




Lecture #3

Phenological responses to environmental change:

Examples and potential outcomes

USGS science for a changing world

USA npn National Phenology Network









*"**Phenology affects nearly all aspects of ecology and evolution. Virtually all biological phenomena— from individual physiology to interspecific relationships to global nutrient fluxes—have annual cycles and are influenced by the timing of abiotic events.**"* - Jessica Forrest and Abraham Miller Rushing, Proc. Roy. Soc. (2010)

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

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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

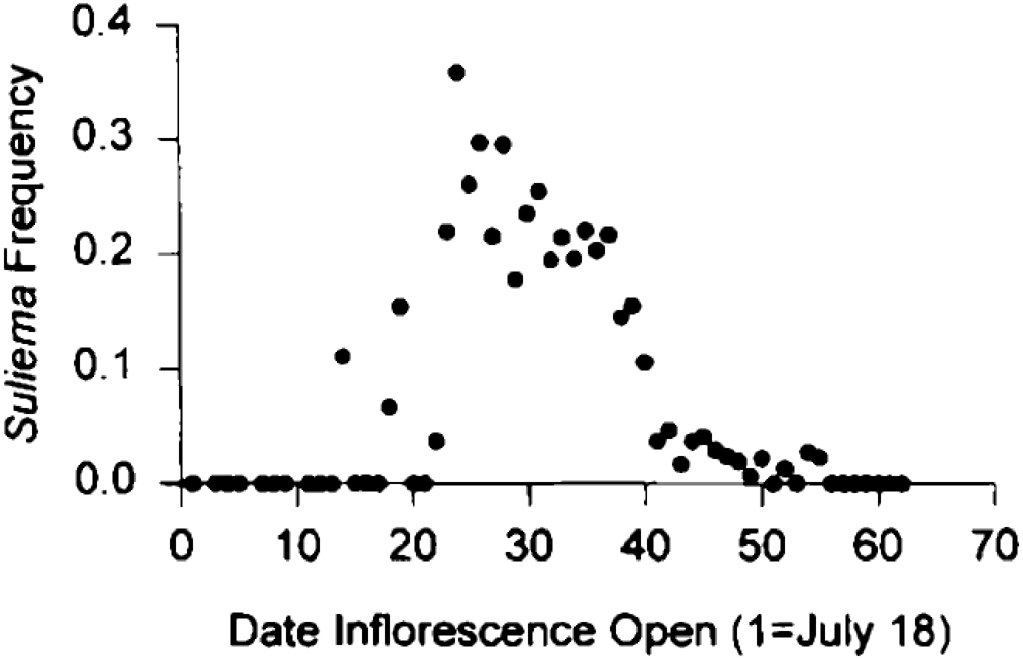
Ecological Significance of Phenology in Sunflowers

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

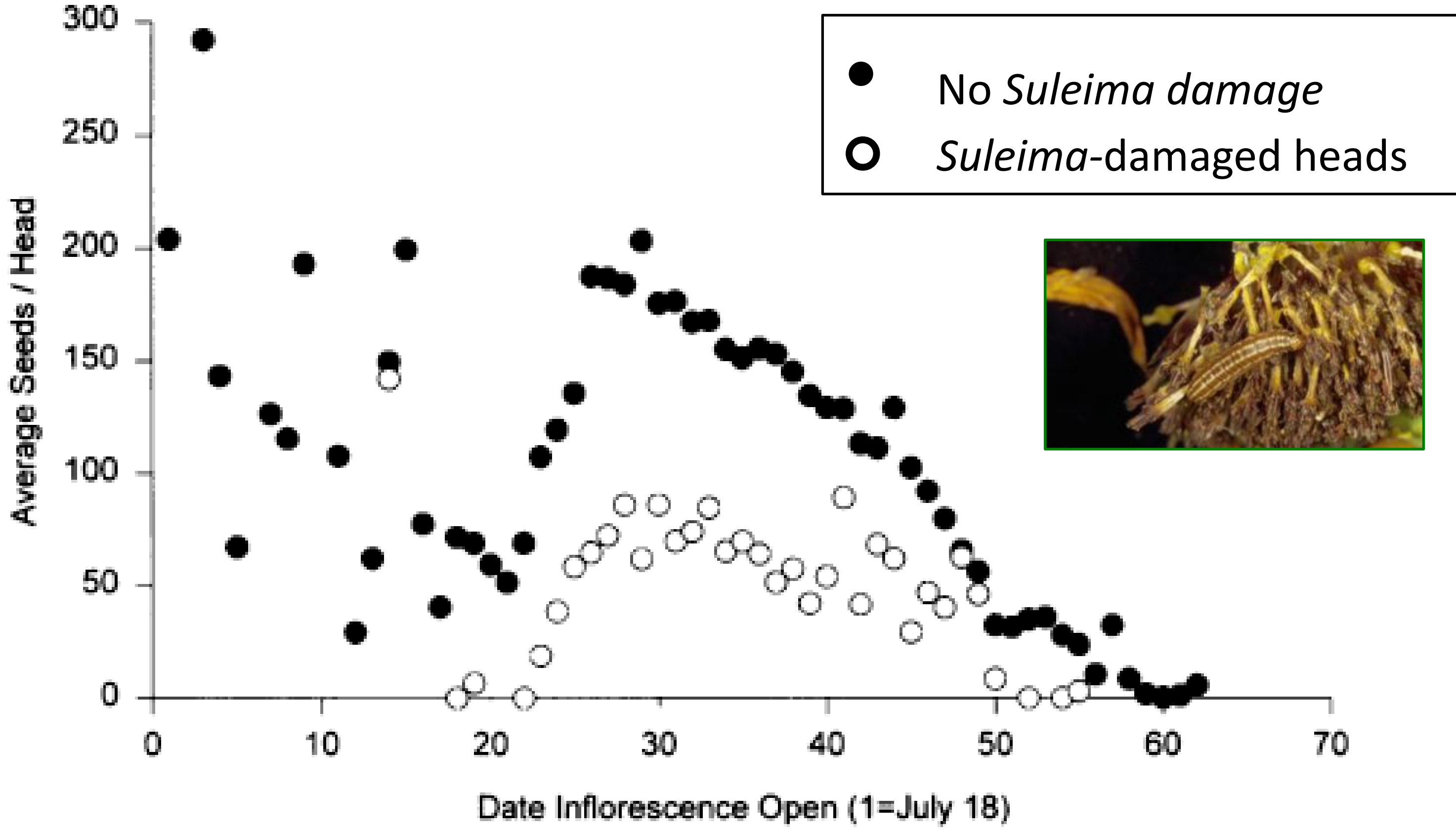
Pilson, 2000, *Oecologia*

The timing of flowering may be associated with the magnitude of herbivory



Pilson, 2000, *Oecologia*

Herbivore damage profoundly affects individual fitness



Pilson, 2000, *Oecologia*

Outline

- 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)**
- Phenological mismatches induced by climate change
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Manipulative studies have shown that even short-term climate change can affect flowering phenology

PNAS

Divergence of reproductive phenology under climate warming

Rebecca A. Sherry[*,†], Xuhui Zhou[*], Shiliang Gu[‡], John A. Arnone III[§], David S. Schimel[¶], Paul S. Verburg[§], Linda L. Wallace[*], and Yiqi Luo[*]

[*]Department of Botany and Microbiology, University of Oklahoma, Norman, OK 73019; [‡]Department of Agronomy, Yangzhou University, Yangzhou 225009, China; [§]Division of Earth and Ecosystem Sciences, Desert Research Institute, Reno, NV 89512; and [¶]Terrestrial Sciences Section, National Center for Atmospheric Research, Boulder, CO 80305

Edited by Christopher B. Field, Carnegie Institution of Washington, Stanford, CA, and approved November 8, 2006 (received for review July 6, 2006)

Sherry et al. 2007

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

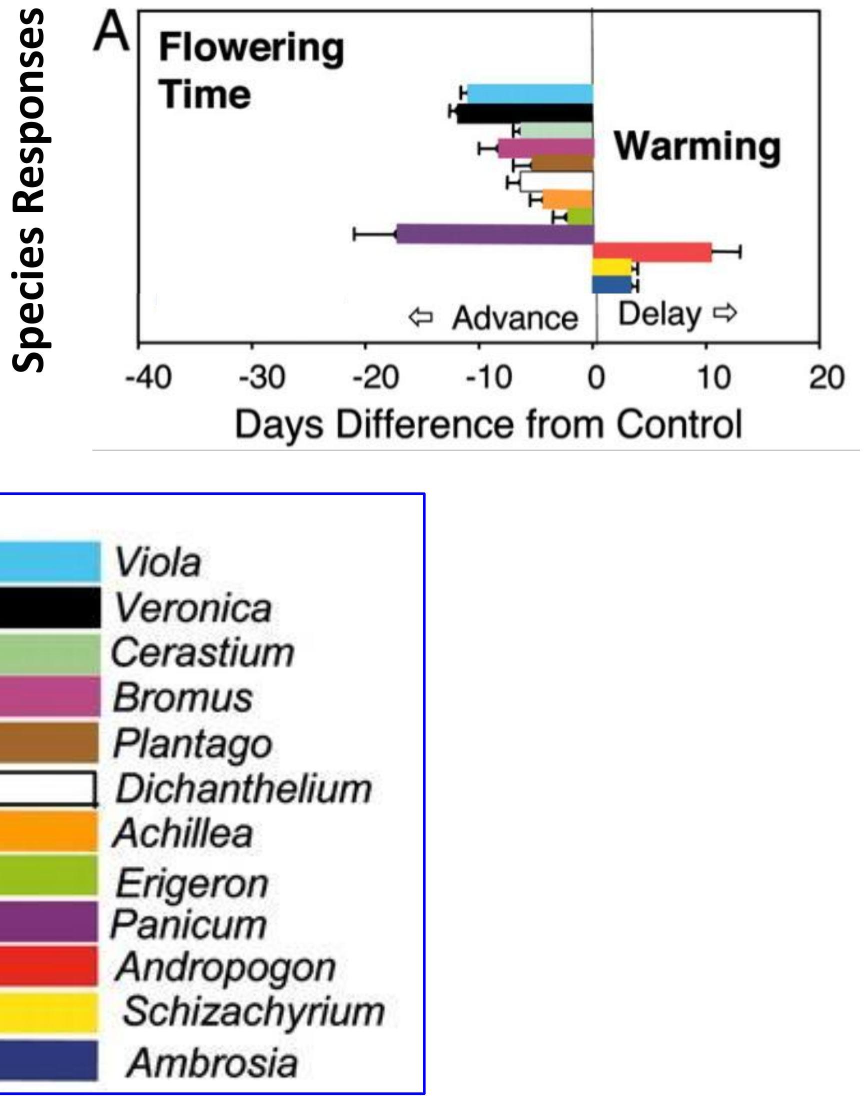
Experimental Design: four experimental treatments

Plot Treatment	Temperature	Precipitation
1	ambient	ambient
2	**warmed**	ambient
3	ambient	**Doubled (DP)**
4	**warmed**	**Doubled (DP)**

Sherry et al. 2007

Which plant species delay flowering in response to warming?

Which plant species accelerate flowering in response to warming?



Sherry et al. 2007

Which plant species delay fruiting in response to warming?

