Climate Change and Phenology

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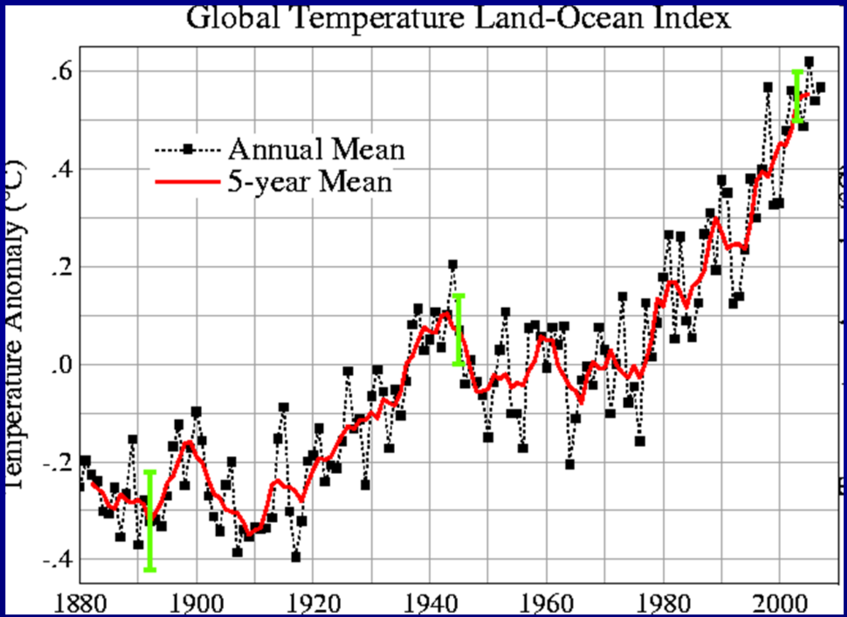
Climate change and phenology:

- Phenological change as evidence of global warming.
- Global warming and the distribution of species.
- Changes in insect life cycles (short and long-term).
- Decoupling of species interactions.
- Atmospheric CO_2, plant quality, and herbivores.

The 10 warmest years since 1000 AD:

1. 2005, 2010
3. 2009
4. 1998
5. 2007
6. 2002
7. 2006
8. 2003
9. 2004
10. 2001

Source: NASA Goddard Institute for Space Studies



Consilience: convergence of evidence

3 independent surface temperature records:
NASA, NOAA, Hadley Climate Research Unit

Corroborated by:

- 2 satellite records of upper and lower troposphere
- Weather balloons
- Proxy reconstructions (e.g. tree rings, boreholes, ice cores, glaciers, coral, etc.)
- Changes in Earth's physical and biological systems.

30 year trends:

1. Increasing air temperature in lower atmosphere.
2. Increasing temperature over land.
3. Increasing temperature over oceans.
4. Increasing sea-surface temperature.
5. Increasing ocean heat content.
6. Increasing humidity.
7. Increasing sea level.
8. Decreasing glacier cover.
9. Decreasing sea ice cover.
10. Decreasing snow cover.

NOAA National Climatic Data Center, 2010

There is no relationship between solar activity and recent warming.

PROCEEDINGS OF THE ROYAL SOCIETY A

FirstCite e-publishing

Proc. R. Soc. A
doi:10.1098/rspa.2007.1880
Published online

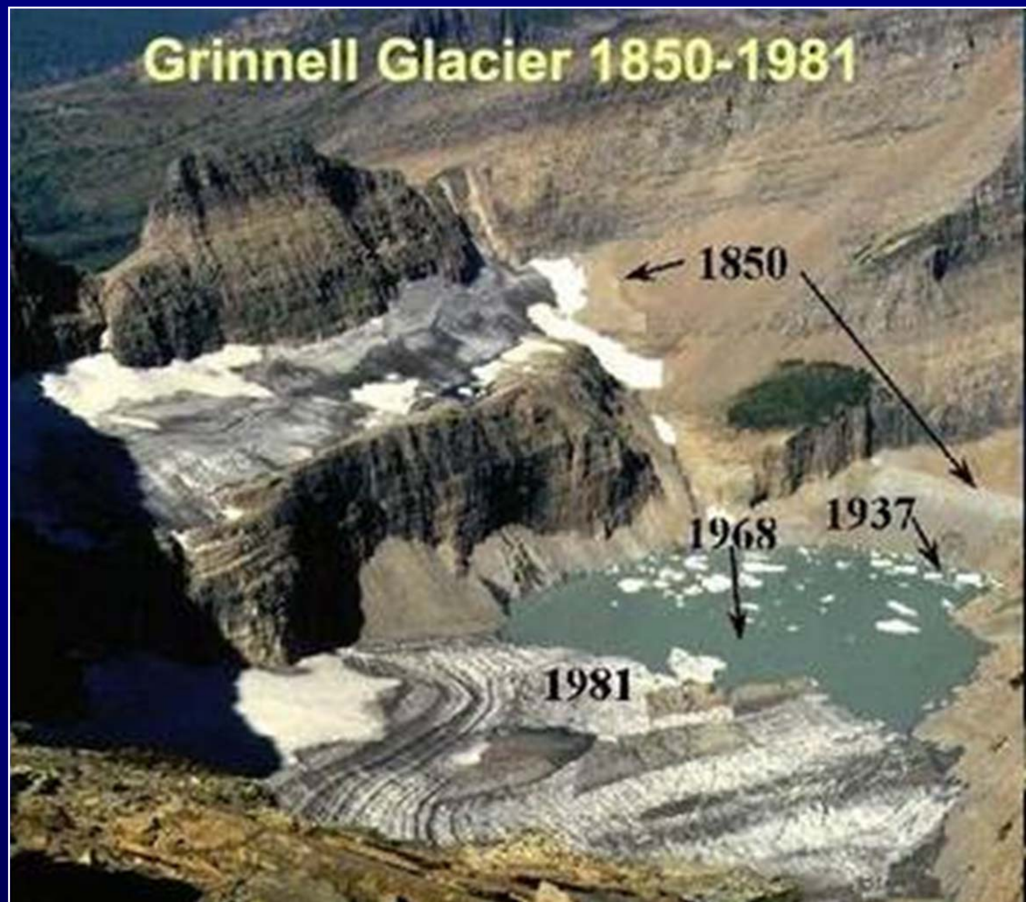
Recent oppositely directed trends in solar climate forcings and the global mean surface air temperature

BY MIKE LOCKWOOD[1,2,*] AND CLAUS FRÖHLICH[3]

[1] *Rutherford Appleton Laboratory, Chilton, Oxfordshire OX11 0QX, UK*
[2] *Space Environment Physics Group, School of Physics and Astronomy, University of Southampton, Southampton SO17 1BJ, UK*

Glacier National Park:

Number of glaciers in 1910 when park formed: 150
Number of glaciers today: 25

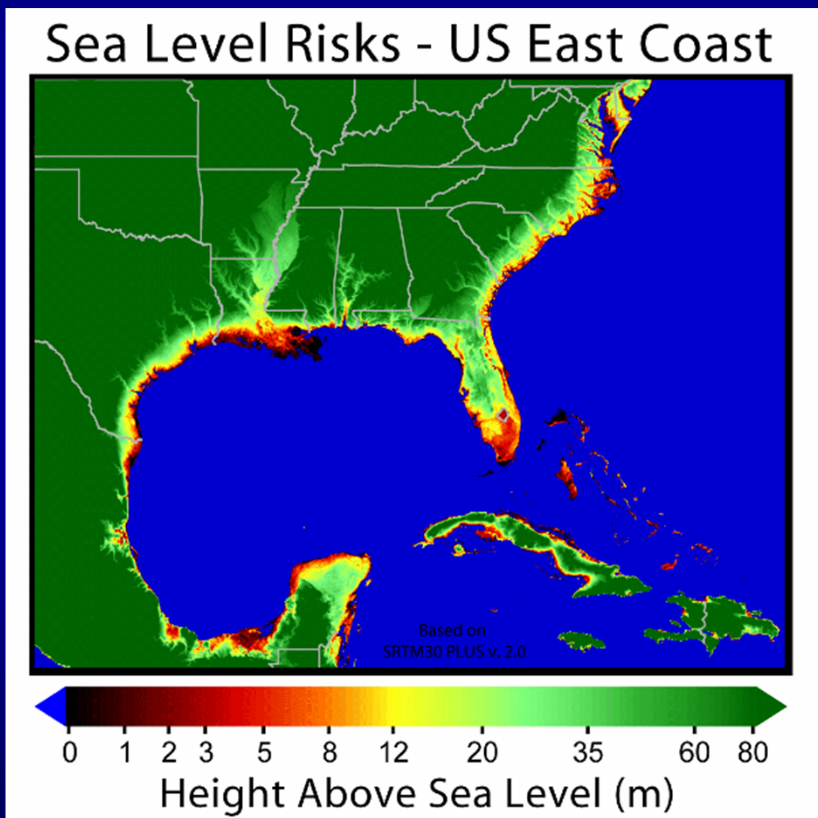


http://www.globalwarmingart.com

Global Change Biology (2007) 13, 2349–2360, doi: 10.1111/j.1365-2486.2007.01440.x

Sea-level rise and drought interactions accelerate forest decline on the Gulf Coast of Florida, USA

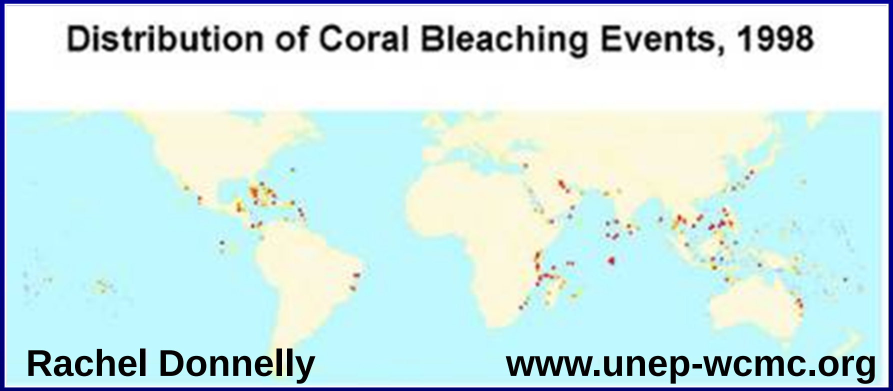
LARISA R. G. DESANTIS*, SMRITI BHOTIKA†, KIMBERLYN WILLIAMS‡ and FRANCIS E. PUTZ§



http://www.globalwarmingart.com

http://discoverbiodiversity.com/LarisaDeSantis.html

Coral is bleaching across the globe



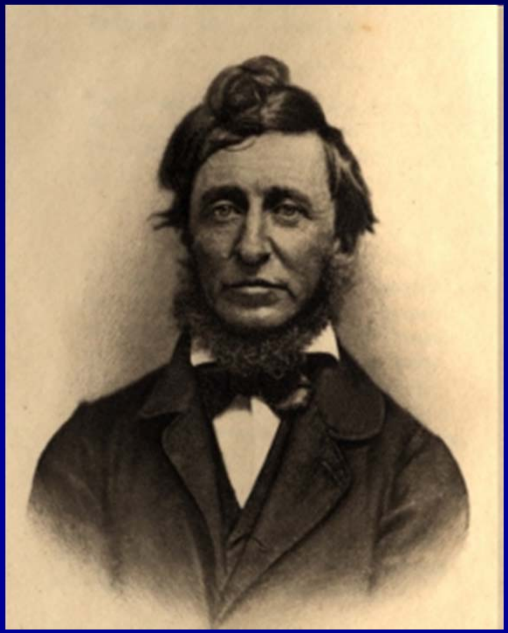
Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. *Marine and Freshwater Research* 50:839–866.

