Synthesis of data from the PhenoCam network: Phenological Controls on Forest Productivity

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Growing season length, which is influenced by year-to-year variability in weather, has a strong influence on forest productivity. Deciduous forests are more sensitive in this regard than evergreen forests.

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http://www.nsrcforest.org

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Project Summary

Phenology is the study of recurring lifecycle events influenced by seasonal environmental changes, and classic examples include flowering by plants and migration by animals. By regulating deciduous forest canopy duration, phenology exerts a strong control on both spatial and temporal patterns of primary productivity (i.e. forest growth). With previous funding from NSRC, we established a collaborative research network ("PhenoCam") that uses networked digitial cameras—webcams—to provide automated monitoring of canopy phenology across the Northern Forest region. We are using the imagery from these cameras (deployed at a dozen established research sites) to track the phenology of canopy development and senescence with previously-developed algorithms and image analysis techniques.

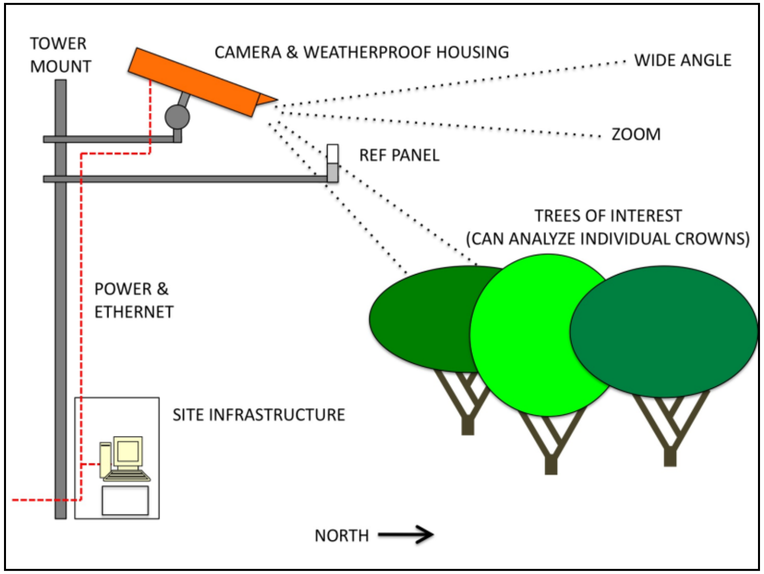
In this project, we used camera data, and ground observations of phenology, in conjunction with measurements of forest productivity, and computer simulation models, to answer the basic questions about how phenology controls spatial (across sites) and temporal (year-to-year) variability in phenology. We highlight two key results here. First, We found that at individual sites, a 10 d longer growing season (i.e. due to earlier leaf out in spring, or delayed autumn senescence) increased annual gross productivity by about 10%, but annual net carbon uptake by about 20%. We found that productivity of deciduous forest sites was more sensitive to growing season length than was productivity of conifer sites. Second, analyzing data from spring 2010, when across much of New England early leaf onset (due to unusually warm weather) was followed by a late-spring frost event, we estimated the "carbon cost", in terms of reduced ecosystem productivity, of frost damage.

Background and Justification

Phenology has been shown to be a robust integrator of the effects of year-to-year climate variability and longer-term climate change on natural systems (e.g., recent warming trends). There is a need to better document biological responses to a changing world, and improved phenological monitoring at scales from individual organisms to ecosystems, regions and continents will contribute to achieving this goal. The USA-National Phenology Network is being designed and organized to engage federal agencies, environmental networks and field stations, educational institutions, and mass participation by citizen scientists in the development of a continental-scale phenological monitoring program. The PhenoCam network is actively working with USA-NPN and participating in this effort.

We initiated PhenoCam in order to provide automated, near-surface remote sensing of canopy phenology across the Northern Forest region of New England, upstate New York, and adjacent Canada. Image analysis of archived webcam images provides an objective means by which canopy phenology can be monitored and quantified, at relatively low cost and with minimal personnel expenses, without the need for a human observer. The monitoring network will, over time, provide a unique and scientifically valuable long-term data set on seasonal patterns of phenology across the Northern Forest.

