Keeping a (Digital) Eye on Nature's Clock

Students use digital cameras to monitor plant phenology

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Many of your students probably take pictures daily. Whether snapshots of their friends at a Justin Bieber concert or of their latest skateboard trick, these images document changes in a student's life. Digital cameras can do more, however, than record memories to post on Facebook. They can also help students examine changes in their environment. This article shows how to use a digital camera as a "scientific visualization tool" to monitor plant phenology over the course of a year.

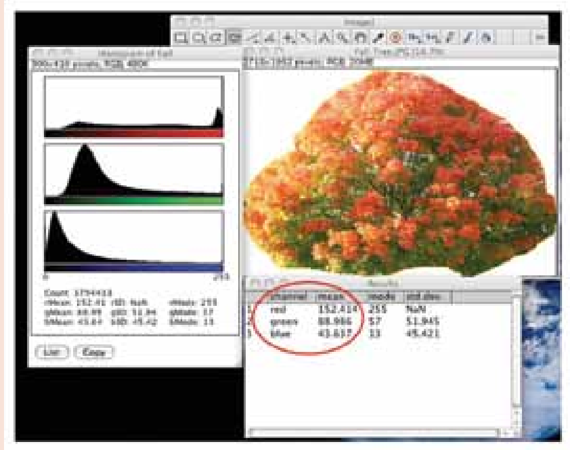
Phenology, or the study of periodic natural events, is a growing body of science that is important to understanding our changing climate. By visually analyzing changes in nature, students can learn about their environment and provide scientists with valuable data to aid in global climate change research.

The activities described here align with several of the Scientific and Engineering Practices of *A Framework for K–12 Science Education* (NRC 2012), as students plan and carry out their own investigations, analyze and interpret data, use mathematics and computational thinking, and construct evidence-based explanations.

Such widespread technology as digital photography has been recommended for use in science classrooms for nearly two decades [*Benchmarks for Science Literacy* (AAAS 1993, pp. 47–48, 56–57) and the *National Science Education Standards (NSES)* (NRC 1996, pp. 190–192)]. A 2004 article in this journal noted, "Digital cameras open up enormous possibilities in the science classroom, especially when used as data collectors" (Leonard et al. 2004, p. 34). Nowadays, digital photography is ubiquitous; even many cell phones have a built-in high-quality digital camera; accordingly, we should show students how their cameras and smart phones can become tools of scientific measurement.

FIGURE 1

Screen shot from ImageJ software.