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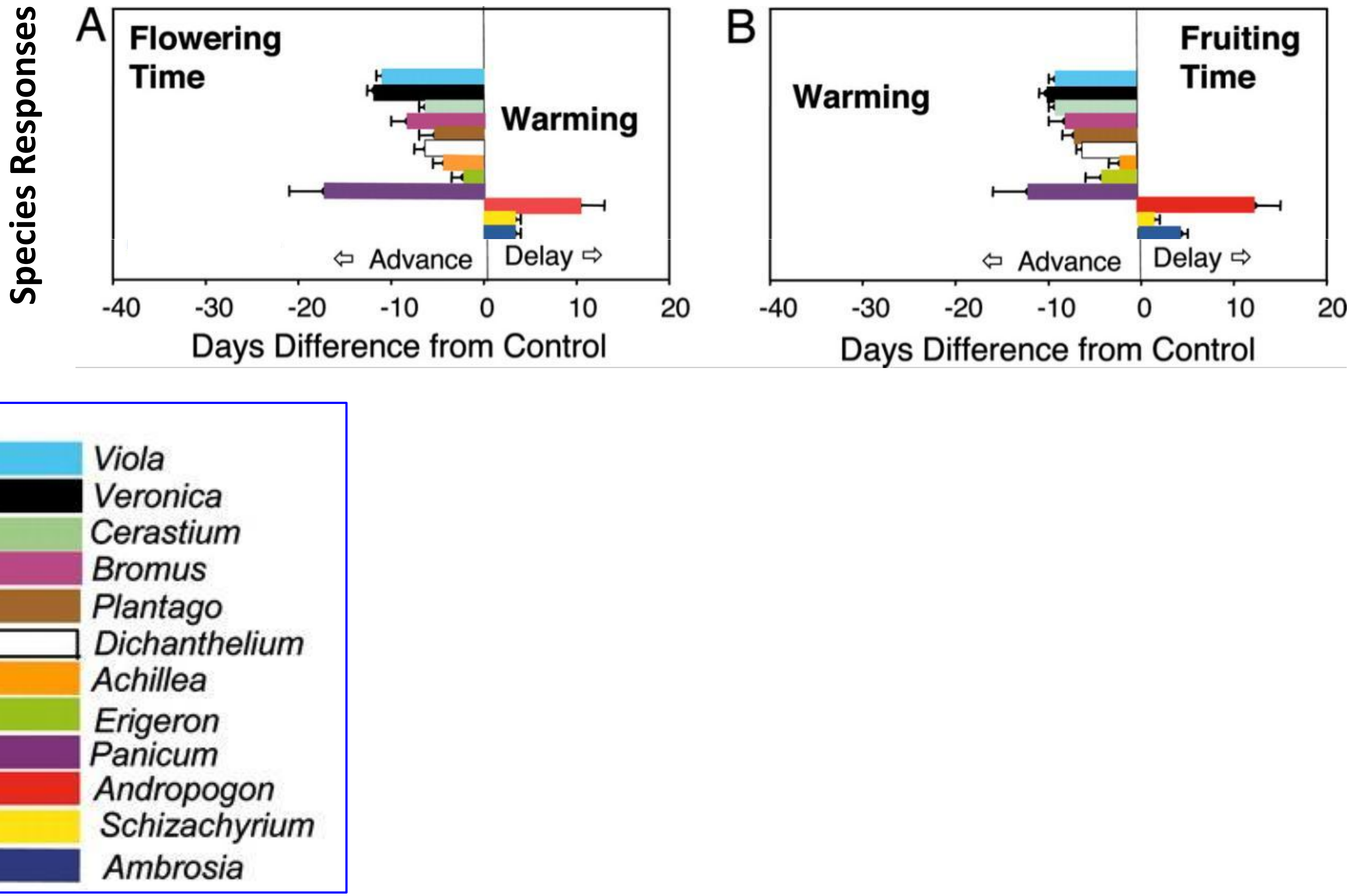
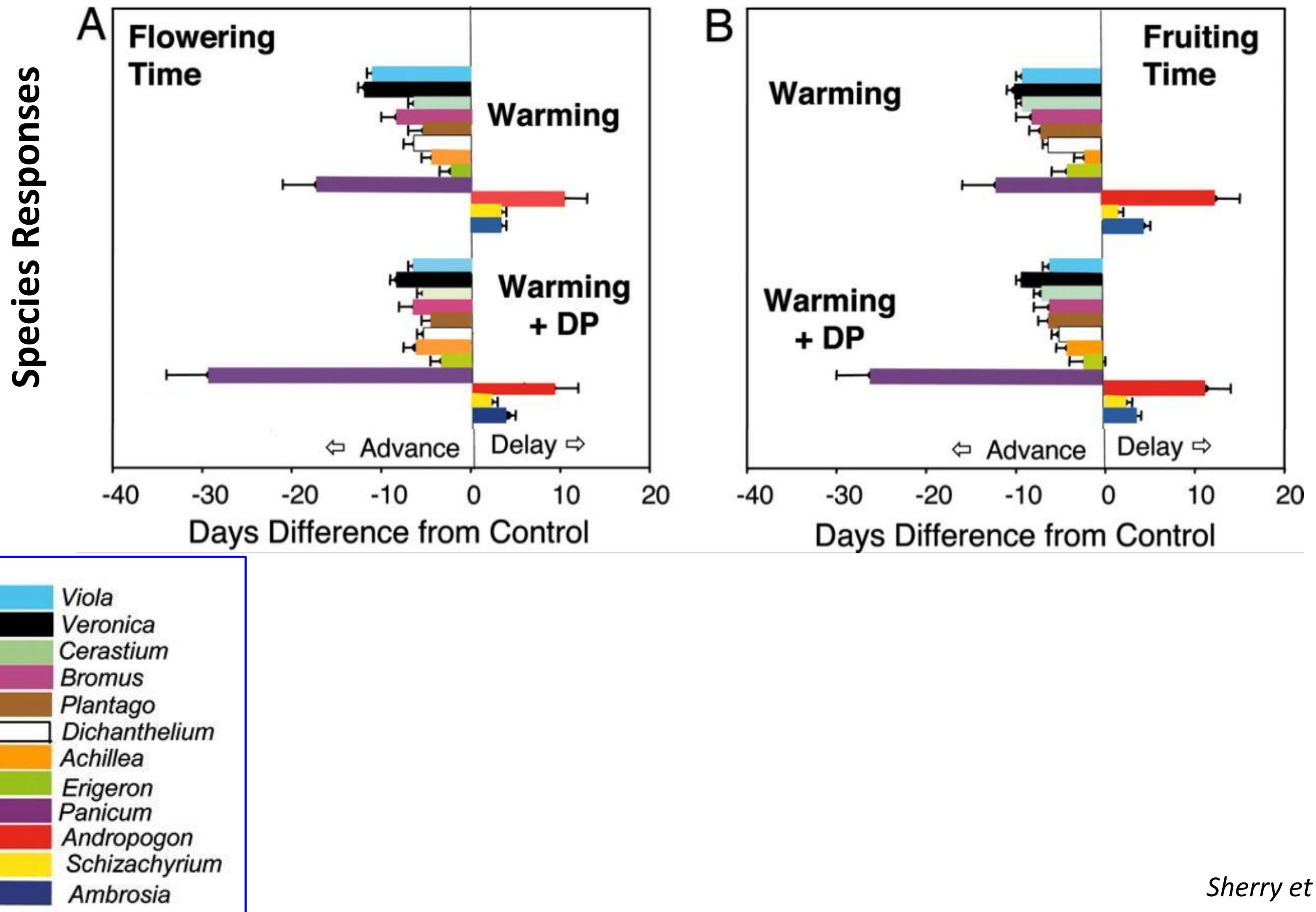