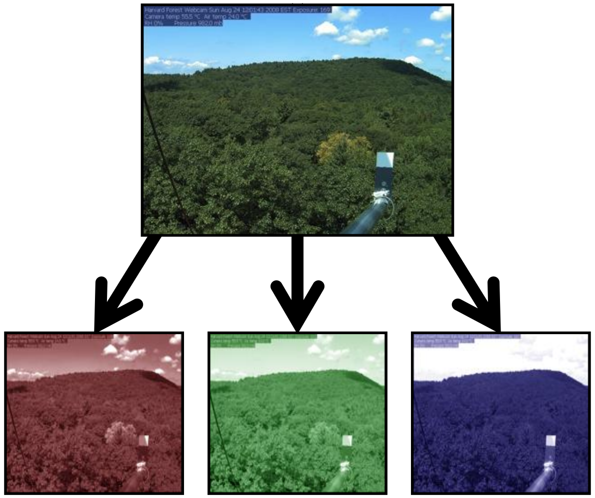
Methods



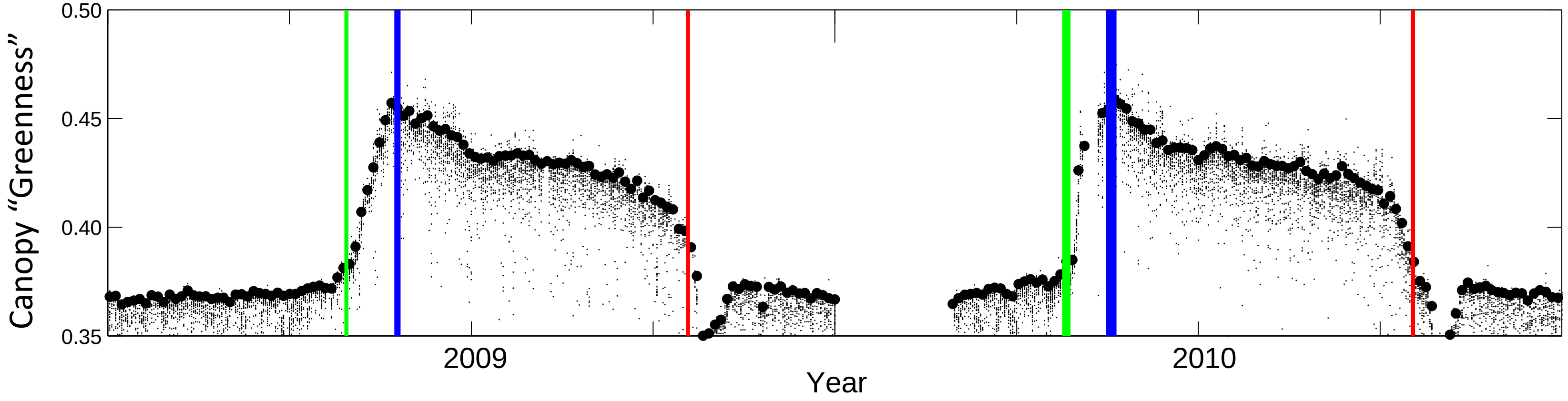
- Webcam phenology: a form of "Near surface" remote sensing
- Commercially available webcam mounted on tower
  - Faces north
  - 15° below horizontal
  - Spatial integration (but individual crowns could be analyzed)
  - Images recorded every 30 minutes, uploaded by ftp to web page
- Provides a permanent visual record
- Image analysis (RGB channel extraction) to quantify phenological changes in "greenness" and "redness"
- Not a calibrated instrument—but neither are field observers!

Methods

- These camera images are a permanent record of what the canopy looked like at a specific point in time (Harvard Forest through the seasons), and we can look at the images and visually estimate the date when leaves emerged in spring or when they began to change color in autumn.
- However, we can also directly extract quantitative data from the images. Digital camera images use the the red-green-blue additive color model, which says that we can reproduce any color through some combination of the three primary colors
- We can split each image into these three components, quantify the intensity of each, and develop a quantitative measure of canopy greenness.

