Project Summary

Project title: Phenology as a management tool to forecast climate-driven shifts in species abundance and invasiveness

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Categories: Regional ecological response models
Vulnerability and risk assessments

Keywords: climate change; invasive species; phylogenetics; phenology; population declines

Abstract: A major focus of current ecological research and natural resource management is to understand how climate change is affecting ecosystems and to improve predictions of how ecosystems might respond to future climate change. Recently, researchers have shown that phenological responses to climate change and phylogenetic relationships are linked to changes in abundance and invasiveness. There is great potential for using phenology and phylogeny as management tools to predict species responses to climate change, particularly changes in abundance and invasiveness, because they are relatively easy to measure. We propose to test this concept through a regional assessment of phenological datasets in the northeastern United States, a region with both legacy (historical) data sets and active phenological research. The USA National Phenology Network (USA-NPN) and NatureServe will collaborate to develop a prototype module for uploading, storing, and allowing scientific and public access to legacy phenology and abundance data. The USA-NPN, the Northeastern Regional Phenological Network (NE-RPN), and NatureServe will then encourage scientists, managers, educators, and citizen scientists in the region to upload existing phenology and abundance data to the module. We already have many commitments of data, and soon expect to have more commitments. Finally, we will use these data to analyze spatial and interspecific variation in phenology and links among phenology, phylogeny, and abundance to identify species likely to be either vulnerable or invasive under different climate change scenarios. Throughout the project, we will involve managers at partner organizations, such as the National Park Service, U.S. Fish and Wildlife Service, and Massachusetts Department of Fisheries and Wildlife, to ensure that our models and other project outputs will inform management decisions. We will make our models and predictions available through the USA-NPN and NE-RPN and through peer-reviewed publications. By bringing together many partners to analyze legacy data and forecast ecological responses to climate changes, this project contributes toward central goals of the National Climate Change and Wildlife Science Center, the USGS Science Strategy, and other government agencies involved in climate change and natural resource management.

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Other principal investigators: Abraham Miller-Rushing (The Wildlife Society and USA National Phenology Network), Rob Solomon (NatureServe), and Richard Primack (Boston University)

Research focal area: Regional ecological response models and vulnerability and risk assessments

Objectives and justification
<u>Need</u>
A major focus of current ecological research and natural resource management is to understand the impacts of climate change on ecosystems and to improve predictions of how ecosystems might respond to climate change in the future. Recently, researchers have shown that phenological responses to climate change and phylogenetic relationships are linked to changes in abundance and invasiveness (Møller et al. 2008, Willis et al. 2008, Willis et al. submitted). Species with phenologies that are strongly correlated with temperature tend to maintain stable population sizes, increase, or become invasive, whereas species with phenologies that are not correlated with temperature tend to decline in population size, sometimes disappearing from local communities (Møller et al. 2008, Willis et al. 2008, Willis et al. submitted) (Fig. 1). Thus, phenological responses to climate change may serve as an indicator for future shifts in population sizes and invasiveness. In addition, species that are closely related to one another and share a common phylogeny and evolutionary history tend to have similar phenological responses to climate change (Willis et al. 2008, Willis et al. submitted).

Fig. 1. Conceptual diagram illustrating results from Willis et al. (2008). The x-axis refers to the absolute value of the correlation between phenology and temperature as determined from legacy data.

