

SOP 9 – Selecting, Deploying and Maintaining Automated Digital Cameras

Northeast Temperate Network
Version 1.10

Overview

Digital timelapse photography can be an important data source for long-term phenological research, providing a consistent and objective stream of data at optimal frequency in both accessible and remote locations. This SOP describes procedures for selecting, deploying and maintaining automated digital cameras for long-term phenological observation of individual plants and vegetation canopies.

Selecting a digital camera

Comparison of a variety of camera types of varying price and quality showed little difference in ability to detect phenological trends among image datasets collected using inexpensive, outdoor webcams (cameras directly addressable via Internet Protocol) and game and plant cameras (basic time-lapse cameras targeted at hobbyists for outdoor use; herein called plant-cams), and images taken by more expensive webcams and digital single lens reflex cameras (Sonntag et al. 2012). For this protocol, NETN uses both outdoor webcams and plant-cams.

The choice between an outdoor webcam or a plant-cam for a specific site is made by park personnel considering the availability of site infrastructure, user skills, and to some extent, cost. Webcams require an external power supply and computer-network infrastructure at the monitoring site, and also require some degree of user skill or previous experience in networking and photography. Alternatively, plant-cams are less expensive than webcams, and rely on batteries for power and memory cards for image storage. Plant-cams can be placed anywhere and operated by users with minimal training, but must be visited periodically to download images and replace batteries.

Webcams designed primarily for *indoor* use did not perform adequately in pilot testing and are not used as part of this SOP.

Choice of specific camera model will vary depending upon budget and availability. Recommended plant-cams include Wingscapes PlantCam (model WSCA04; no longer available for purchase as of spring 2013) and Wingscapes TimelapseCam 8.0 (model WSCT01; about \$100). The TimelapseCam has higher photo resolution and more flexibility for photo scheduling than the former, but no laser aiming feature. Recommended outdoor webcams include models from the StarDot NetCam, Axis and Vivotek product lines; for these webcams, cost of camera and accessories will be \$500-\$1000 or more. In particular, StarDot has been responsive to designing webcams that meet the needs of scientific professionals, such as by working to incorporate metadata into image files. Other makes and models of cameras designed for *outdoor* use may be selected for use with this SOP.

Camera housing and accessories

Plant-cams such as the Wingscapes models typically incorporate weatherproof housing as part of the unit. If so, no additional housing is needed. Despite being designed for outdoor use, outdoor webcams will likely need additional weatherproof housing installed. Pilot testing successfully used inexpensive Vitek VT-EH10 camera enclosures (approx. \$25).

The Wingscapes outdoor camera mounting bracket (approx. \$10) is useful for mounting Wingscapes plant-cams. Wingscapes PlantCams use external SD memory cards and batteries (4 AAs for TimelapseCam). This SOP recommends using rechargeable batteries; high capacity batteries should last approximately one month. At high resolution, the WSCA04 will store 750 photos per GB (enough for 15 days per GB if photos are taken every 30 minutes around the clock). The WSCT01 will store about 450 photos per GB at its highest resolution, for about 10 days per GB. Therefore a 4 GB card should be sufficient to match the maximum deployment length with AA batteries. For longer deployments, a solar power option is available from Wingscapes (about \$80).

Aiming and mounting the camera

Cameras are used to monitor individual plants as well as vegetation canopies. Images from individual plant monitoring are analyzed for leaf “greenness” and/or flowering phenophases. For monitoring individual plants, the camera is aimed at the plant or plants of interest (of a species selected from the park’s list of monitored species in a particular habitat). Plants growing in the sun will provide more consistent illumination and image quality. The camera field of view may be set to contain the entire plant (for a small plant) or a section of the plant (i.e., a specific branch of a tree), and should be consistent with the field of view from prior years. Consider future plant growth and allow space for growth within the field of view. To capture flowering phenology, consider the geometry of this species’ flowering parts during camera placement (ie “nodding” flowers may best be photographed from below while upright flowers from above). The ideal setback distance from camera to plant will vary with plant size and site layout. Table S9.1 provides examples of geometric relationships between camera setback distance, camera FOV, and image resolution to assist in camera placement. If possible, the camera should point north to minimize maximize illumination by the sun and minimize lens flare.

Table S9.1. Example of geometric relationships between camera field-of-view (FOV), image size, area covered and pixel resolution, at two camera setback distances, for StarDot NetCam IR camera and Wingscapes PlantCam and TimelapseCam.

