Mark D. Schwartz *Editor*

Phenology: An Integrative Environmental Science

Second Edition

Springer

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Foreword

I was both surprised and delighted when Mark D. Schwartz asked me to write the foreword for the 2nd Edition of *Phenology: An Integrative Environmental Science*. I came into phenological science and networks fairly recently and, frankly, through the back door. In August 2004, Pat Mulholland (Oak Ridge National Laboratories), David Breshears (University of Arizona), and I convened a 3-day workshop in Tucson, Arizona, on how existing and planned national networks in the U.S.A. might be used to understand, monitor and forecast ecological responses to climate variability and change (http://www.neoninc.org/documents/neon-climate-report.pdf).

David, Pat, and I gathered 30 prominent scientists, encompassing the fields of ecology, hydrology, and climatology. It fast became clear in the group that there were serious mismatches in assumptions and scales of investigation, not just mutually-unintelligible jargon. Some pressed to make comprehensive measurements at a few sites to get at complex responses in ecological process, while others advocated broad scale monitoring to reveal emergent and large-scale patterns driven by climatic variations and trends.

The tension at the 2004 workshop only served to reinforce my own prejudices about some of the interdisciplinary challenges facing global change biology. If ecologists are to be successful in distinguishing competing and interacting causes of large-scale ecological changes and associated feedbacks to the atmosphere and hydrosphere, they will need to match the spatial and temporal scales of analysis employed routinely by climatologists and hydrologists. A fundamental need are networks of routine, standardized, and integrated observations, on the ground and from space, strategically deployed to gage ecological variability and change across the mosaic of hydroclimatic areas, biomes, and anthromes (a term I learned from Chap. 26 by de Beurs and Henebry) that comprise the United States. . .and the world.

Phenology, the gateway to climatic effects on the biosphere and associated feedbacks to the atmosphere, seemed as good a place to start as any. Right after the 2004 workshop, Steve Running connected me with Mark D. Schwartz.

In collaboration with several colleagues and institutions, including base stable support from the U.S. Geological Survey, Mark and I helped launch the USA-National Phenology Network (USA-NPN).

Previously, I had studied phenology only from afar. To get up to speed, for the past few years I have lugged my copy of the 1st Edition of *Phenology: An Integrative Environmental Science* on planes and even in the field, loaning it repeatedly to students and colleagues, always anxious to get it back. To continue my ongoing education, I have now read each updated and new chapter in the 2nd Edition front to back. This new tome, and the exponential growth in primary literature since the 1st Edition, marks "the rebirth of phenology…as a critical element of global change research" (Richardson et al. 2012, p. 157).

Having toiled at it myself, I very much appreciate that the authors of each chapter pay homage to the history of network development in each country. I spent hours listening to the late Joseph M. Caprio talk about the beginnings of the U.S. Western States Phenological Network in the 1950s, and I can imagine similar stories told by the late Coching Chu, who pioneered phenological networks in China during the 1930s (Chap. 2 by Chen). In 2007, Kjell Bolmgren, then a postdoc at University of California-Berkeley, sat next to me in one of our USA-NPN planning workshops. There was then a gleam in his eye, and there is now something called the Swedish Phenological Network.

This proliferation in networks worldwide is exciting, and with it comes the responsibility to forge a meaningful and effective, global community of practice. Over the long term, some of this could be accomplished through the integration of phenology in higher education. *Phenology: An Integrative Environmental Science* would make a great textbook for a novel course that could be taught globally. Such a course would blend classroom and online learning of first principles, integrated systems, and quantitative and modeling skills with the generation and use of data products from both observational networks and remote sensing. The examples given in Chap. 31 (by de Beurs and others) provide an excellent start.

I will take license here and point to some future directions for a 3rd Edition of *Phenology: An Integrative Environmental Science*. As Helmut Lieth remarked in his Foreword to the 1st Edition, phenology arises from planet Earth tumbling around the sun. Moreover, atmospheric planetary-scale waves drive temporally and spatially averaged exchanges of heat, momentum, and water vapor that ultimately determine and synchronize large-scale patterns in phenology, growth, demography, disturbance, biogeochemical cycling, and atmospheric feedbacks. At its core, phenology is the biological expression of climatology. To make real progress, particularly when it comes to prediction, we must fully engage climatologists to focus on regional to global patterns and sources for seasonal timing variations and trends in the climate system. To date, this has not been a particular focus in the climate community, but it is fertile and essential ground for integrative environmental science and, specifically, phenology.