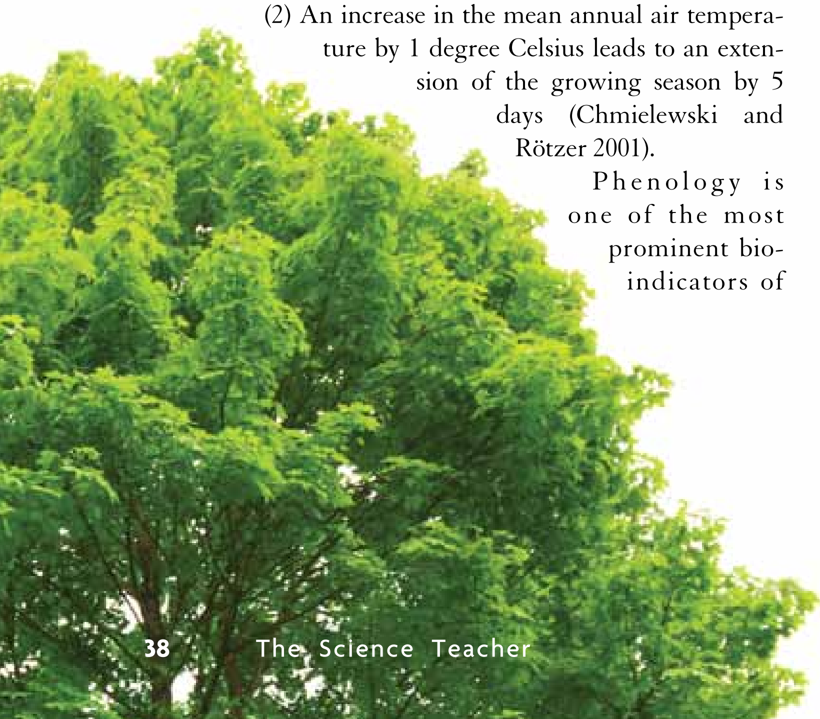


Each pixel on an image will have a digital number (DN) between 0 and 255 associated with the brightness of each channel (red, green, and blue). Using the mean DN values for the red, green, and blue channels over an area, we can calculate the relative percent brightness to account for daily changes in solar illumination (i.e., if the image is darker or lighter at a different time of day).

Phenology, the study of our planet's clock

Spring 2012 was the warmest of recent record. This meant earlier flowering dates for many plant species across the country, but why should we care? Tracking the chronology of periodic phases of plant development can provide data that helps test such hypotheses as: (1) Across the Northern Hemisphere, spring is arriving earlier at a pace of approximately 1.2 days per decade (Haggerty and Mazer 2008), or (2) An increase in the mean annual air temperature by 1 degree Celsius leads to an extension of the growing season by 5 days (Chmielewski and Rötzer 2001).

Phenology is one of the most prominent bio-indicators of biological systems affected by climate change. Significant correlations exist between winter and spring temperatures and spring phenological phases, such as bud burst, leaf unfolding or flowering in mid and higher latitudes (Estrella and Menzel 2006; Soudani et al. 2008). Similarly, leaf senescence ("brown-down") and leaf drop in the fall can relate closely to both temperature and water availability. Such bio-indicators can suggest that our planet's nutrient cycling processes are changing and that farmers and gardeners will have to adjust the timing of planting or harvesting their crops, that migrating insects will have to adjust to new peak pollination times, that students' backyards could provide habitat for plants that require a longer growing season, or that the annual family vacation to see fall colors will have to be postponed.



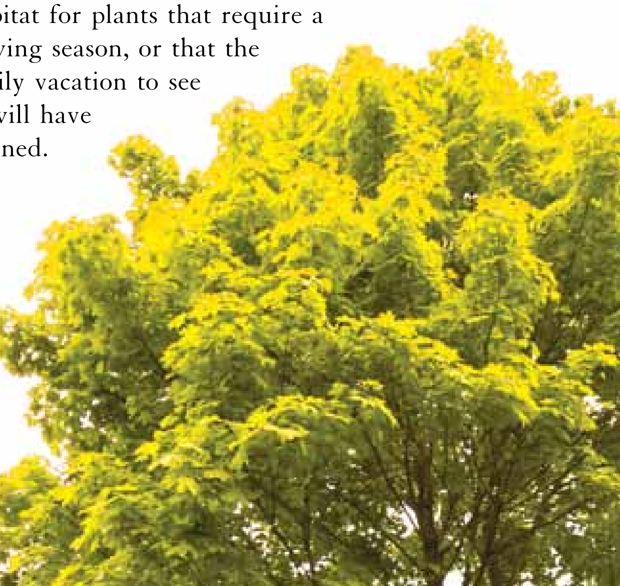


FIGURE 2

A simple spreadsheet can help your students record their data.

This sheet of RGB data recorded by a senior biology student in Minnetonka, Minnesota, is accompanied by photos of the oak tree she examined on September 6 and October 4, 2011. Students can also consider other variables, such as day length, temperature, cloud cover, and dew point. Henson also recorded temperature data (not displayed).