Camera	Format	FOV (degrees)	Image width (pixels)	Camera setback: 2 m (Wingscapes); 25 m (StarDot)		Camera setback: 5 m (Wingscapes); 100 m (StarDot)	
				Total FOV (m)	Pixel size (cm)	Total FOV (m)	Pixel size (cm)
Wingscapes PlantCam	Medium	52	2048	1.6	0.1	4	0.2
Wingscapes TimelapseCam	Wide HD	40	1920	1.3	0.1	3	0.2
StarDot NetCam	Regular	37	1300	15	1	60	5
StarDot NetCam	Wide	94	1300	25	3	100	13

SOP 9 – Selecting, Deploying and Maintaining Automated Digital Cameras

For monitoring “greenness” of a vegetation canopy, the camera is mounted at a location offering a vantage of the canopy, such as an overlook or a tower. The field-of-view must show more canopy than sky (an ideal ratio is 80% canopy and 20% sky). Adjust zoom, if necessary, to achieve this balance. If possible, camera should be mounted 5-10 m above the canopy and looking slightly downward at approximately 10-20°. Also, cameras should be mounted pointing north,



Figure S9.1 Ideal field-of-view for monitoring a canopy at Harvard Forest.

to minimize light interference from the sun and forward scatter. It is important that the area within the camera’s field-of-view that automatically adjusts exposure be aimed at the canopy, not at the sky. Figure S9.1 shows an ideal field-of-view for monitoring a canopy at Harvard Forest.

Install webcams within weatherproof housing as directed by instructions for your specific model. Remember to remove the camera’s lens cap before installing the camera. Slide the camera forward in its housing, so the lens is almost touching the window, to minimize the potential for reflections and glare.

Plant-cams and webcams are mounted firmly to minimize shifts in field of view. Wingscapes plant-cams have two standard tripod nuts embedded in the camera case, and can be mounted on a pole or stake using the Wingscapes outdoor camera mounting bracket (see above under Camera housing and accessories) or on a tripod, or strapped to a tree.

Connecting webcams

For webcams, plug the ethernet and power extension cables into the ports on the camera¹, and into the site’s power supply and LAN router. Check to make sure the camera is on. Then, install the webcam software tools for your model on your computer. Check to see if the camera is detected and note the camera’s IP address. Enter this IP address into your internet browser’s address bar; a page should load with a blue background and a live image from the camera. Depending on your network, the IP address assigned to the camera may change periodically; if this happens, re-run the webcam software tools program to verify the IP. Specific instructions for connecting the Stardot NetCam SC are provided by the PhenoCam network in PhenoCam Installation Instructions by Cory Teshera-Sterne et al. (updated April 2012; available at <http://phenocam.sr.unh.edu/webcam/tools/>).

¹ For StarDot webcams, the ethernet must be plugged in before the power cable.

Deployment metadata

When a camera is deployed, collect camera metadata documenting the camera, site, target image and setup, as shown in Appendix S9.A. Use the camera serial number to uniquely identify each camera. Label each camera with a sticker identifying the organization deploying the units, a request not to tamper with units, a contact phone number, and, if desired, the NETN web page for phenology monitoring for people interested in more information:

<http://science.nature.nps.gov/im/units/netn/monitor/programs/phenology/phenology.cfm>.

Reference panels

Reference panels are used for two purposes. First, periodic photographs of a color standard card are used to verify the camera's color balance settings and to facilitate comparisons between cameras. Second, a simple matte gray reference panel is included in the corner of each image, in order to monitor both day-to-day shifts in color balance (due to changes in weather conditions) and to evaluate long-term stability of the imaging sensor.

The first objective is met by taking pictures of a ColorChecker card (Figure S9.2) under full-sun mid-day conditions (*Note: the conditions under which the ColorChecker picture is taken are very important!* Standardization is most easily obtained under full-sun conditions at mid-day). The ColorChecker card is held in front of the camera, and should fill as much of the field of view as possible. This is done when a camera is first deployed to provide camera-specific baseline data. It is done again each year at the start and end of the growing season. Pictures of the ColorChecker card are considered an important part of a camera's metadata, and these images are re-named and stored in a separate directory to facilitate identification and subsequent analysis.

The ColorChecker is not weatherproof and should not be deployed with the camera. It is kept indoors (in a protective sleeve provided for this purpose), and brought out only for camera verification. Care must be taken to protect the card from water, dirt, oils, and other sources of degradation.

