University of Zurich[UZH]

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Phenology

Terminology Brief Series

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Formal definition: *Phenology is broadly defined as the study of recurring plant and animal life cycle stages, especially their timing and relationships with weather and climate (Schwartz, 2003). The word stems from the Greek word phaino meaning to show or to appear. Leaf unfolding, plant flowering, bird migration or the timing of animal breeding are all examples of phenological events (Figure 1).*

In most disciplines, the term phenology is used interchangeably with seasonality, although the two are complementary in their description of ecosystem functioning; phenology referring to biotic processes, and seasonality referring to non-biological processes (Friedl et al., 2006).
There are many ways to collect and to analyze phenological data. Though considerable efforts are under way to improve this, until present there has been only little standardization on data collection – particularly across biomes and taxa. In terrestrial fields, relationships between various visible biological phenomena and meteorological/climate changes have been studied for a long time. Among these are flowering and leaf unfolding of plants, population dynamics and changes in community structures of insects, timing of oviposition and migration of birds, and so on. In addition to these studies, genetic and ontogenetic mechanisms driving these phenomena have been investigated recently (Vitasse et al. 2009; Aikawa et al. 2010; Kobayashi et al. 2013).

Figure 1: General Flowering in Lambir (Borneo) in 2009. The trees with with/orange canopies are flowering. Photo: Eri Yamasaki

1 Defining Land Surface Phenology (LSP)

The technological and methodological advancements in environmental remote sensing have opened a new avenue for phenological research (White et al., 2009). The field of Land Surface Phenology (LSP) has been defined as the study of seasonal patterns of vegetated land surfaces as observed from remote sensing (Reed et al., 2003; de Beurs & Henebry, 2004; Stöckli & Vidale, 2004; Friedl et al., 2006; Hudson & Keatley, 2010).

LSP acts as an indicator of terrestrial ecosystems' responses to environmental variations, and one that helps to characterize land surface fluxes of energy, carbon and water (Richardson et al., 2013). LSP also provides a connection between the study of plant physiology and that of ecosystem-wide processes; and as such, is very useful to global change studies (Liang & Schwartz, 2009; Zhao et al., 2012).

Though related via the absorption and reflectance of photosynthetically active radiation, LSP and plant phenology are distinct. Plant phenology refers to species-specific life cycle events such as bud burst, flowering or leaf senescence whereas LSP describes seasonal variation representative for a land-surface unit (De Beurs & Henebry, 2010). LSP is derived through pixel values, and as such may represent a mixture of land covers in an area-averaged fashion, and include the confounding effects of soil, snow and atmosphere, as well as potential non-climatic factors influencing the land surface, such as anthropogenic disturbance or fires (White et al., 2009).

2 Defining Phenology in Freshwater Ecology

In contrast to the distinct use of the term phenology in the context of terrestrial ecosystems, it appears that in freshwater ecology phenology (as well as seasonality) cannot be attributed exclusively to either biotic or abiotic factors. Instead, phenology has been used heterogeneously in many studies over the years. Moreover, seasonality in freshwater ecology defines the seasonal succession of different organisms rather than a succession of one ecosystem over a long period of time (Sommer 1985; Padisak 1992; Yoshida et al. 2001).

Similarly to LSP, some authors assign phenology and/or seasonality of lentic ecosystems strictly to biological patterns (e.g. phytoplankton succession, grazing; Figure 2), excluding non-biological factors (Meis et al. 2009; Noges et al. 2010; Berger et al. 2014). The most prominent example for an association of phenology with biological factors in lakes is the Plankton Ecology Group (PEG) Model, which describes the annual phytoplankton succession in freshwater ecosystems (Sommer et al. 1986).

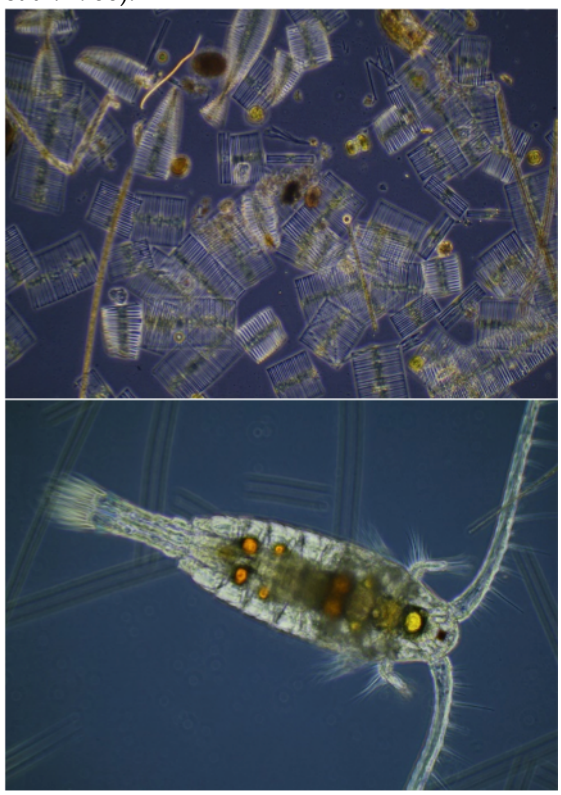

Figure 2: *Fragillaria sp.* (top) and *Diaptomus* (bottom) from Lake Zurich, Switzerland. Photos: Gianna Pitsch

In other studies, however, phenology and seasonality are both attributed not only to biological, but also to physical and chemical processes. Winder & Schindler (2004), for instance, investigate "phenological patterns

among physical and biological components of pelagic ecosystems". Similarly, Straile et al. (2012) bases his so-called "Lake Constance (LC) *Daphnia* phenology model", a model to predict the seasonal dynamics of the zooplankton species *Daphnia*, on "temperature phenology". The physical processes most commonly associated with the terms phenology and/or seasonality are thermal stratification, mixing and weather conditions. Furthermore, the dynamics of ice formation and thawing in lakes are typically described as "ice phenology" (Walsh et al. 1998). Annually reoccurring patterns of chemical substances (phosphate, ammonium and nitrate) in lakes are described as "nutrient seasonality" (Pettersson et al. 2003).