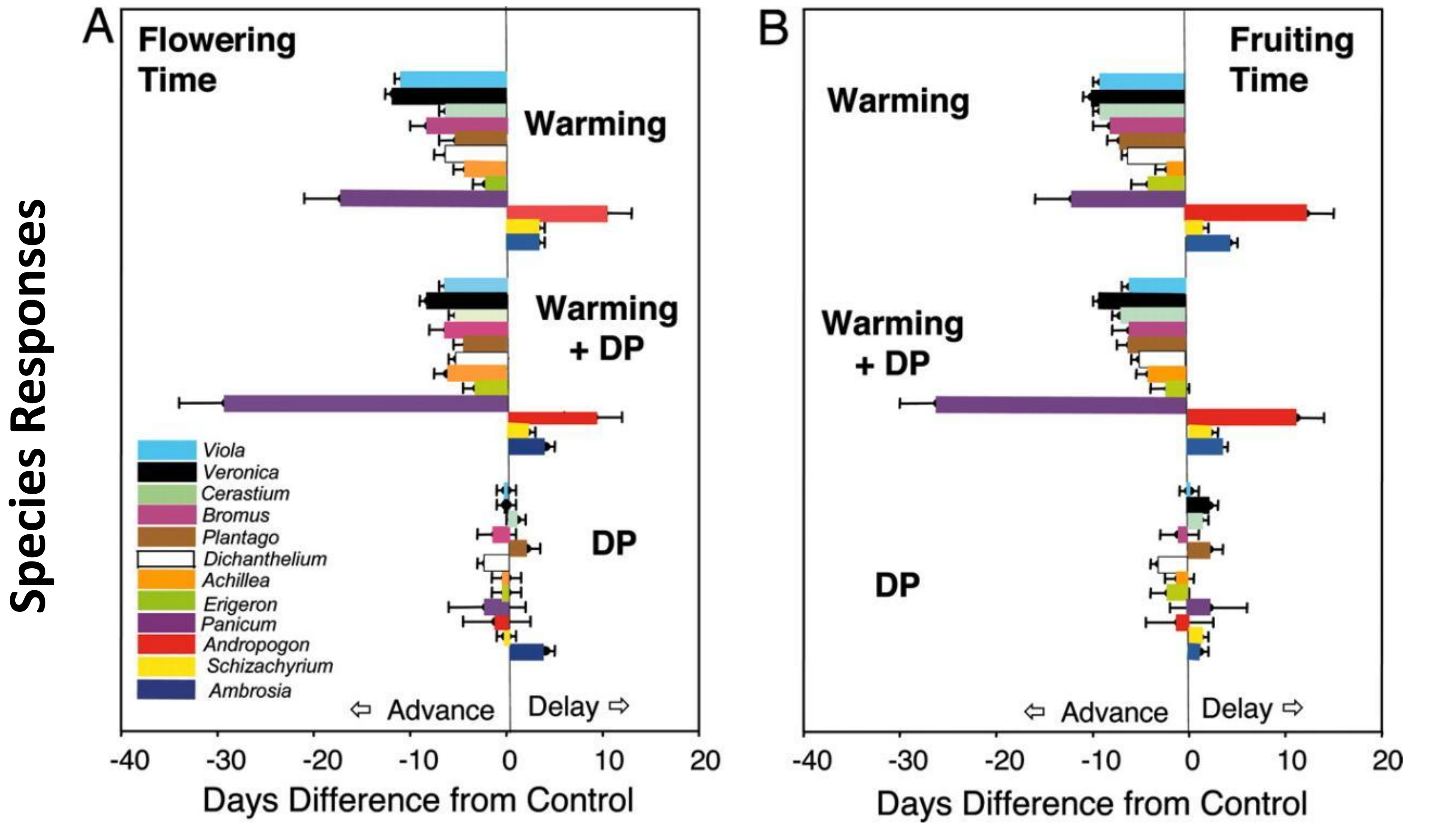
Sherry et al. 2007

Phenological responses to Warming + DP



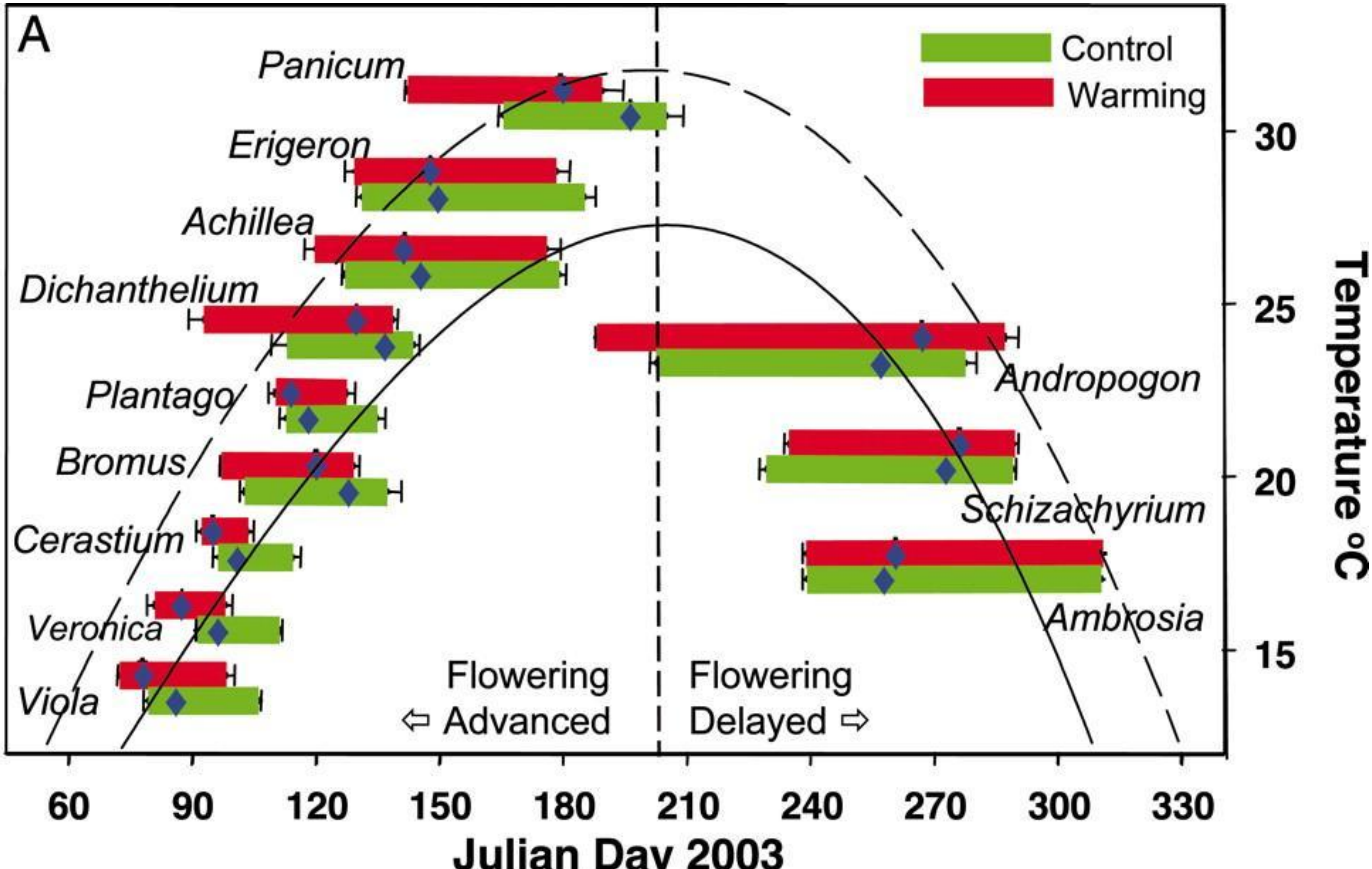
Sherry et al. 2007

Did Doubled Precipitation (DP) influence phenology?



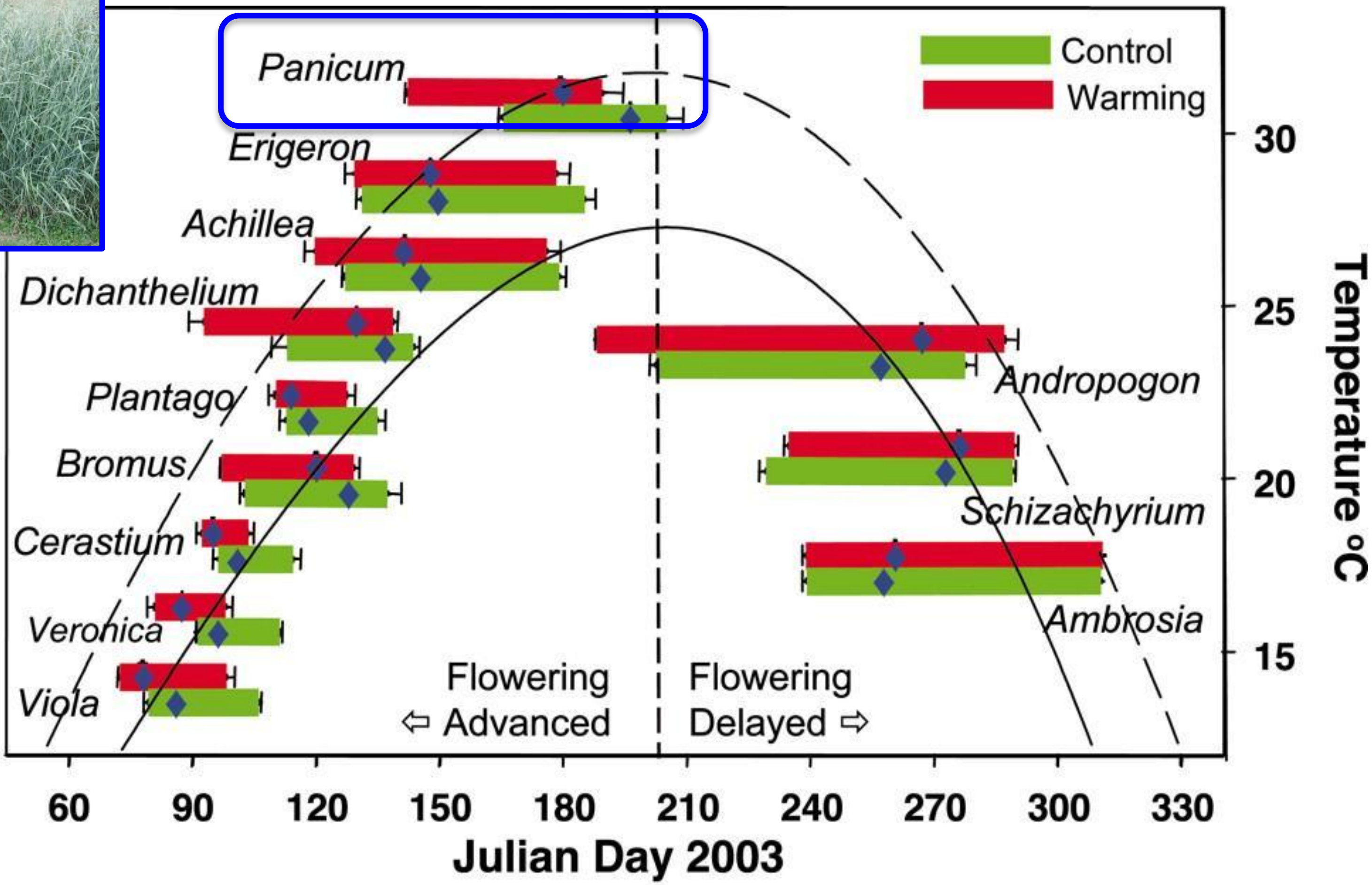
Sherry et al. 2007

Effects of warming on the **onset** and **duration** of reproduction



Sherry et al. 2007

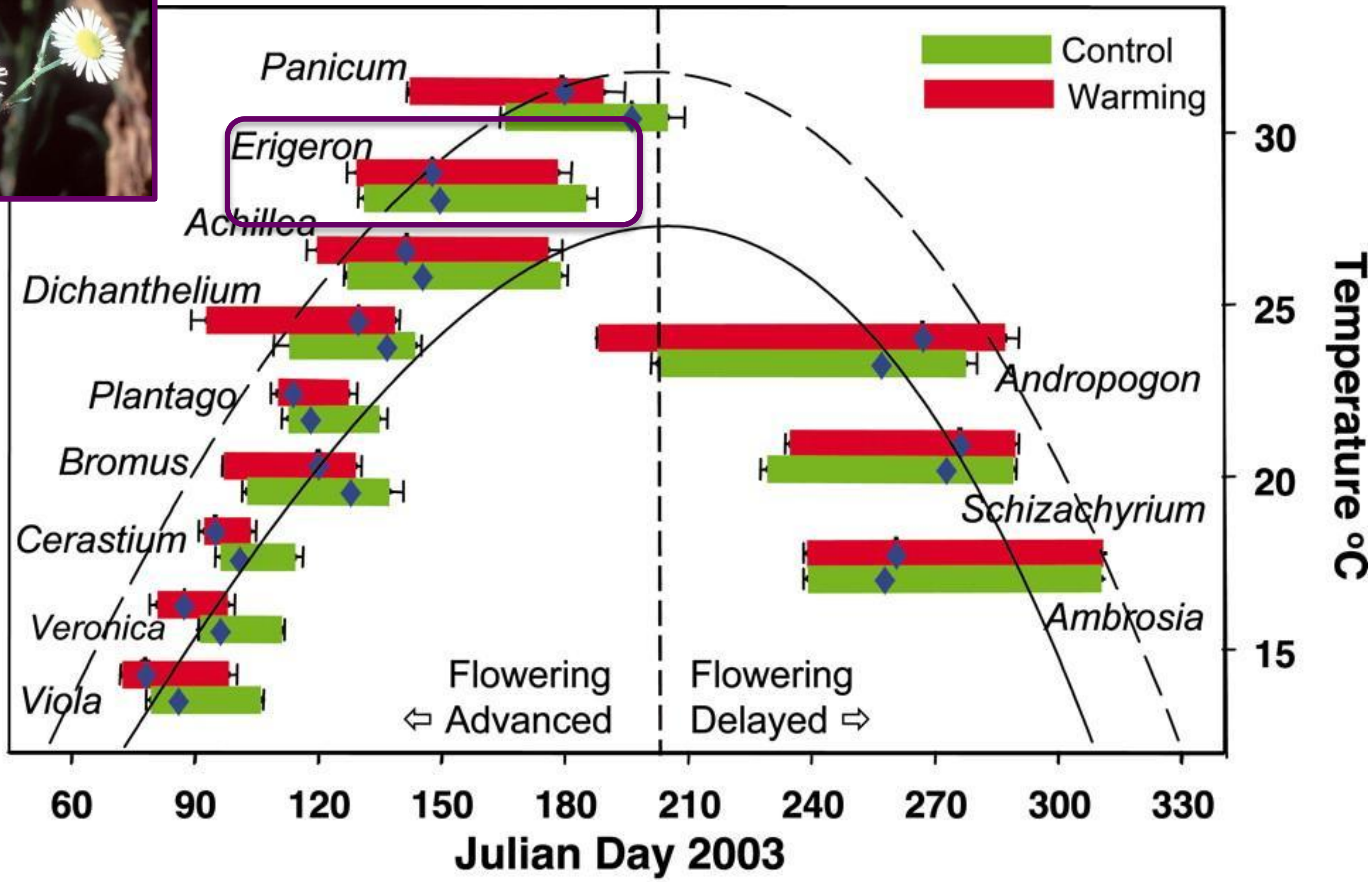
Effects of warming on the **onset** and **duration** of reproduction



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

Sherry et al. 2007

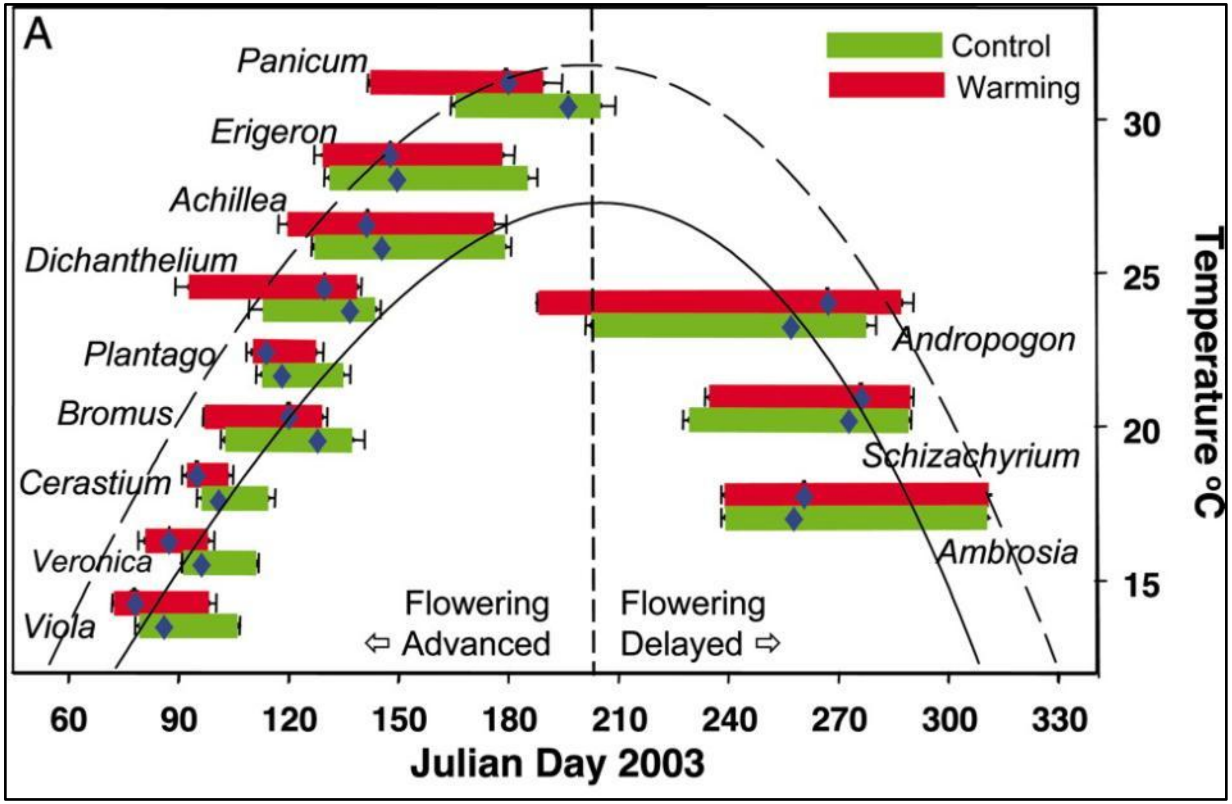
Effects of warming on the **onset** and **duration** of reproduction



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?