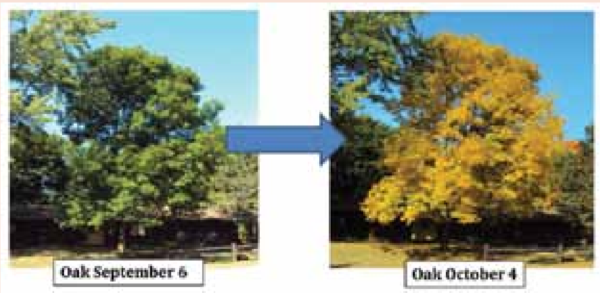


Table of recorded color RGB data for Oak Tree

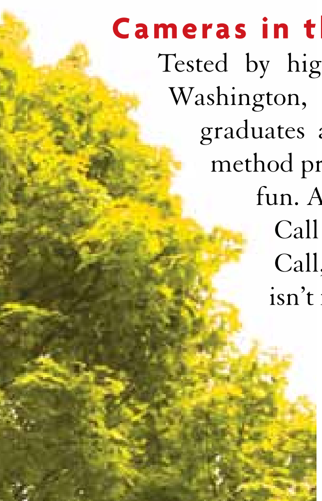
Date	Red	Green	Blue
Sept 6	13	104	63
Sept 7	13	104	63
Sept 8	13	102	65
Sept 9	13	102	65
Sept 12	13	102	65
Sept 13	15	102	63
Sept 14	15	102	63
Sept 15	15	102	63
Sept 16	15	102	63
Sept 17	15	101	64
Sept 19	15	101	64
Sept 20	18	99	63
Sept 21	18	99	63
Sept 22	30	92	58
Sept 26	34	90	56
Sept 27	39	86	55
Sept 28	46	79	55
Sept 29	59	68	53
Sept 30	67	60	53
Oct 1	78	51	51
Oct 2	89	48	43
Oct 3	96	48	36
Oct 4	113	37	30

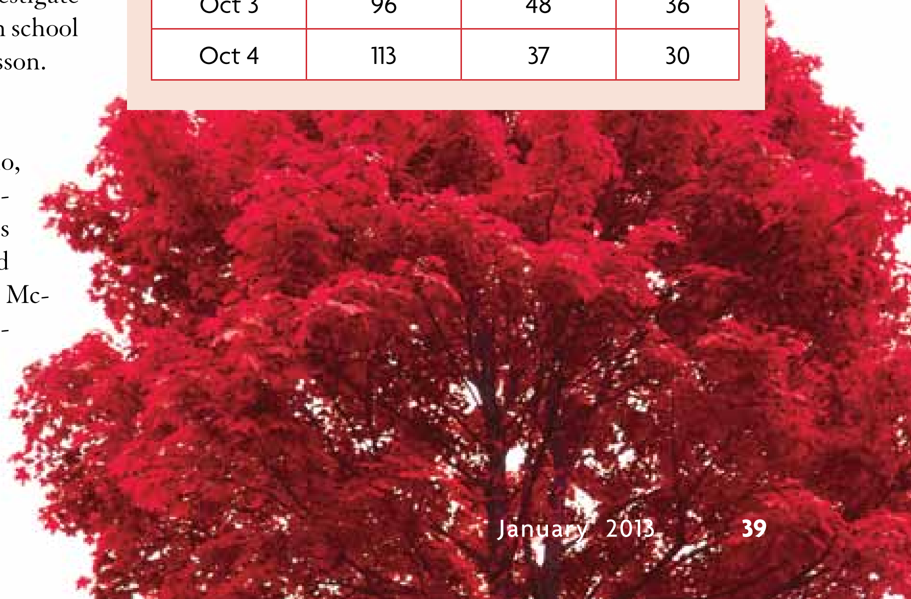
For now, predicting the annual timing of fall leaf coloring and spring green-up remains challenging for scientists due to a lack of ground observations (Delpierre et al. 2008). Recording such phenological changes could have greater implications as well, such as helping to predict how shifts in agricultural production might impact the global food supply. Your students can collect and provide data to aid the scientific community in this challenge.

As a plant canopy begins to green-up in the spring and change color in the fall, students will notice a steady change in the relative percentage of red and green in the canopies' leaves (Figures 1 and 2). These percentages can be calculated from digital images by using ImageJ, a free software program (see "On the web"). Students upload pictures of a single tree or canopy into ImageJ and calculate the relative percentages of red, green, and blue colors, as shown in Figure 1. Detailed procedures are provided in the "Explore" section of Figure 3 (p. 40) and also in Figure 6 (p. 42). Students can investigate annual phenological changes in their backyards or on school grounds using the steps outlined in the following lesson.