Extreme heat reduces and shifts United States premium wine production in the 21st century

M. A. White[*,†], N. S. Diffenbaugh[‡], G. V. Jones[§], J. S. Pal[¶], and F. Giorgi[¶]

PNAS (2006) 103:11217-11222

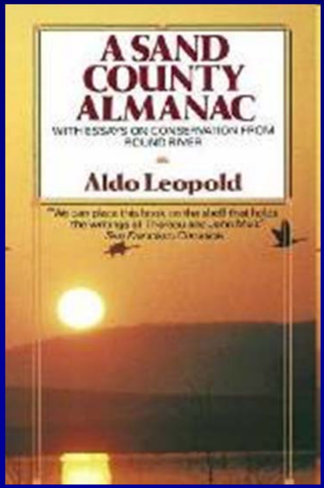
Climate change at Thoreau's Walden Pond



"We determined that plants bloomed seven days earlier on average than they did in Thoreau's times."

Miller-Rushing and Primack. 2008. Global warming and flowering times in Thoreau's Concord: a community perspective. *Ecology* 89:332-341.

Climate change and phenology at Sand County, WI



"The mean of regressions for the 55 phenophases studied was -0.12 day / yr, an overall increase in phenological earliness…"

Bradley et al. 1999. Phenological changes reflect climate change in Wisconsin. *PNAS* 96:9701-9704.

Change in growing season from satellite imagery

(days / decade)

Observation period	Geographic range	Earlier leafout	Longer growing season	Reference
1981 – 1991	45 N 70 N, Eurasia	8	12	Myneni *et al*. (1997a)
1981 – 1999	40 N 70 N, Eurasia	3.5	9.4	Zhou *et al*. (2001)
1981 – 1999	40 N 70 N, North America	4.3	6.3	Zhou *et al*. (2001)
1982 – 2001	25 W 60E; 27 N 72 N, Europe	5.4	9.6	Stöckli & Vidale (2004)

Badeck et al. 2004. Responses of spring phenology to climate change. *New Phytologist* 162:295-309

Bird phenology

Between 1971 and 1995 the laying date for many species of British birds has shifted earlier by an average of 9 days.

(*Nature* 388: 526)

Breeding date of North American common murre advanced by 24 days / decade

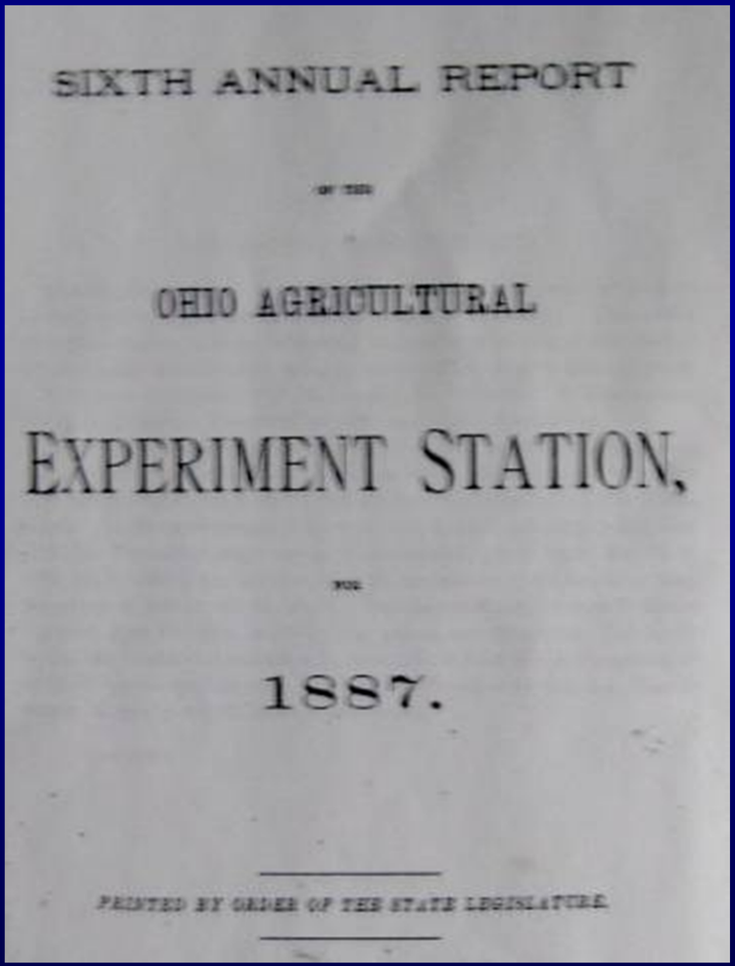
Toad phenology

Bufo bufo in southern England, 1980-2001.

Adult arrival at pond advanced by 11 d per 1°C of warming.

Reading, C. J. 2003. The effects of variation in climatic temperature (1980-2001) on breeding activity and tadpole stage duration in the common toad, *Bufo bufo*. *Sci. Tot. Environ.* 310, 231-236.

Extensive series of phenological records of native plants for Columbus at the dawn of the Industrial Revolution (1882-1887)


SIXTH ANNUAL REPORT

OHIO AGRICULTURAL

EXPERIMENT STATION,

1887.

PRINTED BY ORDER OF THE STATE LEGISLATURE.

OARDC is part of the National Phenology Network that has documented earlier springs in NA

Global Change Biology (2006) 12, 343–351, doi: 10.1111/j.1365-2486.2005.01097.x

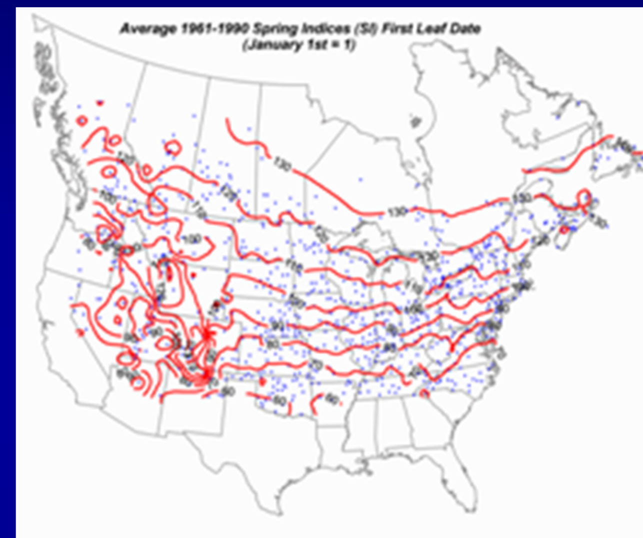
Onset of spring starting earlier across the Northern Hemisphere

MARK D. SCHWARTZ*, REIN AHAS† and ANTO AASA†

*Department of Geography, University of Wisconsin-Milwaukee, Milwaukee, WI 53201-0413, USA,
Vanemuise Str. 46, University of Tartu, 51014 Tartu, Estonia

Abstract

Recent warming of Northern Hemisphere (NH) land is well documented
greater in winter/spring than other seasons. Physical environment response
have been reported, but not details of large-area temperate growing seaso



