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Parks use phenology to improve management and communicate climate change

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Abstract: Climate change presents the dual challenges of (1) understanding its effects and how to manage them and (2) communicating climate change science to promote understanding and action. Here we describe one approach to addressing those challenges: studying climate-driven changes in phenology—the timing of seasonal biological events, such as flowering and migrations. Phenology is critical to people and the functioning of ecosystems, and it is changing wherever climate is changing. Thus it provides information for managers and local examples of effects of climate change that are relevant to park visitors and the communities surrounding parks. Parks, Research Learning Centers, Inventory and Monitoring Networks, and Cooperative Ecosystem Studies Units across the country are piloting methods, such as citizen science and remote sensing, for monitoring phenology and using the results to inform science, management, and education. These activities are gaining momentum and are poised to make significant contributions to our understanding of the effects of climate change and how best to communicate climate change science to the public.

Key Words: citizen science, climate change, Cooperative Ecosystem Studies Units, Inventory and Monitoring Networks, phenology monitoring, Research Learning Centers, Acadia NP, Great Smoky Mountains NP, Lowell NHP, Santa Monica Mountains NRA

Introduction

Rapid climate change—such as recent changes in climate that are occurring more rapidly than at any time since the last glacial maximum—presents two particularly formidable challenges for national parks and society in general. First, we must improve our understanding of the effects of climate change and how to manage them. Second, we must communicate the science of climate change in a concrete, noncontroversial (or minimally controversial) way that promotes understanding and action. In the National Park Service (NPS), many efforts are under way to address these two challenges (http://www.nps.gov/climatechange). Here, we describe one promising approach that addresses both challenges simultaneously: studying climate-driven changes in phenology—the timing of seasonal biological events, such as flowering and migrations.

Phenology has played an important role in the lives of people, plants, and animals through history. Human subsistence has depended on knowing when food plants are available and when game species arrive or depart on migrations. Much of ecological theory and many of our management practices recognized this, but assumed that phenology was relatively stable from one year to the next, in part because climate, which drives the timing of many phenological events, was long thought to be fairly stable, or “stationary” (Milly et al. 2008).

In a period of rapid climate change, though, understanding phenology becomes even more important. Almost every ecological relationship and process—including predator-prey and plant-pollinator interactions, the spread of disease, pest outbreaks, and water and carbon cycling—depends on the timing of phenological events (Forrest and Miller-Rushing 2010). As climatic conditions change, phenology changes, and so do these ecological relationships and processes. These shifts are further complicated because the phenologies of different species change at different rates and in different directions, some occurring earlier, others later (Sherry et al. 2007; Thackeray et al. 2010). In some cases this may lead to mismatches, as has occurred in parts of Europe where pied flycatchers (*Ficedula hypoleuca*) are now breeding too late relative to when their primary food source, winter moth caterpillars, is available; where this mismatch is most severe, populations of pied flycatchers are declining by up to 90% (Both et al. 2006). Changes in phenology also vary across space, as is evident in the earlier-than-average spring green-up and flowering of most plants in the northern United States, but later in southern regions (Zhang et al. 2007; Von Holle et al. 2010). Right now we are ill-equipped to predict the impacts of phenological changes on species and ecosystems because of a dearth of data describing the phenology of most species and the role of timing in regulating species interactions and ecological processes.

In addition to its role in ecosystem functions, phenology provides one of the most fundamental ways people relate to nature. Phenological events mark the changing of seasons: the emergence of leaves and butterflies and the sounds and activities of birds, frogs, and other animals herald the arrival of spring; fall foliage and crop harvest mark the onset of autumn and winter in much of the country. Because phenology is tightly coupled with climate and is changing wherever climate is changing, it provides a way that people can “see” climate change and its impacts wherever they are.

Phenology and national parks

Climate-driven changes in phenology are highly consequential to national parks because they are linked to important processes such as outbreaks of forest pests and increases in fire severity in the West (Hicke et al. 2006; Westerling et al. 2006), declines in and disappearance of wildflower populations in the Northeast (Willis et al. 2008) (fig. 1), and the spread of invasive species throughout the country (Willis et al. 2010). Timing of festivals tied to phenological events, such as flower displays or migrations, is changing because of both global climate change and urbanization (Aono and Kazui 2008; Primack et al. 2009). In Boston, for example, the annual lilac festival at the Arnold Arboretum now occurs three weeks earlier than it did 90 years ago (Loth 2011). Visitor seasons will likely shift as timing of the growing season shifts, lengthening in some areas and shortening in others. Parks can play a key role in understanding the causes and consequences of these changes: they contain some of our country’s most valued and unaltered landscapes and are distributed along ecological, climatological, and geographical gradients, making them ideal locations for investigating ecological responses to climate change.

