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Citation	Kosmala, Margaret, Alycia Crall, Rebecca Cheng, Koen Hufkens, Sandra Henderson, and Andrew Richardson. 2016. "Season Spotter: Using Citizen Science to Validate and Scale Plant Phenology from Near-Surface Remote Sensing." Remote Sensing 8 (9) (September 1): 726. doi:10.3390/rs8090726.
Published Version	10.3390/rs8090726
Citable link	http://nrs.harvard.edu/urn-3:HUL.InstRepos:28553711
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Article

Season Spotter: Using citizen science to validate and scale plant phenology from near-surface remote sensing

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Academic Editor: name
Received: date; Accepted: date; Published: date

Abstract: The impact of a rapidly changing climate on the biosphere is an urgent area of research for mitigation policy and management. Plant phenology is a sensitive indicator of climate change and regulates the seasonality of carbon, water, and energy fluxes between the land surface and the climate system, making it an important tool for studying biosphere-atmosphere interactions. To monitor plant phenology at regional and continental scales, automated near-surface cameras are being increasingly used to supplement phenology data derived from satellite imagery and data from ground-based human observers. We used imagery from a network of phenology cameras in a citizen science project called Season Spotter to investigate whether information could be derived from these images beyond standard, color-based vegetation indices. We found that engaging citizen science volunteers resulted in useful science knowledge in three ways: first, volunteers were able to detect some, but not all, reproductive phenology events, connecting landscape-level measures with field-based measures. Second, volunteers successfully demarcated individual trees in landscape imagery, facilitating scaling of vegetation indices from organism to ecosystem. And third, volunteers' data were used to validate phenology transition dates calculated from vegetation indices and to identify potential improvements to existing algorithms to enable better biological interpretation. As a result, the use of citizen science in combination with near-surface remote sensing of phenology can be used to link ground-based phenology observations to satellite sensor data for scaling and validation. Well-designed citizen science projects targeting improved data processing and validation of remote sensing imagery hold promise for providing the data needed to address grand challenges in environmental science and Earth observation.

Keywords: citizen science; crowdsourcing; phenology; PhenoCam; landscape ecology; spatial scaling, vegetation indices

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1. Introduction

Plant phenology, the timing of life history events such as leaf-out, flowering, seed-development, and senescence, is highly sensitive to weather, and is thus a key indicator of the impacts of climate change on Earth's biota [1]. Warming spring temperatures over the past half century have caused plant species across the temperate zone to leaf out earlier [2,3]. Likewise, delayed autumn chilling has widely delayed leaf senescence [2–4], though the timing of spring phenology modifies this effect [5].

Currently, plant phenology is studied on the ground at the scale of the individual [6] or at broader scales using vegetation indices derived from satellite imagery [7] or near-surface automatic digital cameras [8]. Vegetation indices are typically used to track continuous photosynthetic activity of vegetation, whereas ground-based field measurements are often needed to determine discrete phenological events, including reproductive phenology [9,10]. Estimates of the effects of climate change on plant phenology using data at different scales vary [11], and so there is need to integrate phenology measures at different scales.

Midscale phenology cameras can provide a link between these different scales of observation by extracting information beyond vegetation indices from the camera imagery [10]. Because the spatial scale of these near-surface images is much finer than that of satellite imagery, details such as the presence or color of flowers, the foliation and color of individual tree canopies, and the occurrence of precipitation events (including rain, fog and snow) can be seen directly in camera images. Documenting the phenological state of individuals is typical of on-the-ground phenology data gathering efforts. However, phenology cameras have rarely been used to produce information beyond landscape-scale leaf canopy state (but see [12]).

Extracting these sorts of details—rather than general patterns of “vegetation greenness”—from phenology camera images requires sophisticated image analysis that has not yet been automated, and the sheer volume of imagery makes manual image analysis prohibitive for networks of more than a handful of cameras. Citizen science provides a solution for analyzing large image data sets to extract information that cannot yet be easily extracted by computational means [13]. Citizen scientist volunteers have successfully classified galaxy types from astronomical telescope images [14], found interstellar dust particles in electron microscope images [15], and identified animal species in camera trap images [16].

