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The Pulse of Our Planet

PHENOLOGY AND CLIMATE CHANGE

By Jake F. Weltzin

Robins, daffodils, the first salmon up the river, the lilac in the front yard … they all seem to be arriving a little earlier. In fact, they are. When we examine the evidence available for different taxonomic groups of animals and plants as described in many peer-reviewed articles, we see the harbingers of spring arriving earlier, including:

- Salmon (Salmo salar) migrations up rivers in Connecticut and Maine were 6.5-8 days earlier every decade between 1977 and 2002 (Juanes 2005).
- Yellow-bellied marmots (Marmota flaviventris) emerged from hibernation in Colorado about 30 days earlier between 1975 and 2007 (Inouye 2000).
- American robins (Turdus migratorius), perennial harbingers of spring, are arriving about 15 days earlier than they had been previously, as recorded in Colorado from 1981 to 2006 (Inouye 2000).
- A recent analysis of 203 species conducted on published datasets from the northern hemisphere indicates an overall spring advancement across the northern hemisphere of 2.8 days per decade (Parmesan 2007).

Now that most scientists agree that our planet is indeed warming due to human activities (IPCC 2007), we are led to ask how organisms, natural processes, and ecosystems are responding. The answers to these questions are key to developing informed forecasts of and strategies for adapting to climate change. The USA-National Phenology Network was created to help answer just such questions.

Phenology Today: A Science Comes Into Its Own

Phenology, derived from the Greek word phaino, meaning to show or appear, is the study of the timing of natural events including plant and animal life cycles, particularly the timing of biological events that are influenced by environmental changes in temperature, weather, and/or climate. Common examples of phenological events include the dates of first openings of leaf and flower buds, the timing of hibernation, hatchings, emergence of insects, and the timing and patterns of bird migrations. The passing of the seasons, recorded in the seasonal cycles of organisms, is the most pervasive source of biological variability on Earth. Each “phenophase” gives scientists a measure of the environment as experienced by the Earth’s organisms. By studying phenology, we can monitor the direction and course of our changing climate through data gathered and analyzed from daily observations of the natural world.

Phenology is a critical component of the biosphere and the climate system at all scales. From cell division to individual organisms to landscapes and satellite imagery, the phenological pulse of entire regions can be tracked and linked. For example, specific data about tree growth, such as when trees first spout leaves, are related to ecosystem carbon sequestration, energy, and hydrological fluxes—all important indicators of climate change. With a little bit of training, citizens can observe and record this kind of information as accurately as scientists. This sort of data can, in turn, be linked to the spectral signature of the forest canopy as detected by digital cameras or air- or space-borne spectral imagery. Verifying and fine-tuning phenological observations across various scales can enable researchers to better assess how local to global-scale changes in weather and climate are affecting different components of the Earth’s biosphere.

The synchronicity of the phenological phases of different plants and animals, or lack thereof, affects the future structure and function of an ecosystem in other ways. For example, many natural events such as insect breeding and some bird migrations are based on day length rather than temperature. This can result in ecological mismatches. Flowers, for instance, may bloom before their pollinators arrive, leaving both out of luck. In other cases, migratory birds may arrive on their summer breeding grounds after their primary food source has come and gone. Such mistimed behav-
ior has already been noted across many parts of the globe. A mismatch of flowering with the presence of a pollinator could easily begin a cascade effect that could completely reorganize an ecosystem.

The phenological attributes of an ecosystem or habitat also reflect its biodiversity and structure, as well as its ability to regulate biogeochemical cycles and to sustain life. Scaling from the individual to higher levels of organization, as well as across elevational gradients, allows scientists to employ simple and inexpensive methods to monitor phenology. In addition to effects of climate change, phenology can be used in areas such as human and wildlife health, resource management, gardening, agriculture, and forestry, as described in Table 1.

Much of the projected global warming due to buildup in greenhouse gases will affect the timing of annual plant and animal life cycle events in ways that are vital to scientific, ecological, and public interest. In the United States, scientific phenological efforts have traditionally been tied to agricultural applications and the illustration of extreme climatic effects such as flooding and drought at the local scale. Over the last decade, however, scientists have increasingly realized the potential of the science of phenology to help us understand interactions between the atmosphere and biosphere. Networks to capture and study phenological data have been in place in Europe, Canada, Australia, and China. However, in the United States, only the phenology of lilacs has been recorded at near-continental scales, and even this information is relatively sparse. To understand and properly manage wildlife and habitat in the United States, this country must begin to collect and analyze phenological data on a much broader scale.

To respond to the need for more data, in 2005 an interdisciplinary group of scientists began work to establish a national network in the United States—including federal and environmental organizations, educational institutions, and citizen scientists—to monitor the phenology of plants and animals across the country. The plan was for this network to serve as a coast-to-coast science and monitoring network focused on repeated and integrated plant and animal phenological observations, and to help link the information collected with other data sources and analytical tools.

**The USA National Phenology Network**

The work begun in 2005 grew into a full pilot project in the spring of 2008, known as the USA National phenology network.
Phenology Network (NPN), with participants across the United States collecting data about the response of plants, animals, and ecosystems to climate change. The primary goal of this network is to collect detailed data that can help scientists, naturalists, and the public understand and predict the trajectory of climate change. Data and analyses drawn from the network will be crucial in understanding specifically how species and ecosystems are responding to changes in global climate and in developing management plans for adapting to these changes.