References

Aikawa, S., Kobayashi, M. J., Satake, A., Shimizu, K. K., & Kudoh, H. (2010). Robust control of the seasonal expression of the *Arabidopsis* FLC gene in a fluctuating environment. Proceedings of the National Academy of Sciences of the United States of America, **107**, 11632–7.

Berger, S., Diehl, S., Stibor, H., Sebastian, P. and Scherz, A. (2014). "Separating effects of climatic drivers and biotic feedbacks on seasonal plankton dynamics: no sign of trophic mismatch." *Freshwater Biology* 59(10): 2204-2220.

De Beurs K, Henebry G (2010) A land surface phenology assessment of the northern polar regions using MODIS reflectance time series. *Canadian Journal of Remote Sensing,* **36**, 87-110.

De Beurs KM, Henebry GM (2004) Land surface phenology, climatic variation, and institutional change: Analyzing agricultural land cover change in Kazakhstan. *Remote Sensing of Environment,* **89**, 497-509.

Friedl M, Henebry GM, Reed BC *et al.* (2006) Land Surface Phenology. In: *A Community White Paper Requested By NASA.* (ed Nasa).

Hudson IL, Keatley MR (2010) *Phenological research: methods for environmental and climate change analysis*, Springer.

Kobayashi, M. J., Takeuchi, Y., Kenta, T., Kume, T., Diway, B., & Shimizu, K. K. (2013). Mass flowering of the tropical tree Shorea beccariana was preceded by expression changes in flowering and drought-responsive genes. *Molecular Ecology*, *22*(18), 4767–82. doi:10.1111/mec.12344

Liang L, Schwartz MD (2009) Landscape phenology: An integrative approach to seasonal vegetation dynamics. *Landscape Ecology,* **24**, 465-472.

Meis, S., S. J. Thackeray, et al. (2009). "Effects of recent climate change on phytoplankton phenology in a temperate lake." *Freshwater Biology* 54(9): 1888-1898.

Noges, P., R. Adrian, et al. (2010). "The Impact of Variations in the Climate on Seasonal Dynamics of Phytoplankton." Impact of Climate Change on European Lakes: 253-274.

Padisak, J. (1992). "Seasonal Succession of Phytoplankton in a Large Shallow Lake (Balaton, Hungary) - a Dynamic Approach to Ecological Memory, Its Possible Role and Mechanisms." *Journal of Ecology* 80(2): 217-230.

Pettersson, K., K. Grust, et al. (2003). "Seasonality of chlorophyll and nutrients in Lake Erken - effects of weather conditions." *Hydrobiologia* 506(1-3): 75-81.

Reed BC, White M, Brown JF (2003) Remote sensing phenology. In: *Phenology: An Integrative Environmental Science.* pp Page.

Richardson AD, Keenan TF, Migliavacca M, Ryu Y, Sonnentag O, Toomey M (2013) Climate change, phenology, and phenological control of vegetation feedbacks to the climate system. *Agricultural and Forest Meteorology,* **169**, 156-173.

Schwartz MD (2003) *Phenology: an integrative environmental science*, Springer.

Sommer, U. (1985). "Seasonal Succession of Phytoplankton in Lake Constance." *Bioscience* 35(6): 351-357.

Sommer, U., Z. M. Gliwicz, et al. (1986). "The Peg-Model of Seasonal Succession of

Planktonic Events in Fresh Waters." Archiv Fur Hydrobiologie 106(4): 433-471.

Stöckli R, Vidale PL (2004) European plant phenology and climate as seen in a 20-year AVHRR land-surface parameter dataset. *International Journal of Remote Sensing*, **25**, 3303-3330.

Straile, D., R. Adrian, et al. (2012). "Uniform Temperature Dependency in the Phenology of a Keystone Herbivore in Lakes of the Northern Hemisphere." *Plos One* 7(10).

Vitasse, Y., Delzon, S., Bresson, C. C., Michalet, R., & Kremer, A. (2009). Altitudinal differentiation in growth and phenology among populations of temperate-zone tree species growing in a common garden. *Canadian Journal of Forest Research*, *39*(7), 1259–1269. doi:10.1139/X09-054

Walsh, S. E., S. J. Vavrus, et al. (1998). "Global patterns of lake ice phenology and climate: Model simulations and observations." *Journal of Geophysical Research-Atmospheres* 103(D22): 28825-28837.

White MA, De Beurs KM, Didan K *et al.* (2009) Intercomparison, interpretation, and assessment of spring phenology in North America estimated from remote sensing for 1982,Äì2006. *Global Change Biology*, **15**, 2335-2359.

Winder, M. and D. E. Schindler (2004). "Climatic effects on the phenology of lake processes." *Global Change Biology* 10(11): 1844-1856.

Yoshida, T., Kagami, M., Gurung, T. B. and Urabe, J. (2001). "Seasonal succession of zooplankton in the north basin of Lake Biwa". *Aquatic Ecology* 35: 19–29.

Zhao J, Wang Y, Hashimoto H, Melton FS, Hiatt SH, Zhang H, Nemani RR (2012) The Variation of Land Surface Phenology From 1982 to 2006 Along the Appalachian Trail. *IEEE Transactions on Geoscience and Remote Sensing*.