We created the citizen science project Season Spotter (seasonspotter.org) to analyze images from phenology cameras. Season Spotter uses images from the PhenoCam network, the largest near-surface phenology camera network in the world. It consists of 300 elevated cameras located primarily in North America and spans a wide range of ecosystem types (Figure 1) [8,17]. Automated processing of PhenoCam images produces a vegetation index (G_{CC}, “green chromatic coordinate”) that indicates the relative amount of green in a predefined region of interest in each image [18]. This G_{CC} index can then be used to infer the seasonal progression of leaf emergence and expansion, leaf color change, and senescence in the same manner as satellite-sensor-derived vegetation indices like NDVI and EVI [19]. G_{CC} has also been shown to mirror the dynamics of carbon dioxide fluxes as measured by co-located eddy covariance instrumentation [20].

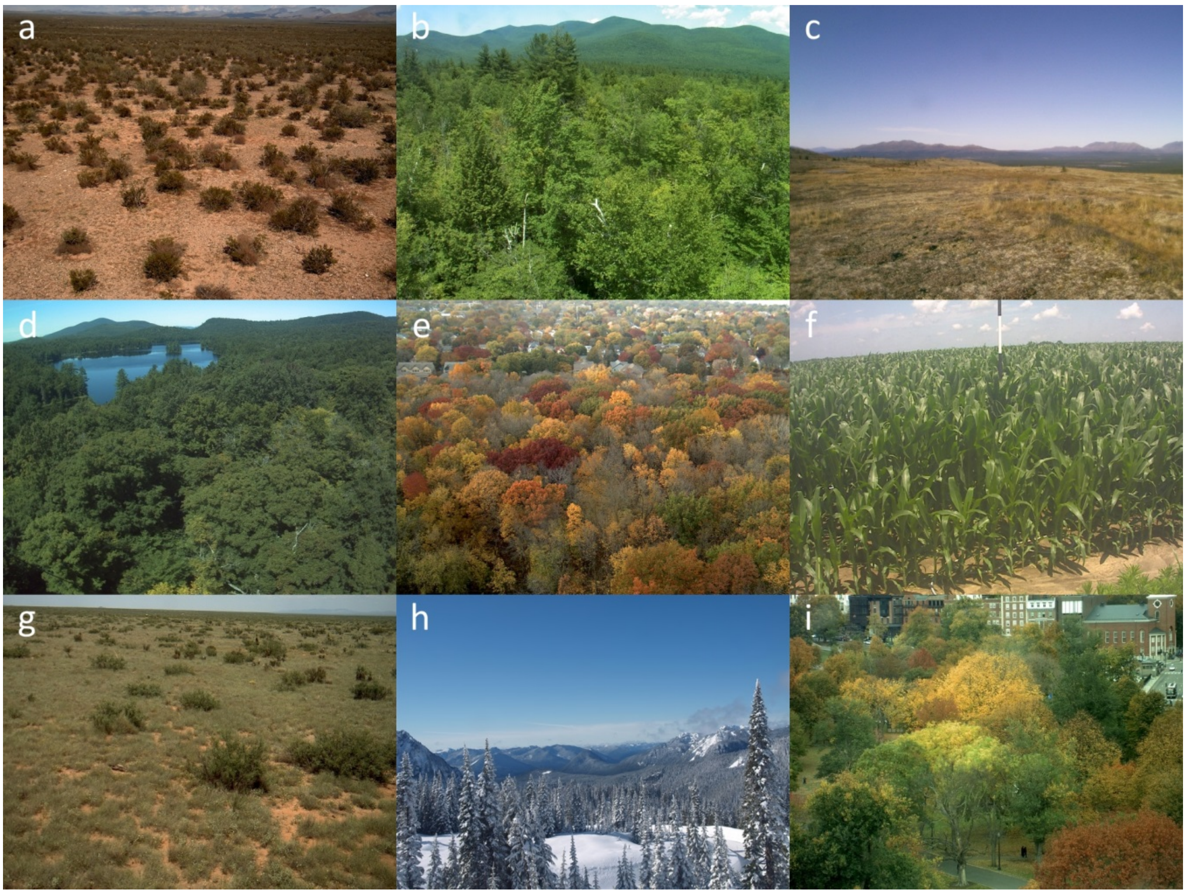

Figure 1. Examples of landscape images as seen by phenology cameras in the PhenoCam network. Shown are sites (a) jerbajada; (b) bartlettir; (c) snipelake; (d) arbutuslake; (e) downerwoods; (f) uiefmaize; (g) ibp; (h) mountranier; (i) bostoncommon. See Table 1 for site descriptions.

Season Spotter presented PhenoCam images from across a wide range of ecosystem types to volunteers using an online interface and asks the volunteers questions about these images. We algorithmically combined the volunteers' answers into usable classifications. Season Spotter asked volunteers to: identify the reproductive and vegetative states of deciduous trees, evergreen trees, shrubs, grasses, forbs, and crops; identify poor quality images and those containing snow; outline individual trees at forested sites; and make phenological comparisons between two images taken at the same site.

Our goals for leveraging human visual perception using Season Spotter were threefold. First, we wanted to discern whether reproductive phenology (e.g. flowers, fruits, seeds) could be detected from these images to provide a complementary data product connecting landscape-level phenology measurements with field-based measures. Second, we wanted to see if individual trees could be identified and their vegetation indices calculated to facilitate scaling from local to regional scales. And third, we wanted to use citizen scientists' assessments of spring and autumn start and end dates to evaluate dates calculated automatically from vegetation indices.

2. Materials and Methods

2.1. Citizen Science: Season Spotter

We created the online citizen science project Season Spotter (seasonspotter.org) using the Zooniverse Project Builder (www.zooniverse.org/lab) [21]. The Zooniverse is an online citizen science platform with 1.1 million current users, which hosts a variety of projects in need of volunteers to support data processing tasks. The Season Spotter site consists of a landing page, which allows volunteers to choose whether they want to answer multiple-choice questions about PhenoCam images or demarcate specified regions on the images (Figure 2).