Sherry et al. 2007

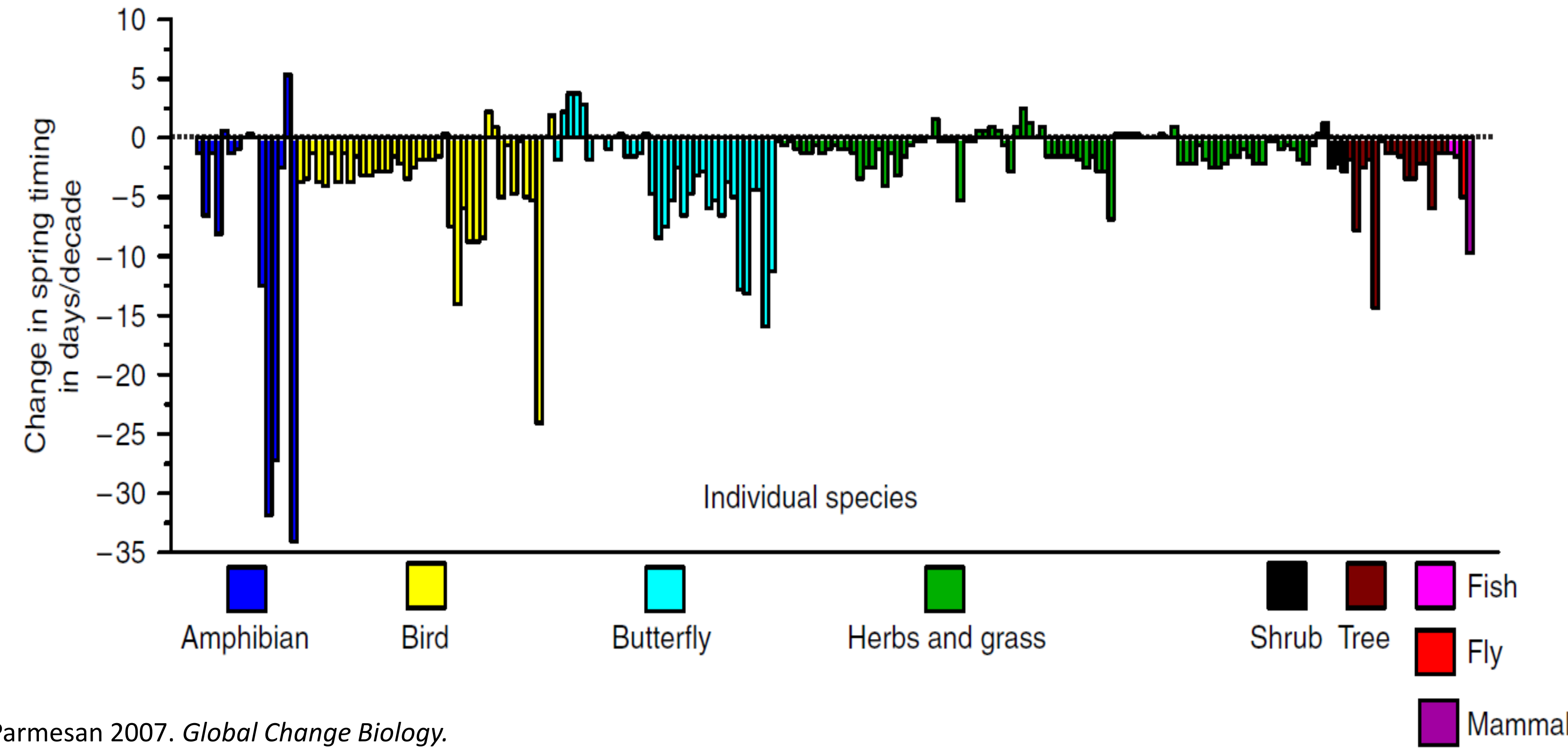
Do organisms exhibit similar phenological responses to climate change?

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



Parmesan 2007. *Global Change Biology.*

- 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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  - ❖ **Influence human societies (Ziska et al. 2011)**
- 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

Asthma and Allergy Foundation of America

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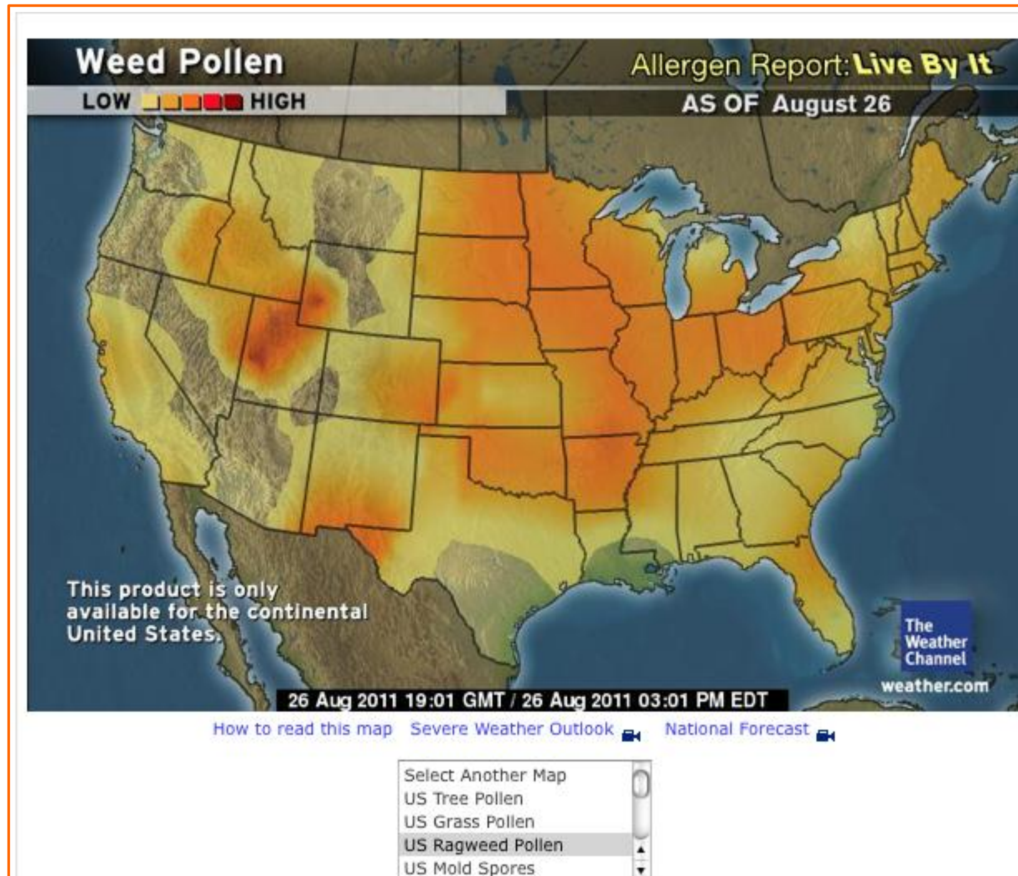
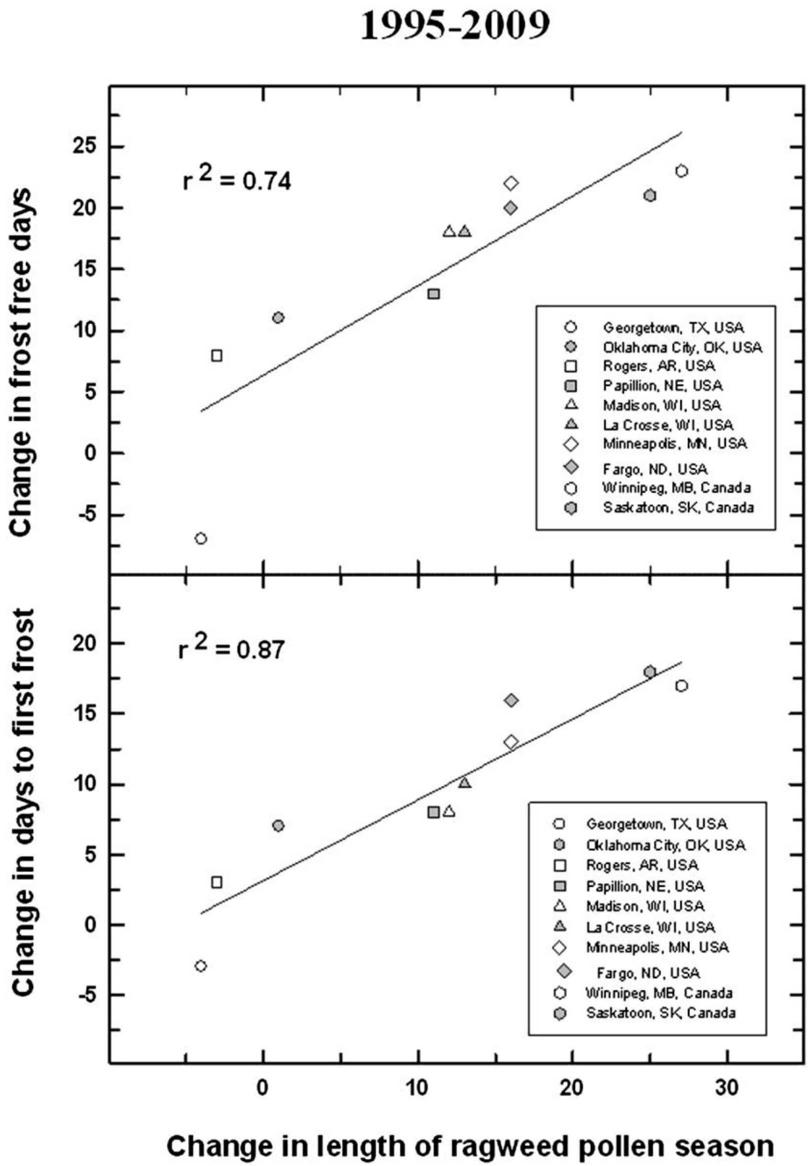
Asthma and Allergy Foundation of America

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



Ziska et al. 2011 *PNAS*

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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

but

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

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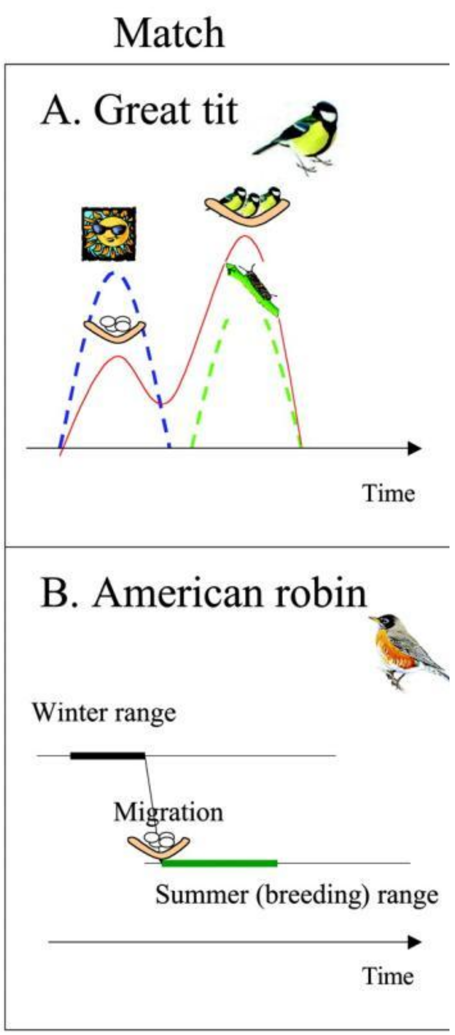

