

EXAMINING SPRING PHENOLOGY OF FOREST UNDERSTORY USING DIGITAL PHOTOGRAPHY

Liang Liang, Mark D. Schwartz, and Songlin Fei¹

Abstract.—Phenology is an important indicator of forest health in relation to energy/nutrient cycles and species interactions. Accurate characterization of forest understory phenology is a crucial part of forest phenology observation. In this study, ground plots set up in a temperate mixed forest in Wisconsin were observed with a visible-light digital camera during spring 2007. High-frequency microclimatic data were collected concurrently. A green pixel extraction technique was used to derive phenological patterns from digital photos. Correlations were examined between derived phenology signals and climatic variables. Results indicate that though understory phenology was generally correlated with spring warmth accumulation, its daily change rate was significantly correlated with air moisture variability rather than with temperature-based weather fluctuations. We inferred that understory flush regime during springtime in a mesic temperate forest could depend more on precipitation than on temperature, due to the presumably shallower root systems. Furthermore, the study suggests that visible-light digital photography is an effective, easy-to-implement method for observing understory phenology and for other forest monitoring tasks.

INTRODUCTION

Phenology tracks periodic life-cycle events driven primarily by changes in meteorological conditions (Schwartz 2003). A warming climate has led to shifts in the timing of plant phenology over the past half-century as detected from both observations and retrospective models (Menzel and others 2006, Schwartz and others 2006). Systematic monitoring of plant phenology is important for improved understanding of vegetation dynamics within the complex ecological context (Liang and Schwartz 2009). Within forest ecosystems, understory plant communities form an important component that influences the general composition and health of forests (Fei and Steiner 2008, Kaeser and others 2008). Observing forest understory phenology is necessary for gaining insight into how forest ecosystems would respond to the changing environment.

Given the multiplicity of species present on the forest floor and their respective physiologies in relation to growth stages, synthesizing understory phenology observed at the species level is difficult. We believe that reading the aggregated “greening” effect is an option for practical forest understory phenology observation and that digital photography serves as a useful tool for objective assessment. Applications of digital photography to phenological quantification have been recently investigated using networked or robotic imaging systems for forest canopies and selected plant species (Richardson and others 2007, Graham and others 2009). Applying such techniques to observations conducted under field conditions holds potential for effectively capturing phenological signals from the forest understory within areas of interest. In addition, the improved accuracy

¹Postdoctoral Scholar (LL) and Assistant Professor (SF), Department of Forestry, University of Kentucky, Lexington, KY 40546; Professor (MDS), Department of Geography, University of Wisconsin, Milwaukee, WI 53211. LL is corresponding author: to contact, call (859) 257-5666 or email at liang.liang@uky.edu.

of measurement allows the detection of delicate interrelationships between understory plant phenology and microclimatic variables. Such inter-relationships have rarely been addressed by previous studies.

STUDY AREA

The study area is located in the Park Falls Range District of the Chequamegon National Forest in northern Wisconsin. The field sampling plots were set up near an AmeriFlux tower (WLEF, 45.946°N, 90.272°W). The gently sloping topography underlying the forest is covered with soils developed from glacial-fluvial deposits. The area has a humid continental climate with annual average temperature of 4.8° C, and annual precipitation around 810 mm, as recorded by the closest weather station at Park Falls. The forest is composed of 70 percent deciduous (such as *Populus tremuloides*, *Acer* spp., and *Alnus regosa*) and 30 percent conifer (such as *Abies balsamea*, *Pinus resinosa*, and *Thuja occidentalis*) tree species. More than 100 understory plant species are commonly found on the forest floor (Brososke and others 2001).

METHODS

FIELD MEASUREMENTS

Phenology of understory vegetation cover was investigated with digital photography during spring 2007. Twenty-one 1-m² ground plots were outlined in the study area. Each plot was set using a PVC pipe “square” and marked with stakes at four corners. These understory plots were observed every other day from April 27 to May 25, 2007. A consumer-grade Kodak DX4530 visible-light digital camera was used to take nadir-pointing photos over each plot on each observation day. The observation was mostly conducted during the morning to early afternoon on each day. The species composition of each plot was recorded by digital photos. The understory plants were dominated by grasses and herbs; saplings of woody species were present in a few plots. Concurrently with phenology observation, microclimatic data were collected with automatic HOBO sensors (Onset Computer Corp. Bourne, MA) deployed across the study area. These sensors took ambient air temperature and humidity readings (at shelter height) every 10 minutes.