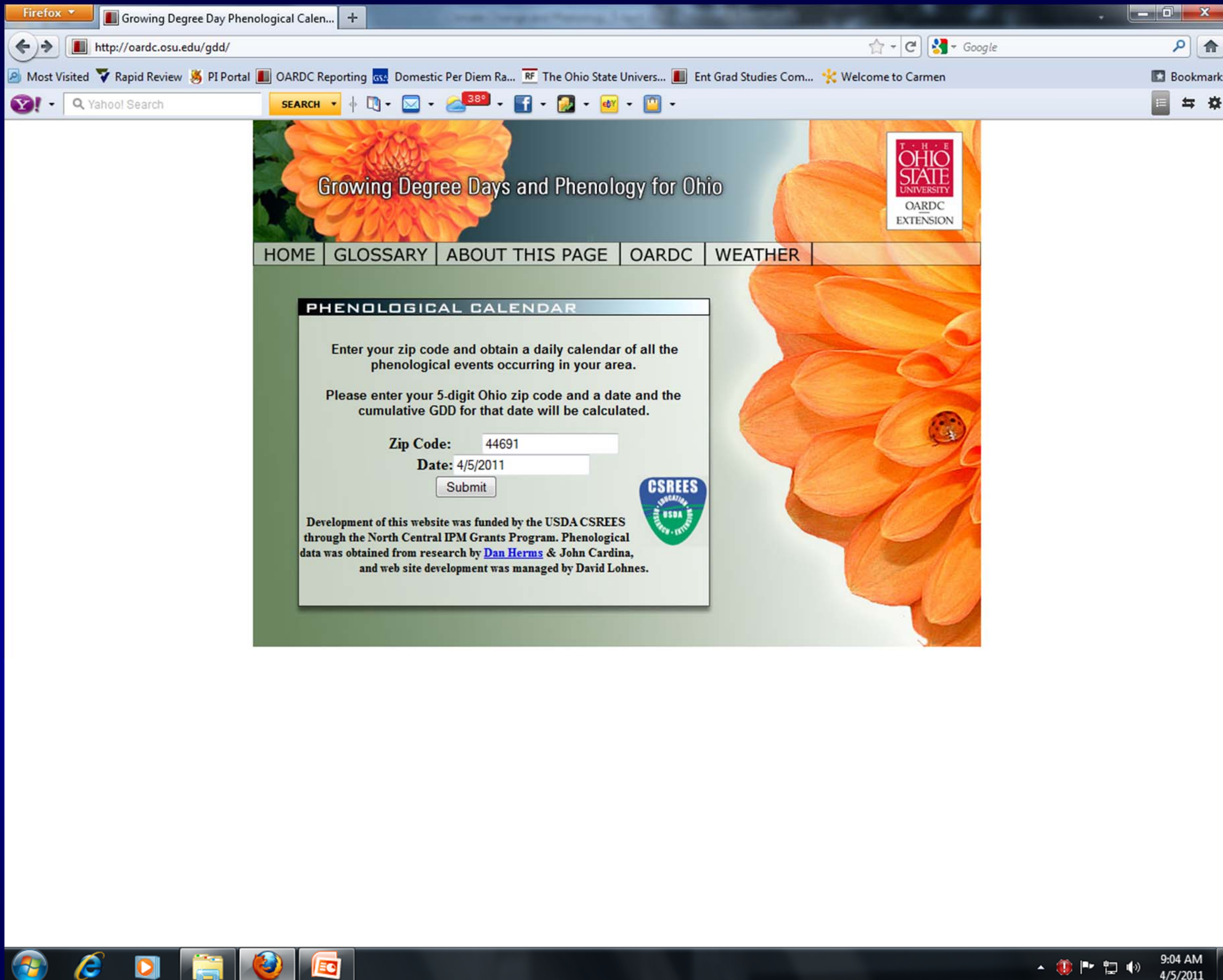
Lilac bloom as a phenological indicator of continental-scale climate change.

Black vine weevil now emerging 2-3 weeks earlier than in 1970


D.G. Nielsen, Ohio State University


Gina Penny


D.G. Nielsen, Ohio State University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PHENOLOGICAL CALENDAR
Enter your zip code and obtain a daily calendar of all the phenological events occurring in your area.
Please enter your 5-digit Ohio zip code and a date and the cumulative GDD for that date will be calculated.
Zip Code: 44691
Date: 4/5/2011
Submit
CSREES
Development of this website was funded by the USDA CSREES through the North Central IPM Grants Program. Phenological data was obtained from research by Dan Herms & John Cardina, and web site development was managed by David Lohnes.
9:04 AM
4/5/2011

http://www.oardc.ohio-state.edu/gdd

Growing Degree Days and Phenology for Ohio

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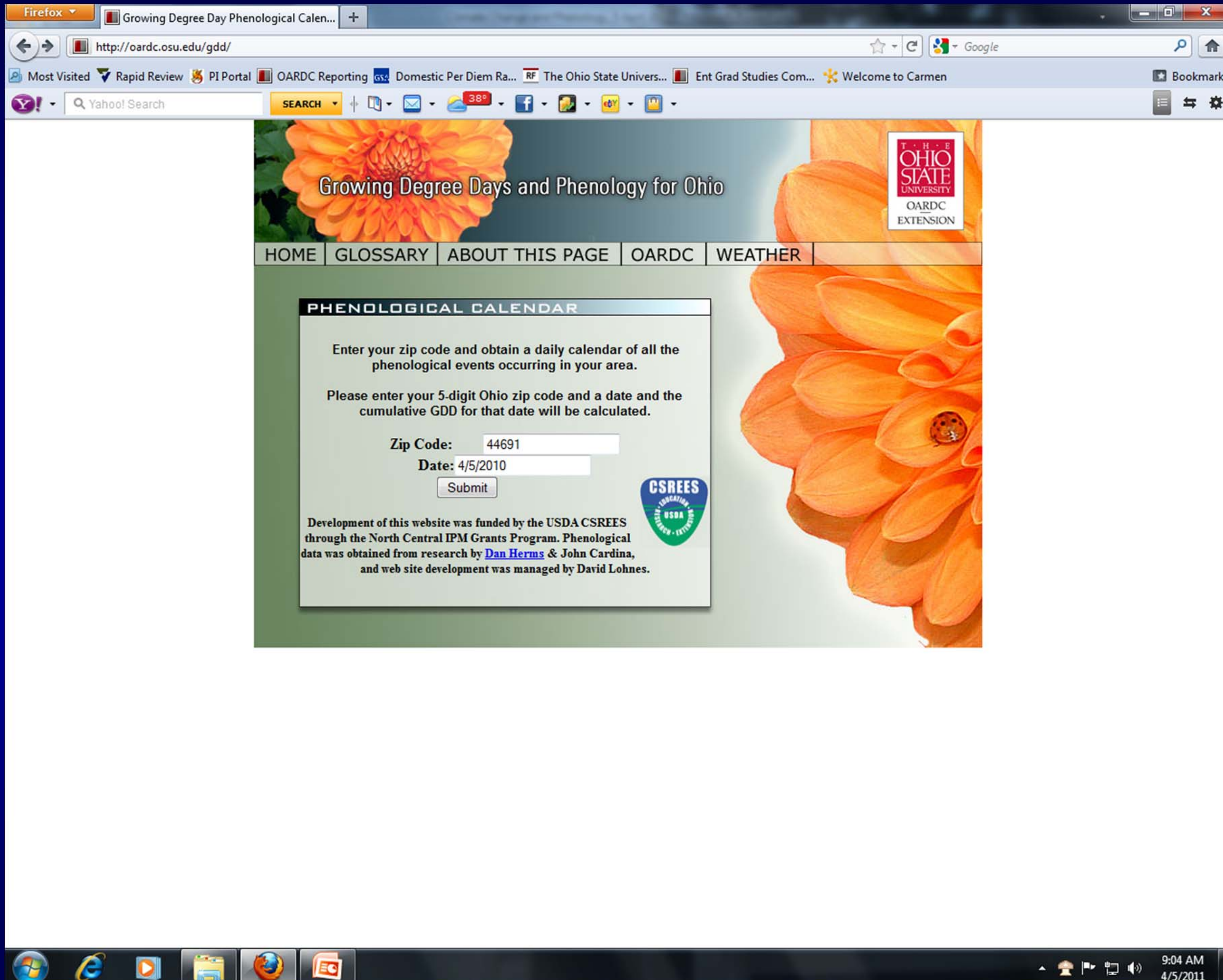
The GDD of Wooster on 4/5/2011 is 43

Summary of Phenological Events

Species	Phenological Event	GDD	Link
Silver Maple	first bloom	34	F P P
Corneliancherry Dogwood	first bloom	40	F F
Silver Maple	full bloom	42	F P P
Species	**Event**	**Growing Degree Days**	**Link**
Wooster		43	
Red Maple	first bloom	44	F P P
Speckled Alder	first bloom	52	F F
Northern Lights Forsythia	first bloom	58	F
Japanese Pieris	first bloom	60	F F
Red Maple	full bloom	75	F P
Star Magnolia	first bloom	83	P P F
White Pine Weevil	adult emergence	84	F
Border Forsythia	first bloom	86	F F
Eastern Tent Caterpillar	egg hatch	92	F
Manchu Cherry	first bloom	93	F F
Northern Lights Forsythia	full bloom	94	F
Speckled Alder	full bloom	97	F F
Corneliancherry			



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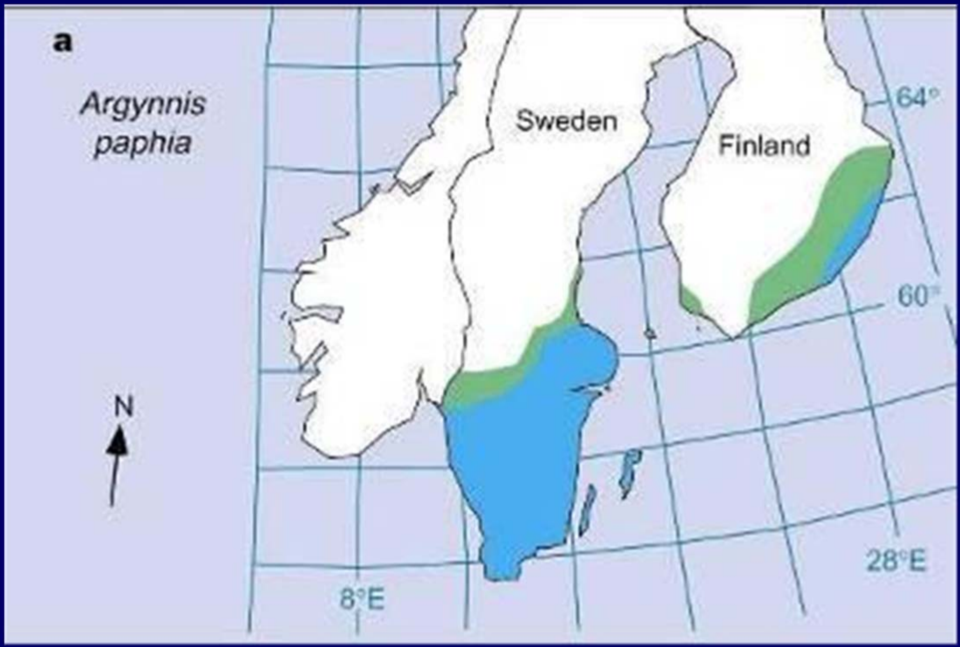
9:04 AM
4/5/2011

Species	Event	Growing Degree Days	Link
Border Forsythia	first bloom	[illegible]	F F
Eastern Tent Caterpillar	egg hatch	92	F
Manchu Cherry	first bloom	93	F F
Northern Lights Forsythia	full bloom	94	F
Speckled Alder	full bloom	97	F F
Corneliancherry Dogwood	full bloom	98	F F
Norway Maple	first bloom	116	F M
Border Forsythia	full bloom	116	F F
Species	**Event**	**Growing Degree Days**	**Link**
Wooster		**117**	
Chanticleer Callery Pear	first bloom	123	F F F
Sargent Cherry	first bloom	127	F F
Larch Casebearer	egg hatch	128	F
Japanese Pieris	full bloom	129	F F
Saucer Magnolia	first bloom	133	P P F
Common Floweringquince	first bloom	137	F F
Bradford Callery Pear	first bloom	142	F F
European Pine Sawfly	egg hatch	144	F F
Weeping Higan Cherry	first bloom	145	M F
PJM Rhododendron	first bloom	147	M
Norway Maple	full bloom	149	F F
Chanticleer Callery Pear	full bloom	149	F F F
Inkberry Leafminer	adult emergence	150	M
Star Magnolia	full bloom	151	P P F
Sargent Cherry	full bloom	151	F F

In this century, the range of 23 of 35 European butterfly species shifted north 35-240 km

Argynnis paphia



Parmesan et al. 1999. Nature 399:579-583

The largest recorded bark beetle outbreak in human history in northern British Columbia where winters used to be too cold for the beetles to survive.

http://www.for.gov.bc.ca/hfp

http://www.garna.org/

Dezene Huber, UNBC

Kurz et al. 2008. Mountain pine beetle and carbon feedback to climate change. *Nature* 452:987-990.