Stenseth and Mysterud, 2002, *Proceedings of the National Academy of Sciences*

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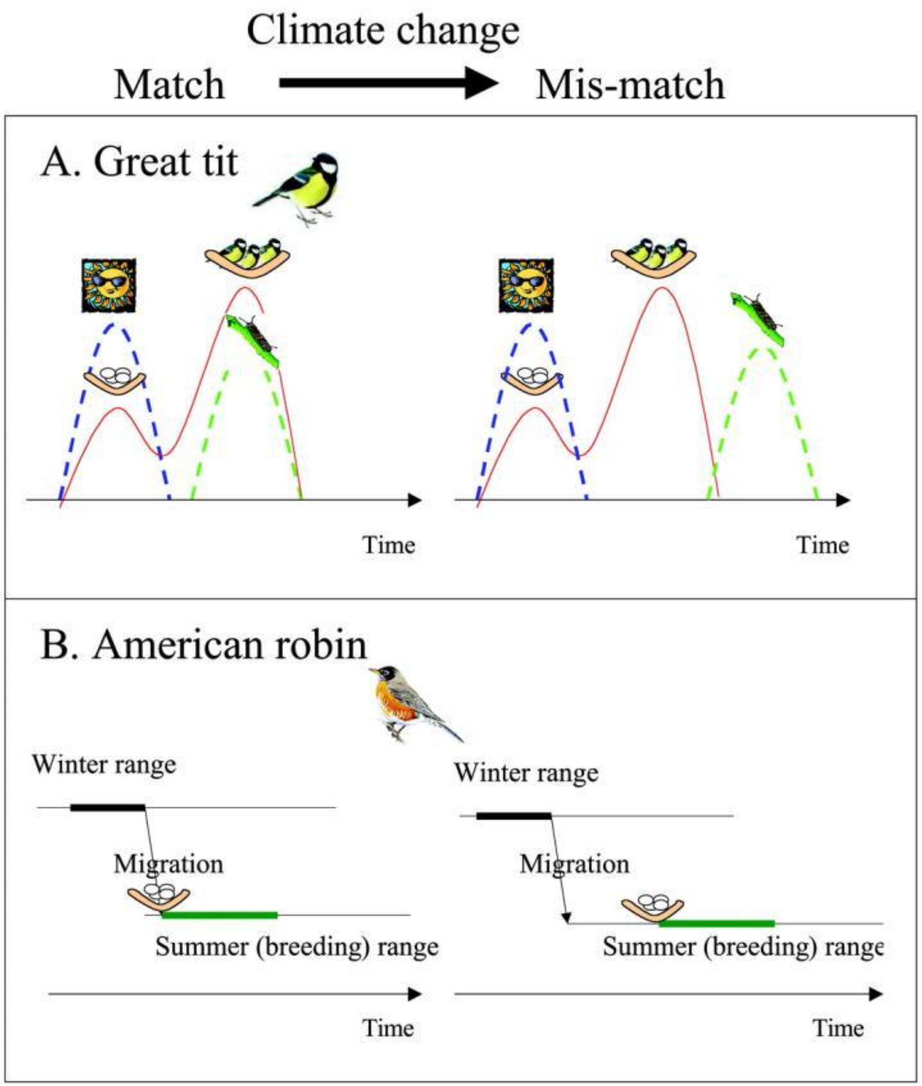

Stenseth and Mysterud, 2002, *Proceedings of the National Academy of Sciences*

Phenological mismatches can cause population declines

Leafing out earlier

English oak

Both et al. 2006 *Nature*

Phenological mismatches can cause population declines

Leafing out earlier

English oak

Emerging earlier

Winter moth

Both et al. 2006 *Nature*

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Pied flycatcher

Migrating the <u>SAME</u> time each year

Both et al. 2006 *Nature*

Phenological mismatches can cause population declines

Leafing out earlier

English oak

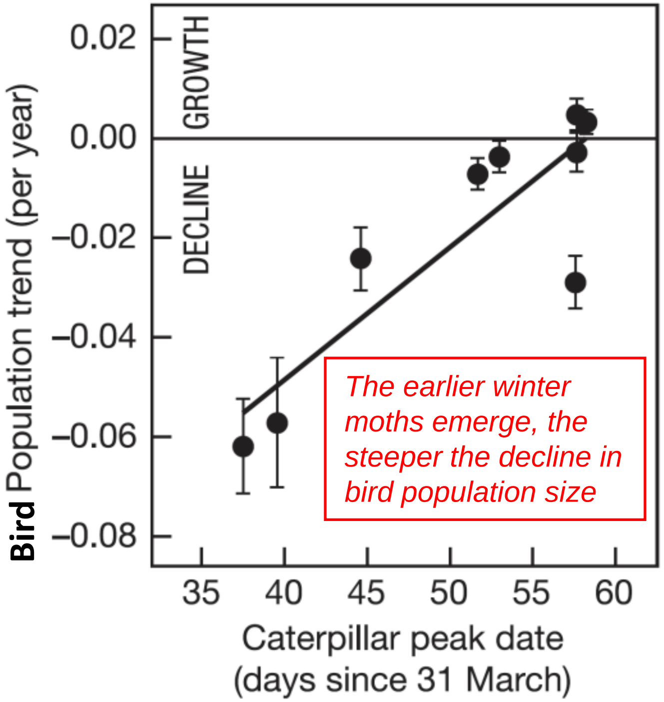
Emerging earlier

Winter moth

Pied flycatcher

Migrating the <u>SAME</u> time each year

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



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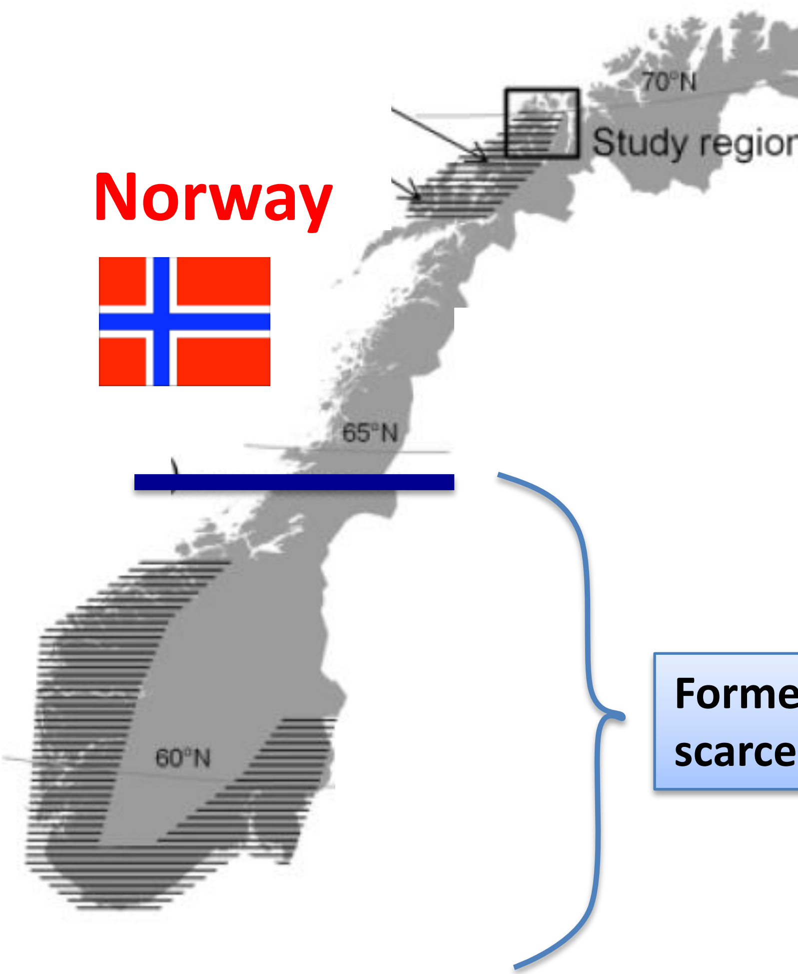
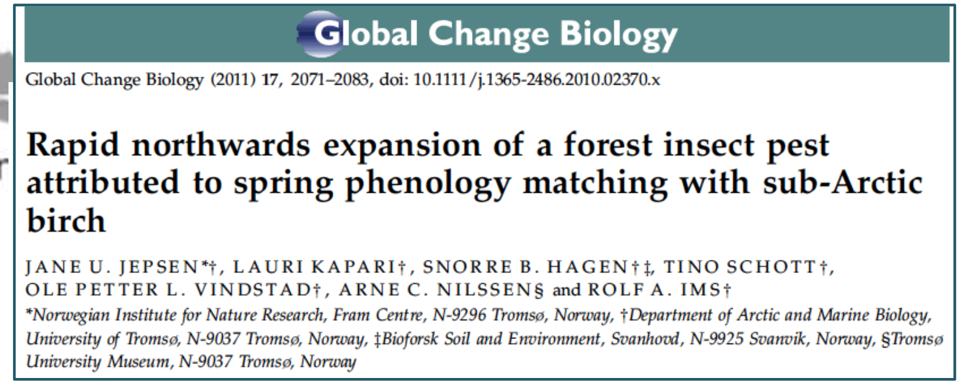
The geographic ranges of some species may **shift** as the climate changes

Norway





Global Change Biology

Global Change Biology (2011) 17, 2071–2083, doi: 10.1111/j.1365-2486.2010.02370.x

Rapid northwards expansion of a forest insect pest attributed to spring phenology matching with sub-Arctic birch

JANE U. JEPSEN*†, LAURI KAPARI†, SNORRE B. HAGEN†‡, TINO SCHOTT†, OLE PETTER L. VINDSTAD†, ARNE C. NILSSEN§ and ROLF A. IMS†

*Norwegian Institute for Nature Research, Fram Centre, N-9296 Tromsø, Norway, †Department of Arctic and Marine Biology, University of Tromsø, N-9037 Tromsø, Norway, ‡Bioforsk Soil and Environment, Svanhovd, N-9925 Svanvik, Norway, §Tromsø University Museum, N-9037 Tromsø, Norway

Former range of the scarce umber moth

The geographic ranges of some species may **shift** as the climate changes

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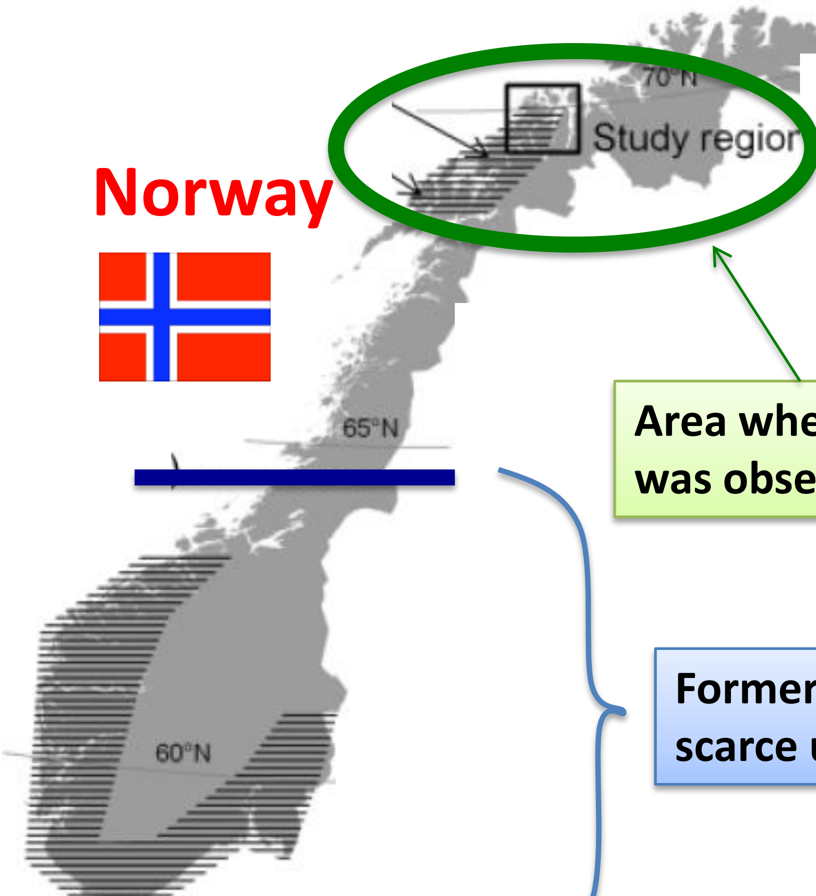
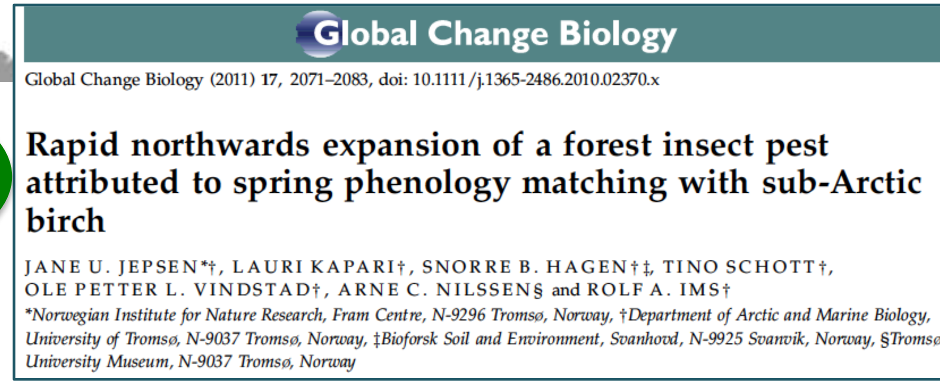


