Lecture #3
Phenological responses to environmental change: Examples and potential outcomes
Outline

• Biological significance of phenological schedules
• Phenological responses to climate change
• Phenological mismatches induced by climate change
• Long-term outcomes of phenological change in wild populations
  ❖ Geographic range shifts
  ❖ Adaptation
  ❖ Extinction
### Importance of matching the timing of life-history events with environmental conditions

#### Requirements for survival

- Avoid harsh climatic conditions (e.g., high temperatures)
- Avoid times when resources are scarce (e.g., drought)
- Minimize interactions with **antagonists**:
  - Pathogens
  - Herbivores / Predators
Importance of matching the timing of life-history events with environmental conditions

**Requirements for survival**

Avoid harsh climatic conditions (e.g., high temperatures)

Avoid times when resources are scarce (e.g., drought)

Minimize interactions with **antagonists:**
- Pathogens
- Herbivores / Predators

**Evolutionary adaptation**

Environmentally vulnerable phenophases coincide with favorable climatic conditions (e.g., snowmelt)

Phenophases with high resource demands (e.g., fruit production, fledging) coincide with high resource availability (e.g., soil moisture, food sources)

Phenophase displays (flowers, ripe fruits) maximize interactions with **mutualists**
- Pollinators
- Seed dispersal agents
Ecological Significance of Phenology in Sunflowers

*Helianthus annuus* inflorescences are consumed by several insect species.

*Suleima helianthana*, the sunflower bud moth, is a *destructive predator* with a big appetite for *individual flowers* within each inflorescence.

Pilson, 2000, *Oecologia*
The timing of flowering may be associated with the magnitude of herbivory

Pilson, 2000, Oecologia
Herbivore damage profoundly affects individual fitness

- No *Suleima* damage
- *Suleima*-damaged heads

Pilson, 2000, *Oecologia*
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• Biological significance of phenological schedules

• **Phenological responses to climate change**
  - Have been documented with manipulative studies (Sherry et al. 2007)
  - Vary among taxa (Parmesan 2007)
  - Influence human societies (Ziska et al. 2011)

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Manipulative studies have shown that even short-term climate change can affect flowering phenology.
Experimental Design:

- Species were planted into experimental plots
- Manipulated **temperature** and **precipitation**
- Monitored the flowering and fruiting phenology of 12 prairie species for one year

Sherry et al. 2007
**Experimental Design:** four experimental treatments

<table>
<thead>
<tr>
<th>Plot Treatment</th>
<th>Temperature</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ambient</td>
<td>ambient</td>
</tr>
<tr>
<td>2</td>
<td><strong>warmed</strong></td>
<td>ambient</td>
</tr>
<tr>
<td>3</td>
<td>ambient</td>
<td><strong>Doubled (DP)</strong></td>
</tr>
<tr>
<td>4</td>
<td><strong>warmed</strong></td>
<td><strong>Doubled (DP)</strong></td>
</tr>
</tbody>
</table>

Sherry et al. 2007
Which plant species delay *flowering* in response to warming?

Which plant species accelerate *flowering* in response to warming?

![Bar chart showing flowering time differences](chart.png)

Sherry et al. 2007

Species Responses:
- Viola
- Veronica
- Cerastium
- Bromus
- Plantago
- Dichanthelium
- Achillea
- Erigeron
- Panicum
- Andropogon
- Schizachyrium
- Ambrosia
Which plant species delay fruiting in response to warming?

Which plant species accelerate fruiting in response to warming?

Sherry et al. 2007
Phenological responses to Warming + DP

Sherry et al. 2007
Did Doubled Precipitation (DP) influence phenology?

Sherry et al. 2007
Effects of warming on the **onset** and **duration** of reproduction

Sherry et al. 2007
Effects of warming on the **onset** and **duration** of reproduction

Some species exhibit strong phenological responses to warming. What are some implications of this observation?

Sherry et al. 2007
Effects of warming on the **onset** and **duration** of reproduction

Some species do **NOT** exhibit phenological responses to warming. What are some implications of this observation?

Sherry et al. 2007
Warming and overlap of flowering among species

What are some potential consequences of plant phenological shifts for:

• Pollinators?
• Seed dispersal agents?
• Herbivores?
Do organisms exhibit similar phenological responses to climate change?
Do organisms exhibit similar phenological responses to climate change?