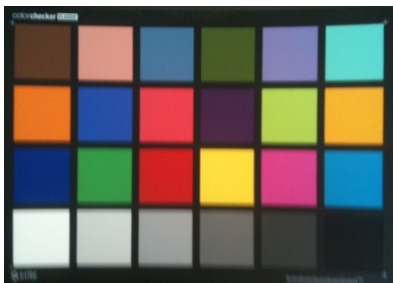


Figure S9.2. X-Rite ColorChecker Classic card used to verify camera color balance and sensitivity prior to and during field deployment. The card is available online for about \$70 at B&H Photo, see www.bhphotovideo.com/c/product/465286-REG.

PhenoCam Image Processor (PCIP) software is used to determine the color (as R, G and B values) of different squares in the ColorChecker card. Instructions for downloading and using this software are found in SOP 10 – Processing Image Data. Alternatively, the Macintosh OS utility, “Digital Color Meter”, can easily perform this color determination. The (R,G,B) values

SOP 9 – Selecting, Deploying and Maintaining Automated Digital Cameras

for a selection of squares in the ColorChecker are recorded as metadata for each camera, as shown here:

ColorChecker Square

Date	Row	Col.	Color	R	G	B
8 May 2013	2	2	blue	28	56	140
8 May 2013	2	5	green	170	210	70
8 May 2013	3	4	red	197	10	26
8 May 2013	3	5	pink	208	40	117

To compare two cameras, for camera A assume that the blue square in column 2, row 2, has a color of (R_A, G_A, B_A) , while for camera B the same square has a color of (R_B, G_B, B_B) . Then, color data for a vegetated region of interest from camera A can be re-scaled to match the color balance of camera B by multiplying the red channel by (R_B/R_A) , the green channel by (G_B/G_A) and the blue channel by (B_B/B_A) . Note that this re-scaling is not strictly necessary for successful analysis, and re-scaling can be applied at a later time as long as the metadata described above are available.

To check changes in the camera's color sensitivity over time, e.g. consider A and B not as different cameras but as measurements at the start and end of the growing season. In this case, the analysis focuses on changes in the relative sensitivity of R, G and B color channels, e.g. R to G, G to B, or R to B. If any of the ratios $(R_A/G_A)/(R_B/G_B)$, $(G_A/B_A)/(G_B/B_B)$, or $(R_A/B_A)/(R_B/B_B)$ are < 0.9 or > 1.1 , then the camera is a candidate for replacement, as shifts over time in the sensitivity of different color channels will make data interpretation challenging.

The second objective of monitoring day-to-day variability is met by mounting a small reference panel in the camera's field of view so that the panel is included in every picture (Figure S9.3). Unfortunately, changes in illumination geometry, and the effects of this on panel brightness and apparent color, make it difficult to use the reference panel as a true standard (i.e. that can be used for post-hoc calibration or correction), but the reference panel is nevertheless important as a means of verifying day-to-day camera functionality.

The reference panel is easily made from a Carlon rectangular plastic electrical box cover (Available at http://www.lowes.com/pd_130189-223-HB1BL_0_), spray painted with matte gray primer (e.g., Rust-Oleum 12 Oz. Gray Primer Flat Spray Paint, http://www.lowes.com/pd_89137-90-1680830_0_). The panel is re-painted annually.

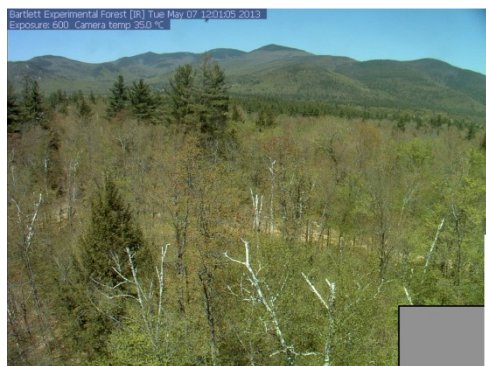


Figure S9.3. Sample image showing grey reference panel included in the camera field of view. Verify that the panel is at least 20x20 pixels in size.

SOP 9 – Selecting, Deploying and Maintaining Automated Digital Cameras

For aerial cameras (mounted on towers, building roofs, etc.), mount the panel on a horizontal pole on an adjustable mount (such as a U Bolt) at a distance of about 3' from the camera to panel. One drawback of this method is that the panel will not always be illuminated the same as the canopy at which the camera is pointed. For ground-mounted cameras, mount the panel on a vertical pole as close as possible to the vegetation of interest. Verify that the size of the panel in the image is no smaller than 20 x 20 pixels. In both cases, the panel is mounted vertically.