Cameras in the classroom

Tested by high school students across Idaho, Washington, and Minnesota, and by undergraduates at the University of Idaho, this method proved to be insightful, simple, and fun. A summer institute student at the McCall Outdoor Science School in McCall, Idaho, remarked, "Techy-stuff isn't for me, but this was pretty fun.





It was kind of like art, you know, playing with colors. And, it's easy once you figure it out. It will be cool to compare trees in my hometown."

Students in both the Earth and life sciences can monitor changes in plant coloration with a digital camera as independent research or a group project. For example, as a senior biology research project, a student at Minnetonka (Minnesota) High School examined the phenological differences between a native Minnesota white oak and a non-native gingko and found that a longer growing season favors the gingko. She plotted points throughout the fall of the relative percentage of red and green in each tree and found that the gingko's peak coloration was delayed by more than a month as compared to the white oak (Figures 2 [p. 39] and 4). The intersection of the red and green lines on her graph indicates the time just before peak coloration occurred; she used this

FIGURE 3

"5-E" lesson plan assessing leaf color change using ImageJ.

Engage

- Discuss the role of phenology and the timing of natural events. Show time-lapse videos of changing seasons (find many on YouTube).
- Ask students: "How can changing growing seasons affect you?"
- Tie this discussion to climate change. Ask students how their data could be compared with data from students in other classrooms in your region or state or around the world—and be used by scientists.
- Explain remote sensing and the importance of ground validation using satellite imagery (learn more at the "ESRI Change Matters" website; see "On the web").
- Ask students: "What methods would you use to monitor the changing colors of a tree?"

Explore

- Download a free software program called ImageJ (see "On the web").
- Learn to use the ImageJ software with a video tutorial (see "On the web"). Students upload pictures of their tree or canopy into ImageJ and calculate the relative percentage of red, green, and blue on the trees leaves (Figure 1, p. 38).
- In ImageJ, students crop their pictures so only the tree's leaves remain. Then they can select "Analyze -> Tools -> Color Histogram." A "brightness" value appears associated with the red, green, and blue channels (Figure 1).
- Using these brightness values, students calculate the relative percentage of red, green, and blue in the image (Figure 1).
- See Figure 6, p. 42, for directions on standardizing your data.