Parmesan (2007) conducted a meta-analysis to address this question

• Combined the results of several studies that tested similar hypotheses
• Used meta-analysis of many studies to detect trends on a large scale.
• Evaluated 203 species
Phenological Responses to Climate Change Vary Among Taxa

• Magnitude of phenological response depends on the type and species of organism

• How might interacting species (plants-pollinators; predator-prey) respond to climate change?
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• Phenological mismatches induced by climate change

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  - Geographic range shifts
  - Adaptation
  - Extinction
The timing of phenological schedules influences the human population in numerous ways.
10-20% of Americans experience ragweed (Ambrosia sp.) allergies
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Map showing an estimate of ragweed pollen abundance in the United States on August 26, 2011

http://www.weather.com/maps/activity/allergies/
The ragweed allergy season has increased in length as a function of climate

1995-2009

\[ r^2 = 0.74 \]

\[ r^2 = 0.87 \]
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Phenological mismatches: a potential outcome of climate change

Phenological mismatches occur when:

1. the **timing of the availability** of an important resource (such as food) changes in response to climate

2. the **timing of the demand** for the resource does **NOT** change.
Phenological mismatches: a potential outcome of climate change

Phenological mismatches occur when:

1. the **timing of the availability** of an important resource (such as food) changes in response to climate

   **but**

2. the **timing of the demand** for the resource does NOT change.

Stenseth and Mysterud, 2002, *Proceedings of the National Academy of Sciences*
Phenological mismatches: a potential outcome of climate change

Phenological mismatches occur when:

1. the **timing of the availability** of an important resource (such as food) changes in response to climate

   [Diagram showing mismatch for a great tit]

   - Climate change
   - Match -> Mis-match
   - Time

2. the **timing of the demand** for the resource does **NOT** change.

   [Diagram showing mismatch for an American robin]

   - Winter range
   - Migration
   - Summer (breeding) range
   - Time

Stenseth and Mysterud, 2002, *Proceedings of the National Academy of Sciences*
Phenological mismatches can cause population declines

Leafing out earlier

Both et al. 2006 Nature
Phenological mismatches can cause population declines

Leafing out earlier

Emerging earlier

English oak

Winter moth

Both et al. 2006 *Nature*
Phenological mismatches can cause population declines

Leafing out earlier

Emerging earlier

English oak

Winter moth

Pied flycatcher

Migrating the SAME time each year

Both et al. 2006 Nature
Phenological mismatches can cause population declines

Bird populations have declined by 90% where food for nestlings peaks early in the season and the birds are now mistimed.

The earlier winter moths emerge, the steeper the decline in bird population size

Both et al. 2006 Nature

Leafing out earlier

Emerging earlier

Winter moth

English oak

Pied flycatcher

Migrating the SAME time each year
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The geographic ranges of some species may **shift** as the climate changes.

**Former range of the scarce umber moth**

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*Norwegian Institute for Nature Research, P.O. Box 1080 Blindern, N-0317 Oslo, Norway. †Department of Arctic and Marine Biology, University of Tromsø, N-9037 Tromsø, Norway. ‡Bioforsk Soil and Environment, Steinheim, N-9925 Steinkvik, Norway. §Tromsø University Museum, N-9037 Tromsø, Norway.*

[Global Change Biology](https://doi.org/10.1111/j.1365-2486.2010.02370.x)
The geographic ranges of some species may **shift** as the climate changes.
The geographic ranges of some species may **shift** as the climate changes.

The scarce umber moth, one of several pests that attacks birch trees.

Birch (*Betula pubescens var. czaerepanovii*)

*Jepsen et al. 2011, Global Change Biology*
The geographic ranges of some species may **shift** as the climate changes.

The scarce umber moth, **one** of several pests that attacks emerging birch buds.

Severe defoliation in Scandinavian birch stands.

Photos: A. Nilssen

Image: www.birchmoth.com
Evidence of increasing temperatures at study sites in northern Norway

Mean annual temperature (deg C)

Tromsø

Bardufoss

Jepsen et al. 2011, *Global Change Biology*
In recent years, the scarce umber moth was observed in northern Norway.

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Solid line = scarce umber moth
Dashed line = winter moth (another birch pest)

Former range in Norway

Jepsen et al. 2011, Global Change Biology
In recent years, the scarce umber moth was observed in northern Norway.

Solid line = scarce umber moth
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Jepsen et al. 2011, *Global Change Biology*
In recent years, the scarce umber moth was observed in northern Norway.

Solid line = scarce umber moth
Dashed line = winter moth (another birch pest)

Jepsen et al. 2011, *Global Change Biology*
Warming promotes increased matching of plant & pest phenologies

- In experimental climate chambers
- Suggests that warming has resulted in phenological shifts that have allowed scarceumber moth populations to move northward

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Jepsen et al. 2011, *Global Change Biology*
What are some other ways that species ranges may shift in response to climate change?
What are some other ways that species ranges may shift in response to climate change?

