Asko Noormets
Editor

Phenology of Ecosystem Processes

Applications in Global Change Research

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Editor
Asko Noormets
Department of Forestry and Environmental Resources
North Carolina State University
920 Main Campus Drive
Raleigh NC 27695
USA

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Cover image: The "phenological clocks" of different processes (GEP – gross ecosystem productivity, ET – evapotranspiration, ER – ecosystem respiration) indicate the intensity of a given flux by the width of the colored band (A. Noormets and K. Kramer). The background is a mosaic of photos from Harvard Forest EMS Tower webcam, courtesy of Andrew Richardson.

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Preface

The effect of warming temperatures on biological processes has been well documented (Badeck *et al*. 2004; Parmesan and Yohe 2003), and is evidenced by changes in the timing of discernible life cycle events, like leaf-out and flowering of plants, and migration and reproduction of animals. It is implicit that these life cycle events are representative indicators of a change in some underlying process. Ever more sophisticated general circulation and ecosystem productivity models have narrowed the boundaries of uncertainty sufficiently to bring attention to the effect of the seasonal timing of ecosystem processes, notably carbon and water exchange. It is becoming increasingly evident that both interannual and regional variation have a strong phenological component (Baldocchi 2008). The associated changes in surface energy balance and partitioning (Wilson and Baldocchi 2000) both affect and are driven by vegetation phenology (Alessandri *et al*. 2007; Baldocchi 2008; Morisette *et al*. 2008). Quantifying the seasonality of these processes is required for constraining ecosystem productivity models (Kramer *et al*. 2002), refining remote sensing (RS) estimates of ecosystem properties (Morisette *et al*. 2008) and narrowing the uncertainty bounds on global biogeochemical models (Olesen *et al*. 2007). While the vegetation-index-based assessments (e.g. Goetz *et al*. 2005) broadly corroborate ground-based observations of long-term trends of lengthening growing season (Menzel 2000, 2003; Menzel *et al*. 2005), the patterns of interannual variation in land surface reflectance and vegetation processes do not always coincide (Badeck *et al*. 2004; Fisher *et al*. 2007). We hypothesize that the power of RS monitoring of vegetation processes would be improved if the calibration of the reflectance data was done against the process of interest (as opposed to validating a RS gross productivity product against a degree-day model of bud-break, for example). This is all the more important when considering that even ground-based observations may yield conflicting results when data collected with different methods is compared, because they may entail different (and sometimes implicit) assumptions (Parmesan 2007). Furthermore, process-based approach is required because even closely related processes do not have the same environmental drivers and same sensitivities to them. For example, the onset of ecosystem respiration is generally delayed in relation to gross productivity in temperate deciduous and boreal conifer forests (Falge *et al*. 2002). While continuous in nature, the driving factors of these processes vary seasonally (Davidson and Holbrook, current volume; Carbone and

Vargas 2008). Thus, the changes in ecosystem processes, including biogeochemical fluxes, exhibit *phenological* change, as per the definition of phenology by Lieth (1974): *"Phenology is the study of the timing of recurrent biological events, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species"*.

The recent increased interest in the seasonality of ecosystem processes has already revealed several novel aspects, some of which force us to reconsider earlier paradigms and assumptions. For example, the observed seasonality of tropical rainforest carbon balance has been found to be opposite to all earlier model predictions (Saleska *et al*. 2003) and strongly influenced by the degree of anthropogenic disturbance (Huete *et al*. 2008). The long-held view of urban heat island effect on the timing of bud-break is challenged by the latest global analysis (Gazal *et al*. 2008). And a common picture has emerged from previously divergent pieces of evidence about the effect of delayed autumn senescence on forest carbon balance (Piao *et al*. 2008). Several novel findings also emerge from the syntheses presented in the current volume. Notably, some phenological patterns seem reflected in diurnal cycles, potentially providing a novel insight into continuities across temporal scales. Billmark and Griffis (Chapter 6) report that the rate of morning increase in isotopic discrimination changes seasonally, whereas Davidson and Holbrook (Chapter 8) discuss how the diurnal hysteresis in the relationship between soil respiration and temperature indicates seasonal changes in the primary driving factor. In all, the chapters in the current volume present examples of how phenology is measured and considered in various analyses of ecosystem biogeochemical processes, give a brief overview of the background of each question, and propose new approaches for quantifying phenological patterns. The recognition of the urgency of climate change related issues (Gore 2006), the potential implications of disparate responses in ecologically related organisms (Fussmann *et al*. 2007; Parmesan 2007), and calls for more realistic representation of seasonal changes in regional climate models (Morisette *et al*. 2008), have brought much attention to phenology. We hope that the current collection of studies helps those new to the field get an overview of its scope, provides a reference to people active in the field, and serves as an educational aid for courses on climate change and ecosystem ecology. The current volume is not intended to present a comprehensive overview of the field of land surface phenology. The two chapters on this (10 and 11) only highlight the most common contact points with ecosystem ecology and provide an example of how these two approaches have been applied together. Upon completing this book, we hope the reader will develop his or her own vision of the seasonality of ecosystem processes, detectable as distinctly as the purple of an opening bud of a lilac.

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Raleigh

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