Lecture #1
Introduction to Phenology, the Science of the Seasons

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Global concern about climate change
Global concern about climate change

“We need to treat climate change not as a long-term threat to our environment but as an immediate threat to our security and prosperity” - John Ashton, United Kingdom Ambassador on Climate Change to the United Nations (2011)
Increasing research on climate change

Recent search on “climate change” of the Web of Science database found over 83,000 journal articles published between 1904 and 2011
Increasing research on climate change

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Comparing historical photos with present-day images provides evidence of climate change.

Rongbuk Glacier and Mt. Everest
Comparing historical photos with present-day images provides evidence of climate change.

Rongbuk Glacier and Mt. Everest
Large amounts of glacial ice have been lost.
Large amounts of ice have been lost.

See the ice climber (above) to get an idea of the glacier’s size!
Comparison of historic and present-day photos taken at *similar times of the year* in the Sierra Nevada, California.

Dana Glacier

Lyell Glacier

Darwin Glacier

http://www.glaciers.pdx.edu/Thesis/Basagic/snglac.html
Phenology is the study of seasonal biological events observed in plants, animals, or microbes.
Studying **seasonal biological events** of plants, animals, or microbes is another way to evaluate the effects of global climate change.
Climate influences the **phenology** of biological processes that affect our daily lives.
I. **Climate Change Crash Course**: Brief overview of *climate change* science

II. **Introduction to phenology**

III. **Methods**: How is phenology studied?

IV. **Patterns**: On what *scales* is phenology studied? What are some patterns that have been observed at these scales?

V. **Phenology and Climate Change**: How does phenological research contribute to our understanding of climate change?
Scientific consensus on climate change

IPCC established in 1988 and formed several **working groups** (WG’s)

- WG1: Science of climate system & climate change
- WG2: Vulnerability of socio-economic & natural systems
- WG3: Mitigating climate change

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United Nations Framework Convention on Climate Change (UNFCCC) 1994
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Kyoto Protocol 1997

Nobel Peace Prize 2007

“Climategate”
Scientific consensus on climate change

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Climate scientists have been cleared of fraud following independent investigations conducted by:

• UK House of Commons
• US National Research Council
• Scotland’s Judicial Appointments Board
• US Dept. of Commerce at the behest of Sen. James Inhofe (R, OK)
Climate Change: What is happening?

- How is the climate changing over time?
“Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.” – IPCC 2007
Winter is warming almost twice as fast as summer.

Nights are warming faster than days.

What are some consequences for:

- snow pack & spring thaw?
- plants & animals?
- our agrifood system?
Climate Change: What is happening?

What are major greenhouse gases?

Which is at the highest concentration?
Climate Change: What is happening?

**Radiative Forcing**

- a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system
- an index of a given factor’s importance as a potential driver of climate change.
Climate Change: What is happening?

Examine the changes in radiative forcing from 1800-2000.

Does the observed pattern suggest that CO$_2$ makes a large contribution to climate change relative to the other gases?
Climate Change: What is happening?

Examine the changes in radiative forcing from 1800-2000.

Does the pattern observed suggest that CO$_2$ makes a large contribution to climate change relative to the other gases?

<table>
<thead>
<tr>
<th>Gas</th>
<th>Change in concentration</th>
<th>Change in radiative forcing</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$</td>
<td>~125 ppm</td>
<td>↑ 1.5</td>
</tr>
<tr>
<td>methane</td>
<td>~1000 ppb</td>
<td>↑ 0.5</td>
</tr>
<tr>
<td>nitrous oxide</td>
<td>~55 ppb</td>
<td>↑ 0.1</td>
</tr>
</tbody>
</table>
What are the major **anthropogenic** sources of CO₂ emissions?

What are the major natural* **biological** causes of atmospheric CO₂ fluctuations?

*non-anthropogenic

**Hint:** click on this link to watch a video

Leaf phenology in Japan
Climate change and precipitation

More droughts have been recorded
Climate change and precipitation

Rising temperatures promote **increased evaporative cloud formation**, which can lead to fewer, more intense rain events (**repackaged precipitation**)

“repackaged” rain

**Annual precipitation trends 1901-2005**

Data from NOAA’s National Climate Data Center
Climate change and precipitation

Rising temperatures promote increased evaporative cloud formation, which can lead to fewer, and more intense rain events (repackaged precipitation)

“repackaged” rain

- Which regions of the United States have received less rain over time?
- Which regions have received more rain?

Drought Index

Annual precipitation trends 1901-2005

Data from NOAA’s National Climate Data Center
“Phenology... is perhaps the simplest process in which to track changes in the ecology of species in response to climate change.” - IPCC 2007
Outline

I. **Climate Change Crash Course**: Brief overview of climate change science

II. **Introduction to phenology**

III. **Methods**: How is phenology studied?

IV. **Patterns**: On what scales is phenology studied? What are some patterns that have been observed at these scales?

V. **Phenology and Climate Change**: How does phenological research contribute to our understanding of climate change?
What is **phenology**?

Phenology is the study of seasonal biological events observed in plants, animals, or microbes.
What is **phenology**?

- Phenology is the study of the timing of 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*) in response to weather and climate.

- From the Greek word *phaino*, meaning to show or appear.

