



Phenology at the crossroads?

Annette Menzel (1,2)

(1) Chair of Ecoclimatology, Technische Universität München, Germany (amenzel@wzw.tum.de), (2) Institute for Advanced Study, Technische Universität München, Germany

Phenology is the study of the timing of natural events such as plant growth or animal migration. Currently nearly 500 papers are published annually that include 'phenolog*' in their title; many are related to anthropogenic change. Since seasonal events are triggered predominantly by climate, phenology has emerged as a key asset in identifying fingerprints of climate change in natural systems, especially since recent warming has been mirrored by significantly advancing spring events.

Phenological changes have been reported across continents, habitats and taxa, predominantly as mean temporal changes ('trends') or as relationships to temperature and other drivers ('responses'), and have been summarised in various meta-analyses. However, a considerable variability in observed trends and responses is reported along with mixed messages of the footprint of climate change in nature. Phenology has made considerable advances but is now at a crossroads of understanding this variability. At the same time a change of emphasis in explanation, prediction and adaptation is emerging, which needs a full acknowledgement of this variability; likely yielding to more plasticity and resilience.

In this review, I summarize current knowledge and recent insights into the role of

- different observation methods, their accuracy and their target phenophases
- observed events, species, traits, ontogenetic effects
- species-specific safeguarding strategies, e.g. chilling, photoperiod
- additional drivers other than climate, e.g. nutrients, GHG, biotic effects, anthropogenic / agricultural management
- seasonal as well as spatio-temporal variation, effects of regional climate changes and analogous climates.

This review clearly demonstrated that, comparable to weather and climate ensembles, only a full consideration of variation in responses allows a complete understanding of ecological, cultural and socioeconomic consequences of these phenological changes.