

Phenology Seminar Modules

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Overview

These educational discussion modules have been designed for college-level instructors to engage students in discussions about the integrative nature of phenological research. The modules are aimed at an audience of advanced undergraduate or early graduate students in the biological and environmental sciences. Each module includes:

- A list of general goals for student learning
- An overview of the module topic
- Brief summaries of selected peer-reviewed articles on the module topic
- A Glossary of relevant terms
- Questions to generate discussion among seminar participants
- Two to four selected peer-reviewed primary and/or review articles

There are a total of **nine** seminar modules; each module focuses on a different aspect of phenological research, incorporating a range of scientific disciplines, including ecology, evolution, biogeography, environmental science, and climatology. We encourage instructors to build from this foundation by integrating activities such as literature searches and data-driven analyses into their curriculum. Each module could be adapted for other audiences, particularly advanced high school students or motivated nature enthusiasts in informal science education settings. For more phenology-based educational resources, visit the Education page of the California Phenology Project (www.usanpn.org/cpp/education) or the USA National Phenology Network (www.usanpn.org/education).

Modules

1. Synthetic Studies Of Phenology: Reviews And Meta-Analyses

- Forrest, J., and A. J. Miller-Rushing. 2010. Toward a synthetic understanding of the role of phenology in ecology and evolution. *Philosophical Transactions of the Royal Society B-Biological Sciences* 365:3101-3112.
- Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology Evolution and Systematics* 37:637-669.
- Parmesan, C. 2007. Influences of species, latitudes and methodologies on estimates of phenological response to global warming. *Global Change Biology* 13:1860-1872.
- Wilczek, A. M., L. T. Burghardt, A. R. Cobb, M. D. Cooper, S. M. Welch, and J. Schmitt. 2010. Genetic and physiological bases for phenological responses to current and predicted climates. *Philosophical Transactions of the Royal Society B-Biological Sciences* 365:3129-3147.

2. Back To The Future: The Use of Historical Records in Phenological Research

- Miller-Rushing, A. J., and R. B. Primack. 2008. Global warming and flowering times in Thoreau's concord: A community perspective. *Ecology* 89:332-341.
- Primack, D., C. Imbres, R. B. Primack, A. J. Miller-Rushing, and P. Del Tredici. 2004. Herbarium specimens demonstrate earlier flowering times in response to warming in Boston. *American Journal of Botany* 91:1260-1264.
- Robbirt, K. M., A. J. Davy, M. J. Hutchings, and D. L. Roberts. 2011. Validation of biological collections as a source of phenological data for use in climate change studies: a case study with the orchid *Ophrys sphegodes*. *Journal of Ecology* 99:235-241.

3. Plant-Climate Interactions

- Haggerty, B. P., and L. F. Galloway. 2011. Response of individual components of reproductive phenology to growing season length in a monocarpic herb. *Journal of Ecology* 99:242-253.
- Inouye, D. W. 2008. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. *Ecology* 89:353-362.
- Thomson, J. D. 2010. Flowering phenology, fruiting success and progressive deterioration of pollination in an early-flowering geophyte. *Philosophical Transactions of the Royal Society B-Biological Sciences* 365:3187-3199.

4. Animal-Climate Interactions

- Møller, A. P., D. Rubolini, and E. Lehikoinen. 2008. Populations of migratory bird species that did not show a phenological response to climate change are declining. *Proceedings of the National Academy of Sciences of the United States of America* 105:16195-16200.
- Moyes, K., D. H. Nussey, M. N. Clements, F. E. Guinness, A. Morris, S. Morris, J. M. Pemberton, L. E. B. Kruuk, and T. H. Clutton-Brock. 2011. Advancing breeding phenology in response to environmental change in a wild red deer population. *Global Change Biology* 17:2455-2469.
- Ozgul, A., D. Z. Childs, M. K. Oli, K. B. Armitage, D. T. Blumstein, L. E. Olson, S. Tuljapurkar, and T. Coulson. 2010. Coupled dynamics of body mass and population growth in response to environmental change. *Nature* 466:482-U485.

5. Phenological Mismatches: Causes and Consequences

- Edwards, M., and A. J. Richardson. 2004. Impact of climate change on marine pelagic phenology and trophic mismatch. *Nature* 430:881-884.
- Post, E., and M. C. Forchhammer. 2008. Climate change reduces reproductive success of an Arctic herbivore through trophic mismatch. *Philosophical Transactions of the Royal Society B-Biological Sciences* 363:2369-2375.

- Visser, M. E., A. J. van Noordwijk, J. M. Tinbergen, and C. M. Lessells. 1998. Warmer springs lead to mistimed reproduction in great tits (*Parus major*). *Proceedings of the Royal Society of London Series B-Biological Sciences* 265:1867-1870.

6. Phenological Responses to Climate Change I: Adaptation And Evidence of Natural Selection On Phenological Traits

- Stinson, K. A. 2004. Natural selection favors rapid reproductive phenology in *Potentilla pulcherrima* (Rosaceae) at opposite ends of a subalpine snowmelt gradient. *American Journal of Botany* 91:531-539.
- Visser, M. E. 2008. Keeping up with a warming world; assessing the rate of adaptation to climate change. *Proceedings of the Royal Society B-Biological Sciences* 275:649-659.

7. Phenological Responses To Climate Change II: Demographic and Geographic Range Shifts

- Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421:37-42.
- Jepsen, J. U., L. Kapari, S. B. Hagen, T. Schott, O. P. L. Vindstad, A. C. Nilssen, and R. A. Ims. 2011. Rapid northwards expansion of a forest insect pest attributed to spring phenology matching with sub-Arctic birch. *Global Change Biology* 17:2071-2083.

8. Phenological Responses To Climate Change III: Mating System Shifts

- Gaston, A. T., H. G. Gilchrist, M. L. Mallory, and P. A. Smith. 2009. Changes in seasonal events, peak food availability, and consequent breeding adjustment in a marine bird: a case of progressive mismatching. *Condor* 111:111-119.
- Rainio, K., A. P. Tottrup, E. Lehikoinen, and T. Coppack. 2007. Effects of climate change on the degree of protandry in migratory songbirds. *Climate Research* 35:107-114.

9. Socio-phenology: How Might Phenological Shifts Influence Human Populations?

- Ziska, L., K. Knowlton, C. Rogers, D. Dalan, N. Tierney, M. A. Elder, W. Filley, J. Shropshire, L. B. Ford, C. Hedberg, P. Fleetwood, K. T. Hovanky, T. Kavanaugh, G. Fulford, R. F. Vrtis, J. A. Patz, J. Portnoy, F. Coates, L. Bielory, and D. Frenz. 2011. Recent warming by latitude associated with increased length of ragweed pollen season in central North America. *Proceedings of the National Academy of Sciences of the United States of America* 108:4248-4251.
- Tao, F., M. Yokozawa, Y. Xu, Y. Hayashi, and Z. Zhang. 2006. Climate changes and trends in phenology and yields of field crops in China, 1981-2000. *Agricultural and Forest Meteorology* 138:82-92.