The National Park Service is taking a leadership role in the effort to monitor phenology and improve our understanding of the effects that phenological changes will have on plants, animals, and people. Our strategy is three-pronged: (1) observe phenology in the field, (2) share and analyze data and information to increase their value, and (3) communicate with and engage the public. We are just beginning our work in these areas, but it is rapidly progressing.

There are a diversity of initiatives and approaches to monitoring phenology throughout the system of national parks, with different goals, audiences, and target species. To emphasize the range of activities and how they meet parks' needs, we briefly describe three NPS phenology projects and use them as examples in subsequent sections: (1) monitoring across the Northeast Temperate Inventory and Monitoring Network (NETN), including the collaboration of member parks and the Schoodic Education and Research Center at Acadia National Park, Maine; (2) the California Phenology Project (CPP), a collaboration among 19 parks, two Research Learning Centers (RLCs), five Inventory and Monitoring (I&M) Networks, and the Californian Cooperative Ecosystem Studies Unit (CESU); and (3) monitoring at Great Smoky Mountains National Park and its associated Appalachian Highlands Science Learning Center. Each of these projects involves extensive collaboration with other agencies, nongovernmental organizations, and academic institutions.

Making observations on the ground

Most current NPS phenology monitoring efforts rely on volunteers to make field observations. This citizen science approach works well because most people already observe phenology every day—they just do not write down their observations. Therefore, the oversimplified keys to monitoring phenology on the ground are to identify monitoring goals, recruit individuals to observe the phenological phases of interest—say, leaf expansion, birdcalls, or a bee visiting a flower—and have participants record their observations in a standard way.

To help with standardization, the National Park Service is working with the USA National Phenology Network (USA-NPN; see sidebar) and many other organizations and individuals to develop monitoring standards and online tools for training, data submission, reporting, mapping, and graphing. The standards for monitoring ensure that everyone is making the same basic observations, which facilitates aggregation and integration of observations across sites and species while providing flexibility so monitoring efforts can pursue different goals.

For example, NETN monitoring projects began with a focus on science, addressing questions such as how phenology is related to invasiveness, water relations, and other natural resource issues. The project in Great Smoky Mountains National Park began with a focus on education, giving participants a way to engage in climate change science and see local impacts of climate change. The California Phenology Project blends science and education objectives related to understanding resource response to climate change. No matter the initial impetus, all three programs are moving toward having equally strong science *and* education components.

Additionally, in the NETN and CPP monitoring efforts, different parks are testing and implementing different approaches. Individual parks rely on various mixes of trained volunteers, staff, and automated cameras and audio recorders to make field observations (fig. 2). The mix each park uses depends on the monitoring goals and capacity of their volunteer community and park staff. Phenology monitoring projects under way in the National Park Service are actively testing these and other approaches to find which ones best achieve their science and education goals.

In addition to collecting field observations, parks are identifying historical data sets that can help them increase the length of their monitoring records. For example, the Great Smoky Mountains Institute at Tremont, a nonprofit environmental education center, is analyzing and building on more than 30 years of phenology data (fig. 3). Many scientists, amateur naturalists, gardeners, and others habitually record their observations of flowers, fruits, birds, butterflies, and other phenological phases and events. Data sets like these have turned up across the country, often in unexpected places, and have led to valuable scientific insights (Ledneva et al. 2004; Miller-Rushing et al. 2006; MacMynowski and Root 2007; Crimmins et al. 2010) (fig. 4). Many parks almost certainly have undiscovered phenology data sets in their collections or in collections or attics of organizations and individuals in surrounding communities. These records can help scientists and resource managers understand local impacts of climate change and can be used by interpreters and educators to communicate those impacts to the public.