The reference panel is included as a region of interest when analyzing images for seasonal changes in vegetation green chromatic coordinate (g_{cc}) using PCIP software. The g_{cc} of the reference panel should be ≈ 0.33 (indicating a grey that is an equal mix of red, green and blue) throughout the year, and should not show obvious seasonality.

Digital camera settings

Most configuration settings are kept on default or automatic settings. One exception is that “white balance” (sometimes referred to as “color balance”) is set manually to the “fixed” setting (sometimes referred to as “manual” or “outdoor” settings) for webcams, if possible, in order to minimize in-camera processing of day-to-day changes in illumination.² For TimelapseCam, set white balance to “SUNLIGHT”. Set date and time settings to local standard time on plant-cams before initial use. Avoid using daylight savings time. Specific settings for the Stardot NetCam SC are included in PhenoCam Installation Instructions by Cory Teshera-Sterne et al. (updated April 2012).

Imprinting options for date, time or camera are used if available on the specific camera. For example, TimelapseCam should be set to imprint camera name, date and time on each photo.

Focusing

Adjust focus manually, if possible³, to obtain a sharp image; it may be helpful to focus on a specific object in the image, such as a branch. For plant-cams, capture and examine a test image onsite (using a laptop or digital frame); then adjust focus as needed. Wingscapes sells an \$80 accessory for viewing photos.

Mounted and aimed webcams are focused on a sunny day with a nearby laptop connected to the camera's configuration pages. Specific instructions for focusing the Stardot NetCam SC can be found in PhenoCam Installation Instructions by Cory Teshera-Sterne et al. (updated April 2012).

Frequency of images

Canopy images are recorded at least every 30 minutes, from 04:00 – 20:00 hours (i.e., 4 am to 8 pm). This frequency is designed to optimize the dataset for canopy analysis using PhenoCam methods which use a 3-day moving window (Sonntag et al. 2012). Since day length varies

² Terminology for these settings varies among camera brands.

³ TimelapseCam has manual focus. PlantCam does not.

SOP 9 – Selecting, Deploying and Maintaining Automated Digital Cameras

over the course of the season, some images before and after the summer solstice will be taken at night. These dark images are very small (in terms of storage space) and are easily filtered out of the dataset prior to analysis.

Plant-cams or other digital cameras aimed at individual plants record images hourly from 8 am to 5 pm (for a total of 10 images per day). For plant-cams, in the Setup Menu, set Time Lapse Interval to be “1 HOUR,” and make sure Photo or Video? option is set to “Photo.”

Image file format, size and filename

There is always a trade-off between resolution and file storage, because higher resolution images use more storage space. Current recommended file resolution is 1 megapixel.⁴ For example, a digital image that is 1024 x 768 is approximately 1 MP. For Wingscapes plant-cams, choose photo quality to be WIDE HD (1920 x 1080), or HIGH (2592 x 1944) for TimelapseCam; choose MEDIUM (2048 x 1536) for PlantCam. Images are saved as JPEG files.

Image file naming follows this format: PARK####_YYYY_MM_DD_HHMMSS.jpg, where PARK is the four-letter park acronym and #### is the four-digit USA-NPN site number. YYYY_MM_DD_HHMMSS is the date and time the photo was taken. For cameras which do not allow custom file naming (such as TimelapseCam), images are renamed immediately after downloading using Bulk Rename Utility software, as described in Appendix A of SOP 11 - Data Management and Quality Assurance/Quality Control.

Maintenance and troubleshooting

Plant-cams are visited about 1 week after initial deployment, to ensure that the camera is still aimed and functioning properly. Thereafter, plant-cams are visited periodically to change batteries and memory cards. Rechargeable batteries and memory cards are given unique numbers and labeled with a permanent marker to aid in trouble-shooting. Maintenance datasheets (Appendix S9.A) are completed at each visit.

Webcam IP's are checked at least weekly to ensure that images are updating regularly, that the window is not dirty or obscured, and that the camera field of view is still as desired (e.g., the housing has not shaken loose). Many problems can be fixed simply by temporarily unplugging the ethernet cable to the camera and at the same time cycling the camera's power (i.e., shut the power off and then turn power back on). It is also useful to check the status lights for the camera and LAN router sockets. Specific instructions for maintaining and trouble-shooting the Stardot NetCam SC are included in PhenoCam Installation Instructions by Cory Teshera-Sterne et al. (updated April 2012).

