

# **Biological Significance of Phenology**

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# Phenology:

- **A biological clock**
  - Initiation and end of the growing season
  - Timing of ice-out
  - Timing of migration
  - Timing of reproduction
  - Synchrony
- **An object of natural selection**
- **Can be studied at many scales**
- **Amenable to experimental manipulation**

# Phenology, con't.

- **Applications to conservation biology**
- **An indicator of climate change**
- **Amenable to modeling**
- **Applied as well as basic biology**
- **A variety of species studied**

# Initiation and end of the growing season

- **Agriculture**

- Robeson, S. M. (2002). "Increasing growing-season length in Illinois during the 20th century." Climatic Change **52**: 219-238.
- Williams, T. A. and M. T. Abberton (2004). "Earlier flowering between 1962 and 2002 in agricultural varieties of white clover." Oecologia **138**(1): 122-126.

- **Natural communities**

- Molau, U., U. Nordenhäll, et al. (2005). "Onset of flowering and climate variability in an alpine landscape: A 10-year study from Swedish Lapland." American Journal of Botany **92**(3): 422-431.
- Schwartz, M. D., B. C. Reed, et al. (2002). "Assessing satellite-derived start-of-season measures in the coterminus USA." International Journal of Climatology **22**(14): 1793-1805.

# Timing of ice-out

- Futter, M. N. (2003). "Patterns and trends in Southern Ontario lake ice phenology." Environmental Monitoring and Assessment **88**(1-3): 431-444.
- Stewart, I. T., D. R. Cayan, et al. (2004). "Changes toward earlier streamflow timing across Western North America." Journal of Climate **18**: 1136-1155.

**The Nenana Ice Classic  
was created in 1917**



**On average, the  
Tanana River  
breakup occurs 5.5  
days sooner than it  
did back in 1917.**



# Timing of migration

- Mason, C. F. (1995). "Long term trends in the arrival dates of spring migrants." Bird Study **42**: 182-189.
- Loxton, R. G., T. H. Sparks, et al. (1998). "Spring arrival dates of migrants in Sussex and Leicestershire (1966-1996)." The Sussex Bird Report **50**: 182-196.
- Quinn, T. P. and D. J. Adams (1996). "Environmental changes affecting the migratory timing of American shad and sockeye salmon." Ecology **77**(4): 1151-1162
- Brotton, J. and G. Wall. 1997. Climate change and the Bathurst caribou herd in the Northwest Territories, Canada. Climatic Change **35**:35-52
- Cotton, P. A. (2003). "Avian migration phenology and global climate change." PNAS **100**(21): 12219-12222.
- Vertical migration of large ungulates

# Timing of reproduction

- **Flowering phenology**
  - Robertson, C. (1895). "The philosophy of flower seasons, and the phænological relations of the entomophilous flora and the anthophilous insect fauna." American Naturalist **29**: 97-117.
- **Fruiting phenology**
  - Wheelwright, N. T. (1985). "Competition for dispersers, and the timing of flowering and fruiting in a guild of tropical trees." Oikos **44**: 173-192.
- **Dispersal phenology**
  - Willson, M. F. and C. J. Whelan (1993). "Variation of dispersal phenology in a bird-dispersed shrub, *Cornus drummondii*." Ecological Monographs **63**(2): 151-172.
- **Amphibian reproduction**
  - Frogwatch USA
- **Avian reproduction**
  - Visser, M. E., A. J. Van Noordwijk, et al. (1998). "Warmer springs lead to mistimed reproduction in great tits (*Parus major*)." Proceedings of the Royal Society London, Series B **265**: 1867-1870.

# Timing of reproduction, con't.

- **Mammalian reproduction**

- Réale, D., A. G. McAdam, et al. (2003). "Genetic and plastic responses of a northern mammal to climate change." Proceedings of the Royal Society B **270**(1515): 591-596.

- **Reproductive isolation**

- Schuster, W. S., D. L. Alles, et al. (1989). "Gene flow in limber pine: evidence from pollination phenology and genetic differentiation along an elevational transect." American Journal of Botany **76**: 1395-1403.