Efforts to analyze all of these historical data and new observations to inform park management are just getting under way. In the Southwest, phenology observations are being used to time the treatment of invasive species, such as buffelgrass (*Pennisetum ciliare*). In other areas, researchers are attempting to identify temporal mismatches that may be occurring between interacting species and are exploring the relationships between phenology and pest outbreaks, streamflow, fire, and carbon sequestration. Data collected in parks are also feeding into national efforts to model future changes so that we can better anticipate the consequences of phenological changes to come.

Sharing and communicating

To be sure, the National Park Service is not alone in its effort to monitor phenology and to understand the causes and consequences of phenological changes. It coordinates with the USA National Phenology Network and its many partners, including a wide variety of government agencies, nongovernmental organizations, academic institutions, and individuals, which dramatically increases the power of our work. As part of a community, we have access to data that can greatly increase the density of observations in a particular area and that provide a regional context that would otherwise be missing. Collaboration helps improve our monitoring and education techniques and facilitates rapid adoption of innovations developed by our partners. Our work reaches a far wider audience through our collaborators, whether that audience is researchers, managers, educators, or the public.

U.S. Fish and Wildlife Service/Kate Eschelbach

Figure 5. Phenology training at Santa Monica Mountains National Recreation Area. This training was a part of the California Phenology Project, which involves collaborations among parks, RLCs, I&M networks, the Californian CESU, and area universities.

Collaboration *within* the Park Service also improves the ability of our phenology monitoring projects to achieve their goals. Because of the interdisciplinary nature of phenology monitoring—its implications for science, education, and management of a range of natural resources, such as air, water, and wildlife—collaborations across park divisions, RLCs, I&M Networks, and CESUs are necessary (fig. 5, above). To enable this collaboration and communication, we organized a special session at the biannual meeting of the George Wright Society in March 2011, initiated an e-mail list focused on phenology in the National Park Service (http://webmail.itc.nps.gov/mailman/listinfo/npsphenofans), and established a Web site with information about NPS activities related to phenology (www.usanpn.org/nps). Additionally, each of the three projects in California, the Northeast, and Great Smoky Mountains National Park has formed committees and working groups to deal with particular issues, such as identifying indicator species, developing training materials, managing data, and sharing educational resources. The products of these committees and working groups are, in turn, feeding into the development of standard operating procedures.

Engaging the public

Phenology is a particularly effective means to communicate climate change because it is so strongly based on place. Local phenological changes connect climate change to people's day-to-day lives and to the places they live or recreate. Local phenological changes are not theoretical or distant but are "here and now," and are easy for anyone to observe. Because of the close link between phenology and climate, phenological changes are occurring virtually everywhere and provide concrete examples where other impacts of climate change may be difficult to see or describe.

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Observing phenology and actively participating in national-scale climate change research give participants firsthand experience in how scientific research is conducted and why climate science matters at the local level. This experience can enhance participants' understanding of science content and process, encourage them to see themselves as science learners, and may encourage some to take action to promote climate change mitigation and adaptation (Weber 2006; Bonney et al. 2009). Furthermore, volunteers who assist in data collection in parks can continue their monitoring at home through many citizen science programs (see usanpn.org or citizenscience.org). Data collected by volunteer observers are not superfluous but rather constitute valuable scientific observations that have led to important insights (e.g., Torti and Dunn 2005; Wolfe et al. 2005; Crimmins et al. 2010).

An important way for local community members to participate and contribute is by identifying historical phenology data. Acadia National Park recently hosted an event asking park staff and community members to share observations of local phenological events—everything from deer breeding to cruise ship seasons. In the course of discussion, people identified many "shoebox" data sets stored on bookshelves or in attics or photo albums. This engages people in the process of science, connects them with our country's heritage of natural history observation, and yields valuable data for science, management, and education.

The future

Monitoring phenology in parks has the potential to advance many science and education goals of the National Park Service and the United States more broadly. Phenological monitoring can contribute to priorities like getting youth outside, engaging local communities, building scientific literacy, preserving America's great outdoors, and advancing climate change science. Phenology monitoring complements ongoing efforts in the National Park Service, such as the Climate Change Response

Program, the Climate Change Interpretive Competency Subject Matter Expert Group, the Place-based and Climate Change Education Partnership, and monitoring activities in the Inventory and Monitoring Program focused on climate change.

Of course, using phenology observations to achieve meaningful science and education objectives can be challenging, and requires communicating across disciplines, acquiring funding and other support, identifying leaders and partners, and identifying and implementing the best approaches. The National Park Service and the broader phenology monitoring community are well poised to address these challenges. Costs of volunteer-based monitoring are low relative to the benefits to parks and park visitors. In an era of climate change, phenology monitoring makes important contributions to identifying and understanding environmental changes and to engaging and educating park staff and visitors.