⁴ Calculated by multiplying by image width in pixels by image length in pixels.

SOP 9 – Selecting, Deploying and Maintaining Automated Digital Cameras

Literature Cited

Sonnentag, O., K. Hufkens, C. Teshera-Sterne, et al. 2012. Digital repeat photography for phenological research in forest ecosystems. *Agricultural and Forest Meteorology* 152:159-177.

Teshera-Sterne, C., et al. 2012. PhenoCam Installation Instructions.
https://dl.dropbox.com/u/29219356/PhenoCam_Install_Instructions.doc

Revision History

Version #	Date	Revised by	Changes	Justification
1.00	May 2012	Geri Tierney	Adapted from: Digital repeat photography for phenological research: camera deployment and image processing protocol (Sonnetag and Richardson, June 2011); PhenoCam Installation Instructions (Teshera-Sterne and Richardson, May 2011); and Wingscapes Timelapse Camera User Guide (2010). Added reference panel description from Andrew Richardson.	
1.01	Oct 2012	Geri Tierney	Added filenaming guidance and specific settings for TimelapseCam.	
1.02	Nov 2012	Andrew Richardson, Michael Toomey, Geri Tierney, Steve Klosterman	Replaced Appendix B with reference to PhenoCam document. Included file naming procedure. Editorial comments.	
1.10	May 2013	Geri Tierney, Michael Toomey, Andrew Richardson	Reduced frequency of images from plant-cams and other cameras aimed at individual plants. Clarified need for frequent images for canopy photos. Added table relating camera FOV, image size, distance to target and resolution. Added metadata collection sheet. Revised reference panel procedure now uses simple grey panel. Check with Andrew Richardson in 2014 re: ongoing research on reference panels.	Response to review. Reference panel procedure revised as per A. Richardson's ongoing research.

Appendix S9.A. Camera Deployment Metadata

Equipment:

Camera(s)
Writing utensil
Empty SD cards
Charged batteries
Camera housing (for webcams)
Laptop (for webcams)
Mounting bracket (optional for Wingscapes plant-cams)
Mounting pole, tripod or straps (for Wingscapes plant-cams)
Colorchecker card
Reference panel with mounting hardware
Tools for mounting

Date: _____ Location/Park: _____ Site #: _____

Lat: _____ Long: _____

Camera make/model:

Camera serial or unit number:

View target (canopy or plant):

Plant species in view:

Monitored plant ID (if any):

What direction is the camera pointing (north is preferred)?

For webcam, what is the internet connection and camera address?

What power source or specific battery type does this camera use?

Appendix S9.B. Sample Plant-cam Maintenance Datasheet

Equipment:

- Writing utensil
- Empty SD cards
- Charged batteries

Date: _____ **Location/Park:** _____ **Site #:** _____

Lat: _____ **Long:** _____

Unit #	Empty/Taken Out		Full/Put In		Notes
	SD Card	SD Card	Battery	Battery	

Plant-cam checklist

- ___ Replace batteries
- ___ Replace SD cards
- ___ Record SD card and battery numbers in datasheet
- ___ Check the unit and cables over for any damage or needed adjustments
- ___ Remember to shut all units and battery cases

SOP 10 – Processing Image Data

Northeast Temperate Network

Version 1.03

Overview

Digital timelapse photography can be an important data source for long-term phenological research, providing a consistent and objective stream of data at optimal frequency in both accessible and remote locations. This SOP provides specific procedures for processing digital image files to track seasonal development of individual plants and vegetation canopies. Red-green-blue (RGB) color channel information is extracted and transformed to green chromatic coordinate (g_{cc}) as an indicator of canopy greenness which is tracked over time. This analysis is performed on image datasets collected from outdoor netcams and plantcams maintained by NETN, as well as on image datasets collected from various cameras by volunteers at NETN designated photopoint sites. Analysis is performed using PhenoCam Image Processor, a stand-alone software program developed by Koen Hufkens. In future work, we plan to incorporate methods for scaling-up to connect this dataset to satellite imagery. In addition, we are developing procedures to track development of flowering and other phenophases in image datasets.