EXTRACTING PHENOLOGICAL SIGNALS

Digital photos taken with a visible-light camera contain separable red-green-blue (RGB) color bands. Different algebraic combinations of the brightness values of these color bands were utilized to quantify greenness of plants (Graham and others 2006, Richardson and others 2007). A recent study suggests that hue-saturation-luminance (HSL), which is translatable from RGB color bands, provides more accurate estimation of leaf pigment alterations by separating luminance/brightness (affected by illumination conditions) from the hue (Graham and others 2009). We therefore adopted this color-band transformation method to construct metrics of understory phenology for this study.

Each digital photo was cropped to include only the 1-m² plot area marked by four corner sticks. The RGB color bands were translated into HSL color space, and then a range of hue values (192-288) was applied to extract green pixels. The percentage of these green pixels was computed for each photo and used as the phenometric value of the understory at the time of observation. Preprocessing of digital photos was conducted with the Paint.NET program. Band algebra and green pixel extraction were performed using IMAGINE 9.2 software (ERDAS, Atlanta, GA).

COMPARISON WITH CLIMATIC VARIABLES

Temperature-based climatic indices were calculated for daily maximum, mean, and minimum temperatures and temperature range. In addition, accumulated growing degree hours (AGDHs) were calculated from the hourly mean temperature based on 0 °C threshold over selected time windows with an arbitrary start date of April 5, 2007. Likewise, we calculated precipitation-related climatic indices: daily max/mean/min/range of absolute humidity (AH), relative humidity (RH), and air water potential (WP). Air water potential in relation to plant transpiration was calculated using the Kelvin equation for temperature and relative humidity (Lambers and others 1998, Kirkham 2004). Daily advance rate of understory phenology averaged across plots was then compared with the averaged values of climatic variables using correlation analysis.

RESULTS

PHOTO-BASED PHENO-METRICS

An example from one of the ground plots is provided to demonstrate the binary image series with green pixels (shown in white) distinguished from the background (shown in black) using an HSL-based thresholding method for counting greenness percentages (Fig. 1). The incremental changes of green pixels with time could be clearly identified in the photos.

