USA National Phenology Network Phenology Model Workshop Report

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

In March 2016, the USA National Phenology Network (USA-NPN, www.usanpn.org) National Coordinating Office (NCO) convened a two and a half day workshop at the University of Arizona in Tucson, Arizona. This meeting was attended by 12 researchers with expertise in phenology, ecology and geography and a strong interest in predictive phenology models. The primary goal of the workshop was to identify efficient and practical approaches for the USA-NPN to produce continental-scale predictions of phenological transitions in a range of species, and at various timeframes (historical, near-real-time, and forecasted), given the data currently available in the National Phenology Database maintained by the USA-NPN. The meeting also served to bring together and engender communication among active researchers on the topic of phenology modeling and to foster the establishment of a phenology modeling community of practice. Ultimately, this was a venue for participants to converge on a vision for a framework to develop the next generation of predictive continental-scale phenological models that will be outlined in a peer-reviewed manuscript.

INTRODUCTION

The USA National Phenology Network (USA-NPN, www.usanpn.org) was established in 2007 to bring together professional and citizen scientists, land managers, policy makers, and educators with common goals of collecting and using phenology data and information in science and decision-making applications. The National Coordinating Office (NCO) of the USA-NPN facilitates the collection of phenology data through collaborations with partners and individual scientists, and through *Nature's Notebook* (www.naturesnotebook.org). Data collected through *Nature's Notebook* and following USA-NPN protocols are maintained in the National Phenology Database (NPDb), a growing resource supporting research and management. Phenology data are collected by observers throughout the United States, with a focus on plant and animal species that have been identified as high priority for the study of phenology. Phenology data housed within the NPDb have great value for understanding and predicting phenological responses to climate change and for future conservation planning; this value is evidenced by research publications using these data (www.usanpn.org/pubs/results).

The two primary goals of the USA-NPN are to Advance Science and to Inform Decisions (USA-NPN National Coordinating Office 2014). The development of phenology models, which predict the timing of phenological transitions based on abiotic conditions, are crucial for achieving these goals. Phenology models can be run on continuous gridded climate and abiotic surfaces to generate maps showing the timing of phenological transitions. Following this approach, models can be used to generate phenology maps for varying timeframes, including years past, near-real-time, short-term forecast, and decades into the future, limited only by the availability of gridded climate and abiotic input data. Such models and resultant phenology maps are essential for understanding the implications of ongoing climate change on populations, species, communities, and ecosystems, and for improved understanding of carbon cycling and other seasonal processes. In addition, robust models can aid in a variety of applications including invasive species management, vulnerability of crop species to frost and pests, and the characterization of asynchrony between interacting species.

To explore the most efficient and fruitful approaches for applying models to generate phenology maps at a variety of timeframes, USA-NPN National Coordinating Office staff sought input from top active researchers in the field over the course of a three-day workshop. This report summarizes the discussions and outcomes of the workshop.

WORKSHOP GOALS

The primary goal of the workshop was to identify efficient and practical approaches for the USA-NPN to produce continental-scale predictions of phenological transitions in a range of species, and at various timeframes (historical, near-real-time, and forecasted), given the data currently available in the NPDb maintained by the USA-NPN. Both predictive phenology models and maps of phenological transitions generated using these models are products that the USA-NPN intends to create and share widely (Gerst et al. 2016).

The meeting also served to bring together and engender communication among active researchers on the topic of phenology modeling and to foster the establishment of a phenology modeling community of practice.

Stated workshop objectives included:

(1) foster and organize a community of interest focused on phenology models,
(2) identify gaps in knowledge and determine what models and data are needed,
(3) determine approaches to developing new models and building upon existing models, and
(4) evaluate approaches to validate models.

WORKSHOP FORMAT

Fifteen participants attended the two and a half day workshop March 8-10, 2016 in Tucson, Arizona, including 12 academic researchers (see Appendix A for workshop agenda and Appendix B for participant list). Day One of the workshop consisted of presentations by the NCO staff (Jake Weltzin, Kathy Gerst, and Theresa Crimmins) which described the structure and vision of the USA-NPN, the USA-NPN data and data product framework, and recent advances in the development of gridded products from accumulated temperature and the Extended Spring Indices. Next, each of the participants described their past, ongoing, and/or future work relevant to the development of phenology models through ten-minute presentations (Appendix C).