Using phenology and phylogeny as indicators of species vulnerability to climate change is particularly attractive because phenology is often relatively easy to observe and there are known relationships between phenology and demography (Stenseth and Mysterud 2002, Visser and Both 2005). For species that are difficult to observe, observations of closely related species may provide useful proxies. Existing models that use phenology data to forecast changes in species abundance and invasiveness in response to climate change are promising, but remain untested outside of a single site (Willis et al. 2008, Willis et al. submitted). Additionally, despite the recognized value of phenological data,
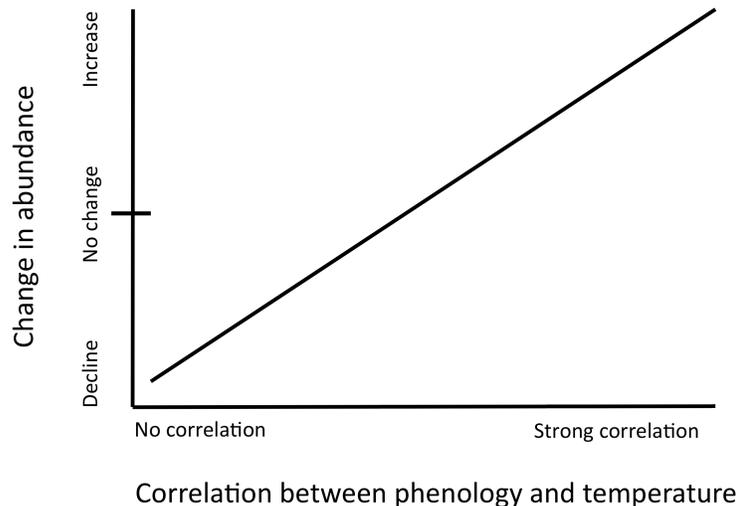
no good mechanism exists for compiling and analyzing historical phenology datasets. Such a mechanism is necessary to assemble adequate data to estimate changes in phenology and to predict species vulnerability to climate change.

The objectives of our project are to:
1. Develop a prototype process and software module for uploading, storing, and allowing access to legacy (historical) phenology and abundance data.
2. Compile existing data on phenology and abundance.
3. Examine spatial and interspecific variability in phenology.
4. Analyze links among phenology, abundance, and phylogeny.
5. Develop and implement models to predict future shifts in phenology, species vulnerability to climate change, and likelihood of invasiveness.
6. Identify species likely to decline or become invasive in response to climate change.

These objectives help to fulfill central goals of the new National Climate Change and Wildlife Science Center (NCCWSC) (U.S. Geological Survey 2009), the U.S. Geological Survey (USGS) Science Strategy (U.S. Geological Survey 2007), USGS Climate Change Strategy (in review), and the U.S. Fish and Wildlife Service (FWS) Strategic Plan for Responding to Accelerating Climate Change (U.S. Fish and Wildlife Service 2009). Other agencies and nonprofits have also acknowledged the need for understanding ecological responses to climate change and identifying species vulnerable to climate change. We have developed this proposal in collaboration with several natural resource management agencies (see letters of support) and have designed our project outputs specifically to meet their needs.

Background
Phenology is a key aspect of nearly all ecological phenomena and processes and many management decisions. Moreover, shifts in phenology are among the most sensitive and important biological responses to climate change (IPCC 2007, Field et al. 2008). Importantly, climate-driven changes in the timing of phenological events such as flowering and migrations have varied across space and among species (Parmesan 2007, Primack et al. 2009a). This variation can affect the demography and abundance of species in many ways (Stenseth and Mysterud 2002, Visser and Both 2005). For example, if plants leaf out earlier in response to a warming climate, they may gain a competitive advantage relative to less responsive species (Brooker 2006). If birds do not respond to a warming climate and breed too late in the breeding season, they may not have access to adequate food, particularly if the phenology of their primary food source has advanced. This sequence of events has already been documented for one species (Both et al. 2006). Species that can adjust their migration and breeding to a changing climate, and maintain synchrony with food sources, may increase in abundance relative to less responsive species (Visser and Both 2005, Both et al. 2006). Thus, it is not surprising that phenological response to climate change is linked to changes in species abundance and invasiveness (Møller et al. 2008, Willis et al. 2008, Willis et al. submitted). As the timing of phenological events change, some relationships will be disrupted, leading some species to increase in abundance and others to decline.

Recent findings show that phenological responses to climate change are phylogenetically conserved in plants—i.e., groups of evolutionarily related species tend to exhibit similar responses (Willis et al. 2008). In Concord, Massachusetts, the flowering times of some groups of related species, such as lilies and bladderworts, have tended not to track changes in climate, and these groups of species have declined dramatically over the past 150 years (Willis et al. 2008,

Primack et al. 2009b). This pattern may also occur in other taxonomic groups because closely related species often share traits through common ancestry (Wright and Calderon 1995). If so, entire groups of species may be vulnerable to climate change, possibly easing the identification of vulnerable species, but also possibly leading to the declines of genera or families.