Explain

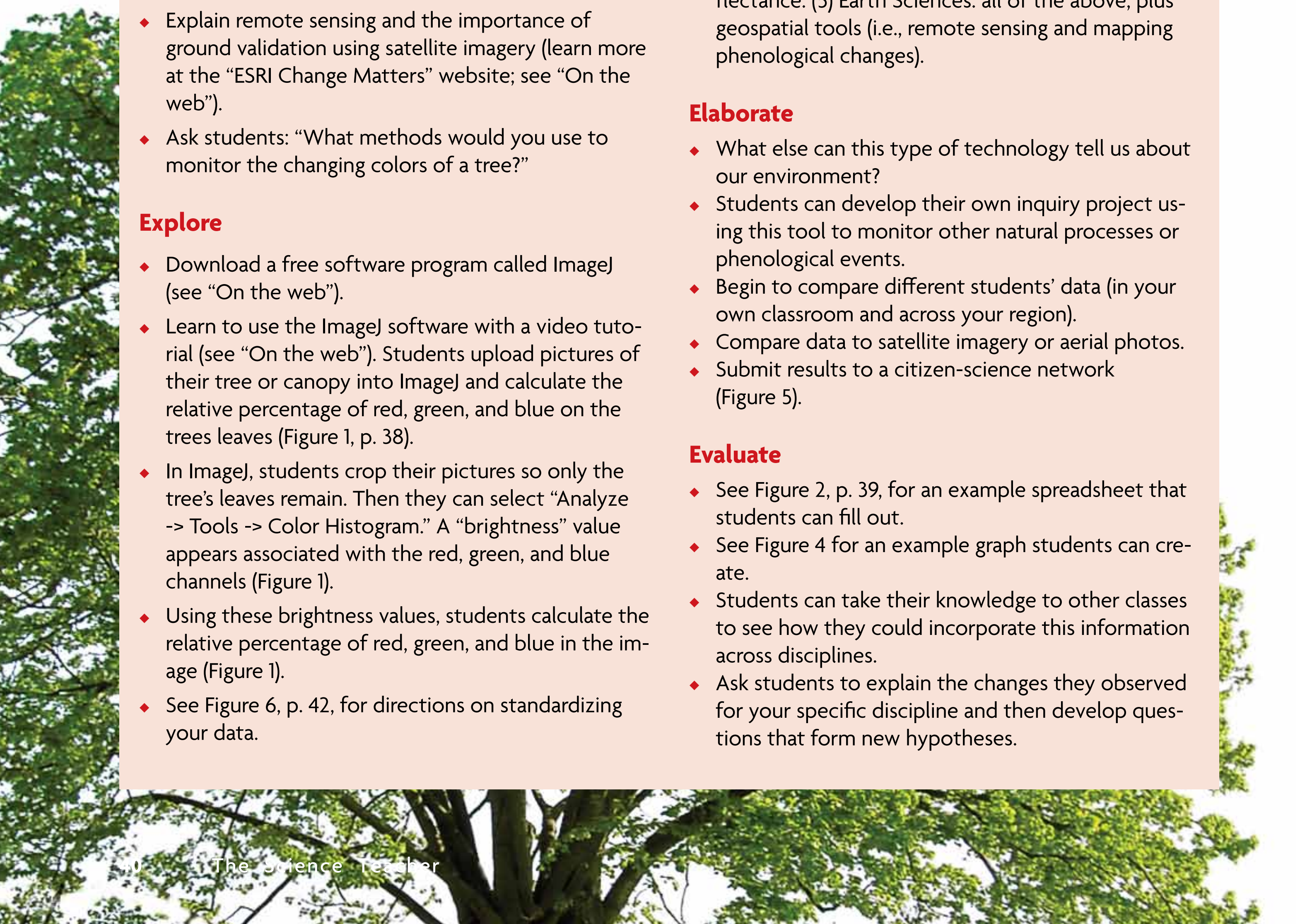
- Be creative! Aside from graphing the data (Figure 4), there are many ways this exercise can be used in science classes:
- (1) Biology: biological changes in leaf and environment; (2) Chemistry: nitrogen and phosphorus leaving the leaf and retreating back into the branch of the tree. (3) Environmental Science: climate change responses, how will different systems be affected? (4) Physics: electromagnetic spectrum, light reflectance. (5) Earth Sciences: all of the above, plus geospatial tools (i.e., remote sensing and mapping phenological changes).

Elaborate

- What else can this type of technology tell us about our environment?
- Students can develop their own inquiry project using this tool to monitor other natural processes or phenological events.
- Begin to compare different students' data (in your own classroom and across your region).
- Compare data to satellite imagery or aerial photos.
- Submit results to a citizen-science network (Figure 5).

Evaluate

- See Figure 2, p. 39, for an example spreadsheet that students can fill out.
- See Figure 4 for an example graph students can create.
- Students can take their knowledge to other classes to see how they could incorporate this information across disciplines.
- Ask students to explain the changes they observed for your specific discipline and then develop questions that form new hypotheses.



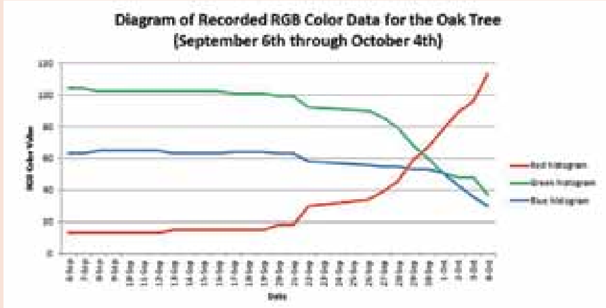
to draw her conclusion. As an assessment tool, this student also wrote a full report on the process, tying in temperature and day-length as explanatory variables.