*USA National Phenology Network, www.usa.npn.org*
Phenology is the science of the seasons

Other examples:

- Migration of gray whales
- *Ceanothus* blooms in the chaparral
- Migration of monarch butterflies
- Seasonal availability of local produce
Phenology is the science of the seasons

The seasonal status of plants & animals

Phenology is an **integrative** science

- Scientific disciplines
  
  **Life sciences:**
  biology, ecology, evolution, botany, zoology, microbiology, physiology, ecosystem ecology, ecoinformatics & more

  **Physical sciences:**
  chemistry, physics, meteorology, climatology, geography, hydrology, & more
Phenology is the science of the seasons

The seasonal status of plants & animals

Phenology is an **integrative** science

Scientific disciplines

- Technology
  - On-the-ground monitoring
  - Remote sensing – cameras, microphones, satellites, weather stations, eddy flux towers
  - On-line data management
Outline

I. Climate Change Crash Course

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III. Methods: How is phenology studied?
   - Hands-on data collection
   - Remote sensing
   - Legacy (historical) data

IV. Patterns

V. Phenology and Climate Change
Collecting phenological data: \textit{hands-on empirical observations}

\textbf{Examples:}

- 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)
Flowering phenology of an individual within a single flowering season

Elegant clarkia, Clarkia unguiculata

Photo: Jose Montalva

Photo: Alisa Hove

Photo: Alisa Hove

K:

Time

Climate Change

Intro to Phenology

Methods

Patterns

Phenology & Climate Change
Collecting phenological data

1. Tag individuals or designate areas for sampling

2. Record organisms’ seasonal progression

Sample Data Sheet

<table>
<thead>
<tr>
<th>Plant ID</th>
<th>21 Feb 11 # open flowers</th>
<th>28 Feb 11 # open flowers</th>
<th>5 Mar 11 # open flowers</th>
<th>15 Mar 11 # open flowers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>
Phenological schedule of an individual

Open Flowers

Flowering duration


Climate Change Intro to Phenology Methods Patterns Phenology & Climate Change
Phenological schedule of an individual

Why is the curve shaped this way? --- abiotic vs. biotic causes

What are some potential ecological consequences of the pattern observed here?
Phenological schedule of a population
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Collecting phenological data: remote sensing

Webcams

- Photos taken repeatedly over time
- The number of colored pixels in photos can be used to estimate phenological status

Data courtesy of Keely Roth

Image: Kevin Brown
Collecting phenological data: remote sensing

**Webcams**

- Can provide phenological measurements within a single season (**intra-seasonal**)
- Measurements can be combined across years (**inter-seasonal**) to provide a long-term view of phenology

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**Flowering time-lapse @ Coal Oil Point Natural Reserve, Santa Barbara, CA**

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**Flowering Progression in Image**

- First flower in population
- Peak flowering
- Last flower in population

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**Webcams**

- Can provide phenological measurements within a single season (**intra-seasonal**)
- Measurements can be combined across years (**inter-seasonal**) to provide a long-term view of phenology
Collecting phenological data: *remote sensing*

**Satellite Imagery** provides phenological observations across whole landscapes

**Vegetation Index**

- A *metric* that describes the greenness – relative density and health of plant life – for each pixel in a satellite image

Collecting phenological data: *remote sensing*

A commonly used vegetation index is the **NDVI**

- **Normalized Difference Vegetation Index**
- Ranges from -1.0 – 1.0
  - < 0.1: no vegetation (e.g., snow, barren rock, sand)
  - 0.2 - 0.5: sparse vegetation (e.g., senescing crops)
  - 0.6 – 0.9: dense vegetation (e.g., dense forests during peak growth)

*Satellite images of landscape seasonal “green-up” & “brown-down” in Southern California*

Images: Brian Haggerty
Collecting phenological data: *remote sensing*

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*Satellite images of landscape seasonal “green-up” & “brown-down” in Southern California*

Images: Brian Haggerty
Using remote sensing to visualize phenological changes over time

- Webcam images from the Bartlett Experimental Forest, New Hampshire
- Satellite images showing NDVI in several Northeastern states (including all of New Hampshire!)

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Early phenological observations from Thoreau’s journals

“I saw this morning for the first time the bobolink, gold robin [most likely a northern oriole], and kingbird." May 10, 1853

• Thoreau made daily observations about plants animals every spring from 1851-1858

• The phenological data in Thoreau’s journals provided the foundation for ongoing long-term studies of phenology!

Long term data show that, in the northern hemisphere, co-occurring species are flowering earlier in the spring than they did 100 – 150 years ago.
Herbaria are essential resources for many phenological studies!

- House specimens that were collected up to hundreds of years ago
- Provide clear examples of plant phenophases at certain dates
- Provide valuable ecological information

Photo: Cheadle Center for Biodiversity and Ecological Restoration
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Biological scales at which phenological observations can be recorded.
Temporal scales at which phenology is studied

1. **intra-seasonal**: phenological observations within a single season

   *For example: flowering phenology during from late-winter through spring*
Temporal scales at which phenology is studied

2. inter-seasonal: phenological observations over multiple years

Miller Rushing and Primack (2008)
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Changes in the **timing of spring activity** have been observed in several species.

But the **magnitude** of phenological response depends on type of organism.
Phenological responses to climate change

Earlier “leaf-out” at Lowell Cemetery in Lowell, Massachusetts

Miller-Rushing et al. 2006. *American J. Botany*
Phenology as a *fingerprint* of climate change

One individual lilac, *in Vermont*
Phenology as a **fingerprint** of climate change

Early spring phenology is common among thousands of diverse organisms.

**One individual lilac, in Vermont**
Phenology as a fingerprint of climate change

Earlier spring phenology is common among thousands of diverse organisms.

One individual lilac, *in Vermont*

Plants & animals worldwide are tracking the earlier onset of spring by shifting the timing of their spring activities.
Phenology is an indicator of climate change impacts

HAZARDS
- Wildfires
- Pests & Diseases
- Invasions

CULTURE
- Festivals
- Ecotourism
- Wildflower displays

HEALTH
- Flu season
- Allergies
- Agriculture