invasive species spread.

Many of our cultural events and recreational pastimes also revolve around the seasons (e.g., festivals and ecotourism).

Seasonal events have broad implications for human health. *How many students suffer from allergies? How many students get flu shots?* The timing of the flu season and the timing of the allergy season affect millions of people worldwide. Phenology also influences crop yields, and thus our food supply.

Slide 14: outline

There are five main parts of this lecture. **Note to instructors:** The sections shown here can be presented together as a single lecture or pair of lectures (depending on time constraints). Alternatively, each section could be presented independently of the others and/or inserted into other lecture material.

1. **Climate Change Crash Course**: Brief overview of climate change science
2. **Introduction: What is phenology?** In this section, students will: (1) learn that phenology is the study of the timing of seasonal biological events that can be observed in plants, animals, and microbes; (2) see some examples of phenological traits, and (3) learn about the scientific disciplines that are regularly integrated into phenological research.
3. **Methods: How is phenology studied?** In this section, students will consider three commonly used phenological data collection methods: hands-on monitoring, remote sensing, and the use of historical records (legacy data).
4. **Patterns**: In this section, students will review the major biophysical scales of organization. The section examines various phenological patterns that have been observed at these scales and discusses some potential causes of these patterns.
5. **Phenology and Climate Change**: This section presents evidence strongly suggesting that phenology is an indicator of climate change.

Slides 15-20: scientific consensus on climate change – background information

- In response to growing global concern about climate change, the Intergovernmental Panel on Climate Change (IPCC) was established in 1988. The IPCC formed several working groups (WG's), each of which focused on a particular aspect of climate change. The focus of each WG is described in Slide 15. Each working group also published assessment reports (AR's) every five to six years.
- The 1990 Assessment Report contributed to the UNFCC in 1994

- The 1995 Assessment Report contributed to the Kyoto Protocol in 1997
- In 2007, the authors of the IPCC Assessment Report were awarded the Nobel Peace Prize for their work.
- Some students may recall the "Climategate" issue wherein hacked emails among researched scientists were used to assert that climate data had been "faked" and that climate change predictions were false.
- **But** climate scientists have been cleared of **all** fraud following multiple independent investigations conducted by: UK House of Commons, US National Research Council, Scotland's Judicial Appointments Board, and a GOP commissioned investigative panel (US Dept. of Commerce at the behest of Sen. James Inhofe (R, OK))
- It is important to convey that the scientific consensus on this issue is strong and that the international scientific community agrees that climate change is actually happening.

Slide 21: how is the climate changing over time?
The next series of slides uses graphs to illustrate climatic trends over time. Before discussing the trends indicated by the graphs, be sure to introduce the horizontal and vertical graph axes and their corresponding units on this slide.

Key results shown by this figure include:

- Global land surfaces are warming
- Global sea levels are rising
- Snow cover in the northern hemisphere appears to be declining

Slide 22: land and sea trends
Temperatures are rising both on land and in the ocean. But land is warming faster than ocean… *Why might this be?* This is because water has higher a specific heat capacity than land. So, although the ocean is taking longer to warm than land is, the ocean also will *hold onto that warmth longer*. This is worrisome for oceanic circulation as well as for plants and animals in the ocean.

Slide 23: U.S. winter hardniness zones are changing
This slide demonstrates warming trends in the United States. The Arbor Day Foundation recently updated its U.S. Hardiness Zones based on data from 5,000 National Climatic Data Center cooperative stations across the continental United States. This figure shows that temperatures are changing in the United States; winters are experiencing the most pronounced warming. Potential questions to bring up with students are provided on the slide.

Slide 24: greenhouse gases
This figure from the IPCC 2007 Summary Report shows changes in three major greenhouse gases over time. The greenhouse gases shown are carbon dioxide, which is measured in parts per million (ppm), as well as methane, and nitrous oxide, which are measured in parts per billion. Students should be able to look at the graph and figure out the CO_2 is the most concentrated greenhouse gas in the atmosphere.

Slides 25-27: greenhouse gases and radiative forcing
Radiative forcing is a measure of the influence that a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of a factor as a potential climate change mechanism.

Have students examine changes in radiative forcing of the three greenhouse gases between 1800-2000. Students should try to figure out which of the three greenhouse gases makes the largest contribution to climate change. A table is provided to facilitate this thought process. Students should observe that CO_2 concentrations have increased dramatically in recent years and that this change has had a large affect on radiative forcing.