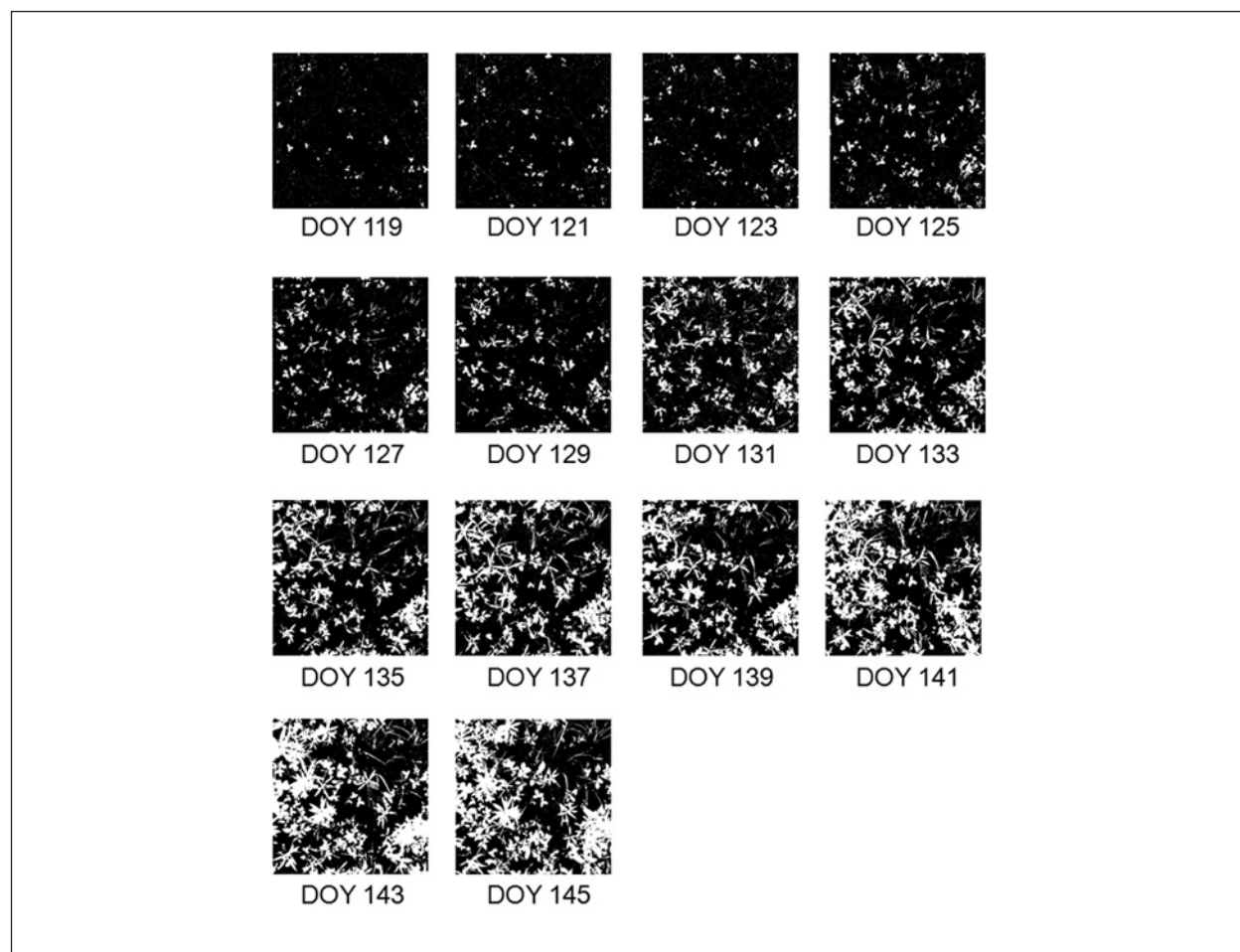


Figure 1.—Binary images of green pixels extracted from digital photos using thresholds based on HSL color space transformed from RGB bands (plot E09, spring 2007).

Each plot yielded a time series of phenological development measured with the photo-based pheno-metrics. The percent green cover averaged across plots showed consistent sensitivity to time and a stable upturning trend, which matches subjective knowledge about the understory greening process in spring (Fig. 2).

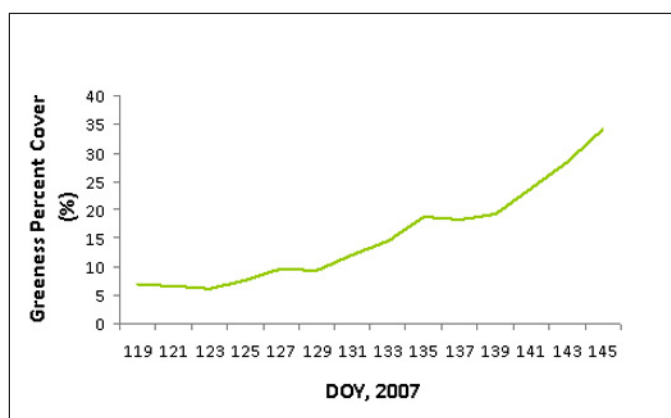


Figure 2.—Time series of averaged pheno-metrics: percent greenness cover of forest understory, spring 2007.

CORRELATIONS BETWEEN PHENO-METRICS AND CLIMATIC VARIABLES

Pearson correlation coefficient and significance values for pairs of daily increment rates of percent green cover and temperature-based climatic indices (AGDHs, growing degree hours [GDHs] over antecedent temporal windows up to 6 days, and daily temperature variables) are provided in Table 1. A strong positive correlation (0.724) was found between green pixel percentage index and AGDHs at the 99-percent confidence level. However, other pairs of phenological and temperature variables did not show significant correlations. A visual comparison between HSL-based pheno-metric advance rates and AGDHs indicated that the AGDH value was not sensitive to daily variation but matched the variation in the height of the peaks of the daily greenness increment, which increased with time (Fig. 3).