- **Competition**

- Levin, D. A. and W. W. Anderson (1970). "Competition for pollinators between simultaneously flowering species." American Naturalist **104**: 445-467.
- Mosquin, T. (1971). "Competition for pollinators as a stimulus for the evolution of flowering time." Oikos **22**: 398-402.

- **Aquatic organisms too**

- Paasivirta, L., T. Lahti, et al. (1988). "Emergence phenology and ecology of aquatic and semi-terrestrial insects on a boreal raised bog in Central Finland." Holarctic Ecology **11**: 96-105.

# Synchrony

- Edwards, M. and A. J. Richardson (2004). "Impact of climate change on marine pelagic phenology and trophic mismatch." Nature **430**(7002): 881-884.
- Winder, M. and D. E. Schindler (2004). "Climate change uncouples trophic interactions in an aquatic ecosystem." Ecology **85**(8): 2100-2106.
- Cresswell, W. and R. McCleery (2003). "How great tits maintain synchronization of their hatch date with food supply in response to long-term variability in temperature." Journal of Animal Ecology **72**(2): 356-366.
- Dixon, A. F. G. (2003). "Climate change and phenological asynchrony." Ecological Entomology **28**(3): 380-381.

# An object of natural selection

- **Environmental selection**

- Cannell, M. G. R., M. B. Murray, et al. (1985). "Frost avoidance by selection for late budburst in *Picea sitchensis*." Journal of Applied Ecology **22**: 931-941.

- **Competition**

- Kochmer, J. P. and S. N. Handel (1986). "Constraints and competition in the evolution of flowering phenology." Ecological Monographs **56**: 303-325.
- Rathcke, B. (1988). "Flowering phenologies in a shrub community: competition and constraints." Journal of Ecology **76**: 975-994.

- **Predators and parasites**

- Waldbauer, G. P. and W. E. LaBerge (1985). "Phenological relationships of wasps, bumblebees, their mimics and insectivorous birds in northern Michigan." Ecological Entomology **10**: 99-110.
- Lyons, D. B. (1999). "Phenology of the native parasitoid *Sinophorus megalodontis* (Hymenoptera : Ichneumonidae) relative to its introduced host, the pine false webworm (Hymenoptera : Pamphiliidae)." Canadian Entomologist **131**(6): 787-800.

# Natural selection, con't.

- **Herbivory**

- Crawley, M. J. and M. Akhteruzzaman (1988). "Individual variation in the phenology of oak trees and its consequences for herbivorous insects." Functional Ecology **2**: 409-415.
- English-Loeb, G. M. and R. Karban (1992). "Consequences of variation in flowering phenology for seed head herbivory and reproductive success in *Erigeron glaucus* (Compositae)." Oecologia **89**: 588-595.
- How, S. T., W. G. Abrahamson, et al. (1993). "Role of host plant phenology in host use by *Eurosta solidaginis* (Diptera, Tephritidae) on *Solidago* (Compositae)." Environmental Entomology **22**(2): 388-396.

- **Pollination**

- Jennersten, O., L. Berg, et al. (1988). "Phenological differences in pollinator visitation, pollen deposition and seed set in the sticky catchfly, *Viscaria vulgaris*." Journal of Ecology **76**: 1111-1132.
- Widén, B. (1991). "Phenotypic selection on flowering phenology in *Senecio integrifolius* a perennial herb." Oikos **61**: 205-215.

# Can be studied at many scales

- **Global**

- Botta, A., N. Viovy, et al. (2000). "A global prognostic scheme of leaf onset using satellite data." Global Change Biology **6**(7): 709-.

- **Latitudinal**

- Guitian, P. (1998). "Latitudinal variation in the fruiting phenology of a bird-dispersed plant (*Crataegus monogyna*) in Western Europe." Plant Ecology **137**(2): 139-142.

- **Regional**

- Caprio, J. M. (1993). "Western regional phenological summary of information on honeysuckle and lilac first bloom phase covering the period 1956-1991."
- van Vliet, A. J. H., R. S. de Groot, et al. (2003). "The European Phenology Network." International Journal of Biometeorology **47**(4): 202-212.
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# Scales, con't.

- **State**

- Zhao, T. T. and M. D. Schwartz (2003). "Examining the onset of spring in Wisconsin." Climate Research **24**(1): 59-70.