Journal of Applied Ecology

Journal of Applied Ecology 2010, **47**, 1036–1043 doi: 10.1111/j.1365-2664.2010.01848.x

Climate change and range expansion of an aggressive bark beetle: evidence of higher beetle reproduction in naïve host tree populations

Timothy J. Cudmore[1], Niklas Björklund[2], Allan L. Carroll[3] and B. Staffan Lindgren[1]*

Ghost Forests, Global Warming, and the Mountain Pine Beetle (Coleoptera: Scolytidae)

Outbreaks of the mountain pine beetle are an important part of ecological cycles in western pine forests and have provided researchers with insights into both the beetle's and the forest's evolutionary adaptability

Jesse A. Logan and James A. Powell

Logan and Powell (2001) *Amer Entomol*. 47:160-173

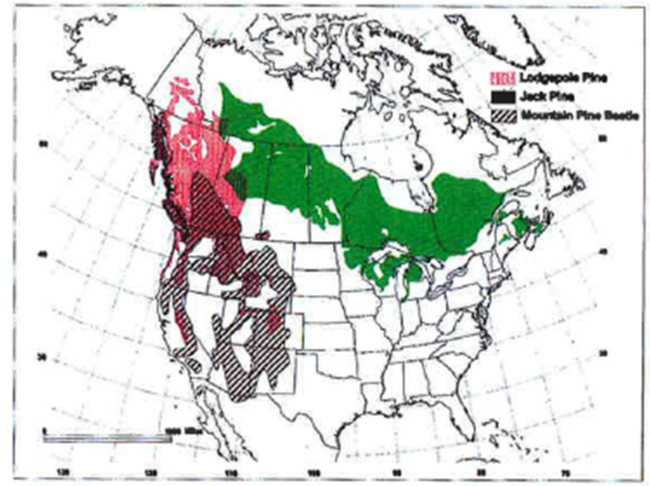
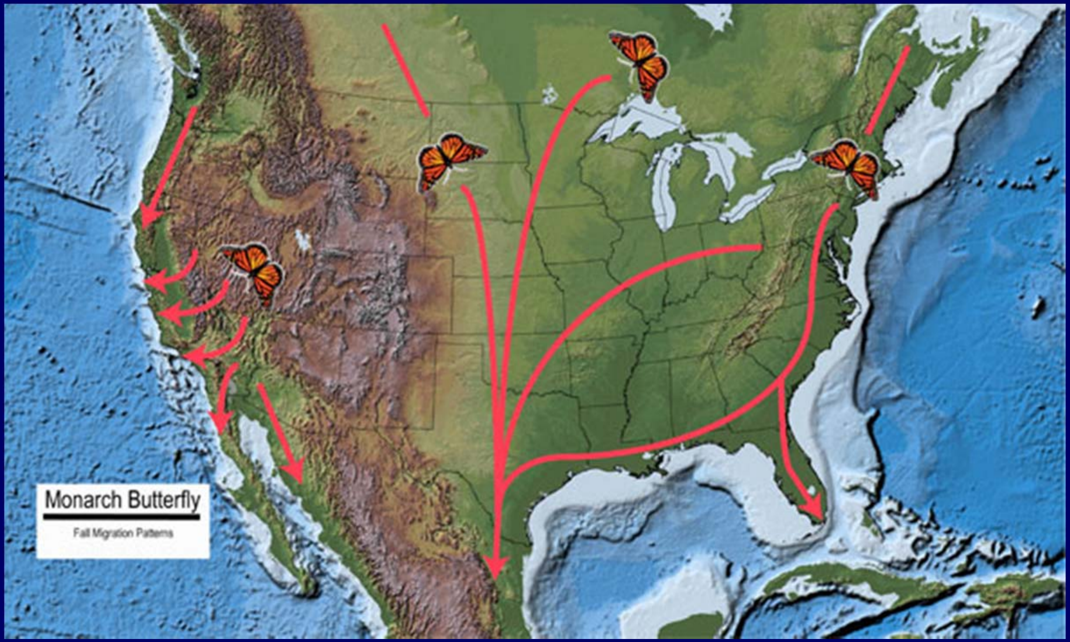


Fig. 10. Approximate current distribution of mountain pine beetle (hatched), lodgepole pine (red), and jack pine (green). As can be seen in this figure, the Great Plains provides an effective barrier separating mountain pine beetles from the U.S. distribution of jack pine. If this barrier is breached to the north due to a warming climate, then there is no apparent reason why a waterfall effect would not follow, spilling across the North American continent to jack pine in the Great Lakes region. Lodgepole pine and jack pine distributions are from map 21, Little and Critchfield (1969); and Canadian distribution of the mountain pine beetle is adapted from a map that can be found at the British Columbia Ministry of Forests website (http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/beetle/figure1.htm).

Fig. 2. The ecological services provided by whitebark and other high-elevation pines are many and varied. (A) The Rocky Mountains serve as headwaters for major rivers in North America. Most water accumulates as winter snow. As can be seen from the "windrows" of snow captured by the snow-fence effect of these limber pines, the high-elevation five-needle pines are important factors in the conservation and distribution of water. This ecological benefit is nowhere more appreciated than the arid west. (B) Many species of wildlife are dependent on the high nutritional quality of whitebark pine seeds, including the endangered grizzlies of the Greater Yellowstone Area. In years of poor seed production, the number of adverse encounters between the great bear and humans increases significantly (Mattson et al. 1992) (photo courtesy of Barrie Gilbert).

Mexico cuts down trees to save monarch butterflies

Many fir trees in Mexico that provide winter homes for monarch butterflies are being killed by bark beetles.



Implications of Climate Change for Agricultural Pest Management

OARDC SEEDS Interdisciplinary Project

Robin A. J. Taylor
Department of Entomology

John Cardina
Department of Horticulture & Crop Science

Daniel A. Herms
Department of Entomology

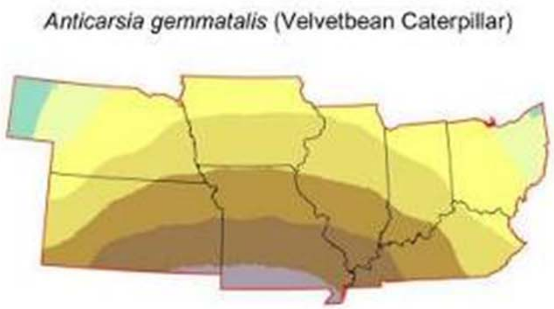
Richard H. Moore
Human and Community Resource Development

Phenological Modeling

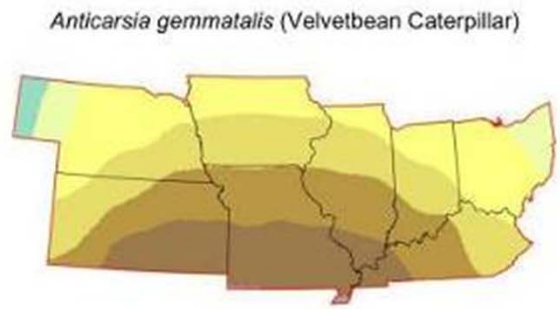
1. Based on GFDL (NOAA) global circulation model CM2-SRES-B1 scenario developed for IPCC-4A

2. Assumes political will exists to stabilize climate warming by 2050

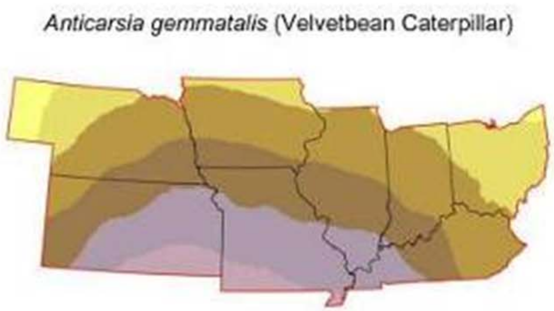
Velvetbean Caterpillar



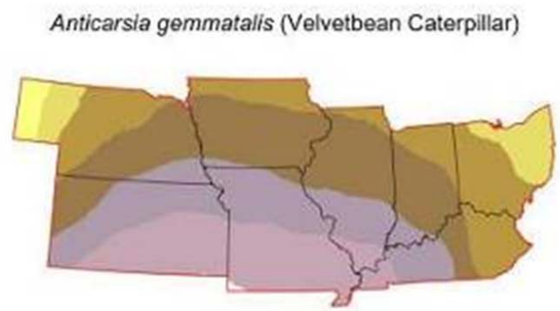
Generations per Year 1901-1950



Generations per Year 1951-2000



Generations per Year 2001-2050

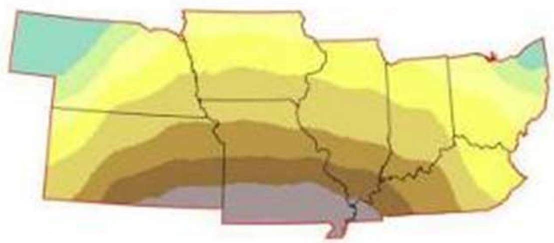


Generations per Year 2051-2100

European Corn Borer

www.organicgardeninfo.com

Ostrinia nubilalis (European Corn Borer)