Results from the correlation analysis for understory phenology and averaged moisture indices (variables based on WP, RH and AH) are also provided in Table 1. Green pixel percentage measures demonstrated significant correlations with moisture variables at confidence levels of 95 percent or above. Visual comparison of the pheno-metric daily increment rate and mean WP demonstrated a clear correspondence of their temporal variation patterns (Fig. 4).

Table 1.—Correlations (Pearson correlation coefficient and significance values, 2-tailed) between pheno-metrics and climatic variables (significant values < 0.05 with corresponding correlation coefficients are indicated in bold letters).

	GDHs_1d	GDHs_2d	GDHs_3d	GDHs_4d	GDHs_5d	GDHs_6d	AGDHs
Cor.	0.333	0.433	0.542	0.477	0.399	0.320	0.724
Sig.	0.266	0.140	0.056	0.099	0.177	0.286	0.005
	TMean	TMax	TMin	TRange			
Cor.	0.073	0.121	0.339	-0.203			
Sig.	0.812	0.693	0.257	0.506			
	WPMean	WPMax	WPMin	WPRange	RHMean	RHMax	RHMin
Cor.	0.708	0.435	0.732	-0.729	0.611	0.119	0.765
Sig.	0.007	0.137	0.004	0.005	0.027	0.699	0.002
	RHRange	AHMean	AHMax	AHMin	AHRange		
Cor.	-0.799	0.616	0.700	0.500	0.528		
Sig.	0.001	0.025	0.008	0.082	0.064		

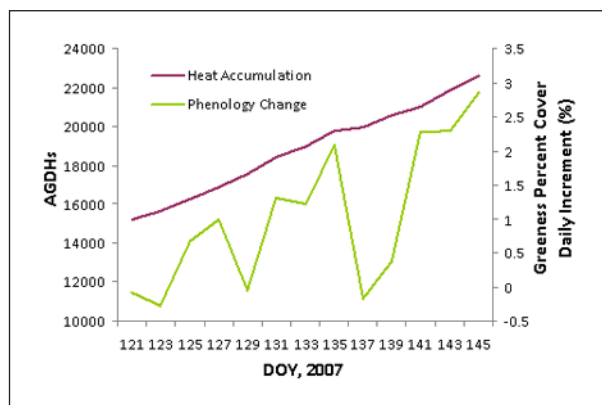


Figure 3.—Time series of daily increment of percentage greenness cover and accumulated growing degree hours (AGDHs), spring 2007.

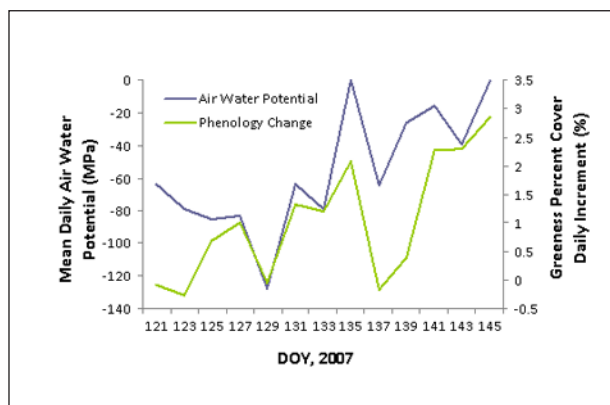


Figure 4.—Time series of daily increment of percent greenness cover and mean daily air water potential, spring 2007.

DISCUSSION

The significant correlation between forest understory phenology and AGDHs indicated a generally accelerated rate of grass flushing with spring warmth accumulation (Fig. 3). In other words, the daily increase of greenness percentage cover was greater in the late spring, associated with the increase of accumulated heat. However, AGDHs and daily GDHs were not correlated with the actual occurrences of understory flush as indicated by percent greenness cover change. Rather, each spur of the understory growth responded to increased moisture content in the air, presumably triggered by springtime precipitation events. Such a water-dependent phenology regime is common in the semi-arid environment. In the mesic forest investigated in this study, understory phenology could be susceptible to minor drought spells, likely due to the relatively shallow root systems of understory species. Actually, a field-observed drought around May 17, 2007 could have significantly reduced the normal growth of understory plants on the forest floor (Figs. 3 and 4). We also noticed in the field that a rapid understory flush occurred following an intense rainfall, confirming the relationship suggested by the data analysis. In summary, precipitation appears to be a more direct driver of understory phenology variation. Heat accumulation plays an underlying role that limits the degree or intensity of each understory flush.