For example, the annual phasing of temperatures advanced about 1.5 days over the Northern Hemisphere, due in large part to changes in atmospheric circulation in the 1980s, but we are not totally sure why (Stine et al. 2009; Stine and Huybers 2012).

Additionally, so-called warming holes[1] extend from the southeastern U.S. across the Atlantic from Scandinavia to Siberia and northern China. Such warming holes have muted advances and even delayed spring onset in the southeastern U.S. and Eurasia, and have been explained as intrinsic decadal variability in the Pacific (Meehl et al. 2012) and poorly understood interactions between Eurasian snow cover and the Arctic Oscillation (Cohen et al. 2012), respectively. Not all regional trends in phenology can reliably be attributed to greenhouse warming.

Phenology is maturing as a global change science, and with this maturity comes an obligation to get it right. Discrepancies always arise from comparative approaches in global ecology. Recent meta-analyses and cross-method comparisons reveal poor agreement between: (1) seasonality of ecosystem-scale CO_2 exchange in terrestrial biosphere models and actual flux tower measurements (Richardson et al. 2013; but see Kovalskyy et al. 2012); (2) different remote sensing platforms and algorithms used to define start of season (White et al. 2009); and (3) temperature-sensitivities for timing of leaf-out and flowering identified from warming experiments versus historical observations across the Northern Hemisphere (Wolkovich et al. 2012). So how do we choose which numbers are right to use in assessments and models to identify vulnerabilities and predict the future?

The 1st and the 2nd Editions of *Phenology: An Integrative Environmental Science* laid the necessary groundwork for a critical component of global change research. The phenological community should strive to resolve these seminal questions, and I very much look forward to reading the solutions in the 3rd Edition.

Senior Scientist, U.S. Geological Survey Julio L. Betancourt
Reston, VA, USA, March 2013

References

Cohen JL, Furtado JC, Barlow MA, Alexev VA, Cherry JE (2012) Arctic warming, increasing snow cover and widespread boreal winter cooling. Environ Res Lett 26:345–348

Kovalskyy V, Roy DP, Zhang X, Ju J (2012) The suitability of multi-temporal web-enabled Landsat data NDVI for phenological monitoring – a comparison with flux tower and MODIS NDVI. Remote Sens Lett 3:325–334

Meehl GA, Arblaster JM, Branstator G (2012) Mechanisms contributing to the warming hole and the consequent U.S. east–west differential of heat extremes. J Clim 25:6394–6408

Richardson AD, Anderson RS, Arain MA, Barr AG, Bohrer G, Chen G, Chen JM, Ciais P, Davis KJ, Desai AR, Dietze MC, Dragoni D, Garrity SR, Gough CM, Grant R, Hollinger DY, Margolis HA, McCaughey H, Migliavacca M, Monson RK, Munger JW, Poulter B, Raczka BM, Ricciuto DM, Sahoo AK, Schaefer K, Tian H, Vargas R, Verbeeck H, Xiao J, Xue Y (2012) Terrestrial biosphere models need better representation of vegetation phenology: results from the North American Carbon Program Site Synthesis. Global Change Biol 18:566–584

[1] Large regions in the world where either seasonal cooling has occurred or the rate of warming has been slower than elsewhere.