Shifts to higher elevations

- Chen et al. (2011) estimate that species are shifting ~11m higher in elevation/decade
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Phenological schedules may evolve in response to climate change
Phenological schedules may **evolve** in response to climate change

Populations may evolve in response to climate change *if*:

1. Phenological schedules **vary** among individuals within populations.
Phenological schedules may **evolve** in response to climate change

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2. Variation in phenological traits is **genetically based**.

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- Phenological schedules **vary** among individuals within populations.
- Variation in phenological traits is **genetically based**.
Phenological schedules may **evolve** in response to climate change

**Populations may evolve in response to climate change if:**

1. Phenological schedules **vary** among individuals within populations.

2. Variation in phenological traits is **genetically based**.

3. Reproductive fitness **varies** among individuals within populations
Evolution: change in trait values over time

Selected individuals with high fitness

Day of First Flowering

Selected individuals with high fitness

Selected individuals with high fitness

Hypothetical Evolution of Flowering Time Over Multiple Generations
Rapid evolution of flowering time by an annual plant in response to a climate fluctuation

Steven J. Franks*, Sheina Sim, and Arthur E. Weis

“Wet environment” plants: derived from seeds collected in 1997 before an extended drought

“Dry environment” plants: derived from seeds collected in 2004 after an extended drought
Rapid evolution of flowering time by an annual plant in response to a climate fluctuation

Steven J. Franks*, Sheina Sim, and Arthur E. Weis

“Wet environment” plants: derived from seeds collected in 1997 before an extended drought

“Dry environment” plants: derived from seeds collected in 2004 after an extended drought

Note: these seeds originated from the same population. The population, however, experienced different environmental conditions between 1997-2004.
Rapid evolution of flowering time by an annual plant in response to a climate fluctuation

Steven J. Franks*, Sheina Sim, and Arthur E. Weis

“Wet environment” plants: derived from seeds collected in 1997 before an extended drought

“Dry environment” plants: derived from seeds collected in 2004 after an extended drought

- Flowering time is genetically-based in field mustard
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“Wet environment” plants: derived from seeds collected in 1997 before an extended drought

“Dry environment” plants: derived from seeds collected in 2004 after an extended drought

- Flowering time is genetically-based in field mustard

- Grew wet and dry environment plants (and wet x dry hybrids) in two different common environments:
  - A common wet environment and a common dry environment

Franks et al. 2007, PNAS
Rapid evolution of flowering time by an annual plant in response to a climate fluctuation

Steven J. Franks*, Sheina Sim, and Arthur E. Weis

Flowering time advanced significantly between 1997 and 2004

Franks et al. 2007, PNAS
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Extinction Risk and Phenology: climate change and bird migration

Populations of migratory bird species that did not show a phenological response to climate change are declining

Anders Pape Møller*, Diego Rubolini‡, and Esa Lehikoinen§

*Laboratoire de Parasitologie Evolutive, Centre National de la Recherche Scientifique Unité Mixte de Recherche 7103, Université Pierre et Marie Curie, F-75252 Paris Cedex 05, France; ‡Dipartimento di Biologia, Università degli Studi di Milano, I-20133 Milano, Italy; and §Department of Biology, University of Turku, FI-20014, Turku, Finland

Edited by May R. Berenbaum, University of Illinois, Urbana, IL, and approved August 27, 2008 (received for review April 21, 2008)
Extinction Risk and Phenology: climate change and bird migration

- Evaluated the magnitude of **phenological** response to climate change
  - Timing of spring migration by 100 European bird species since 1960
- Identified species whose populations **declined** between 1990-2000

Populations of migratory bird species that did not show a phenological response to climate change are declining

*Anders Pape Møller*, †Diego Rubolini, ‡Esa Lehikoinen

*Laboratoire de Parasitologie Evolutive, Centre National de la Recherche Scientifique Unité Mixte de Recherche 7103, Université Pierre et Marie Curie, F-75252 Paris Cedex 05, France; ‡Dipartimento di Biologia, Università degli Studi di Milano, I-20133 Milano, Italy; and †Department of Biology, University of Turku, FI-20014, Turku, Finland

Edited by May R. Berenbaum, University of Illinois, Urbana, IL, and approved August 27, 2008 (received for review April 21, 2008)
Extinction Risk and Phenology: climate change and bird migration

Møller et al. 2008, PNAS
Summary

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  - Adaptation (Franks et al. 2007)
  - Extinction (Møller et al. 2008)


References