We observed that combinations of understory plant species varied according to different light conditions created by nearby canopies; such heterogeneity may be a major source of variation. Consequently, spatial variations of understory phenology in relation to canopy illumination conditions and plant form variability need to be accounted for in follow-up studies. The strong correspondence between understory phenology and air water potential (derived from temperature and relative humidity) suggests that forest understory phenology could be modeled accurately with both temperature- and moisture-based climatic variables in a temperate forest. Additional efforts are needed to quantify the climate-dependency of forest understory phenology by using multivariate regression models to address questions related to climate change.

Forest understory phenology could be an efficient vegetation health indicator useful in assessing forest structure and detecting change. The study of forest understory phenology also has broader linkages with forest nutrient and energy cycling and species interactions. Digital photography is an easy and cost-effective tool for observing understory phenology. Given the deepening effects of environmental change on forest resources, tracking the long-term dynamics of the often-overlooked understory phenology could further contribute to our knowledge base in support of management and conservation tasks.

ACKNOWLEDGMENTS

Eric Graham from UCLA provided insight into digital photo processing. Two reviewers' careful edits and constructive comments are sincerely appreciated. The research was partially supported by a Doctoral Dissertation Research Improvement Grant, National Science Foundation, BCS-0703360.

LITERATURE CITED

- Brososke, K.; Chen, J.; Crow, T. 2001. **Understory vegetation and site factors: implications for a managed Wisconsin landscape.** *Forest Ecology and Management*. 146(1-3): 75-87.
- Fei, S.; Steiner, K.C. 2008. **Relationships between advance oak regeneration and biotic and abiotic factors.** *Tree Physiology*. 28: 1111-1119.
- Graham, E.A.; Hamilton, M.P.; Mishler, B.D.; Rundel, P.W.; Hansen, M.H. 2006. **Use of a networked digital camera to estimate net CO₂ uptake of a desiccation-tolerant moss.** *International Journal of Plant Sciences*. 167: 751-758.
- Graham, E.A.; Yuen, E.M.; Robertson, G.F.; Kaiser, W.J.; Hamilton, M.P.; Rundel, P.W. 2009. **Budburst and leaf area expansion measured with a novel mobile camera system and simple color thresholding.** *Environmental and Experimental Botany*. 65: 238-244.
- Kaesler, M.J.; Gould, P.J.; McDill, M.E.; Steiner, K.C.; Finley, J.C. 2008. **Classifying patterns of understory vegetation in mixed-oak forests in two ecoregions of Pennsylvania.** *Northern Journal of Applied Forestry*. 25: 38-44.
- Kirkham, M. 2004. **Principles of soil and plant water relations.** Burlington, MA: Elsevier Academic Press. 520 p.
- Lambers, H.; Chapin, F.; Pons, T. 1998. **Plant physiological ecology.** New York, NY: Springer-Verlag. 540 p.
- Liang, L.; Schwartz, M. 2009. **Landscape phenology: an integrative approach to seasonal vegetation dynamics.** *Landscape Ecology*. 24: 465-472.
- Menzel, A.; Sparks, T.H.; Estrella, N.; Koch, E.; Aasa, A.; and others. 2006. **European phenological response to climate change matches the warming pattern.** *Global Change Biology*. 12: 1969-1976.
- Richardson, A.D.; Jenkins, J.P.; Braswell, B.H.; Hollinger, D.Y.; Ollinger, S.V.; Smith, M.L. 2007. **Use of digital webcam images to track spring green-up in a deciduous broadleaf forest.** *Oecologia*. 152: 323-334.

- Schwartz, M.D.; Ahas, R.; Aasa, A. 2006. **Onset of spring starting earlier across the northern hemisphere.** Global Change Biology. 12: 343-351.
- Schwartz, M.D., ed. 2003. **Phenology: an integrative environmental science.** Dordrecht, The Netherlands: Kluwer Academic Publishers. 592 p.

The content of this paper reflects the views of the author(s), who are responsible for the facts and accuracy of the information presented herein.