- **Landscape**

- Weiss, S. B. and A. D. Weiss (1998). "Landscape-level phenology of a threatened butterfly: A GIS-Based modeling approach." Ecosystems **1**(3): 299-309.

- **Community-level**

- Ram, J., S. P. Singh, et al. (1988). "Community level phenology of grassland above treeline in Central Himalaya, India." Arctic and Alpine Research **20**: 325-332.
- Rathcke, B. (1988). "Flowering phenologies in a shrub community: competition and constraints." Journal of Ecology **76**: 975-994.

- **Individual flowers**

- Primack, R. B. (1985). "Longevity of individual flowers." Annual Review of Ecology and Systematics **16**: 15-37.

# Scales, con't.

- **Individual anthers**

- Thomson, J. D. and B. A. Thomson (1992). Pollen presentation and viability schedules in animal-pollinated plants: consequences for reproductive success. Ecology and evolution of plant reproduction. R. Wyatt. New York, Chapman and Hall: 1-24.

- **Pistils**

- Preston, R. E. (1991). "The intrafloral phenology of *Streptanthus tortuosus* (Brassicaceae)." American Journal of Botany **78**(8): 1044-1053.
- Primack, R. B. (1985). Patterns of flowering phenology in communities, populations, individuals, and single flowers. The population structure of vegetation. J. White. Dordrecht, Dr. W. Junk: 571-593.

# Scales, con't.

- **Physiology**

- Steyn, H. M., N. van Rooyen, et al. (1996). "The phenology of Namaqualand ephemeral species. The effect of water stress." Journal of Arid Environments **33**: 49-62.
- Schaber, J. and F. W. Badeck (2003). "Physiology-based phenology models for forest tree species in Germany." International Journal of Biometeorology **47**(4): 193-201.

- **Genetics**

- Pors, B. and P. A. Werner (1989). "Individual flowering time in a goldenrod (*Solidago canadensis*): field experiment shows genotype more important than environment." American Journal of Botany **76**: 1681-1688.
- Weis, A. E. and T. M. Kossler (2004). "Genetic variation in flowering time induces phenological assortative mating: Quantitative genetic methods applied to *Brassica rapa*." American Journal of Botany **91**(6): 825-836.

# Amenable to experimental manipulation

- Wookey, P. A., A. N. Parson, et al. (1993). "Comparative responses in phenology and reproductive development to simulated environmental change in sub-arctic and high arctic plants." Oikos **67**: 490-502.
- Murray, M. B., R. I. Smith, et al. (1994). "Effects of elevated CO<sub>2</sub>, nutrition and climatic warming on bud phenology in Sitka spruce (*Picea sitchensis*) and their impact on the risk of frost damage." Tree Physiology **14**: 691-706.
- Price, M. V. and N. M. Waser (1998). "Effects of experimental warming on plant reproductive phenology in a subalpine meadow." Ecology **79**(4): 1261-1271.
- Arft, A. M., M. D. Walker, et al. (1999). "Responses of tundra plants to experimental warming: Meta-analysis of the International Tundra Experiment." Ecological Monographs **69**(4): 491-511.



# Applications to conservation

- Baumgartner, J. and J. Hartmann (2000). "The use of phenology models in plant conservation programmes: the establishment of the earliest cutting date for the wild daffodil *Narcissus radiiflorus*." Biological Conservation **93**(2): 155-161.
- Cushman, J. H., C. L. Boggs, et al. (1994). "Estimating female reproductive success of a threatened butterfly: Influence of emergence time and hostplant phenology." Oecologia **99**(1-2): 194-200.
- Kannan, R. and D. A. James (1999). "Fruiting phenology and the conservation of the Great Pied Hornbill (*Buceros bicornis*) in the Western Ghats of southern India." Biotropica **31**(1): 167-177.
- Lamont, B. B., T. He, et al. (2003). "Anthropogenic disturbance promotes hybridization between *Banksia* species by altering their biology." Journal of Evolutionary Biology **16**(4): 551-557.
- Sugiura, N., T. Fujie, et al. (2001). "Flowering phenology, pollination, and fruit set of *Cypripedium macranthos* var. *rebunense*, a threatened lady's slipper (Orchidaceae)." Journal of Plant Research **114**(1114): 171-178.