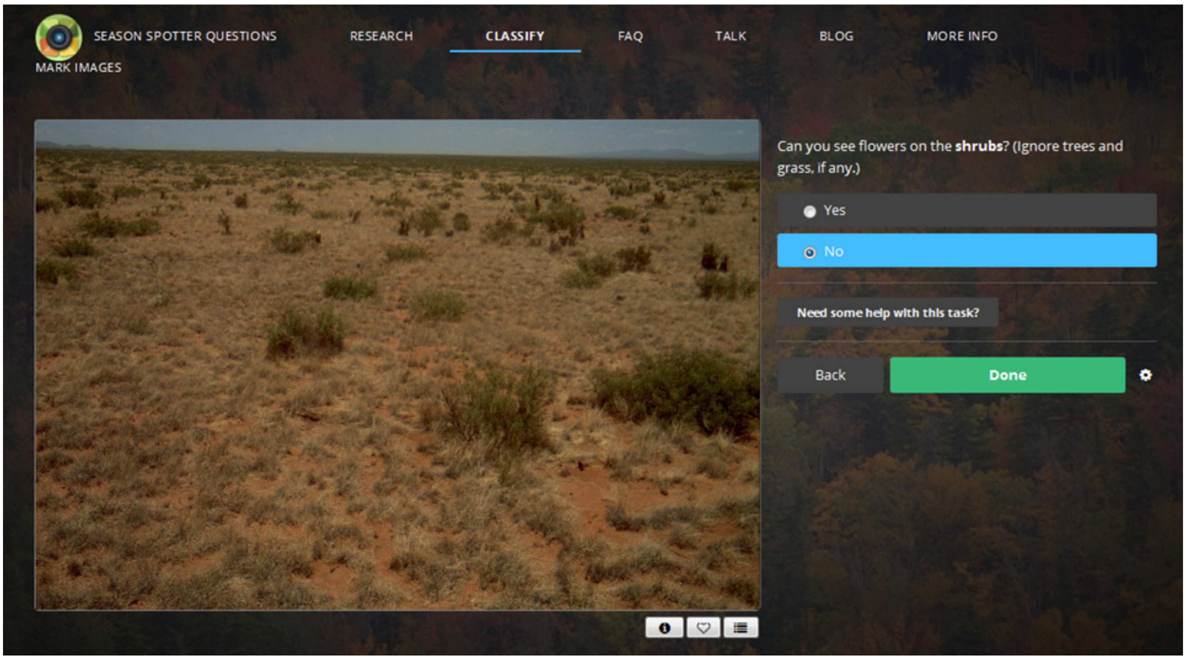

Figure 2. The Season Spotter user interface

After making the choice, each volunteer begins one of multiple randomly-assigned workflows (Figure 3, S1) that are tailored to the different ecosystem types. Each workflow consists of one or more tasks, including answering questions and drawing outlines. When a volunteer begins a workflow, a PhenoCam image is selected and presented to the volunteer along with its associated tasks. For each task, there is a help button that, when clicked, provides the volunteer with detailed instructions for the task to be completed together with example images. When the volunteer has finished answering questions and/or demarcating regions, the project shows a summary of the volunteer's responses and a button to load a new image.

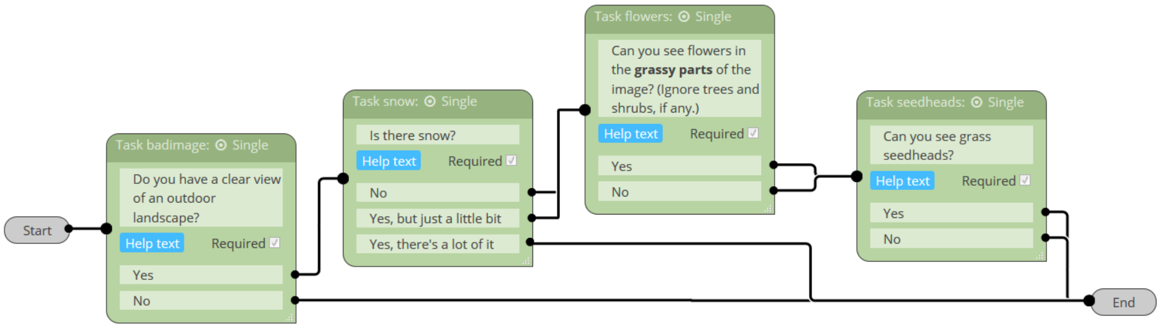

Figure 3. Workflow for PhenoCam images containing grass. See Supplementary Materials Figure S1 for all other workflows.

The summary also provides a button for entering a dedicated chat forum where volunteers can ask questions, comment on images, and interact with the Season Spotter science team and each other. Additional outreach and engagement is regularly conducted via the Season Spotter blog (seasonspotter.wordpress.com), Facebook (www.facebook.com/seasonspotter), and Twitter (twitter.com/seasonspotter).

In May 2015 we tested the Season Spotter project with a group of 39 volunteer beta testers. Using their feedback on a follow-up questionnaire, we modified task questions and added additional instructions and information to increase data quality. On July 21, 2015, we officially launched Season Spotter. The majority of volunteer recruitment occurred through Zooniverse email newsletters, though we undertook multiple recruitment activities [22].

2.2. PhenoCam Images

We uploaded 51,782 images to the Season Spotter project, divided into three groups. Each image came from a PhenoCam site (

Table **1**, Figure 4) and had its top or bottom cropped off to remove date information as well as to provide a more visually pleasing experience. The cropped images ranged from 640x452 pixels to 3888x2592 pixels, and image viewing resolution varied among volunteers by device, operating system, and browser.

Figure 4. Map of PhenoCam sites used in Season Spotter. See

Table **1** for site descriptions.

136