For the remainder of the first day, participants engaged in a discussion focused on identifying common themes in the presentations and of the types of phenology models that can be developed. Additionally, workshop participants received an introduction and overview of the structure of USA-NPN data. On the second day of the workshop, we continued our discussion focused on potential approaches and necessary inputs to create desired models. On the final half-day of the workshop, we began to draft a summary of the applications and approaches in order to create a unified framework for model development, which will be described in a manuscript to be co-authored by the workshop participants.

KEY OUTCOMES

The USA-NPN endeavors to produce continental-scale models and maps of the timing of key phenological transitions (e.g., leaf-out, flowering, leaf coloring, leaf drop) to support the advancement of scientific understanding, to support management decisions and planning, and to communicate with the public. In this workshop, we explored the types of phenological products the USA-NPN might develop, and the best methods for achieving these goals.

Several relevant discussion topics emerged:

Data limitations – The USA-NPN's NPDb houses more than 7.5M records of plant and animal phenology status. However, this dataset represents more than 1,000 species, and spans fewer than 10 years (2009-present). Further, not all of these data are readily useable for predictive modeling – data collected by volunteers tend to be "messy," meaning that they can miss key events and sampling frequency can vary dramatically over the course of the season. Questions were raised regarding whether sufficient data exists for constructing species-level models using these data alone; the answer to this will not be clear until model construction activities are undertaken in earnest. However, early efforts to construct simple models for several species with the richest records in the NPDb have borne fruit (Melaas et al.

2016, Crimmins et al., unpublished data).

Model origin – Phenology models exist in the literature for many species/phenophase combinations, albeit typically constructed using local data. It may be most efficient for USA-NPN to start producing phenology transition maps using published models, either generating maps directly from them, or by creating and validating them using observations housed within the NPDb. Caution was advised, because models constructed using observations from a localized area may not perform well in other portions of the species ranges. The alternative to generating phenology maps using published models would be to construct models from scratch, using data housed in the NPDb alone or in conjunction with other phenology and/or ancillary datasets.

Model granularity – Given the limitations of data housed within the NPDb, combined with the tendency for many species to undergo phenological transitions at similar times of the season, it may be possible to construct models at the taxonomic or functional group level for certain species, rather than at the species level.

Temporal dimension – Once a model has been constructed that predicts the timing of a phenological transition from abiotic independent variables, maps can be constructed for whatever temporal timeframes datasets for the abiotic variables are available. For many phenology models, the primary inputs are climate or weather variables. For temperature and precipitation variables, these are currently available on a daily and sub-daily time step, allowing maps to be updated daily. For some temperature and precipitation products, data are available for the present day and as a short-term forecast (e.g., NCEP RTMA/URMA), making it possible for USA-NPN to produce short-term phenology forecasts. Gridded continental-scale climate/weather variables also exist for various historical timeframes, some extending back as far as 1900 (e.g., BEST); using these datasets, USA-NPN can produce historical phenology maps. Likewise, climate projections exist for several decades into the future, in the form of general circulation models (GCMs) and regional circulation models (RCMs). Producing phenology maps on a 1-3 month/seasonal forecast is limited by the lack of gridded forecast data at this temporal scale. Work is undergoing to fill this gap (Subseasonal to Seasonal Prediction Project, http://public.wmo.int/en). Alternatively, USA-NPN could consider producing coarser categorical-style predictions at this timestep (e.g., earlier than average, average, later than average), leveraging the categorical style of seasonal forecasts currently available.

Given the USA-NPN's current focus on producing continental-scale predictions of phenological transitions at various time steps, the conversations focused on analytical techniques that are best suited for these outputs. Participants recommended several approaches, each with different strengths and potential applications. These included (organized from least to most computationally complex; Table 1):

1. **Interpolation-based approaches**. Observational data maintained by the USA-NPN could serve as the point-based input data for generating continuous regional or continental-scale maps of phenological status for species or groups of taxa. These methods could be very simple – perhaps based on a straightforward interpolation algorithm (e.g., inverse distance weighting or nearest neighbor), and updated regularly, utilizing observer's reports as they are submitted to *Nature's Notebook*. The simplest maps were suggested as a tool for engaging *Nature's Notebook* participants more effectively, giving them the opportunity to help improve the map's accuracy.

2. **Threshold-based approaches**. An extensive body of literature supports the idea that phenological transitions, especially those in the spring season and in regions where temperature is a strongly influential variable, can be predicted based on simple temperature accumulations or on temperature accumulations following a chill accumulation. The USA-NPN could produce maps of phenological transitions by either 1) applying published temperature threshold models to accumulations of temperature over the course of the year; or 2) utilizing observational data in the NPDb to develop or validate existing threshold-style models.