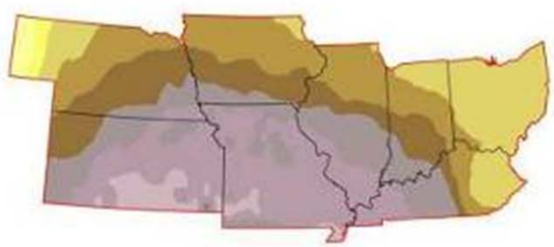


Generations per Year 1901-1950

Ostrinia nubilalis (European Corn Borer)

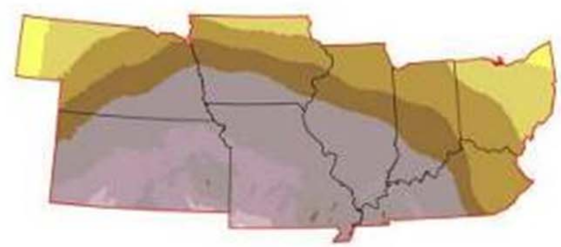
Generations per Year 1951-2000

Ostrinia nubilalis (European Corn Borer)



Generations per Year 2001-2050

Ostrinia nubilalis (European Corn Borer)



Generations per Year 2051-2100

Ecological Effects of Temperature: Host Interactions

Ayers and Scriber (1994) Local adaptation to regional climates in *Papilio canadensis* (Lepidoptera: Papilionidae). *Ecol. Monogr.* 465-482.

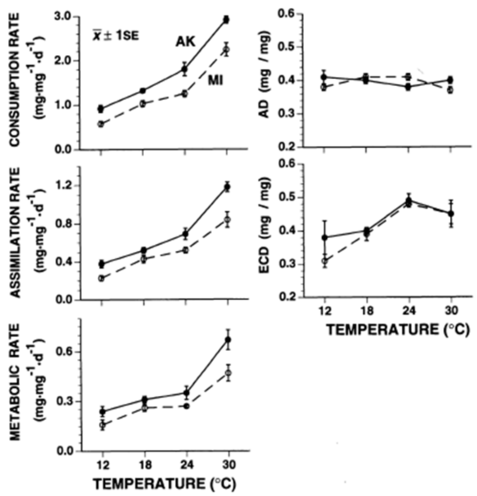


FIG. 5. Dry mass budgets as a function of temperature of *Papilio canadensis* fifth instars feeding on *Populus tremuloides* in 1989. ● and ○ represent *P. canadensis* from Alaska and Michigan, respectively. Corresponding growth rates appear in lower right of Fig. 3.

Elevated metabolic rate (respiration):

- Faster growth rates at lower temp (doubling time : 5.8 vs 9.1 days at 12C
- Faster molts at lower temp

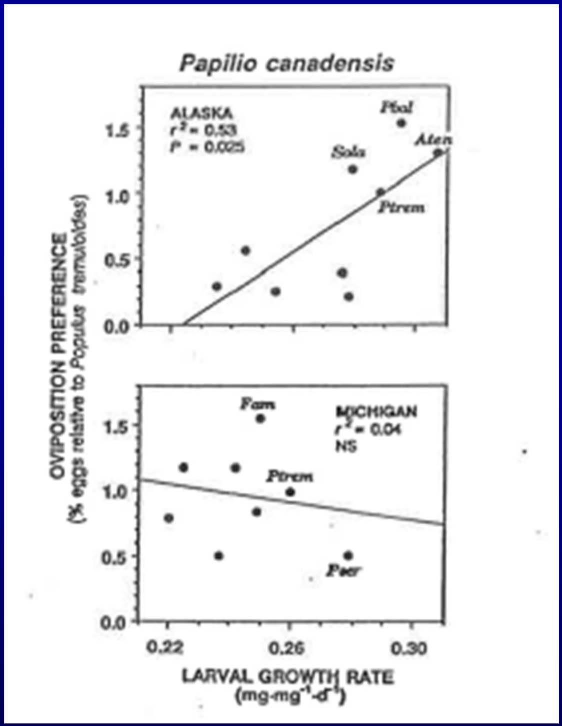
Life history traits:

- 36% larger eggs (but fewer laid)
- Smaller adult body size
- Generate fitness trade-offs

Note: RGR = RCR * AD * ECD

When DD accumulation for completing a generation is not limiting (Scriber & Lederhouse 1992):

Relaxed selection pressure on relative growth rate
Other factors become relatively more important: e.g. enemy free space (differential predation rates on different host plants)



Temperature, host quality, and the distribution of species

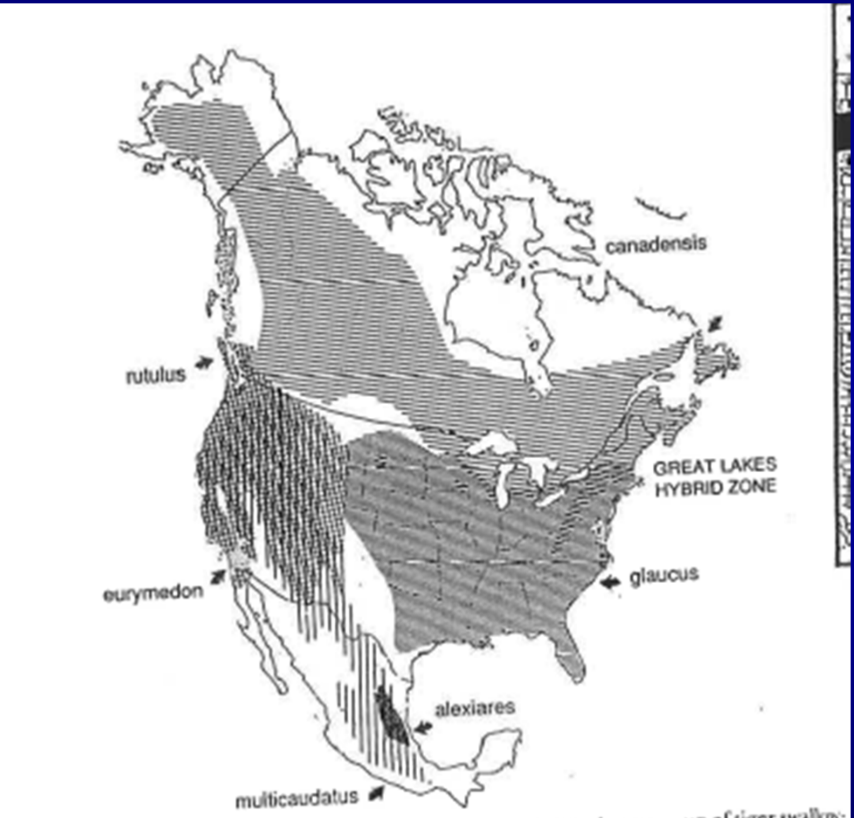
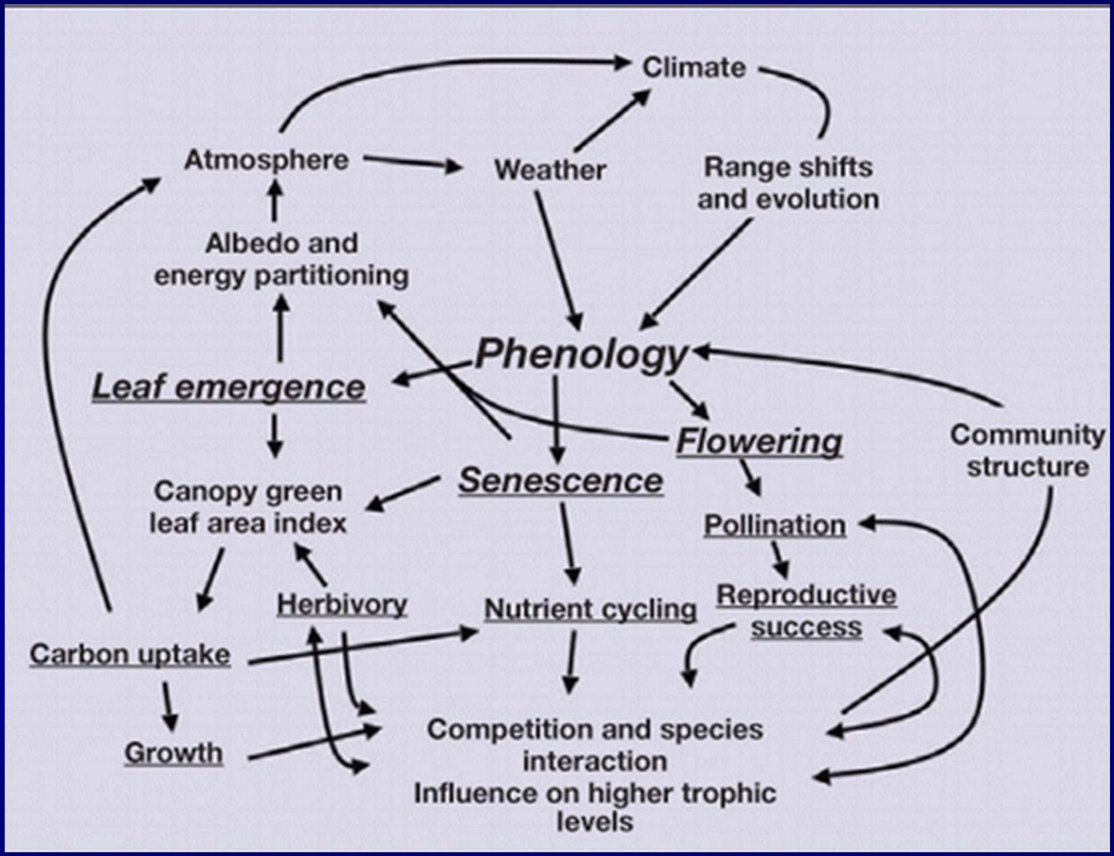


Figure 1 The current geographic distribution of the *Papilio glaucus* group of tiger swallowtail butterfly species in North America. After Brower (1959a); Beutelspacher and Howe (1984).