Richardson AD, Keenan TF, Migliavacca M, Sonnentag O, Ryu Y, Toomey M (2013) Climate change, phenology, and phenological control of vegetation feedbacks to the climate system. Agric For Meteorol 169:156–173

Stine AR, Huybers P (2012) Changes in the seasonal cycle of temperature and atmospheric circulation. J Clim 25:7362–7380

Stine AR, Huybers P, Fung IY (2009) Changes in the phase of the annual cycle of surface temperature. Nature 457:435–440

White MA, de Beurs KM, Didan K, Inouye DW, Richardson AD, Jensen OP, O'Keefe J, Zhang G, Nemani RR, van Leeuwen WJD, Brown JF, de Wit A, Schaepman M, Lin X, Dettinger M, Bailey AS, Kimball J, Schwartz MD, Baldocchi DD, Lee JT, Lauenroth WK (2009) Intercomparison, interpretation, and assessment of spring phenology in North America estimated from remote sensing for 1982 to 2006. Global Change Biol 15(10):2335–2359

Wolkovich EM, Cook BI, Allen JM, Crimmins TM, Travers S, Pau S, Regetz J, Davies TJ, Betancourt JL, Kraft NJB, Ault TR, Bolmgren K, Mazer SJ, McCabe GJ, McGill BJ, Parmesan C, Salamin N, Schwartz MD, Cleland EE (2012) Warming experiments underpredict plant phenological responses to climate change. Nature 485(7399):494–497

Preface

In the preface to the first edition I described my personal phenological research "journey", and reviewed the conditions which enabled the successful creation of a general phenological reference volume in 2003. Those conditions were: (1) sufficient interest in the topic by the general scientific community; and (2) an interconnected community of phenological researchers with the diversity of research expertise necessary to cover the range of required topics.

Looking back over the last 10 years, it is clear that interest in phenological research has grown significantly while an increase in the number and range of scientific publications indicates an expansion in the diversification of the subject. The validity of phenological research is evident by inclusion, in the IPCC's 4th Assessment Report (2007), of a range of phenological records to demonstrate that climate change was having a detectable impact on the natural environment. In addition, a number of national phenological observation networks have been initiated in several countries, including Australia, Sweden, Turkey, and the United States (I am co-founder of the USA National Phenology Network, USA-NPN). Furthermore, two successful interdisciplinary international phenology conferences have also been held: "Phenology 2010" (Dublin, Ireland) and "Phenology 2012" (Milwaukee, Wisconsin, USA).

Thus, over the last decade a dynamic international and interdisciplinary phenological research community has matured, which this second edition of *Phenology: An Integrative Environmental Science* is designed to nurture and serve as we move forward over the coming decade.

Milwaukee, WI, USA, March 2013 — Mark D. Schwartz

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Chapter 1
Introduction

Mark D. Schwartz

Abstract Phenology has been used as a proxy for climate and weather throughout human history particularly in relation to agriculture, but only within the last two centuries has it emerged as a science in its own right. Moreover, during the last half of the twentieth century the value of phenological science has been recognized as an integrative measure of plant and animal responses to climate and other environmental change that can be scaled from a local to a global level. Multiple examples, concepts, and applications of phenology have been systematically compiled to create this book. Together, they serve to reemphasize the valuable contribution of phenological research, in particular related to environmental change, to-date, and highlight the urgent need for more data collection, networks, and global collaborations in the future.

1.1 Basic Concepts and Background

Phenology, which is derived from the Greek word *phaino* meaning to show or to appear, is the study of recurring plant and animal life cycle stages, especially their timing and relationships with weather and climate. Sprouting and flowering of plants in the spring, color changes of leaves in the fall, bird migration and nesting, insect hatching, and animal hibernation are all examples of phenological events (Dubé et al. 1984). Seasonality is a related term, referring to similar non-biological events, such as timing of the fall formation and spring break-up of ice on fresh water lakes.

Human knowledge and activities connected to what is now called phenology are probably as old as civilization itself. Surely, soon after farmers began to continuously dwell in one place—planting seeds, observing crop growth, and carrying out the harvest year after year—they quickly became aware of the connection of

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changes in their environment to plant development. Ancient records and literature, such as observations taken up to 3,000 years ago in China (see Chap. 2), and references in the Christian Bible, testify to a common level of understanding about phenology among early peoples:

> Learn a lesson from the fig tree. Once the sap of its branches runs high and it begins to sprout leaves, you know that summer is near. *Gospel of Mark 13:28*