Area where the moth was observed

Former range of the scarce umber moth



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The geographic ranges of some species may shift as the climate changes

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

Photos: A. Nilssen

Photo: orcaborealis

Birch (*Betula pubsescens var. czaerepanovii*)

Jepsen et al. 2011, *Global Change Biology*

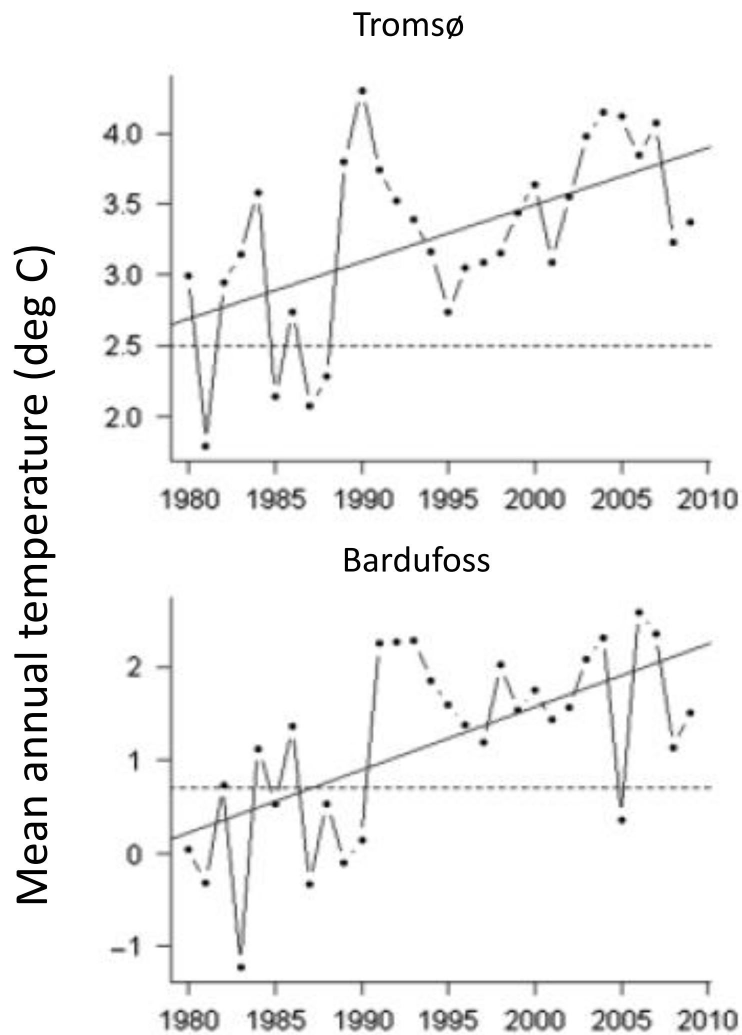
The geographic ranges of some species may **shift** as the climate changes

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

Image: www.birchmoth.com

Severe defoliation in Scandinavian birch stands

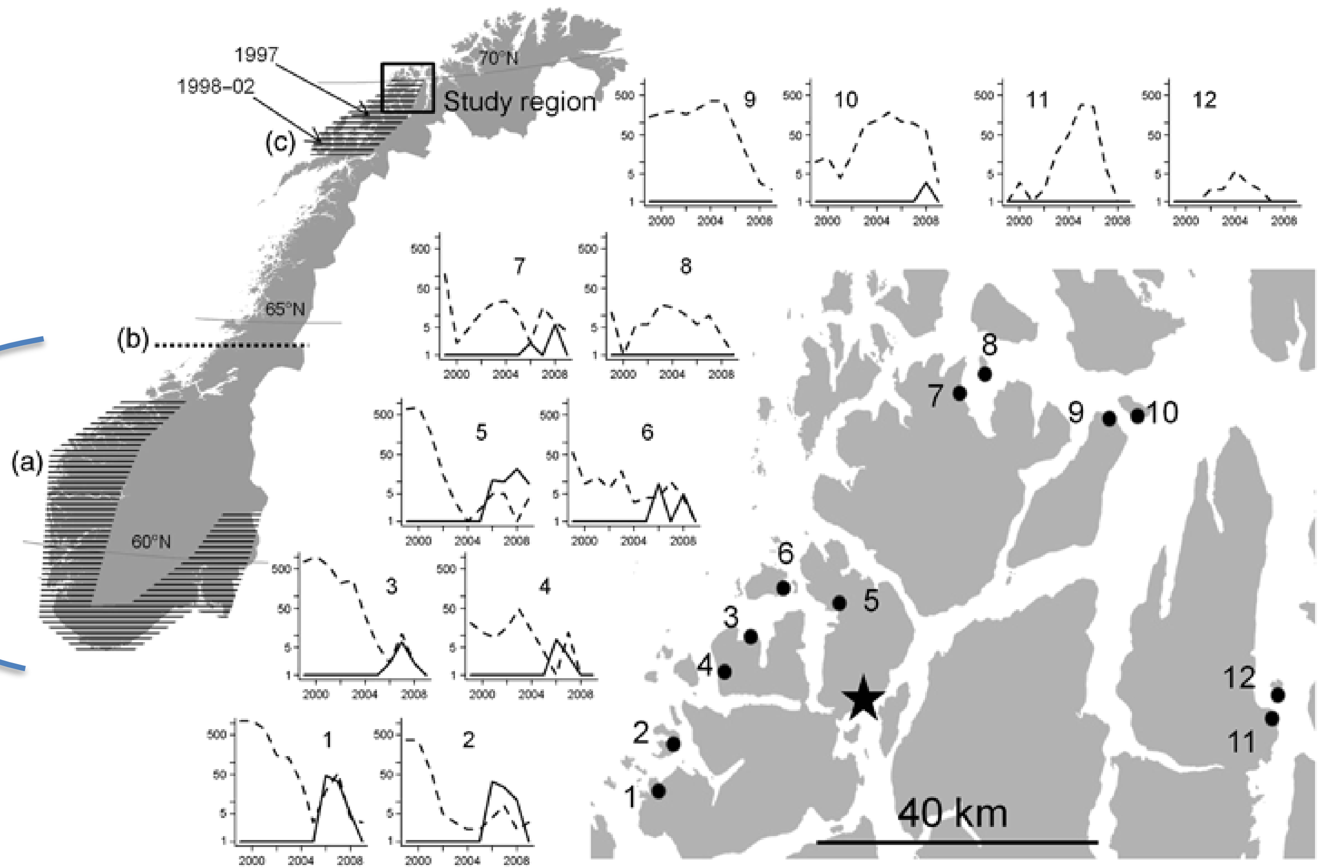
Evidence of increasing temperatures at study sites in northern Norway



Jepsen et al. 2011, *Global Change Biology*

In recent years, the scarce umber moth was observed in northern Norway

Former range in Norway



—— Solid line = scarce umber moth

- - - Dashed line = winter moth (another birch pest)

Jepsen et al. 2011, *Global Change Biology*

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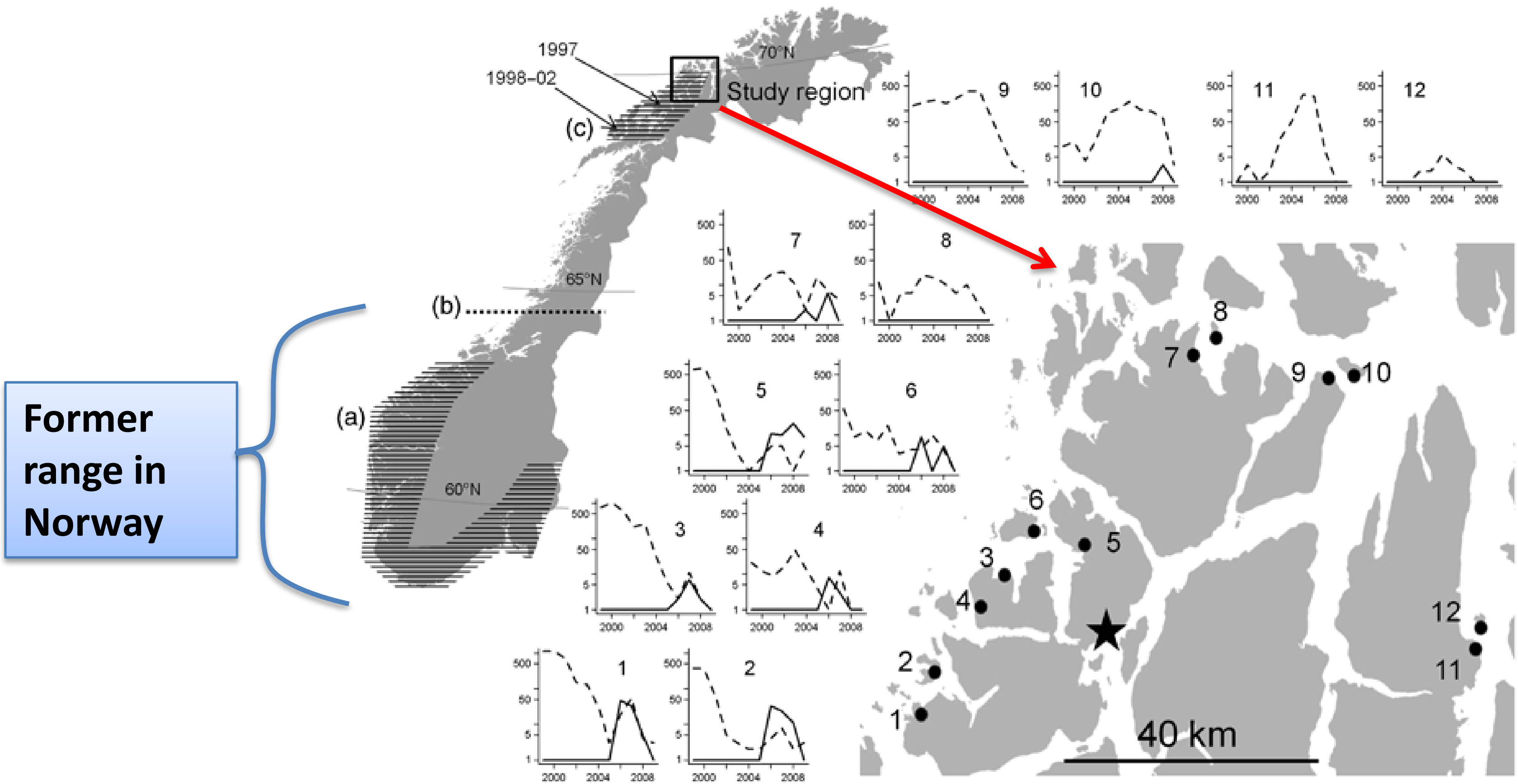