Using phenology and phylogeny as tools to predict species responses to climate change, particularly changes in abundance and invasiveness, has potential to be applied widely across the country. We propose to test the concept, however, through a regional assessment in the northeastern United States. In the Northeast, rapid development and associated changes have already threatened the persistence of many species and have contributed to the spread of invasive species, which are having substantial ecological and economic impacts (Mehrhoff et al. 2003). Also, there is an abundance of ongoing phenological research in the region, including long-term studies at Harvard Forest, Hubbard Brook Ecosystem Study, and in Concord, Massachusetts. There are also several citizen science programs recording phenology in the region, including eBird, Project BudBreak, Mountain Watch, and the Massachusetts Butterfly Club. Together groups in the region have created the Northeast Regional Phenology Network (NE-RPN), which facilitates the linkage of phenology research, citizen science, and management in the region. Many researchers, agencies, and organizations have also documented changes in the abundance of species in the region, in part because of the high density of universities, research stations, and conservation organizations, and a long tradition of naturalist observations. Thus, we will have access to data on the phenology and abundance of many species at many locations (Table 1).

Table1. Datasets that have been committed to the work described in this proposal. An additional 24 datasets containing phenology and abundance data not described here have been committed to our project.

Organization or individual	Phenological event or abundance	Location	Taxa	Timespan
Bird Observer	Bird migrations	Cambridge, MA	Birds	1980-2004
Manomet Center for Conservation Sciences	Bird migrations	Manomet, MA	Birds	1970-present
Colby College	Bird migrations	Maine	Birds	1899-1911
Colby College	Bird migrations	Maine	Birds	1994-present
Dr. Christopher Butler	Bird migrations	Worcester, MA	Birds	1932-1993
Boston University	Flowering	Concord, MA	Plants	1852-present
USA-NPN	Flowering	Northeastern United States	Plants	1965-present
Maine Department of Env. Protection	First bloom	Maine	Plants	2000-present
USA-NPN	Leaf out	Northeastern United States	Plants	1965-present
Hubbard Brook Ecosystem Study	Leaf events	Thornton, NH	Plants	1989-present
Huntington Wildlife Forest (SUNY-ESF)	Various events	Newcomb, NY	Plants/Animals	1988-present
USDA Forest Service Experimental Forests	Various events	Northeastern United States	Plants/Animals	1965-present
Boston University	Abundance	Concord, MA	Plants	1852-present
NatureServe	Abundance	Northeastern United States	Plants	Unknown
NatureServe	Abundance	Northeastern United States	Animals	Unknown
South Central CT Regional Water Authority	Abundance	Southern CT	Plants	1980-present
Yale Myers Forest (Yale University)	Abundance	Union, CT	Plants	1986-present

The work and products we outline in this proposal will interact synergistically with ongoing activities both in the Northeast and across the United States. The models we develop will complement, for example, a new National Park Service-funded collaboration among several regional organizations to integrate phenology monitoring into routine inventory and monitoring activities and management decisions. (A. Miller-Rushing is the principal investigator on this project.) Our project also complements the ongoing work of the Invasive Plant Atlas of New England (IPANE) and a USDA-funded project to test the potential of particular species to

become invasive in the Northeast. (J. Silander is a principal investigator on both of these invasive species projects.)

More broadly, the legacy data module, models, and predictions we develop will be integrated into the USA-NPN and will facilitate the collection of phenology data and increased use of phenology in research and management. Several organizations such as USGS, NPS, FWS, Bureau of Land Management, USDA Forest Service, Cornell Lab of Ornithology, and The Wildlife Society are currently supporting such work on phenology (see letters of support and www.usanpn.org). Finally, our project will be a part of a national assessment of climate-driven changes in phenology, which is being initiated by the USA-NPN and several partners. Our project will serve as an example for regional assessments in other parts of the country.

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