By focusing on phenology, researchers will be better able to separate the natural fluctuations in climate, weather, and phenological responses of plants, animals, and ecosystems from those caused by human-induced climate change. By tracking organisms through time and across space, and by comparing these responses to local and regional weather and climatological patterns (co-occurring across space and time), we will better understand first-principle relationships between organisms and their environment, and thus can better ascribe observed changes to anthropogenic vs. natural variation. For example, the phenology of some plants responds to multiple variables that drive global climate change (e.g., temperature, precipitation, or concentration of atmospheric carbon dioxide) in unpredictable ways. These patterns can be elucidated through concurrent consideration of data from long-term monitoring projects and manipulative experiments.

The pilot program for the 2008 growing season began with experts agreeing upon a core set of plant species representative of large regions within the United States. The experts then determined critical phenophases for monitoring each species, and developed standards for how relevant data should be collected and recorded. The NPN is collaborating with the University of Wisconsin-Milwaukee and Oak Ridge National Laboratories to create databases and technical infrastructures to store and analyze the data that are collected. The NPN is also working with The Wildlife Society (TWS), the U.S. Geological Survey (USGS), and the U.S. Fish and Wildlife Service (FWS) to broaden the network of researchers and other participants who can help in these research efforts. The National Coordinating Office (NCO) of the NPN recently opened its doors on the University of Arizona campus in Tucson to begin the important work of managing the data collected throughout the NPN.

At the Coal Oil Point Natural Reserve, managed by the University of California-Santa Barbara, budding phenologists record flowering data from 21 species of wildflowers, shrubs, and trees in foredune, backdune, and coastal scrub communities.

The Eyes in the Sky: Remote Sensing of Land Surface Phenologies

By Geoffrey M. Hennebry, South Dakota State University

Green plants can reflect a lot of sunlight, particularly in near infrared, the region of light just beyond the limits of our vision. Researchers can use the brightness of the near infrared coupled with vegetation’s high absorption of red light, which is used in photosynthesis, to identify vegetated areas from a vantage point several hundred miles in space. When viewed from orbital sensors, the growth and development of vegetation across the land surface reveals distinctive patterns—land-surface phenomenologies—that relate to land use, vegetation type, disturbance, climate, and recent weather.

Land-surface phenomenologies are important indicators of the exchange of water and energy between the land surface and the atmosphere, and can be used to model the carbon cycle and to monitor crop development and the effects of disturbance on landscapes. Land-surface phenomenologies are different from the specific phenomenologies of plants we observe on the ground. The sensor sees a signal that is a mixture of light reflected from the plants, soil, and other objects in the scene, but at a coarse spatial resolution relative to the size of those objects. In other words, the satellite image is fuzzy, and we need eyes-on-the-ground to complement the eyes-in-the-skies so that we can understand what the sensors see and what they don’t see. The NPN is playing a critical role in providing a framework to bring together different kinds of phenological observations to improve our understanding of phenology in all its forms.
The full potential of the NPN will be reached when phenological measurements from individual plants or animals, entire landscapes, and remote-sensing platforms can be integrated into datasets.

Getting Involved with NPN

To make the best use of available resources, the NPN is working to establish collaborative projects with existing local, state, federal, and non-governmental organizations. The NPN is already partnering with networks such as Ameriflux, National Ecological Observatory Network, and Monarch Watch to develop and improve climate and ecosystem models. Education and outreach are important parts of the network, which is why the NPN is also building education and citizen-science programs to engage groups such as land steward networks, master naturalists and gardeners, and native plant and gardening societies. These outreach programs will allow the public to work alongside scientific professionals to observe and interpret phenological patterns at an unprecedented scale. The NPN’s education and outreach efforts are designed to provide training in tools and applications needed for phenological studies to citizens and to scientists, regardless of their starting level of expertise.

NPN leaders know that these kinds of interactive and interdisciplinary approaches will encourage participants to develop new tools and new approaches to phenological studies. As one example, Project BudBurst last year successfully invited public observers to validate protocols for leafing and flowering of 54 plant species with the intent of tracking spring onset, and is in the midst of an even larger and more successful 2008 season.

Over time, the complexities in the phenologies of plants and animals will be better sorted out through monitoring protocols and the development of long-term datasets such as those being developed by the NPN. We hope these resources will not only provide scientists and policymakers with rich data for understanding and managing wildlife and habitat but will also help make the public more aware of how sensitive plants and animals are to climatic variation. We are confident that the NPN will play a central role in motivating people to become involved in and committed to sustaining the pulse of our planet.

Table 1. Examples of six areas to which phenological research can contribute

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<thead>
<tr>
<th>Scientific Research</th>
<th>Human Health</th>
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<tbody>
<tr>
<td>Effects of climate variability and change, ecological forecast models, ecological synchrony, carbon sequestration, ground truthing for remote sensing, ecohydrology</td>
<td>Timing and prediction of allergy (hay fever) and pulmonary (asthma) problems; study of vector-borne diseases (lyme disease, avian influenza, West Nile virus)</td>
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<tr>
<th>Agriculture</th>
<th>Natural Resources</th>
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<tbody>
<tr>
<td>Timing of management activities (pest and disease control, planting, harvesting, and provision of pollinators), drought monitoring, range management</td>
<td>Prediction of forest pest and disease outbreaks, fire management, invasive species management, watershed management, selection of species and varieties to be used in ‘assisted migration’ to conserve ecosystem services as climate changes</td>
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<th>Tourism and Recreation</th>
<th>Education</th>
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<td>Informing tourists when and where to go for seeing bird migrations, wildflower displays, and fall colors</td>
<td>School children and citizen scientist involvement in scientific observations; establish college curriculum in phenology that encourages local observations and educational use of the data products of the network</td>
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Eggs of a clay-colored sparrow (Spizella pallida) hint at spring’s arrival. The National Phenology Network tracks egg-laying, births, and other events to learn how earlier springs affect wildlife.