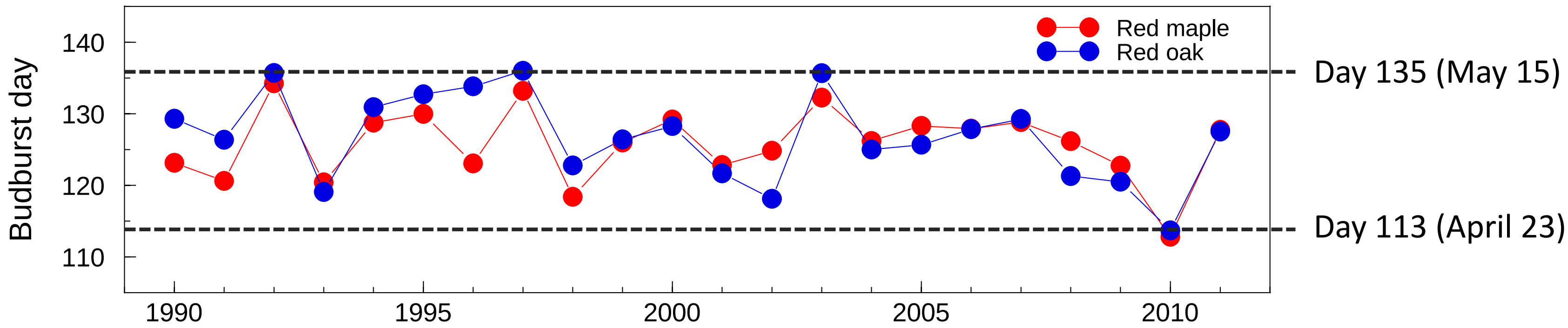


Results: Phenology from Cameras
(Richardson et al. 2012)



- This graph shows two years of canopy greenness derived from imagery from the Harvard forest. Greenness is low in the winter, rises steeply in spring, drops off gradually over the summer, and falls sharply in autumn.
- These transitions correspond to dates of leaf out (green line), peak canopy development (blue line), and autumn coloration (red line), as recorded by John O'Keefe at Harvard Forest, based on his visual assessment of trees in the forest.
- Our camera-based method is providing data that is consistent with ground observations by a human, but data are collected automatically, and at a much higher temporal resolution.

Results: Phenology and forest carbon cycling
(Migliavacca et al. 2012, Richardson et al. PTRS B 2010)



Migliavacca et al. Biogeosci (2012)

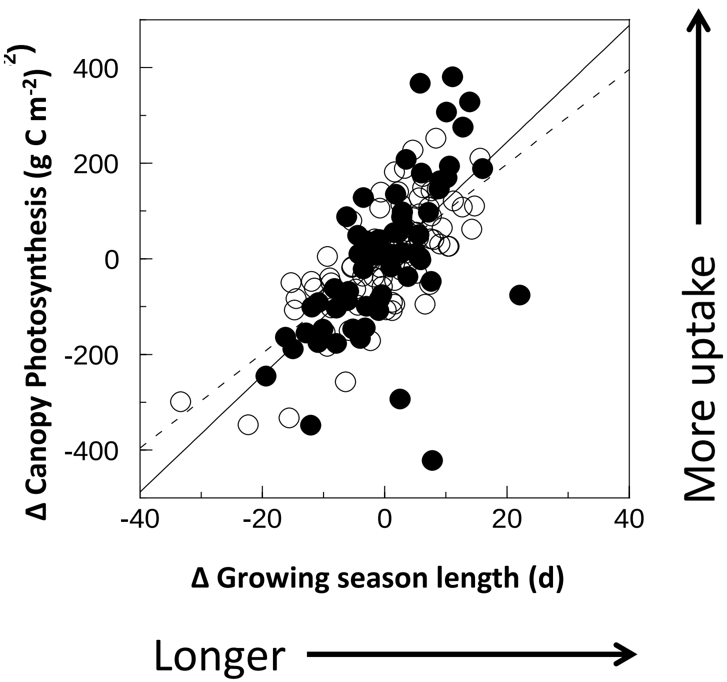
- What is the ecosystem-level impact of a longer growing season?
  - Photosynthesis
  - Net carbon storage
- How do patterns differ across ecosystem types?
- What is the climate sensitivity?