List of Key Acronyms

DN – digital number

g_{cc} – green chromatic coordinate

PCIP – PhenoCam Image Processor software

RGB – red, green, and blue

ROI – region(s) of interest

PhenoCam Image Processor (PCIP)

PhenoCam Image Processor is a stand-alone software program built using Matlab functionality. PCIP can run on computers without a licensed Matlab copy using Matlab Compiler Runtime (MCR) provided with the PCIP installer.

PCIP (also called PhenoCam GUI) can be downloaded from the website <http://phenocam.sr.unh.edu/webcam/tools/>, or obtained from NETN staff. To install and run PCIP, follow the instructions ‘Installing and Using Phenocam’ that comes with the software download.

Selecting regions of interest (ROI)

For tracking seasonal development of greenness in individual plants, we select a region of interest within each image dataset, comprised almost entirely of leaves of that plant. Additional ROIs may be selected for other plants or species represented in the same image dataset. For tracking vegetation canopies, we select one to three ROIs that are representative of the dominant species of vegetation in that region. It is important the ROI be large enough that any minor shifts in the field of view over time will not substantially alter the delineated region. For example, the ROI should fall within an area bordered by enough foliage that a minor shift in field of view will not shift the ROI off the foliage.

ROIs are selected and saved using the analysis software program, as described in the document ‘Installing and Using PhenoCam’. It is very important to save the ROI from each analysis so that they may be used to designate the same region when analyzing images from this site in subsequent years.

Calculating g_{cc}

Long-term datasets of repeat images taken hourly for several months or several years show scene illumination changes due to the daily rotation of the Earth, the Earth's revolution, cloudiness and other changes in overall weather conditions. This variation is unrelated to the variable of interest – canopy greenness. To suppress the influence of these scene illumination changes on time series of canopy greenness we follow the procedure recommended by Sonnentag et al. (2012) and calculate green chromatic coordinate as:

$$g_{cc} = G/[R+G+B]$$

where R, G and B represent, respectively, red, green and blue digital number (DN)

We use PCIP to extract RGB DN within the region(s) of interest.

As a quality check at sites where vegetation canopies are monitored, we select an additional ROI covering the reference panel, and calculate g_{cc} for the reference ROI. The g_{cc} for the reference panel should be essentially stable over time. It may be variable from day to day, because of weather and clouds, but there should be no long-term or seasonal trend in the g_{cc} of the reference panel. If a trend is detected in g_{cc} for the reference panel ROI, this trend must be taken into account during analysis of data from this camera, and both the camera and reference panel should be carefully examined for degradation.

Filtering night-time images

Night-time images are excluded from analysis in PCIP by filtering-out “dark” images from around sunrise or sunset by simple *RGB* thresholding. To do so, ROI-averaged *RGB* triplets (sets of R, G, and B DN) below a predefined threshold are discarded. This threshold is typically set to 15% of maximum DN (i.e., full sun), but in some cases the level may be set lower to avoid data gaps. In pilot testing using webcams, a threshold of 10% was needed in some areas with very high contrast causing deep shadows in order to avoid multi-day gaps in data. If the 15% threshold results in a multi-day gap in data for a particular camera dataset, determine the appropriate threshold for that camera using this method. Examine the frequency distribution of total image brightness (calculated as the sum of R, G and B DN in the PCIP output dataset; see Figure 1 for example). The distribution is typically bimodal with some very dark images (taken at night) being one low-DN peak, and most of the daytime images forming a high-DN peak. In Figure 1, the threshold can then be set to filter out the low-DN images by choosing a data point just above the lower peak of night images, and calculating the % full sun of this data point. Calculate % of maximum DN as total brightness of this data point (sum of R, G and B DN) divided by maximum DN ($256 + 256 + 256 = 768$), then round to the nearest 5%.

Figure S10.1 illustrates this procedure. Note the bimodal distribution: the lower peak represents nighttime photos and the higher peak represents daytime photos. Using the breaking point, 100, we can estimate a day/night threshold of 100/768, or 13% (round to 15%) for the PICP.

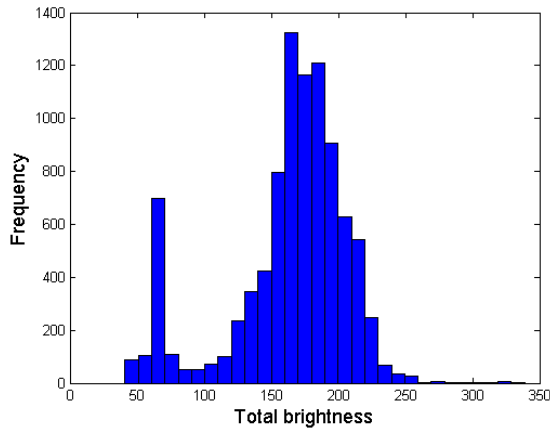


Figure S10.1. Frequency histogram of total image brightness (R+G+B) for one year of images from Harvard forest.