Phenology, Communities, and Ecosystems



Morisette et al. 2009. *Frontiers in Ecology and the Environment* 5(7):253-260

Global warming and phenological asynchrony

Interacting species with differential responses to increased temperature. For example:

Plant - herbivore interactions

Plant - pollinator interactions

Predator-prey interactions

Bird migration and prey availability

Phenological synchrony (and asynchrony)

Phenological Window Hypothesis

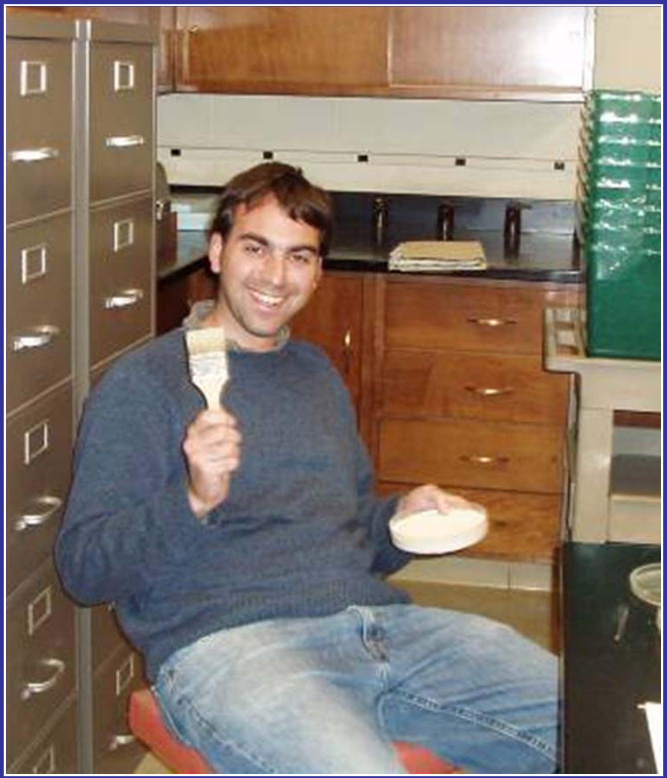
(Feeny 1976, Mattson et al. 1982)

- A “window” of time when host traits are most suitable for the insect

- Predicts that insect growth and survival will decline as host-insect synchronicity is modified

European pine sawfly

(*Neodiprion sertifer*)