Slide 28: climate change and atmospheric CO_2
Use the figure from the IPCC Summary Report (2007) to evaluate the major anthropogenic causes of CO_2 emissions (energy consumption, agriculture, and industry). Given the current emphasis on manufacturing fuel-efficient personal vehicles, does this surprise many of the students? Why or why not?

Demonstrate the link between the Keeling Curve (annual cycle of CO_2) and deciduous forest leafing phenology. Carbon dioxide levels in the atmosphere naturally fluctuate in response to the seasonal activities of plants. The time-lapse of forest canopy green-up and brown-down are excellent visual tools here. Additional green-up and brown-down videos can be found at the following web site run by the University of Edinburgh:
http://www.eeo.ed.ac.uk/homes/lwingate/webcam.html

Slide 29: climate change and precipitation
Use the figure in this slide to demonstrate that more droughts have been recorded in recent years than in past years. In this figure, the red color indicates areas with a high frequency of drought and blue indicates areas with low drought frequency.

Slides 30-31: climate change and precipitation
Rising temperatures promote increased evaporative cloud formation over oceans. This is predicted to result in fewer, but more intense rain events, a phenomenon referred to as ***repackaged precipitation***. A map of annual precipitation trends in the United States shows that some areas have experienced increased rainfall in recent years and others have experienced decreased rainfall in recent years.

Slide 32: phenology as the "fingerprint" of climate change
In its 2007 Assessment Report, the IPCC recommended using phenological monitoring to track the environmental effects of climate change.

Slide 33: return to outline
The rest of this lecture provides a broad introduction to phenology, phenological research, and the role of phenological research in efforts to understand how climate change affects natural systems.

Slides 34-35: phenology defined
- Phenology evaluates plant and animal life cycle stages (e.g., leafing and flowering, emergence of insects, and migration of birds).
- It is also the study of these recurring plant and animal life cycle stages (i.e., **phenophases**), especially their timing and relationships with weather and climate.
- From the Greek word ***phaino***, meaning to show or appear.

Many organisms have intrinsic mechanisms that allow them to time key life cycle events to coincide with favorable environmental conditions. For example, many insects emerge at times of year when their food sources are most abundant.

Potential questions to ask students:
- What is the biological significance of the timing of seasonal life cycle stages?
- How might the timing of these events influence organismal fitness?
- How might the timing of these events influence interspecific interactions?

Slide 36: examples of phenological events
Phenological events occur all around us. Some examples of phenological events include: the onset of spring wildflower displays, dry down of forest fuels, leaf color changes in deciduous forests.

Potential question to ask students:
- What phenological events have they observed?

Slides 37: phenology is an integrative science
Phenological processes are influenced by a wide array of biological (biotic) and physical (abiotic) factors. An organism's phenology is often determined by its genotype and its physiology. Yet phenology can also be determined by abiotic factors such as temperature, precipitation, or resource availability. For example, some desert annual wildflower seeds will only germinate after abundant rains.

Therefore, studies of phenology are often interdisciplinary, involving collaborations among people from different scientific disciplines.

Slide 38: phenology is an integrative science that incorporates several research methods
Phenologists use a variety of techniques to obtain data. These methods range from hands-on ecological monitoring in the field to remote sensing and bioinformatics methods that have emerged in recent years.

Slide 39: revisit the outline
Now that students have a basic idea of what phenology entails, the next section of the lecture will present some practical examples of how phenology is studied.

- Hands-on monitoring
- Remote sensing
- Use of historical (legacy) data sets

Slide 40: repeated measurements over time: hands-on monitoring
Some examples of data collected by researchers and citizen scientists are:

- First flowering date
- Timing of animal emergences (e.g., cicadas)
- Dates when baby animals are observed or fledge
- Arrival dates of migratory animals (e.g., salmon, whales, insects, birds)

Note: these data can be collected multiple times within a single year to evaluate **intraseasonal** phenological patterns and/or collected in multiple years to evaluate phenological patterns on a broader temporal scale.

Slide 41: flowering phenology of a single plant
Within a single season, many plants transition from vegetative growth to reproduction. The onset of flowering can be observed when plants begin producing buds. After this stage, plants then bear open flowers. If those flowers are pollinated, they will then develop into fruits, which contain seeds.