3. **Temporal offset approaches**. In many regions, there is a clear temporal progression among species regarding the timing of their phenological transitions. If a model is developed for one of the earlier species in the progression, it may be possible to predict the timing of transition for later species based on a simple temporal offset (e.g., "once species *x* leafs out, we

expect that species *y* will leaf out 17 days later in this area").These models may need to be developed locally or regionally; the temporal offset between two species may not be constant across their ranges.

4. **Regression based models.** Many regression techniques were discussed. Given the limited nature of the data housed within the NPDb, a hierarchical framework for implementing the models was recommended (e.g., Ibañez et al. 2010). Bayesian techniques were proposed for their strengths dealing with messy and missing data.

5. **Continuous development models.** Phenological development is a continuous process, rather than a discrete event, responding to variable temperatures over a season. This model formulation "properly assimilates variable temperature with continuous development and discrete observations" (Clark et al. 2014). This type of model shows promise for increased accuracy over more basic formulations, however it is complex and data-intensive to implement.

Table 1. General model formulations proposed by workshop participants for USA-NPN for generating continental-scale, historical and/or near-real-time models of phenological transitions.

Method	Strengths	Weaknesses	Necessary inputs for model construction
Simple interpolation-based methods (e.g., inverse distance weighting or nearest neighbor)	Simple and quick to implement – could be updated nightly as observers make reports to *Nature's Notebook*. Holds value for motivating *Nature's Notebook* observers to report observations.	Likely to have large error; would require careful and cautious interpretation and application	*Nature's Notebook* observations
Threshold-based models	Many exist in the published literature; simple to apply to existing USA-NPN AGDD gridded products, if start date and base temp match between models and USA-NPN products	May yield less accurate predictions than more complex model formulations	Long-term phenology observations or space-for-time data (i.e., pool observations in NPDb across sites/years) to establish threshold(s); could also find thresholds in published literature, or establish using optimization approaches
Temporal offset	Could be established using USA-NPN observational data; could readily be refined with incoming reports	May need to be developed locally or regionally	A working model for an "indicator" species, and then the ability to calculate offsets from this model for other species
Regression-based models	In a hierarchical framework, can function well with small sample sizes and missing data; yields an error structure; can incorporate uncertainty (number of days between last No and first Yes report)	Time-consuming to construct; requires technical expertise to construct	Long-term phenology observations or space-for-time data to establish threshold(s); datasets for explanatory variables at appropriate spatial and temporal resolutions
Continuous development models	Superior to more commonly implemented approaches	Data intensive; requires technical expertise to construct	Observations of multiple phenophases on the same individual plants in the same years collected using status-type protocols

Workshop participants pointed out that once phenology models had been constructed or adopted for particular species/phenophases, additional products could be produced, including composite phenophase status maps and regional phenology calendars. Further, regression models would yield species sensitivities to input variables (in the form of the regression coefficients); this is of interest because the USA-NPN plans to make standardized species sensitivities to relevant climate drivers available as a separate resource (Gerst et al. 2016). Making phenology maps available for access and download in raster format, as the USA-NPN plans to do, would enable analysis with myriad other datasets, such as those from remote sensors.

D. Challenges

As described above, the limited and "messy" data currently available in the NPDb, lacking consistent spatial and temporal sampling, will require creative approaches to model development and may limit what is currently possible. In addition, the extent to which various drivers impact phenology is expected to vary by season, species and region. Finally, there are constraints in regards to the available explanatory climatic and geographic data. Each of these concerns will need to be considered when model development is undertaken.

NEXT STEPS

The USA-NPN National Coordinating Office will organize the development of a manuscript that will describe the shared vision for the next generation of predictive phenological models, which will be authored by the workshop participants. We will continue to facilitate collaborations and pursue opportunities to develop phenology models that take advantage of the data available in the NPDb. In addition, we will work towards identifying gaps in the available data to ensure the development of robust and meaningful models that will aid in producing information to inform the research, education, policy and management communities. Finally, we will work to sustain the phenology modeling community of practice established at this workshop.

CONTRIBUTIONS AND ACKNOWLEDGEMENTS

This meeting was supported by Cooperative Agreement G14AC00405 from the United States Geological Survey to the University of Arizona. The workshop was organized by Kathy Gerst, Theresa Crimmins, Sharon Oliver, and Jake Weltzin. This report was written by Kathy Gerst and Theresa Crimmins.