Unfortunately, these ancient "roots" did not translate into systematic data collection across large areas over the centuries, nor did they provide impetus for the early development of phenology as a scientific endeavor and discipline. For a long time the field remained tied almost exclusively to agricultural applications, and even those were only deemed practical at the local scale (i.e., every place was different, and generalizations difficult or impossible). With the establishment of continuous and continental-scale observation networks by the mid-1900s (though still largely confined to Europe, see Chap. 4), and contributions of early researchers such as Schnelle (1955), phenology began to emerge as an environmental science. Lieth's (1974) book was the first modern synthesis to chart the interdisciplinary extent of the field, and demonstrate its potential for addressing a variety of ecological system and management issues. These foundations prepared the way for the first edition of the current book (in 2003) and subsequently this second edition.

1.2 Organization and Use

Phenological research has traditionally been identified with studies of mid-latitude plants (mostly trees and shrubs) in seasonal climates, but other areas of the field are also progressing. Thus, a principal goal in organizing this book was to overcome this mid-latitude plant bias with a structure that would facilitate a thorough examination of wider aspects of plant and animal phenology.

The first section, "Phenological Data, Networks, and Research," adopts a regional approach to assess the state and scope of phenological research around the world with chapters on "East Asia" (2), "Australia and New Zealand" (3), "Europe" (4), "North America" (5, excluding Mexico), "...South and Central America" (6), and "Antarctica" (7). Several major regions, most notably Africa and central Asia were not included due to an inability to identify researchers working in these geographical areas. While some efforts were made in Chaps. 2, 3, 4, 5, 6 and 7 to survey the history of regional data collection and research, more emphasis was given to an assessment of recent developments. My assumption was that since Lieth's (1974) book had make an extensive survey of the history of phenological research up to the early 1970s, there was no great need to reproduce all that historical information in this volume. The final chapter in this section explores plans for developing global phenological networks, "International Phenological Observation Networks" (8).

Part II, “Phenology of Selected Bioclimatic Zones,” examines phenological research in areas outside of mid-latitudes, with chapters on “Tropical Dry Climates” (9) and “Phenology at High Latitudes” (13). Other chapters in this section document phenology in drier mid-latitude biomes, including “Mediterranean Phenology” (10), and “North American Grassland Phenology” (11). A new chapter was added to this edition examining “Mesic Temperate Deciduous Forest Phenology” (12) which has been a traditional region of intensive phenological research. Lastly, the particular responses of “Phenology at High Altitudes” are explored in Chap. 14.

Part III, “Phenological Models and Techniques” presents a survey of phenological research methodologies and strategies. Model building and development is outlined in chapters addressing plants (15), and animal life cycles (16, concentrating on poikilotherms). The challenges of spatial and temporal modeling are explored in Chap. 17, and other chapters address the issues of temperature measurement (20), methods to detect climate change (18) and comparing high-resolution ground and moderate-resolution satellite-derived phenology (19). The next section (Part IV) is devoted entirely to the important area of “Sensor-Derived Phenology”, but now includes both a chapter on “Satellite-Sensor Derived Phenology (21) and the recently emerging “Near-Surface Sensor-Derived Phenology” (22).

Part V, “Phenology of Selected Lifeforms” looks at research and developments in animal phenology, including chapters on “Aquatic Plants and Animals” (23), “Birds” (24), and “Reproductive Phenology of Large Mammals” (25). The final section of the book (Part VI) details “Applications of Phenology” to a variety of topics. Chapter 26 looks specifically at “Vegetation Phenology in Global Change Studies,” Chap. 27 explores frontiers related to “. . .Photosynthesis Phenology in Northern Ecosystems,” and Chap. 28 examines “Phenology and Evapotranspiration.” Several remaining chapters in this section explore applications in traditional field agriculture and horticulture (29) and winegrape growth and care (30). Lastly, selected phenological applications in higher education are examined in the final Chap. (31).

Therefore, this volume’s structure is primarily designed to serve the basic reference needs of phenological researchers and students interested in learning more about specific aspects of the field, or evaluating the feasibility of new ideas and projects. However, it is also an ideal primer for ecologists, climatologists, remote sensing specialists, global change scientists, and motivated members of the public who wish to gain a deeper understanding of phenology and its potential uses.