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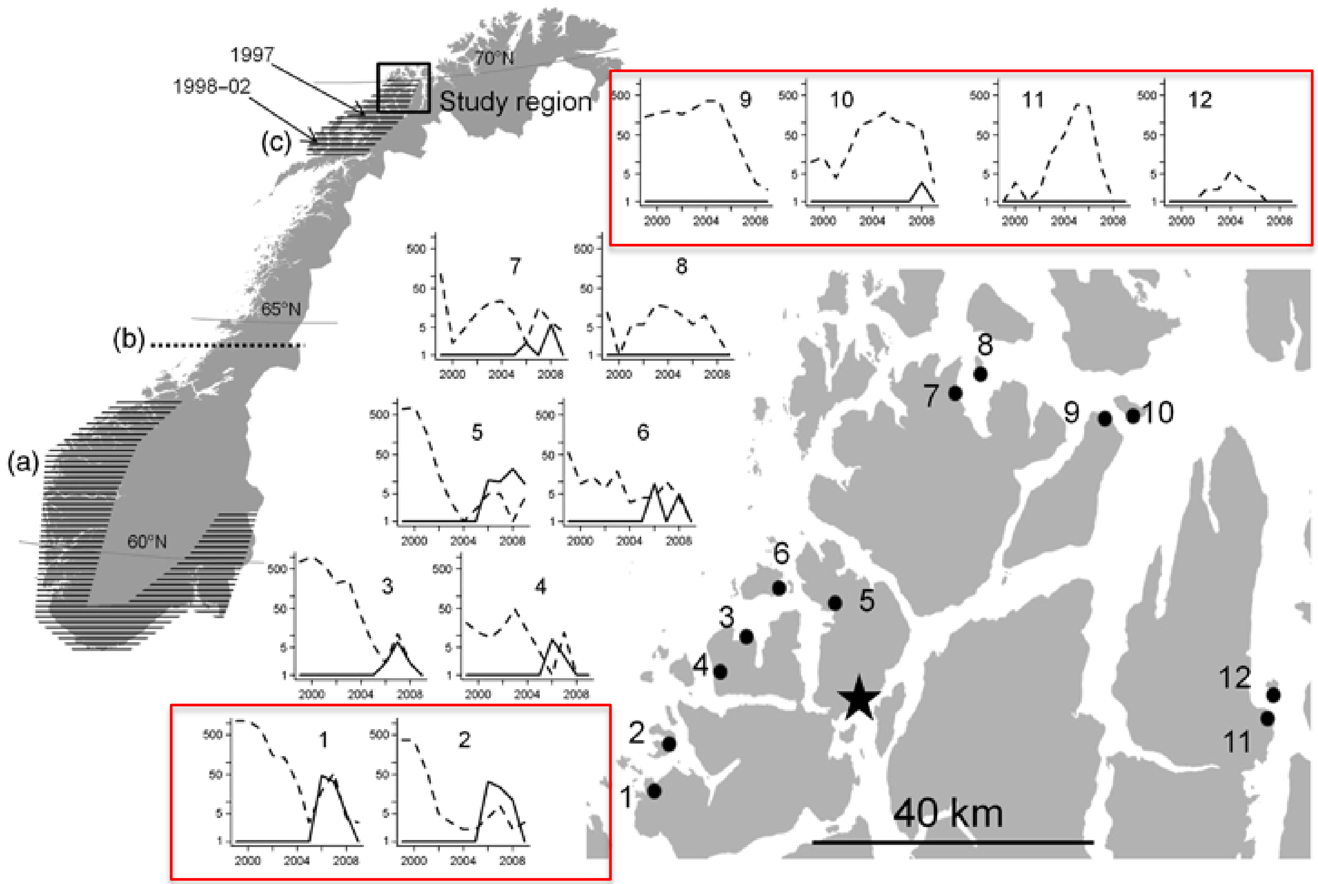

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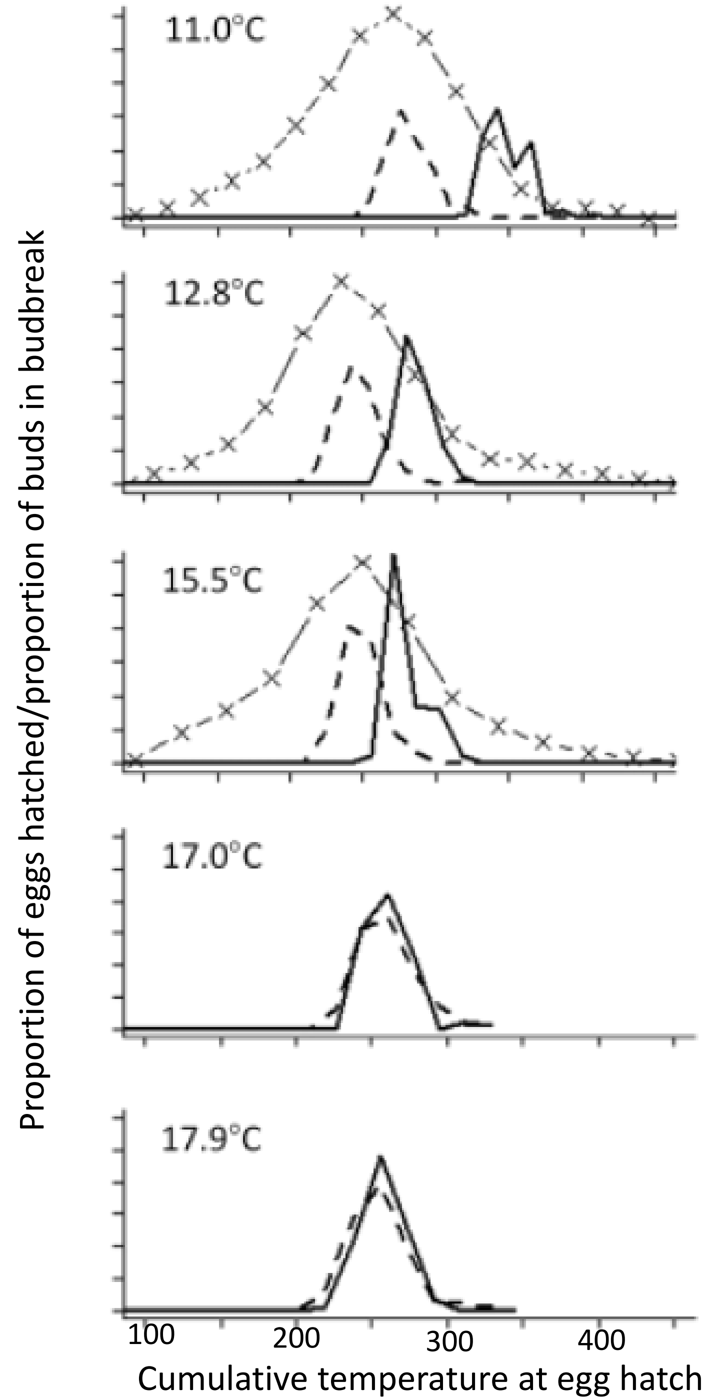
Jepsen et al. 2011, *Global Change Biology*

Warming promotes increased matching of plant & pest phenologies

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

——— = scarce umber moth
– – – – – = winter moth
x– x—x—x–x– = birch bud break



Jepsen et al. 2011, *Global Change Biology*

What are some other ways that species ranges may shift in response to climate change?

Photo: Wayne Bart

What are some other ways that species ranges may shift in response to climate change?


Photo: Wayne Bart

Rapid Range Shifts of Species Associated with High Levels of Climate Warming

I-Ching Chen,[1,2] Jane K. Hill,[1] Ralf Ohlemüller,[3] David B. Roy,[4] Chris D. Thomas[1]*

Science
AAAS

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

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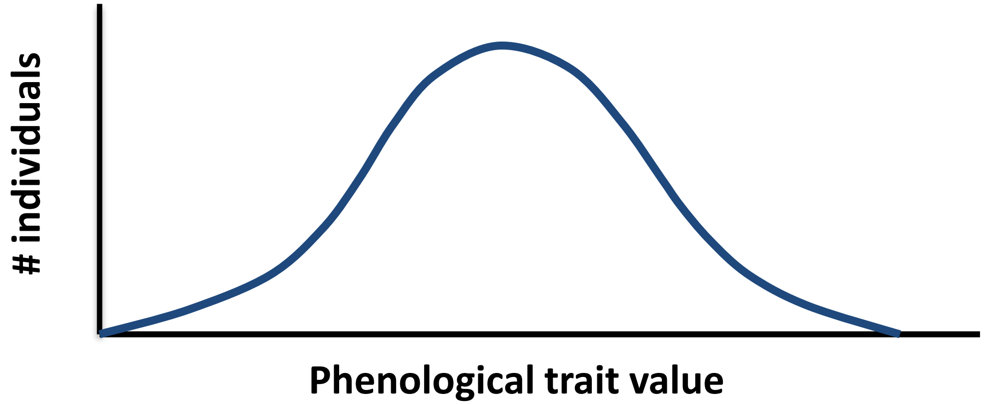
Populations may evolve in response to climate change *if*:

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

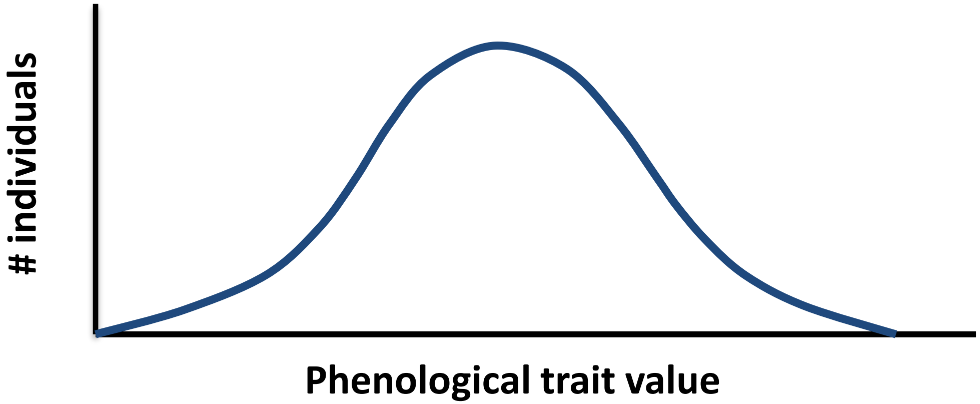


Phenological schedules may evolve in response to climate change

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**.