  +1°C spring temperature

  → +3 d growing season

  → +3% photosynthesis

  → +10% C storage



Richardson et al. PTRS B (2010)

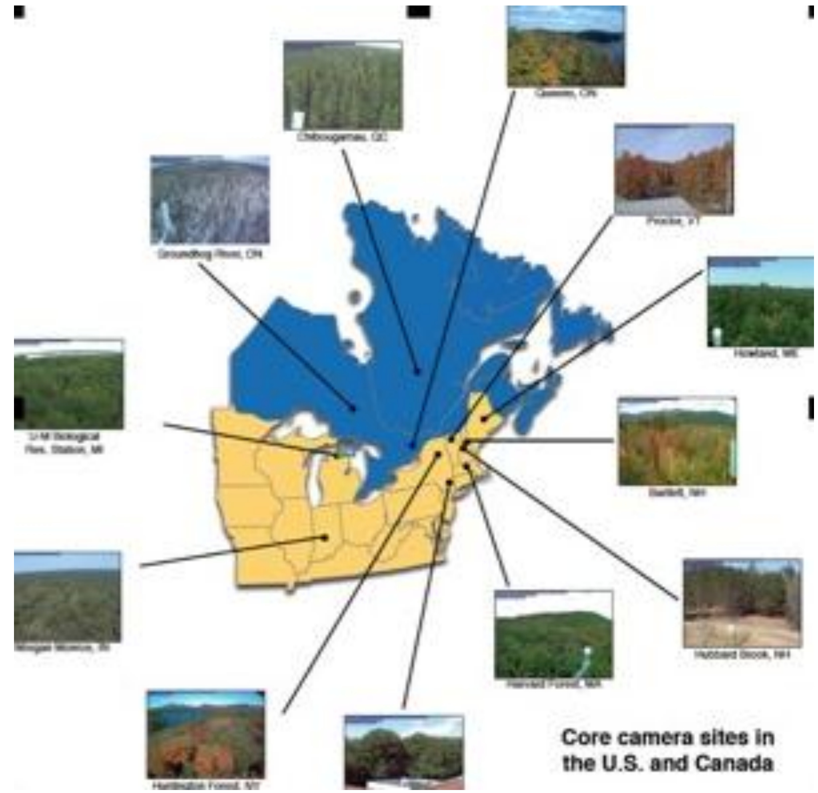
Results: Impact of a late spring frost (Hufkens et al GCB 2012)

- Unusually warm temperatures triggered exceptionally early budburst in spring 2010
- This was followed by a severe frost event across much of northern New England
- The frost event is estimated to have reduced annual gross ecosystem productivity by 7-14% across 8753 km^2 of high-elevation forest
- Frost events following leaf out, which are expected to become more common with climate change, may influence both forest composition and ecosystem productivity.

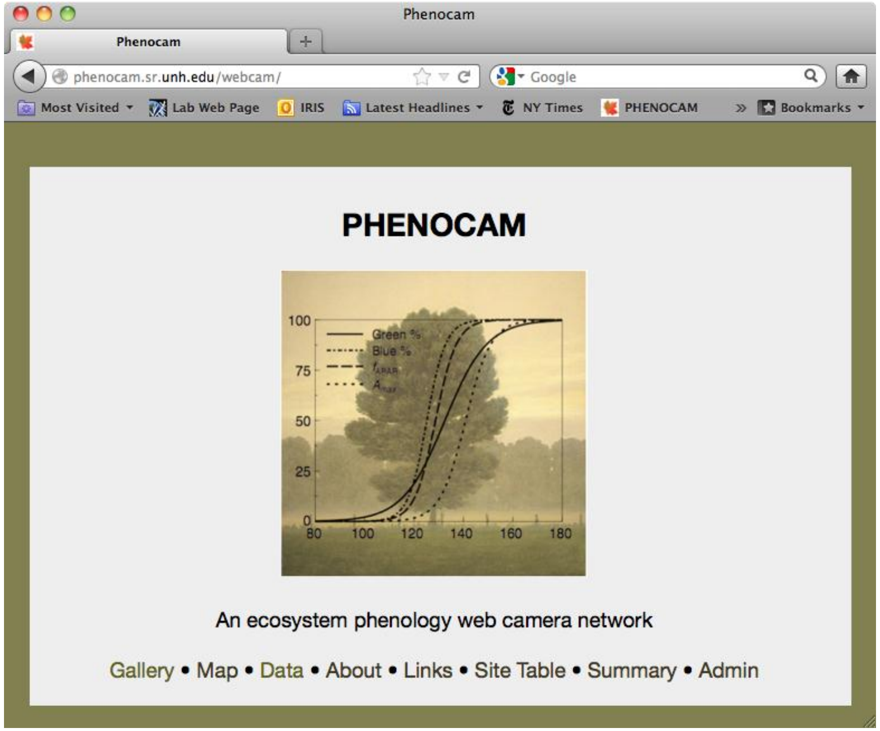
Fig. 1 (a) Frost damage to developing sugar maple leaves and (b) landscape view of frost damage 15 days after the event showing damaged sugar maple trees are interspersed with healthy developing American Beech and yellow birch. Photos supplied by Amey Bailey and Paul Schaberg.