Note to instructors: This slide can be tailored to provide examples of other organisms' phenophases (e.g., insect emergence or the appearance of migratory animals)

Slide 42: collecting phenological data
Collecting phenological data is very straightforward. After a site is chosen, organisms may be tagged and re-visited on a regular basis. During each visit, different phenological measurements are recorded.

A common measurement used to evaluate plant phenology is the number of flowers that are open on a given date. Some researchers may choose to visit their plants daily. In this case, researchers can also record the date each individual's first flower appears (date of first flowering).

Note to instructors: The sample data sheet can also be modified to show students phenological measurements of other organisms (e.g., dates on which certain numbers of baby animals, juvenile, or adult animals are observed at a given site).

Slide 43: visualizing phenological data
Phenological data can then be plotted and one can visualize each plant's **phenological schedule,** i.e., its seasonal progression from pre-flowering to peak flowering to the cessation of flowering (and presumably the onset of fruit production).

Slide 44: flowering phenology of an individual: why is the curve shaped this way?
What biotic and abiotic ecological factors may contribute to the shape of an individual's flowering curve? What are some ecological consequences of the *phenological schedule* shown in this slide?

Students may enjoy brainstorming potential answers to these questions. Some abiotic factors that influence plant phenology are snowmelt, precipitation, and temperature. Some plants may avoid or escape drought by flowering and setting seed during times of the year when soil moisture is abundant and ambient temperatures are above freezing. Plants may also flower when their mutualistic partners (e.g., pollinators and seed dispersal agents) are most abundant and natural enemies (e.g., fungal pathogens and herbivores) are least abundant.

Slide 45: flowering phenology of a population
By collecting data from multiple plants within a single population, we can begin to see how conspecific individuals may interact with one another. For example, some populations may exhibit greater levels of flowering synchrony relative to others.

Slide 46: revisit the outline and transition to describing remote sensing methods
In many instances and study systems, it isn't practical or logistically feasible to visit populations on a regular basis to collect data by hand. For example, populations may be located in remote areas, animals being observed may be difficult to locate, and/or a researcher may wish to observe a large geographic area. In such cases, remote devices such as cameras and satellites may be employed to record repeated measurements over time.

Slides 47-48: remote sensing with on-the-ground cameras
Installing cameras that can snap images at fixed time intervals and/or transmit images via an Internet connection is an excellent way to record phenological variation in a multispecies community.

Here is an example of phenological data collected from a webcam installed at the Coal Oil Point Reserve at the University of California, Santa Barbara. The number of colored pixels in photos taken on a given date can be used as a metric of the phenological status of multiple species in a plant community (that produce similar colored flowers) throughout a single season, or across seasons. Webcams can also be used to record the presence of migrating animals or newly produced offspring.

Slide 49: remote sensing with satellites
Using satellites to record phenological events can complement on-the-ground efforts. Satellites provide a long-distance view of Earth's land surface, and can thus record data at the ecosystems or landscape levels (rather than individual species or populations). The US Geological Survey (USGS) has an excellent overview of remote sensing phenology. Students and teachers can access this overview by clicking on the following link (which is also provided on this slide): http://phenology.cr.usgs.gov/overview.php

Remote sensing satellites record the wavelengths of light reflected by plants and land surfaces. Scientists then use mathematical algorithms to transform light wavelength data into a **vegetation index** that describes the "greenness" of each pixel in a satellite image.

Slide 50: NDVI
A very commonly used vegetation index in phenological research is the NDVI (Normalized Difference Vegetation Index). Very low values of NDVI signify that an area supports little to no growing plants. For example we might expect to see low NDVI values during wintertime in the northeastern United States. By contrast, very high NDVI values indicate that an area supports very dense patches of growing plant material. For instance, we would expect to see high NDVI values during the peak of a growing season in a deciduous forest.

Slide 51: NDVI values
These satellite images taken at different times of the year over Santa Barbara, CA show how NDVI values (and intensity of plant growth) may change over the course of a year.

Slide 52: comparison of webcam phenology images versus NDVI data collected at the Bartlett Experimental Forest in New Hampshire.
This slide shows satellite and webcam images taken near Bartlett Experimental Forest in New Hampshire. This image highlights the large physical scale at which NDVI data can be collected.