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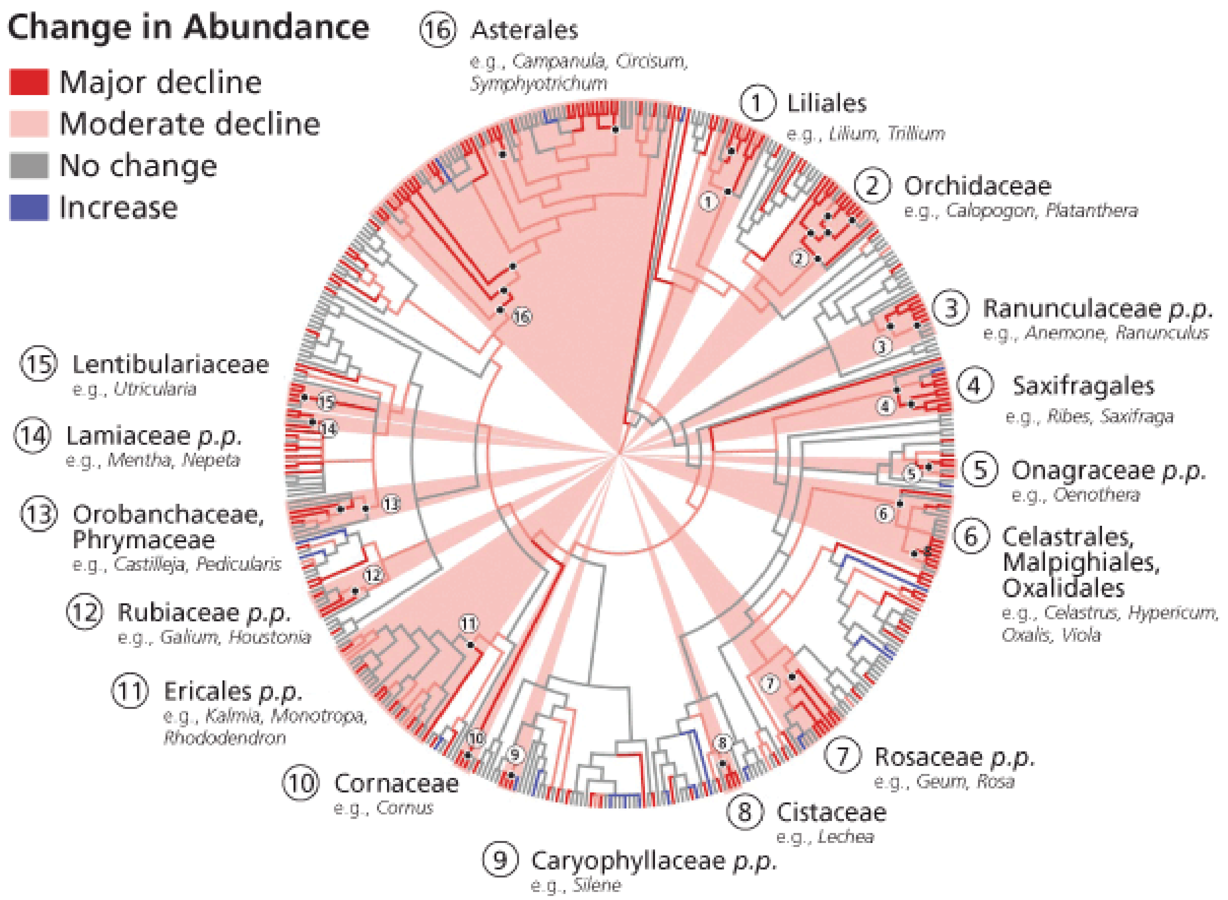
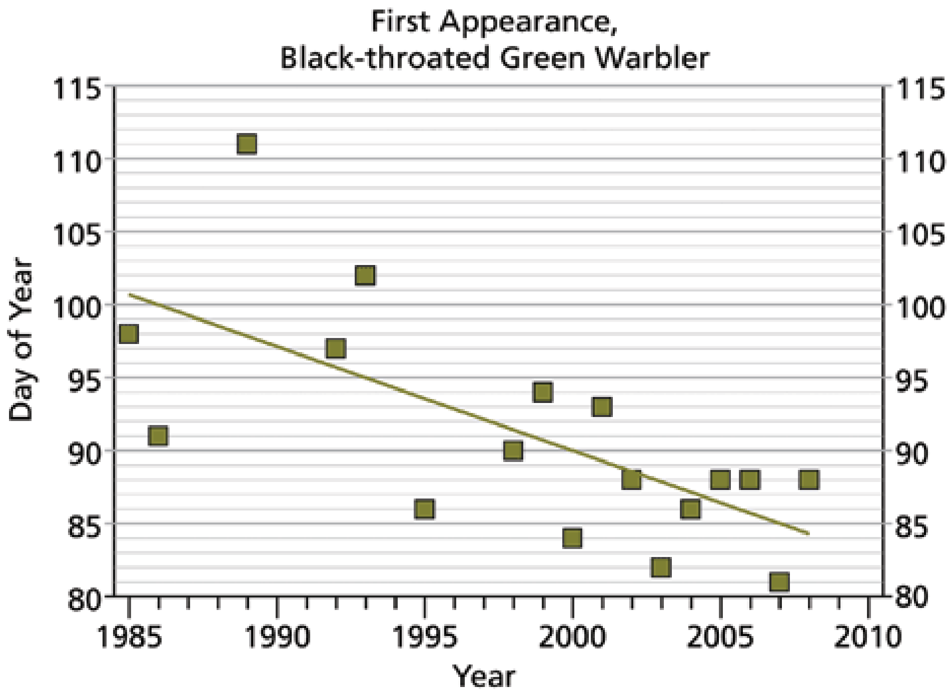