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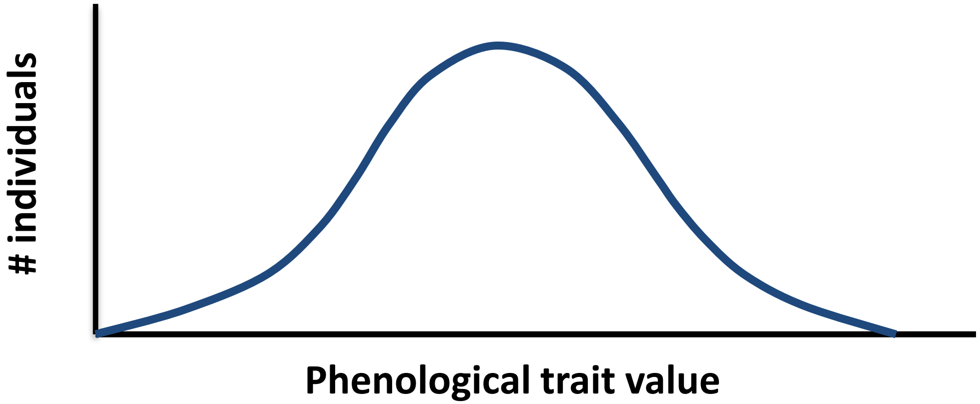
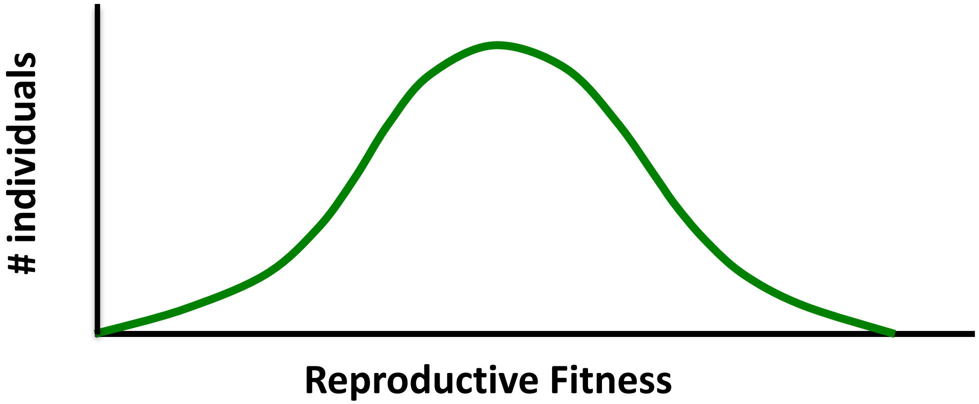
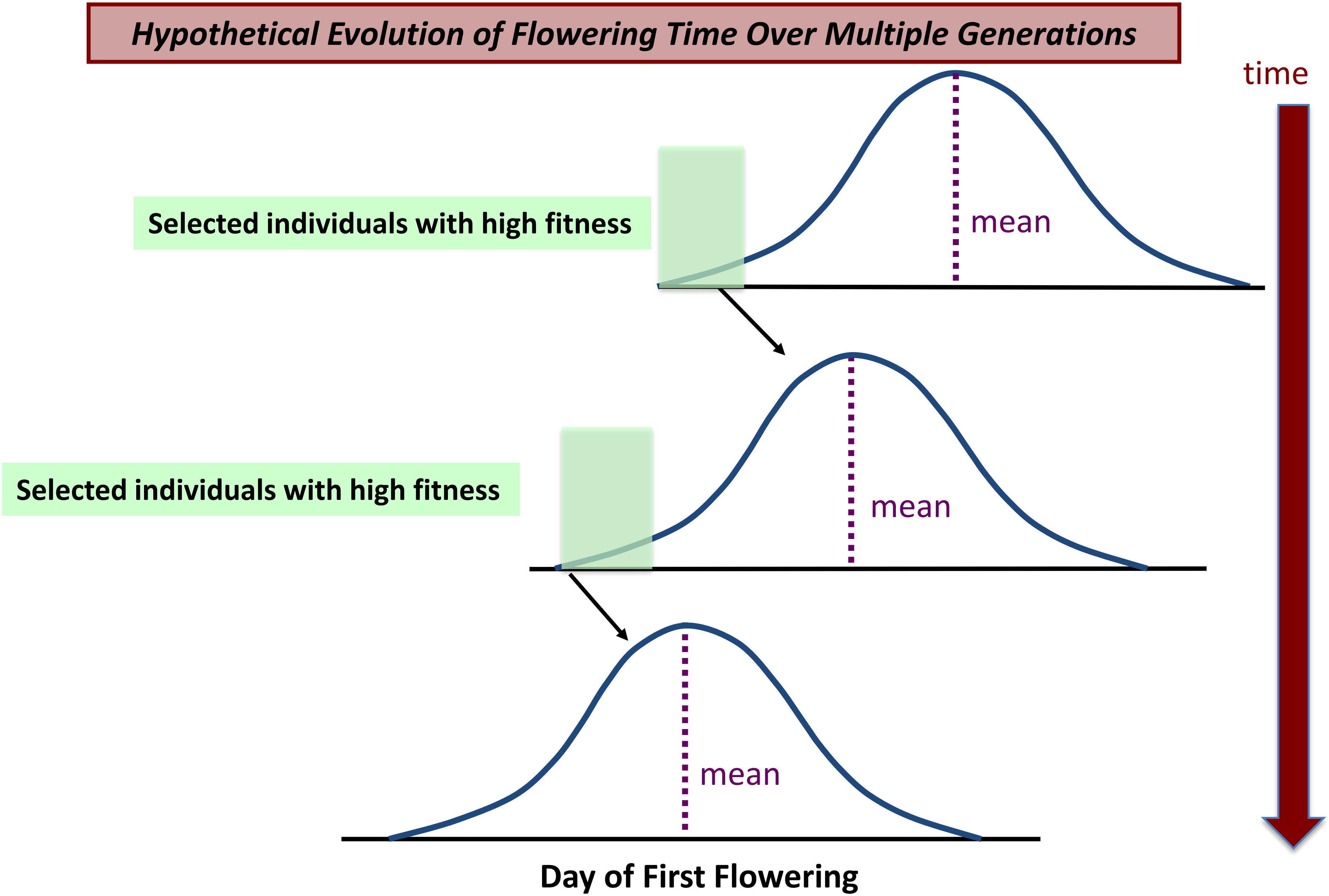


3. Reproductive fitness **varies** among individuals within populations



Evolution: change in trait values over time



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

Field Mustard

Photo: TuenSpaans

Franks et al. 2007, *PNAS*

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Field Mustard

"**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.

Franks et al. 2007, *PNAS*

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- Flowering time is genetically-based in field mustard

Field Mustard

Photo: TuenSpaans

Franks et al. 2007, *PNAS*

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Field Mustard

"**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

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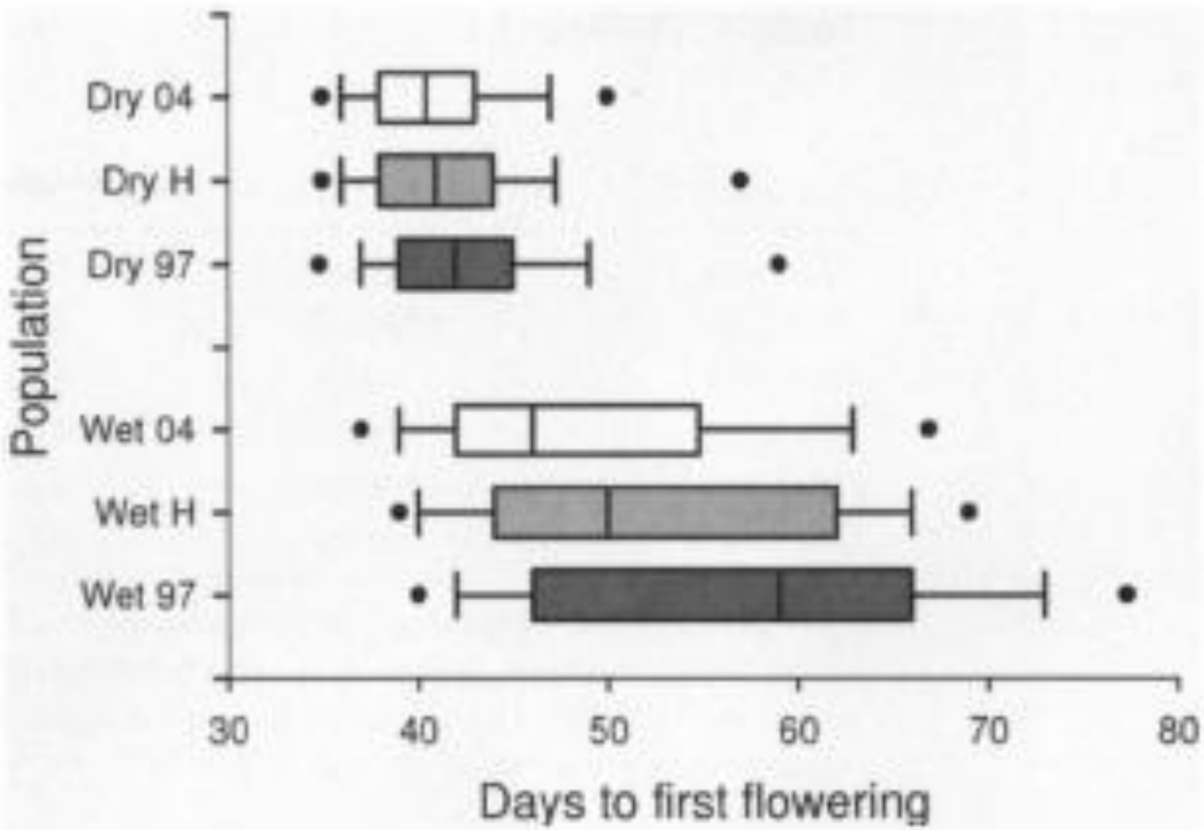

Field Mustard

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

PNAS

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[†,‡], 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

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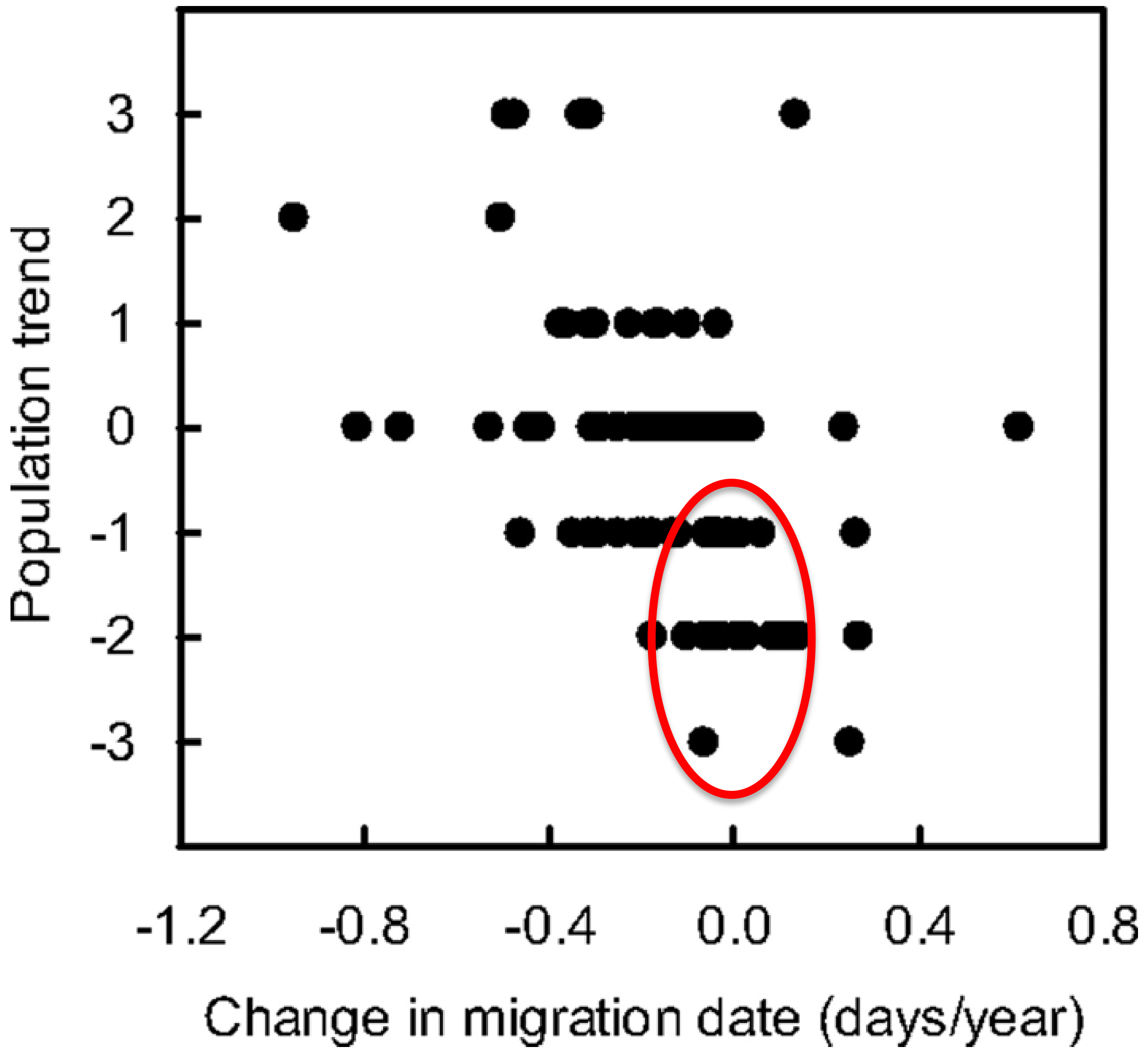
Extinction Risk and Phenology:
climate change and bird migration



Møller et al. 2008, *PNAS*

Summary

- Biological significance of phenological schedules (Pilson 2000)
- 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)
- Phenological mismatches induced by climate change (Both et al. 2006)
- Long-term outcomes of phenological change in wild populations
  - ❖ Geographic range shifts (Jepsen et al. 2011)
  - ❖ Adaptation (Franks et al. 2007)
  - ❖ Extinction (Møller et al. 2008)

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