1.3 Future Directions and Challenges

When I chose the name for this book, I deliberately selected the word “integrative” because of its implication of a process. Phenology is an interdisciplinary environmental science, and as such brings together individuals from many different scientific backgrounds, but the full benefits of their combined disciplinary perspectives to enrich phenological research have yet to be realized. Thus, the term "integrative" as in moving together, rather than "integrated" implying already being together.

The nearly 10 years which have passed since publication of the first edition (in 2003) have seen steady progress in the transmission of "phenological perspectives" into the mainstream of science, especially related to the needs of global change research, but considerable work remains to be done. While other parts of phenological research are still important and need to progress, I still contend that it is global change science that will stimulate, challenge, and transform the discipline of phenology most in the coming decades. In order to maximize the benefits of phenology for global change research as rapidly as possible, commitments to integrative thinking and large-scale data collection must continue. First of all, the limitations of the primary forms of data collection (remote sensing derived, native species, cloned indicator species, and model output) must be accepted. None of these data sources can meet the needs of all research questions, and an "integrative approach" that combines data types provides synergistic benefits (Schwartz 1994, 1999).

The most needed data are traditional native and cloned plant species observations. Networks that select a small number of common and cloned plants for coordinated observation among national and global scale networks will prove the most useful. I am deeply gratified by the role that I have played in the development of the USA National Phenology Network (USA-NPN), using that basic framework. Over the last 10 years USA-NPN has progressed from being little more than an idea in my head, to a real operational network, thanks to efforts of my many dedicated colleagues. Such networks should continue to be created, embraced and (where possible) integrated into the missions of national and global data collection services around the world. A little more than 100 years ago, the countries of the world began to cooperate in a global-scale network of weather and climate monitoring stations. The results of this long-term investment are the considerable progress that has been made in understanding the workings of the earth's climate systems. I continue to believe that we have a similar opportunity with phenological data, and that small investments in national and global-scale observation networks are crucial to global change science, and will yield an impressive return in the years ahead.

References

Dubé PA, Perry LP, Vittum MT (1984) Instructions for phenological observations: Lilac and honeysuckle. Vermont Agricultural Experiment Station Bulletin 692. University of Vermont, Burlington

Lieth H (ed) (1974) Phenology and seasonality modeling. Ecological studies, vol 8. Springer, New York

Schnelle F (1955) Pflanzen-Phänologie. Probleme Der Bioklimatologie, vol 3. Akademische Verlagsgesellschaft, Leipzig

Schwartz MD (1994) Monitoring global change with phenology: the case of the spring green wave. Int J Biometeorol 38(1):18–22

Schwartz MD (1999) Advancing to full bloom: planning phenological research for the 21st century. Int J Biometeorol 42(3):113–118

Part I
Phenological Data, Networks, and Research

Chapter 2
East Asia

Xiaoqiu Chen

Abstract Phenological observations and research have a long history in East Asia. Countrywide phenological networks have been established mostly by national meteorological administrations or agencies during 1950s to 1980s. Since 2000, phenological research has made significant progress in China, Japan, and South Korea. The recent network-related research focuses mainly on three aspects: first, the temporal and spatial variation of plant phenology and its responses to climate change at individual and community levels by means of statistical methods; second, the effect of genetic diversity on phenological responses to climate change; and third, identification and extrapolation of the vegetation growing season on the basis of plant community phenology and satellite data.

2.1 Phenological Observation and Research in China

2.1.1 Historical Background

Modern phenological observation and research in China started in the 1920s with Dr. Coching Chu (1890–1974). As early as 1921 he observed spring phenophases of several trees and birds in Nanjing. In 1931, he summarized phenological knowledge from the past 3,000 years in China. He also introduced phenological principles (e.g. species selection, criteria of phenological observations and phenological laws) developed in Europe and the United States from the middle of the eighteenth to the early twentieth century (Chu 1931). According to his literature survey, phenological observation can be traced back to the eleventh century B.C. in China. The earliest phenological calendar, Xia Xiao Zheng, stems from this period and recorded (on a monthly basis) phenological events, weather,

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astronomical phenomena, and farming activities in the region between the Huai River drainage area and the lower reaches of Yangtze River. In addition, extensive phenological data were recorded in other ancient literatures over the past 3,000 years. These data could to some extent reflect past climate. Using ancient phenological data and other data, he reconstructed a temperature series of the past 5,000 years in China (Chu 1973).