In PCIP, set “dark thres” in the calculation window to be 15, or to the level indicated by analysis of the frequency distribution as described above.

In addition, PCIP allows the user to select minimum and maximum hours of image to include in analysis. Under ‘Calculation Options’, choose a minimum of 4 (i.e., 4 am), and a maximum of 20 (i.e., 8 pm).

Assigning *per90*

To further reduce the influence of short-term changes in scene illumination due to weather and other factors, we use a moving window approach that assigns the 90th percentile of all

daytime g_{cc} values within a three-day window to the center day (*per90*), resulting in three-day g_{cc} . For a long-term time series, a value every third day is sufficient for characterizing seasonal canopy development, and avoids the auto-correlation that would occur in a daily dataset of this type. Sonnentag et al. (2012) stress that the effectiveness of *per90* depends largely on data availability, thus high-frequency image archives are needed (ideally: one image every 30-min during daylight hours, as specified in the Selecting, Deploying and Maintaining Automated Digital Cameras SOP).

Within PCIP, select a window of 3 days, and check the box for 90th perc. (within ‘Calculation Options’).

Detecting phenophases

Figure S10.2 illustrates a typical g_{cc} time series, as derived from a Harvard Forest webcam with the four principal phenophases indicated below. Winter baseline values are typically in the range of 0.33 to 0.40, where lower values are expected in a 100% deciduous canopy as compared to this partially coniferous forest. Spring green-up demonstrates a very rapid increase from the baseline, 0.36 to the summer peak, 0.46. These g_{cc} values gently decline with increasing chlorophyll and aging/darkening of the leaves throughout the summer, dropping to a value of 0.42. At the beginning of fall, leaf coloration rapidly decreases g_{cc} values to a low value of 0.34, below the baseline. Leaf abscission then exposes the grayish tree trunks, which returns g_{cc} to its normal baseline of 0.36. In addition, analysis of red chromatic coordinate (r_{cc}) may be used to quantify autumn coloration.