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APPENDICES

Appendix A: USA National Phenology Network RCN Workshop Agenda

Appendix B: Participant List

Appendix C: Workshop Presentation Titles

Appendix A: WORKSHOP AGENDA

USA-NPN Phenology Model Workshop
Tucson, Arizona
March 8-10, 2016
ENRB2 S215, University of Arizona

AGENDA

Objectives:

- Foster and organize community of interest around development of phenology models
- Identify gaps in knowledge and determine what models and data are needed
- Determine approaches to develop new models and build upon existing models
- Evaluate approaches to validate models

Monday, March 7:

Arrive in Tucson
Stay at Aloft hotel
Dinner on own

Tuesday, March 8:

9:00-10:00 am: Introductions, purpose and goals of the workshop; overview of USA-NPN data resources and data product framework
10:00-11:00 am: Invited participants give 10 minute talks describing current phenology model work
11:00-11:15 am: Break
11:15-12:15 pm: Continued- **I**nvited participants give 10 minute talks
12:15-1:15 pm: Lunch
1:15-2:00 pm: Facilitated discussion to identify top relevant and innovative science questions and applications that can be addressed by creating and testing models using NPN data
2:00-2:45 pm: Facilitated discussion about the state of phenology models, participants vision for next generation of models**.** What opportunities are there to test existing models with NPN data? Generate list of existing models and model types/categories
2:.45-3:00 pm: Break
3:00-4:30 pm: Two breakout groups: (1) Generate/outline workflows for integrating phenology data with relevant driver datasets and/or remotely sensed phenology datasets (2) Generate/outline workflow for testing and improving existing models with NPN and other datasets.
6:30 pm: Optional Group Dinner @ El Charro: 311 N Court Ave, Tucson, AZ 85701

Wednesday March 9:

9:00-10:15 am: Summary of Tuesday pm discussion- What are challenges and opportunities moving forward?
10:15-10:30 am: Break
10:30-noon: Break-out groups: outline solutions, approach, & implementation to major challenges
12:00-1:15 pm: Lunch
1:15-2:00 pm: 15 min presentations by break-out groups
2:00-2:45 pm: Synthesis of workflow activities
2:45-3:00 pm: Break
3:00-4:30 pm: Explore and integrate data
5:30 pm: Optional Happy Hour and Dinner at 1702 Craft Beer and Pizza (1702 E Speedway Blvd)

Thursday March 10th:

9-10:15 am: Value and application of species-specific vs. community models
10:15-10:30 am: Break
10:15-11:30 am: Discuss and outline synthesis publication; assign roles
11:30: Wrap up

Appendix B: Workshop participants

Last	First	Affiliation
Allen	Jenica	University of New Hampshire
Browning	Dawn	New Mexico State Univ
Crimmins	Mike	Univ of Arizona
Crimmins	Theresa	USA-NPN
Diez	Jeffrey	Univ of California-Riverside
Elmendorf	Sarah	NEON
Gerst	Kathy	USA-NPN
Kosmala	Margaret	Harvard
Liang	Liang	University of Kentucky
Melaas	Eli	Boston University
Moore	Dave	Univ of Arizona
Schwartz	Mark	Univ of Wisconsin-Milwaukee
Yu	Rong	University of Nebraska
Weltzin	Jake	USA-NPN
Zurita-Milla	Raul	University of Twente

Appendix C

PRESENTATIONS

The meeting agenda is in Appendix A. The following are the titles of the presentations given the first day of the workshop.

- *The USA National Phenology Network Operational Framework: Capacity for Science and Management – Jake Weltzin, USA National Phenology Network*
- *The USA-NPN: Phenology data and data products – Kathy Gerst, USA National Phenology Network*
- *USA-NPN gridded data products: Progress and plans – Theresa Crimmins, USA National Phenology Network*
- *Exploring Growing Degree Day relationships with USA-NPN observations – Mike Crimmins, affiliation…*
- *Development of the Spring Indices models – Mark Schwartz*
- *Phenological modeling: Integrating volunteered observations, data mining, machine learning and cloud computing approaches – Raul Zurita-Milla*
- *Plant phenology and climate change – Jenica Allen*
- *Making the most of messy phenology data – Sarah Elmendorf*
- *Phenocam and phenology scaling – Margaret Kosmala*
- *Phenology modeling research: Past, present and future – Eli Melaas*
- *Spring and autumn phenological progression model for deciduous trees – Rong Yu*
- *Developing spatially-explicit plant phenology models – Liang Liang*
- *Plant phenology at the Jornada and beyond: Where we are and where we are going – Dawn Browning*
- *Modeling phenology –Jeff Diez*