While many students may analyze individual trees, others may capture the entire plant canopy. This can minimize the randomness of results from a single tree, attributable to its specific microclimate, soil, or other factor. Several middle and high school students in western Washington found that a canopy at a lower elevation changed color approximately four days earlier than one at an elevation 100 meters higher. This is shown in the students' lab write-up and graphs, similar to those in Figure 4.

Assessment can vary with discipline, though individual lab write-ups have been the most common form. These lab reports generally seek to answer a scientific question comparing how two or more different species might respond to a changing climate, or how same species phenology differs at varying elevations, precipitation amounts, sunlight intensities, geologic substrates, soil conditions, or ecological surroundings (i.e., competition). Lab reports have been structured according to scientific practices, include tables and graphs (similar to Figures 2 and 4), and often bring in explanatory variables to help verify the student's conclusion. Following individual lab reports, students in a ninth-grade Earth science class were asked to hypothesize why they saw differences between their measurements and those made by citizen scientists across the country for a similar species. Their analysis was used as an assessment tool following a unit on physical geography.

FIGURE 4

A graph of RGB data from Figure 2.



Your students as citizen scientists

Connecting scientists, teachers, and students has proven to be an effective form of science instruction (Wormstead, Becker, and Congalton 2002). By comparing their own data with that collected by schools and citizen scientists across the country, students can compare when, and to what extent, phenological changes occur across a variety of different ecosystems, elevations, and soil moisture conditions. For example, students can compare their data to digital photographs of ecologically important sites throughout the United States that are posted on the Digital Earth Watch Network website (see "On the web"). Having an interconnected network of schools participating in citizen science creates collaborative learning opportunities, as well as a better understanding of place-based climate in relation to the larger Earth system. Citizen science is the Facebook of classroom discovery. [*Note*: See the December 2012 issue of this journal for more on citizen science activities.]

The organizations listed in Figure 5 use empirical observations to monitor when a flower blooms and when a tree is, for example, 50% yellowed; however, this percentage

FIGURE 5

Citizen science networks.

Students can contribute data and/or adapt their methods from citizen science networks. More information is available at these websites.

Citizen Science Network	Website
(1) The National Phenology Network	*http://usanpn.org*
(2) Project BudBurst/BudBurst Buddies	*http://neoninc.org/budburst*
(3) The Digital Earth Watch Network	*http://picturepost.unh.edu*
(4) The GLOBE Program	*http://classic.globe.gov/fsl/html/templ.cgi?phenology_budburst*

FIGURE 6

Camera calibration.

It is especially important to standardize your data collection. Here are some general rules that we suggest you apply to your projects. Methods adapted from Richardson et. al 2007, 2009.

1. *Make sure your image is a three-color-channel RGB uncompressed JPEG.* This is the default setting for most cameras. A compressed image will suffice, but scientific accuracy improves when the image is uncompressed.
2. *Use the camera's automatic exposure and aperture setting.* This lets the camera respond to ambient light levels, using the entire image to set the exposure. The brightness of any individual pixel is not a direct measure of surface radiance, which is why it is necessary to convert to a percentage of relative brightness, as is demonstrated in Figure 1.
3. *Take images between 11 a.m. and 2 p.m. to minimize the angular reflection of sunlight.*
4. *Use the same camera for every shot.* Using a different camera might change the way that camera automatically adjusts to light levels. Although a low-quality camera, such as those on some cell phones, isn't recommended, it should suffice and produce similar results.
5. *Take pictures only in dry weather conditions.* Image quality can be adversely affected by rain, snow, aerosols, fog, and uneven illumination due to the presence of scattered clouds.
6. *Take all pictures of the same tree from the same perspective.* For example, take the picture from the south side of the tree, 20 meters away, and at eye height. Ideally, students could take pictures of the tree from all cardinal directions and average the relative percentage from each side to get a number that encompasses the entire tree.
7. *Note on species selection*: These methods will work best on any annually changing plants such as deciduous trees, grasses, or crops. However, encourage students to explore species such as coniferous trees or perennial shrubs, as slight changes in plant pigment pools could reveal a small drop of the relative percentage of green during the fall. Encouraging students to be creative with species selection could result in something like monitoring algal changes in a pond.