Dr. Rodrigo Chorbadjian

Constrained life-cycle

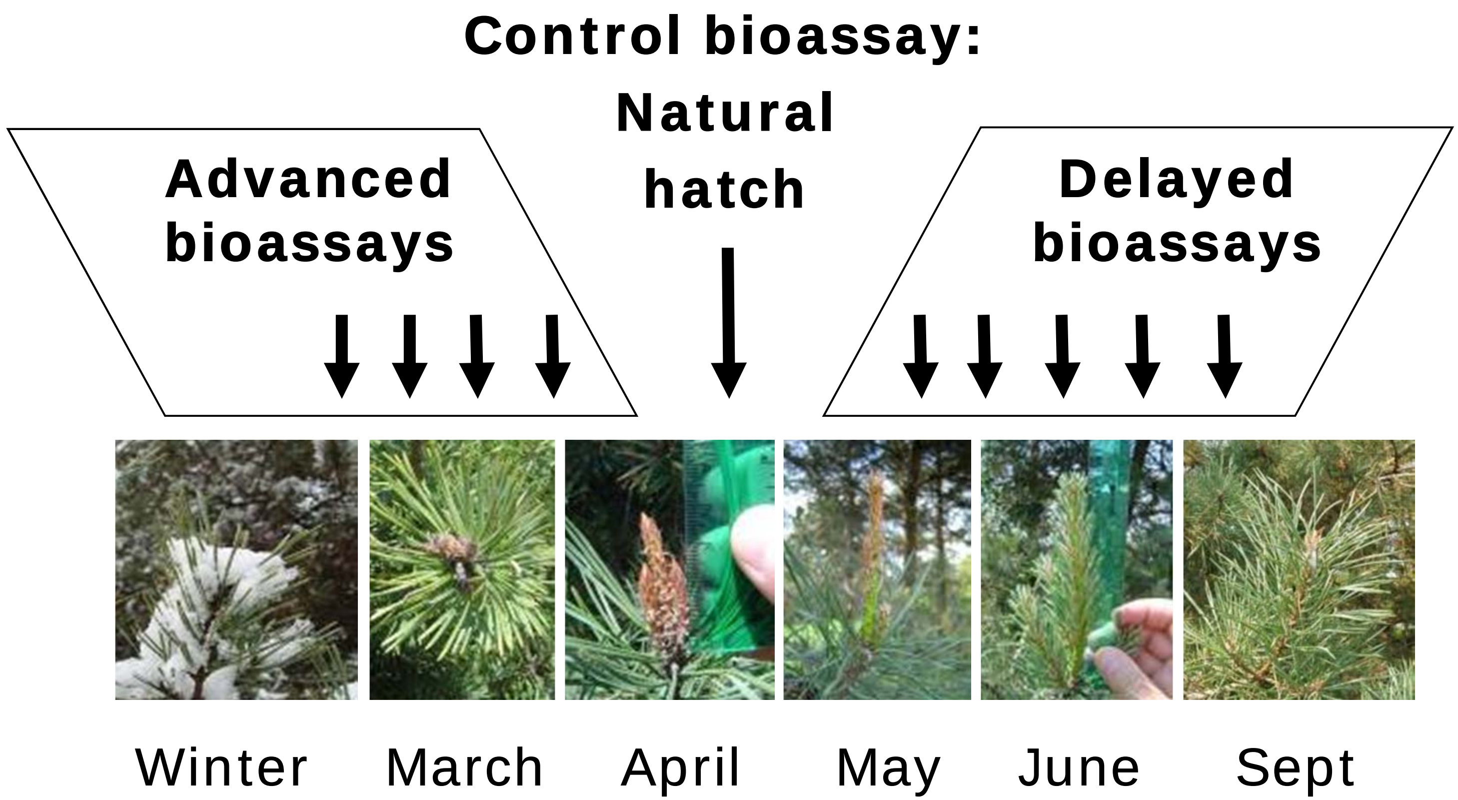
One generation each year

Feeds on previous-year needles during a short window of time

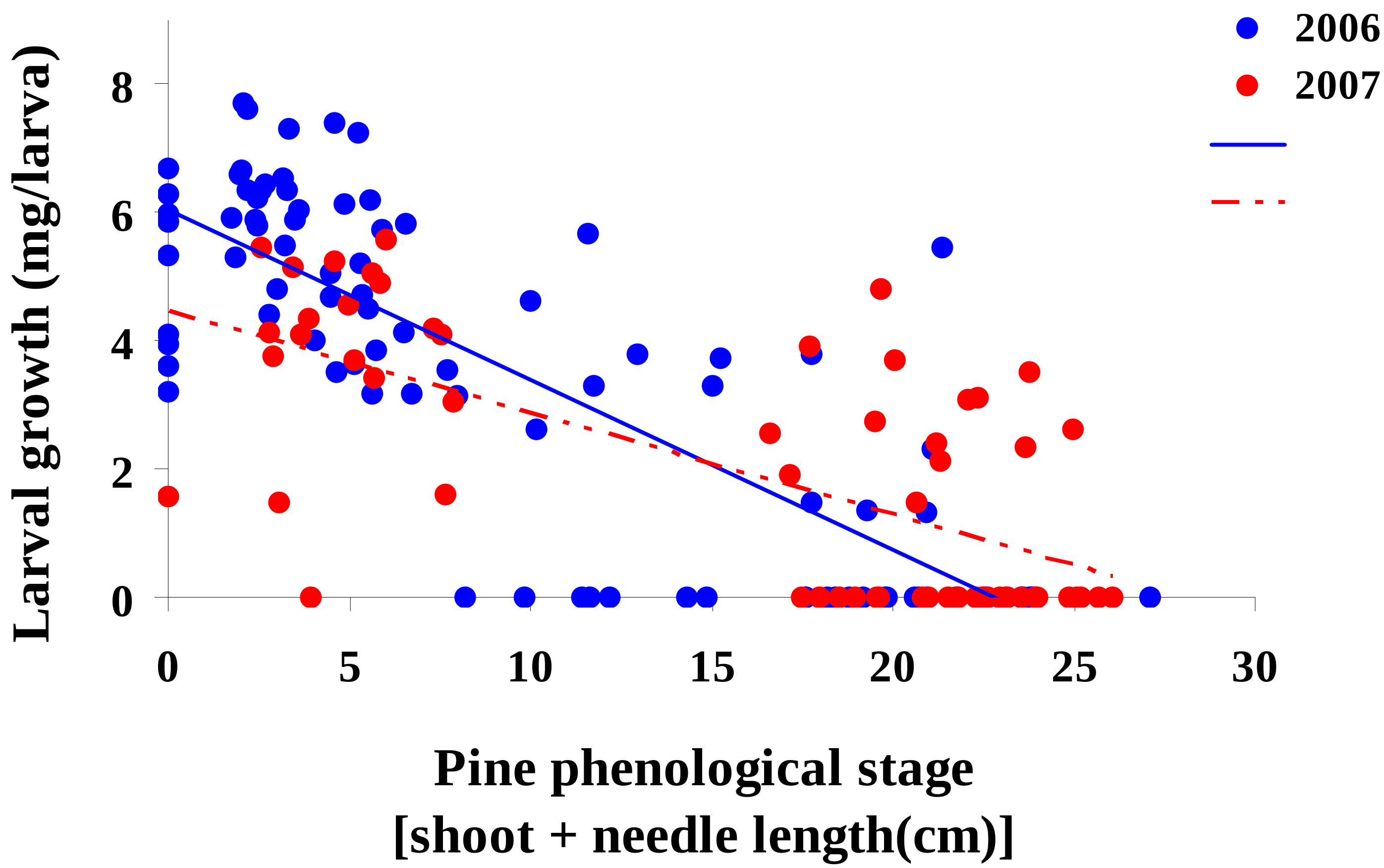
Hatch → cocoon

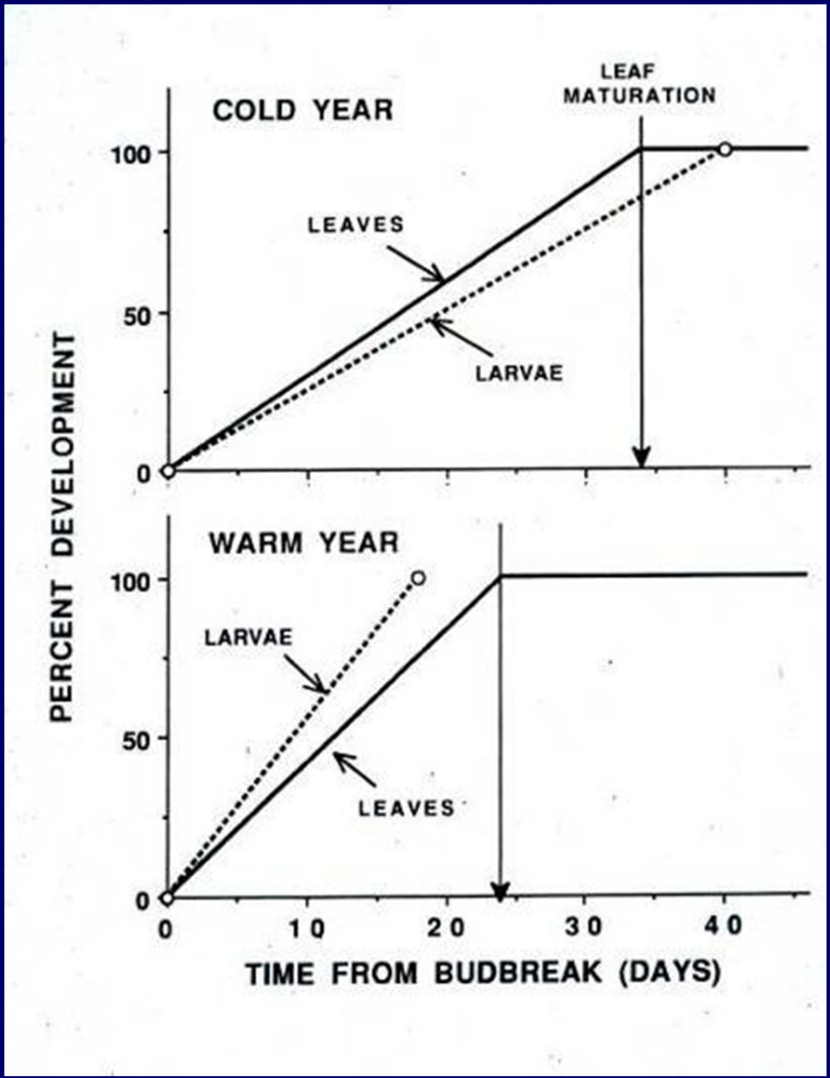
Winter April May June --- Sept

Insect phenology manipulated relative to natural host phenology



As shoots expanded, food quality declined





Phenological race hypothesis

- Mature leaves are of lower nutritional quality than immature leaves
- Insects and leaves have different temperature responses

Changes in temperature during larval development can affect the outcome of the phenological race between plant and herbivore.

Ayres, M.P. (1993) Global change, plant defense, and herbivory. *Biotic interactions and global change* (eds P. M. Kareiva, J. G. Kingsolver & R. B. Huey), pp. 75-94. Sinauer Associates, Sunderland, MA.

Ecological Effects of Temperature: Predator / Parasite Interactions

Encarsia / whitefly interactions

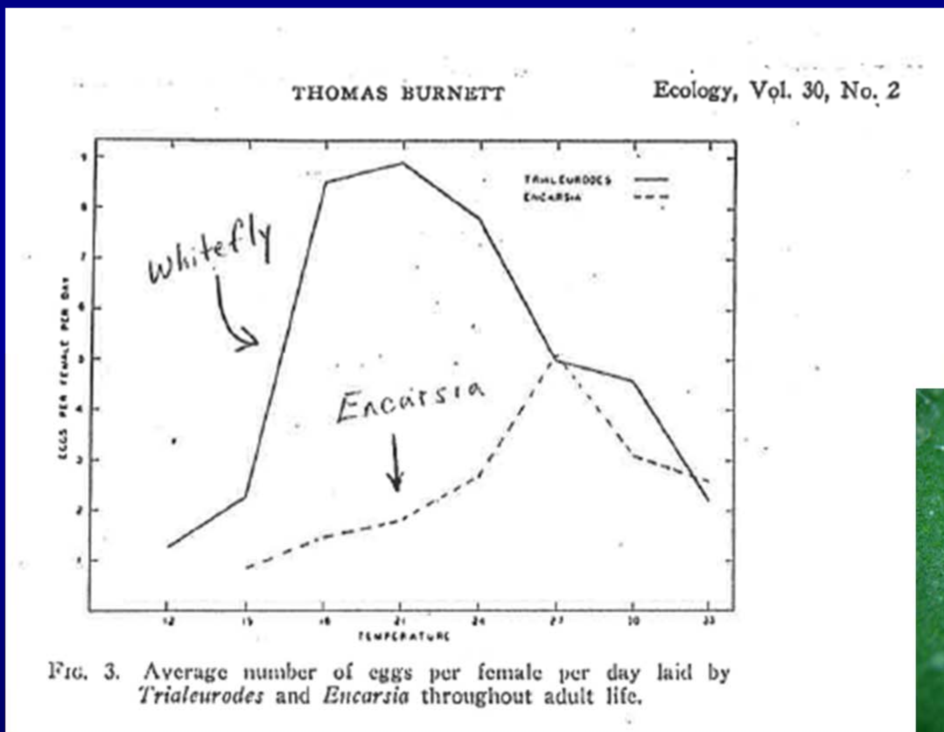
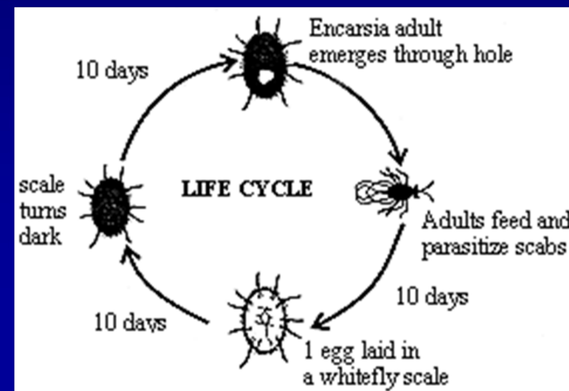


FIG. 3. Average number of eggs per female per day laid by *Trialeurodes* and *Encarsia* throughout adult life.



Plant / pollinator interactions

"A few studies have shown that climate warming may generate temporal mismatches among mutualistic partners.

…their demographic consequences are largely unknown."

Hegland et al. 2009. How does climate warming affect plant-pollinator interactions? *Ecology Letters* 12:184-195.

Accelerated phenology of bird migration

Long-distance migrants have advanced their spring arrival in Scandinavia more than short-distance migrants.

Jonzén et al. 2006. Rapid advance of spring arrival dates in long-distance migratory birds. *Science* 312:1959-1961

Bird phenology and asynchrony with food supply:

Geese not able to acquire adequate body stores quickly enough to breed before the quality of food for their young decreased.

Van Der Jeugd et al. 2009. Keeping up with early springs: rapid range expansion in an avian herbivore incurs a mismatch between reproductive timing and food supply. Global Change Biology 15:1057-1071

J Chem Ecol (2010) 36:2–21
DOI 10.1007/s10886-009-9731-4

REVIEW ARTICLE

Impacts of Elevated Atmospheric CO_2 and O_3 on Forests: Phytochemistry, Trophic Interactions, and Ecosystem Dynamics

Richard L. Lindroth

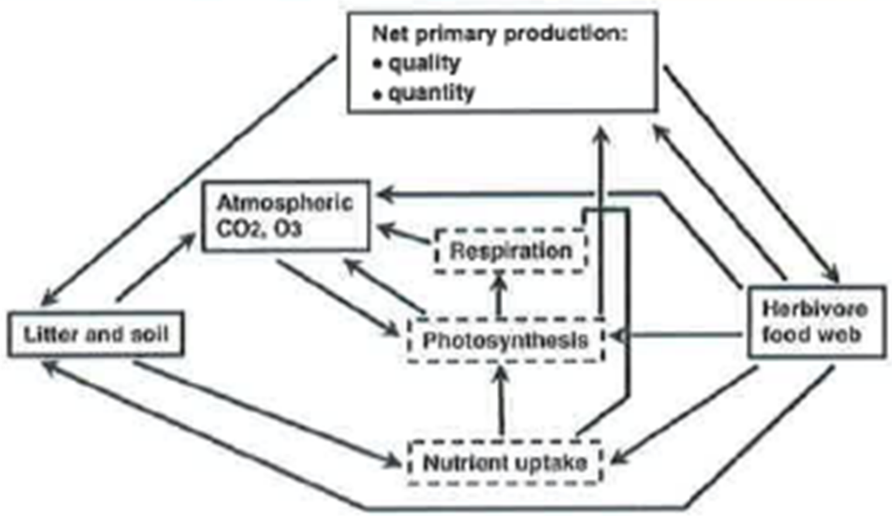
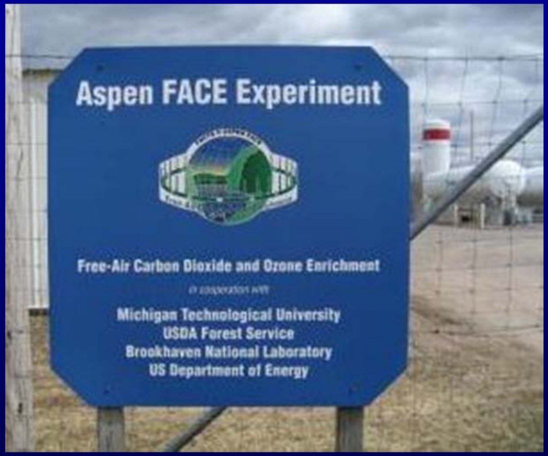


Fig. 1 Carbon cycling and storage in forest ecosystems. Solid boxes represent major pools; dashed boxes represent major plant physiological processes (adapted from Lindroth and Dearing 2005)