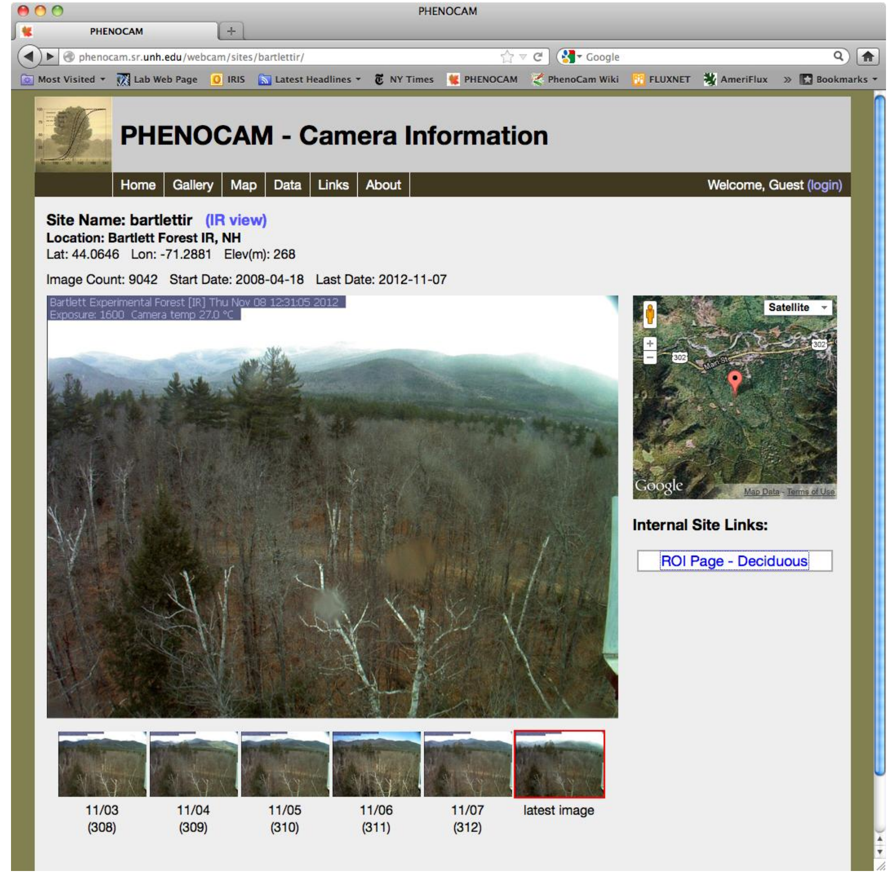
Implications and applications in the Northern Forest region

- Our project improves regional-scale understanding of inter-relationships among phenology, canopy state, ecosystem function (particularly C cycling), and abiotic factors. This knowledge is essential for predicting the effects of climate change on both ecosystem productivity and forest health, a key objective of NSRC Theme 2
- Results from our project are directly relevant to a number of industries in the Northern Forest region, including forest products (land managers want to know how climate change will affect stand productivity and C sequestration) and tourism (with PhenoCam, quantitative, real-time tracking of peak colors can be used to target where “leaf peepers” should go for the best viewing experience).
- This cooperative effort involved researchers active in five states and two Canadian provinces, and thus contributes to the NERC objective of cross-border collaboration.



Results: Outreach Efforts





Through the PhenoCam project web page, images and data from the network are available, in near-real-time, to the general public and the scientific community.

Future Directions

- We continue to operate the network, and new imagery is being added to the database every day
- This is an absolutely unique dataset on vegetation phenology, and will be extremely valuable in coming years as we conduct more analyses of relationships between phenology, environmental drivers, and ecosystem carbon cycling
- With funding from the National Science Foundation, we have expanded the network to provide continental-scale monitoring of vegetation phenology, across a wide range of ecosystem types.

Outcomes and Products

The following peer-reviewed papers and book chapters have been supported in whole or in part by our grant from NSRC

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