Source: Willis et al. 2008

Figure 1. Composite phylogeny of 429 flowering plant species from the flora of Concord, Massachusetts, depicting changes in abundance from 1900 to 2007. Groups with first flowering dates that did not track changes in spring temperatures tended to decline in abundance. Branch color indicates change in abundance. Clades (i.e., groups of species that share a common ancestor) exhibiting declines of 50% or more are indicated with black dots. Each of the most inclusive clades exhibiting these severe declines is indicated in pink and referenced numerically to its clade name. These clades include some of the most charismatic wildflower species in New England, such as anemones and buttercups (Ranunculaceae *p.p.* [*pro parte* or in part, that is, only part of this taxonomic group has declined]); asters, campanulas, goldenrods, pussytoes, and thistles (Asterales); bedstraws and bluets (Rubiaceae *p.p.*); bladderworts (Lentibulariaceae); dogwoods (Cornaceae); lilies (Liliales); louseworts and Indian paintbrushes (Orobanchaceae); mints (Lamiaceae *p.p.*); orchids (Orchidaceae); primroses (Onograceae *p.p.*); roses (Rosaceae *p.p.*); saxifrages (Saxifragales); Indian pipes (Ericales p.p.); and St. John’s worts and violets (Malpighiales).



Data source: Great Smoky Mountains Institute at Tremont

Figure 3. Changes in the first appearance of black-throated green warblers in Walker Valley, Tennessee, Great Smoky Mountains National Park. Trend = 0.7 days/year

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Anonymous

Figure 4a. Photographs showing changes in timing of leaf-out at Lowell Cemetery in Lowell, Massachusetts. Trees lack leaves in the 1868 photograph, shown here. The same trees were fully leafed in the 2005 photograph. Both photographs were taken 30 May.
Source: Miller-Rushing et al. 2006

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Figure 2a. Examples of several methods for collecting phenology data: volunteers, cameras, and audio recorders. The images were taken at (a, shown here) Boston Harbor Islands National Recreation Area, (b) the Harvard Forest Environmental Measurement Site tower site in the PhenoCam network (Richardson et al. 2009), and (c) Marsh-Billings-Rockefeller National Historical Park in Vermont.

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Figure 2b. Examples of several methods for collecting phenology data: volunteers, cameras, and audio recorders. The images were taken at (a) Boston Harbor Islands National Recreation Area, (b, shown here) the Harvard Forest Environmental Measurement Site tower site in the PhenoCam network (Richardson et al. 2009), and (c) Marsh-Billings-Rockefeller National Historical Park in Vermont.

Richard Primack/Boston University

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NPS/Ed Sharron

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