Vanessa Muilenburg

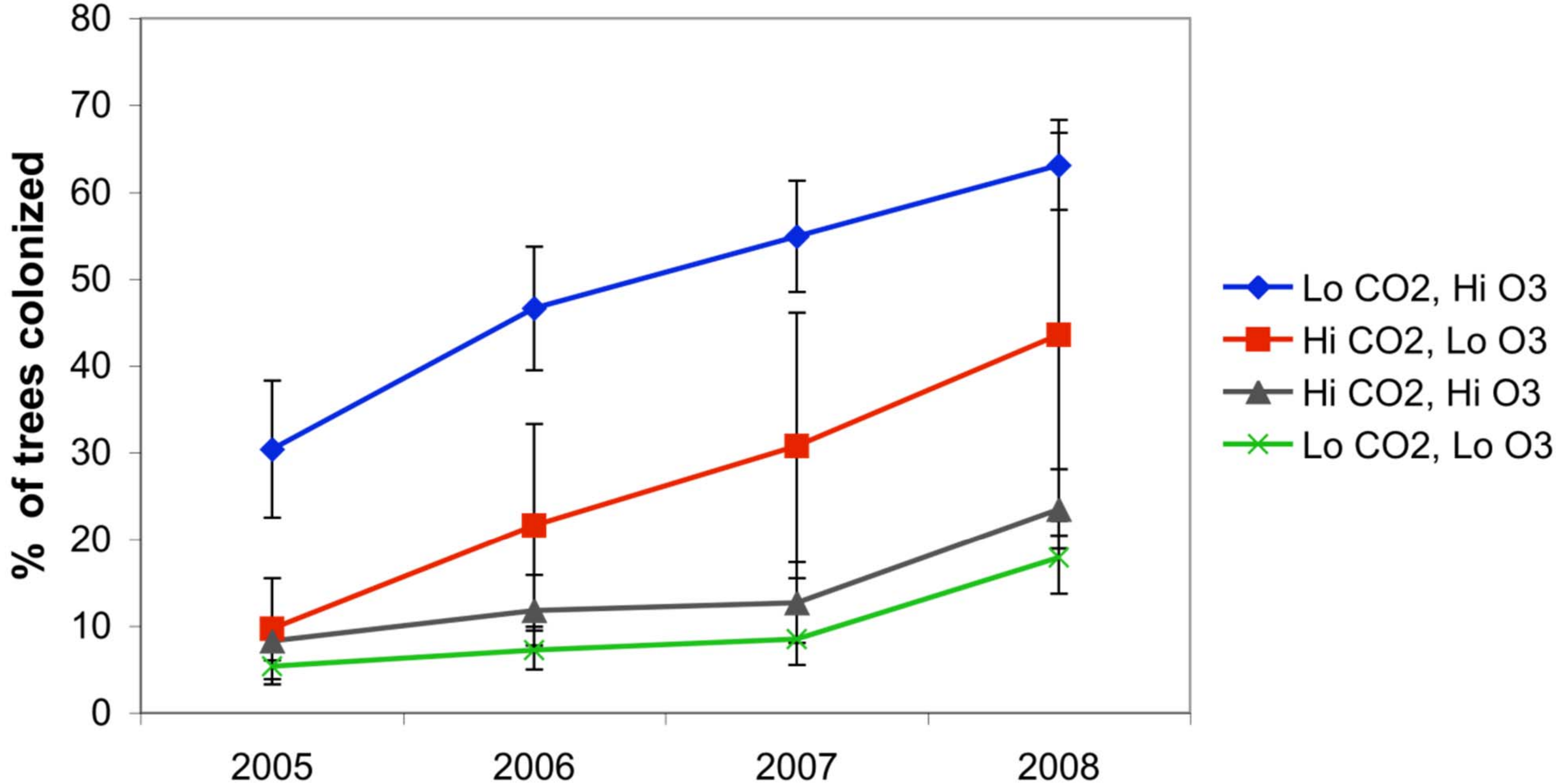


Elevated CO2, bronze birch borer, and the distribution of paper birch





% of Trees Colonized by Bronze Birch Borer



Elevated CO_2, bronze birch borer, and the distribution of paper birch

Insects take a bigger bite out of plants in a warmer, higher carbon dioxide world

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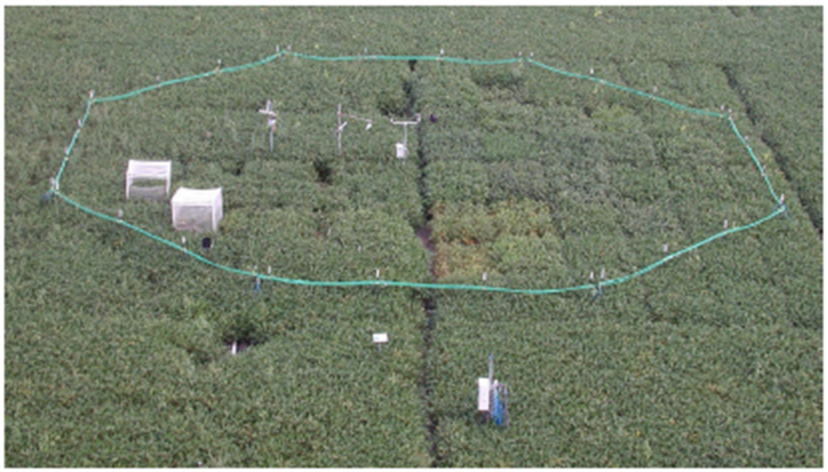
PNAS (2008) 105:1781-1782



Soybean FACE Site, Univ Illinois

Fig. 2. Japanese beetles (*Popillia japonica*) consuming soybean leaves. The Japanese beetle is a broadly polyphagous species introduced into the United States in 1916 that is now expanding its range throughout the Midwest (27). Japanese beetles are attracted to poorly defended, high-sugar soybean leaves that develop under elevated CO_2. Future increases in CO_2 and temperature may further the success of such destructive invasive species (28)

Increased CO_2 often decreases growth and survival of leaf-feeding insects as concentration of protein decreases and defensive compounds increase.

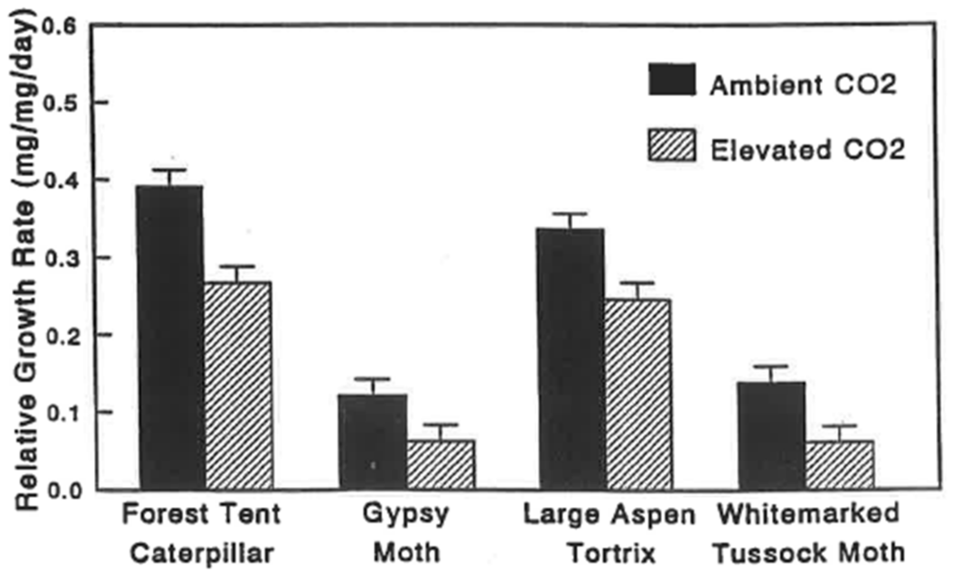


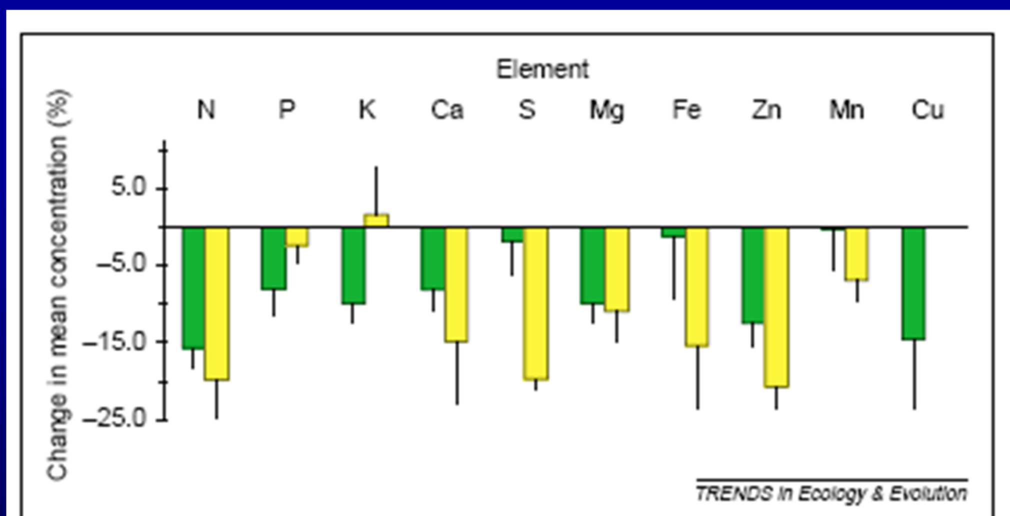
Figure 2. Effects of ambient and elevated CO_2 on the relative growth rate (RGR) of fourth instar forest tent caterpillar, gypsy moth, large aspen tortrix, and whitemarked tussock moth, feeding on quaking aspen. Data are expressed as least square means ± one standard error.

Not just insect nutrition:

Rising atmospheric CO_2 and human nutrition: toward globally imbalanced plant stoichiometry?

Irakli Loladze

Trends Ecol & Evol (2002) 17:457-461



All plants

Grains

Synthesis: Diversity, Distribution, and Abundance

Think about how global warming and elevated CO2 can have interacting effects on development rates, host quality, and nutritional ecology to alter:

- species distributions
- population dynamics
- ecological interactions
- community composition
- evolutionary trajectories


Acknowledgements:
Dr. Matthew Ayres, Dartmouth College
Dr. Lyn Loveless, College of Wooster