# An indicator of environmental change

- Sparks, T. H. and P. D. Carey (1995). "The responses of species to climate over two centuries: An analysis of the Marsham phenological record, 1736-1947." Journal of Ecology **83**(2): 321-329.
- Murray, M. B., M. G. R. Cannell, et al. (1989). "Date of budburst of fifteen tree species in Britain following climatic warming." Journal of Applied Ecology **26**: 693-700.
- MacInnes, C. D., E. H. Dunn, et al. (1990). "Advancement of goose nesting dates in the Hudson Bay region, 1951-1986." Canadian Field Naturalist **104**: 295-297.
- Dewar, R. C. and A. D. Watt (1992). "Predicted changes in the synchrony of larval emergence and budburst under climatic warming." Oecologia **89**: 557-559.
- Menzel, A. (1999). "Phenology as global change bioindicator." Annalen der Meteorologie **39**: 41-43.

# Amenable to modeling

- Hannerz, M. (1999). "Evaluation of temperature models for predicting bud burst in Norway spruce." Canadian Journal of Forest Research Revue Canadienne de Recherche Forestiere **29**(1): 9-19.
- O'Neil, P. (1999). "Selection on flowering time: an adaptive fitness surface for nonexistent character combinations." Ecology **80**(3): 806-820.
- Morales, M. A., G. J. Dodge, and D. W. Inouye. 2005. A phenological mid-domain effect in flowering diversity. Oecologia **142**(1):83-89.
- Piper, E. L., K. J. Boote, et al. (1996). "Comparison of two phenology models for predicting flowering and maturity date of soybean." Crop Science **36**(6): 1606-1614.

# Applied as well as basic biology

- Ghera, C. M. and J. S. Holt (1995). "Using phenology prediction in weed management: A review." Weed Research **35**(6): 461-470.
- Graf, B., H. U. Hopli, et al. (1995). Modelling spring emergence of the apple sawfly *Hoplocampa testudinea* KLUG (Hymenoptera, Tenthredinidae). International Symposium on Computer Modelling in Fruit Research and Orchard Management. R. Habib and P. Blaise. Louvain, International Society for Horticultural Science: 263-271.
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- Ro, T. H., G. E. Long, et al. (1998). "Predicting phenology of green peach aphid (Homoptera: Aphididae) using degree-days." Environmental Entomology **27**(2): 337-343.

# A variety of species

- **Diptera**

- Peng, R. K., S. L. Sutton, et al. (1992). "Spatial and temporal distribution patterns of flying Diptera." Journal of Zoology, London **228**(2): 329-340.

- **Lepidoptera**

- Ellis, W. N. (1997). "Recent shifts in phenology of Microlepidoptera, related to climatic change." Entomologische Berichten **57**: 66-72.

- **Fish**

- Quinn, T. P. and D. J. Adams (1996). "Environmental changes affecting the migratory timing of American shad and sockeye salmon." Ecology **77**(4): 1151-1162

- **Amphibians**

- Corn, P. S. (2003). "Amphibian breeding and climate change: Importance of snow in the mountains." Conservation Biology **17**(2): 622-625.

**What's the longest phenological record in the world?**

# What's the longest phenological record in the world?

- Defila, C. (1996). 45 years of phenological observations in Switzerland, 1951-1995. 14th International Congress of Biometeorology.
- Sparks, T. H., P. D. Carey, et al. (1997). "First leafing dates of trees in Surrey between 1947 and 1996." The London Naturalist **76**: 15-20.
- Menzel, A., N. Estrella, et al. (2001). "Spatial and temporal variability of the phenological seasons in Germany from 1951 to 1996." Global Change Biology **7**(6): 657-666.
- Sparks, T. H. and P. D. Carey (1995). "The responses of species to climate over two centuries: An analysis of the Marsham phenological record, 1736-1947." Journal of Ecology **83**(2): 321-329.
- Phenology of cherry tree flowering in Kyoto, Japan – 900 years!
  - Lamb, H. H. (1977). Climate Past, Present and Future. London, Methuen.