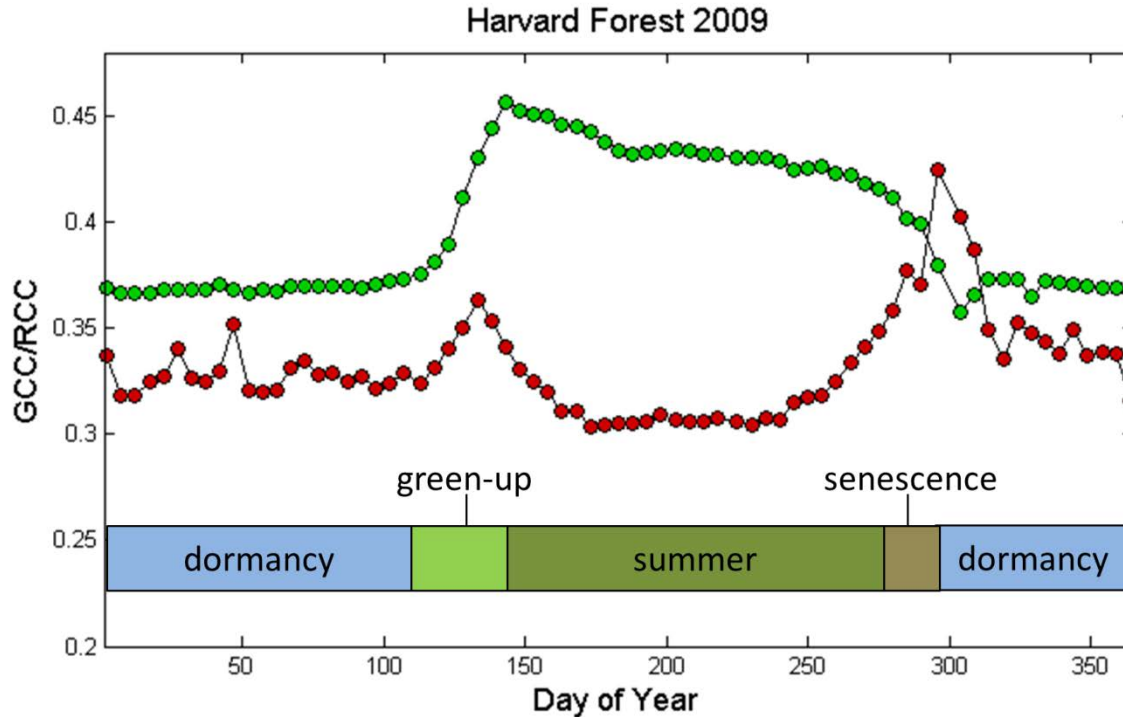


Figure S10.2. g_{cc}/r_{cc} time series from a Harvard Forest webcam in 2009.

The seasonality of greenness at evergreen-dominated forest sites in the northeast US is largely controlled by seasonal changes in chlorophyll and pigment composition of existing foliage rather than growth and senescence of new leaves. Thus NETN evergreen-dominated sites are expected to show a slightly different but still distinct phenology of change in greenness.

Analysis of phenophases for cameras aimed at individual plants

These procedures are a first draft; they will be refined as camera data is collected and personnel become available to analyze the image data.

For plants that have stable areas suitable for automated analysis of g_{cc} (primarily trees and shrubs with stable branches), the procedures described above should be used to automatically extract this information.

For other phenophases, the photos will be reviewed and the phenophases for each day with suitable photography will be recorded in Nature's Notebook. It will help to use a computer with two monitors, so that Nature's Notebook can be open on one screen for data entry, and photos can be viewed on another. The basic procedure (written for Windows XP) is as follows:

- Photos should be organized so that all photos for a given individual and year are in the same folder (see SOP 11- Data Management and QA/QC for file name conventions).
- Open an instance of Windows Explorer on one screen and maximize the application. Navigate to the folder with the correct individual and year, and change the "View" setting to "Filmstrip" (View... Filmstrip in Windows XP). Shrink the size of the file navigation pane if needed to enlarge the photo so plant phenology can be easily viewed.

SOP 10 – Processing Image Data

- Open an instance of Nature’s Notebook on the other screen, log in, and open a data entry form for the individual. Alternatively, print out a data form and record data on the form, then follow up with entry on-line.
- Starting with the earliest photo (the left-most photo if the photos have been named properly), evaluate one photo per day for phenology and record the data in Nature’s Notebook.
 - Make sure to use the correct individual (or portion of individual or patch of individuals; the “focal area”) for recording data, and never change the focal area over the course of a season of data without noting this in Nature’s Notebook (some changes will require setting up a new individual or patch in Nature’s Notebook).
 - It will help to quickly scan through the photo data (beginning, mid-season, and end) to ensure that the camera view did not shift and lose part of the focal area.
 - If recording data from a partial individual (e.g., a tree branch), make sure this is recorded in Nature’s Notebook.
 - Start with the photo taken as close to noon as possible on the first day of monitoring. If that photo is blurry or dark, use the closest photo to noon that allows you to see the plant phenology.
 - If the filmstrip view does not allow you to see phenophases adequately, double-clicking on the image thumbnail at the bottom of Windows Explorer will open the default photo program on your computer; that program should allow you to zoom in on sections of the photo.

Literature Cited

Sonnentag, O., K. Hufkens, C. Teshera-Sterne, et al. 2012. Digital repeat photography for phenological research in forest ecosystems. *Agricultural and Forest Meteorology* 152:159-177.

Revision History

Version #	Date	Revised by	Changes	Justification
1.00	May 2012	Geri Tierney, Andrew Richardson	Adapted from: Digital repeat photography for phenological research: camera deployment and image processing protocol (Sonnentag and Richardson, June 2011); and Digital repeat photography for phenological research in forest ecosystems (Sonnentag et al, 2012)	
1.01	Oct 2012	Geri Tierney, Michael Toomey	Added procedures for running PCIP software.	
1.02	Nov 2012	Brian Mitchell, Geri Tierney, Andrew Richardson, Michael Toomey, Steve Klosterman	Added procedures for evaluating photo data with an observer, for cameras aimed at individual plants. Added procedure for selection of darkness threshold. Editorial changes.	
1.03	May 2013	Geri Tierney, Michael Toomey	Noted future plans to scale-up to connect this dataset to satellite imagery. Updated Figure 1 to show Rcc. Editorial changes.	