can be highly subjective. Digital cameras can validate these otherwise biased observations—and they can reiterate the importance of scientific objectivity to students. By using the techniques outlined in this activity, your students can record their own phenological observations to contribute to the growing body of data collected within the listed networks.

The National Phenology Network (NPN) website (Figure 5, p. 41) includes an interactive tool that allows students to track the phenology of different species across the country. By gaining hands-on data-collection experience and by providing needed data to the scientific community, students can connect to science in a meaningful and inspiring way. Using repeatable and reliable methods not only helps the scientific community establish consistent measurement protocols, it allows students to confidently compare images from different photographers of the same location or images from the same photographer at different times.

At the University of Idaho, undergraduate students in an ecological monitoring and analysis class compared NPN and digital camera methods and results. Student groups collected digital phenology data over the fall semester for select tree species on campus. After the tree canopies fully changed colors, students broke into groups based on tree species and compared their empirically based NPN method results to the digital red and green channel relative percentages over time. Students found that significant differences existed between their own ability to "eyeball" changes in leaf coloration and that of their classmates; when these measurements were plotted alongside digital camera coloration curves, students concluded the digital camera data may provide a more repeatable estimate of plant phenology. Discussion followed on how to minimize observer bias in citizen science observations.

A group of scientists and educators known as the Intermountain-West Climate Education Network (ICE-NET) and the University of Idaho are working to involve high school classrooms across the intermountain west in phenology monitoring as a way to highlight climate-change science. During fall 2012, these classrooms were scheduled to perform methods used in NPN observations, collect ground-based digital images of tree canopies, and be provided with satellite imagery that reveals how "green" a landscape is using Normalized Difference Vegetation Index (NDVI) scenes. These NDVI scenes are available free from Landsat (see "On the web"). The Landsat Program is a series of Earth-orbiting satellites managed by NASA and the U.S. Geological Survey. The satellites provide both raw images and adjusted images (such as "greenness" images, or NDVI). Digital images taken from Landsat satellites have been available since 1972, allowing people to study the many dynamic processes of our planet from space. The next generation of Landsat imagers is slated for launch in early 2013.

The digital camera method plays a crucial role in bridging the gap between single species observations and large-extent satellite imagery. It provides an intermediate step to help students grasp the concept of scale and remote-sensing techniques. Taking digital images at sites across the intermountain-west will provide teachers and students with a dataset to compare and contrast climate across the region. Having an interconnected network of schools participating in citizen science creates collaborative learning opportunities as well as a better understanding of place-based climate in relation to the larger Earth system.

Conclusion

While the activities described here haven't been fully implemented on a large scale, like Project Bud Burst or the National Phenology Network, they have proven to be effective for quantifying leaf color change and a seamless process and learning progression for middle, high school, and college-age students. Using this or another method outlined by one of the above organizations can connect students with methodologies used by "real" scientists and can provide a reliable way for students to see the value of their independent research. Cheap and widely available tools, such as a digital camera and open-source software like ImageJ, can help provide science education with the technological upgrade it needs. ■

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On the web

Digital Earth Watch Network: *http://picturepost.unh.edu*
ESRI Change Matters: *http://changematters.esri.com/compare*
ImageJ Software: *http://rsbweb.nih.gov/ij*
Image J video tutorial: *www.youtube.com/watch?v=jhjyqnxOT3k*
Landsat Normalized Difference Vegetation Index (NDVI) scenes: *http://landsat.gsfc.nasa.gov*
McCall Outdoor Science School: *www.uidaho.edu/cnr/moss*

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