Potential questions to ask students:

- In the northeastern United States, when is the peak growing season? (Summer)
- From which satellite image would the lowest NDVI values be derived? (Winter)
- What are some advantages of webcam-based data collection relative to satellite-based data collection? With webcams, one can record observations at a much finer scale. For example, the phenology of individual plants can be tracked over time. This may be very desirable for scientists studying specific populations and/or species.
- What are some advantages of satellite-based data collection relative to using web-cams? With satellites, one can track phenology over a large geographic scale and observe trends that may be difficult to measure using on-the-ground measurements or webcams.

Slide 53: revisit the outline
Historical records can be immensely useful for researchers seeking to evaluate phenological trends over hundreds of years.

Slide 54: using the observations of early naturalists: Henry David Thoreau
The 19th century philosopher and American naturalist, Henry David Thoreau made daily observations of plants and animals every spring from 1851-1858. Many students may know about Thoreau's significant contributions to American literature and philosophy. But they may be interested and surprised to learn that the phenological data in Thoreau's journals provided the foundation for ongoing long-term studies of phenology!

Slide 55: using legacy data to infer climate change
Miller-Rushing and Primack (2008) used data collected by Thoreau and the famous botanist Alfred Hosmer to compare current and past flowering times of multiple species in Massachusetts. They looked at the change in mean first flowering dates for 33 native and 10 non-native species over time. Symbols correspond to different observers and time periods (e.g., Thoreau is indicated by dark solid squares, Miller-Rushing and Primack are indicated by dark solid circles). All 43 species were not observed in every single year of the study. Therefore, each point was calculated by using the difference between when a species flowered in a particular year and when it flowered in the benchmark year (1893), when all species were observed. Each point represents a mean *difference* in first flowering date from 1893 for all of the species observed in a particular year.

These data show that on average, co-occurring species are flowering earlier in the spring than they did in past centuries.

Slide 56: introduction to herbaria
Herbaria are key resources for many phenological studies. Collections may date back for hundreds of years. Moreover, collected specimens provide clear examples of plant phenophases for a given collection date and collection location.

Slide 57: revisit the outline
Now the students should have a basic understanding of how people conduct phenological research. The rest of the lecture focuses on describing the scales at which phenology is studied and some broad trends that have been observed in recent years.

Slide 58: ecological scales on which phenology is studied
This slide provides a reminder that phenology is studied on a broad range of ecological scales, ranging from the individual to the landscape. Many students understand the difference between individuals, populations, and communities. But it may be helpful to define the terms ecosystem and landscape for them.

- Ecosystems include living organisms, the dead organic matter produced by them, and the abiotic environment within which the organisms live.
- Landscapes are heterogeneous geographic regions composed of distinct and interacting ecosystems.

Slide 59: temporal scales on which phenology is studied: intra-seasonal
Phenological research can occur during a single season (as in our example of individual flowering phenology).

Slide 60: temporal scales on which phenology is studied: inter-seasonal
Phenological studies can also integrate data that spans multiple years, or even decades (as in our example of the herbarium study conducted by Miller-Rushing and Primack (2008)).

Slide 61: revisit the outline
The remainder of the lecture shows some simple examples of phenological responses to climate change.

Slide 62: phenological responses to climate change of different functional groups
This figure shows the phenological responses of different taxa to climate change and highlights that taxa vary in their phenological responses to climate change. Amphibians, in particular, appear to be very sensitive to climate change (with respect to the timing of their spring activity).

Slide 63: phenological response of plants in Massachusetts
The onset of spring is coming earlier than in past years in many temperate regions. These photos were both taken at Lowell cemetery in Massachusetts. Note the difference between the two photos in "leaf out", which is the emergence from winter dormancy of plant buds and leaves.

Slides 64-66: phenology as the "fingerprint of climate change"
These slides highlight two widespread phenological trends that have been observed in numerous plant and animal species:

1. Earlier spring activity is common among many organisms. Flowers are blooming earlier, birds are migrating earlier, and animals are emerging from hibernation/dormancy earlier than in past years.
2. The duration of the growing season is expanding; winters are shortening and springs are lengthening.

Slide 67: conclusion slide
This slide is placed here to encourage the students to reflect on what they've learned about climate change and phenological research. Phenological research has the potential to help us understand both the effects of climate change on biological processes and a myriad of processes that influence quality of our daily lives.