2.1.2 Networks and Data

In 1934, Dr. Coching Chu established the first phenological network in China. Observations covered some 21 species of plants, nine species of animals, some crops, and several hydro-meteorological events, and ceased in 1937 because of the War of Resistance Against Japan (1937–1945). Twenty-five years later the Chinese Academy of Sciences (CAS) established a countrywide phenological network under the guidance of Dr. Chu. The observations began in 1963 and continued until 1996. Observations resumed in 2003, but with a reduced number of stations, species, and phenophases.

The observation program of the CAS network included a total of 173 observed species. Of these, 127 species of woody and herbaceous plants had a localized distribution. Table 2.1 lists the 33 species of woody plants, two species of herbaceous plants, and 11 species of animals that were observed across the network (Institute of Geography at the Chinese Academy of Sciences 1965). During 1973–1986, several stations added phenological observation of major crops, such as rice, winter wheat, spring wheat, corn, grain sorghum, millet, cotton, soybean, potato, buckwheat, rape, etc. The observations were carried out mainly by botanical gardens, research institutes, universities and middle schools according to unified observation criteria (Institute of Geography at the Chinese Academy of Sciences 1965; Wan and Liu 1979). The phenophases of woody plants included bud swelling, budburst, first leaf unfolding, 50 % leaf unfolding, flower bud or inflorescence appearance, first flowering, 50 % flowering, the end of flowering, fruit or seed maturing, first fruit or seed shedding, the end of fruit or seed shedding, first leaf coloration, full leaf coloration, first defoliation, and the end of defoliation. Changes to the stations and in observers over the years resulted in data that were spatially and temporally inhomogeneous. The number of active stations varied over time. The largest number of stations operating was 69 in 1964 and the lowest number occurred between 1969 and 1972 with only 4–6 stations active. The phenological data from 1963 to 1988 were published in form of Yearbooks of Chinese Animal and Plant Phenological Observation (Volume 1–11). Since then, the data have not been published.

In 1980 the China Meteorological Administration (CMA) established another countrywide phenological network. The CMA phenological network is affiliated with the national-level agrometeorological monitoring network and came into operation in 1981. The phenological observation criteria for woody and herbaceous plants, and animals were adopted from the CAS network. There are 28 common species of woody plants, one common species of herbaceous plant and 11 common species of animals. The main phenophases are the same as those of the CAS network. In addition to the natural phenological observations, the network also carries out professional

Table 2.1 Common observation species of the CAS phenological network in China

Latin names
Woody plants
Ginkgo biloba
Metasequoia glyptostroboides
Platycladus orientalis
Sabina chinensis
Populus simonii
Populus canadensis
Salix babylonica
Juglans regia
Castanea mollissima
Quercus variabilis
Ulmus pumila
Morus alba
Broussonetia papyrifera
Paeonia suffruticosa
Magnolia denudata
Firmiana simplex
Malus pumila
Prunus armeniaca
Prunus persica
Prunus davidiana
Albizia julibrissin
Cercis chinensis
Sophora japonica
Robinia pseudoacacia
Wisteria sinensis
Melia azedarach
Koelreuteria paniculata
Zizyphus jujuba
Hibiscus syriacus
Lagerstroemia indica
Osmanthus fragrans
Syringa oblata
Fraxinus chinensis
Herbaceous plants
Paeonia lactiflora
Dendranthema indicum
Animals
Apis mellifera
Apus apus pekinensis
Hirundo rustica gutturalis
Hirundo daurica japonica
Cuculus canorus canorus
Cuculus micropterus micropterus
Cryptotympana atrata
Gryllulus chinensis
Anser fabalis serrirostris
Oriolus chinensis diffusus
Rana nigromaculata