Development of Real-Time Environmental Sensor Technology and Applications for the Northeast: A Proposal from the NERC Northeastern Environmental Sensor Working Group (NESN)

Principal Investigator:

Lindsey Rustad, USDA Forest Service; 271 Mast Road, Durham, NH rustad@maine.edu.

Co-Principal Investigators:

Mary Martin, University of NH; Morse Hall, 8 College Road, Durham, NH mary.martin@unh.edu.
Kevin Rose, Smithsonian Environmental Research Center; 647 Contees Wharf Road, Edgewater MD RoseKC@si.edu.
Jamie Shanley, U.S. Geological Survey; P.O. Box 628 Montpelier, VT 05601jshanley@usgs.gov.
Kathleen Weathers, PO Box AB, Millbrook, NY 12545 weathersk@caryinstitute.org.

Completion Date: January 31, 2018

This project involved a number of sensor-enabled sites within the northeast, establishing a network and website platform to aggregate resources and data into a single-point-of-entry portal. This effort continues under funding from the USDA Forest Service Smart Forests program, where additional site data are being added, instrumentation is being developed, and investigation continues into patterns in biological and enviromental changes during the spring warmup period.

Project funding has supported efforts to visualize and sonify data, and provided proof-of-concept products that form the basis of a funded NSF EAGER grant on the integration of science, art and music.

Funding support for this project was provided by the Northeastern States Research Cooperative (NSRC), a partnership of Northern Forest states (New Hampshire, Vermont, Maine, and New York), in coordination with the USDA Forest Service.
http://www.nsrcforest.org

Project Summary

Recent advances in environmental sensor technology, wireless communications, and software applications have enabled the development of low-cost, low-power multifunctional environmental sensors and sensor networks that can communicate environmental conditions to researchers, managers and the public in real time. This emerging technology generates information at unprecedented temporal and spatial scales, and offers *transformational opportunities* to better understand the physical, chemical and biological 'pulse' of both terrestrial and aquatic ecosystems. These real time 'windows on watersheds' also provide exciting new ways to engage the public, and provide novel tools for educators and students.

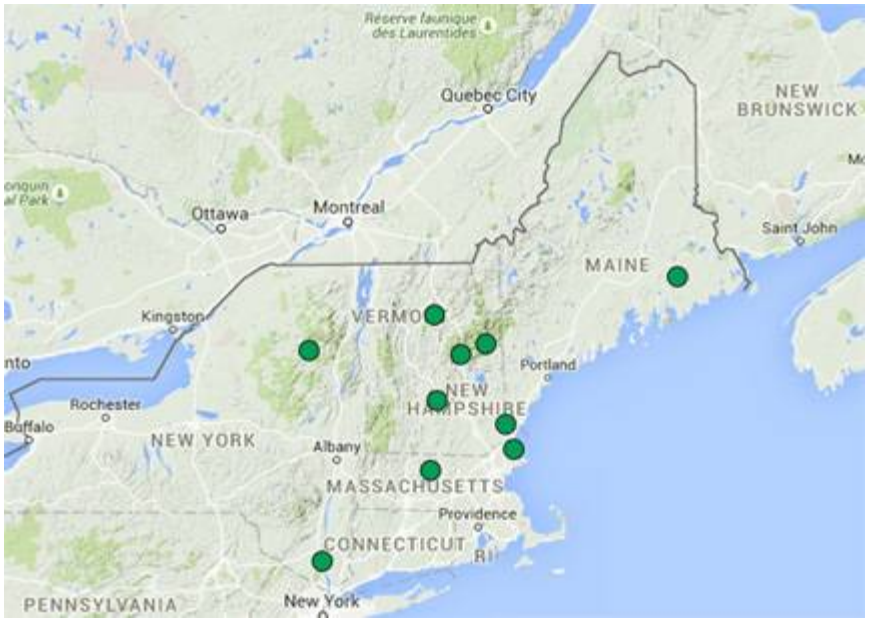
The Northeast Environmental Sensor Network (NESN) is a new working group established through this grant. The charge of the NESN is to help the regional research community develop and share infrastructure and expertise on operating, maintaining, analyzing, and making public environmental sensor data. Ultimately, the vision is to establish -or contribute to- a *regionally distributed, long-term multi-site, multi-sensor platform for detection of short- and longer-term environmental change for northeastern North America.* To address sustainability of this network, we have recently merged resources with the USFS Forest Service Smart Forests network, which has a longer funding timeline.

Project funding has supported the following activities to further the goals of the collaborating sites: (1) Establish an interactive web portal that serves as a demonstration site and information clearinghouse that points users – scientists, educators, and the public – to relevant information sources and real-time data visualizations from ecosystem study sites in the Northeast. (2) Develop tools and displays for merging near real-time data streams from multiple sites to foster data comparison and collaborations among investigators. (3) Use high resolution environmental sensor data to run an ecosystem scale C and N cycling model in real time on daily time steps for the Northeast. (4) Use high resolution environmental sensor data to better understand ecosystem dynamics during the critical winter-to-spring transition in the Northeast. (5) Apply emerging visualization and outreach tools to engage educators and the public. Together, these activities are improving access to - and use of - high frequency real-time data in the Northeast, and are providing a platform for monitoring short- and longer-term ecosystem response to environmental change, and inspire greater interest and understanding of environmental research by the public.

Background and Justification

The 21st century is emerging as a time of great change, including changes in the physical and chemical environment of the earth, the social dynamics and shifting demography of seven+ billion people, the precarious nature of the world economy and the rapid pace of technological development. In the northeastern United States, the Northern Forest comprises over 26 million acres, and provides food, fiber, clean air and water, and other services for 1.3 million residents. A rapidly changing climate, continued inputs of atmospheric pollutants, and current and projected shifts in how the land is used threaten the health and sustainability of the forests of this region. New developments in environmental sensor technology are presenting *transformational opportunities* to better understand the physical, chemical and biological 'pulse' of both terrestrial and aquatic ecosystems with sensor networks distributed both 'vertically' through the plant-soil-air-water continuum and 'horizontally' across the landscape.

The *Northeastern Enironmental Sensor Network* (NESN) brings together a regional research community to develop and share infrastructure and expertise in operating, maintaining, analizing and sharing environmental sensor data. Participants in this network share a goal of contributing to a *regionally distributed, long-term multi-site, multi-sensor platform for detection of short- and longer-term environmental change for northeastern North America.* The NESN strives to build on--and link--existing hydro-meteorological research and monitoring programs at long term research sites in the region, and promote the development of novel applications for examining ecosystem processes with significantly greater temporal and spatial resolution than has previously been possible.



Methods

To meet the objectives of this sensor community, we have undertaken the following activities:

1) Establish an interactive web portal that serves as a demonstration site and information clearinghouse that points users – scientists, educators, and the public – to relevant information sources and real-time data visualizations from ecosystem study sites in the Northeast. The portal will also serve as a forum for the NESN community to share know-how and experience.

2) Develop tools and displays for merging near real-time data streams from multiple NESN sites to foster data comparison and collaborations among investigators.

3) Use high resolution ES data to run an ecosystem scale C and N cycling model in real time on daily time steps for the Northeast.

4) Use high resolution ES data to better understand ecosystem dynamics during the critical winter-to-spring transition in the Northeast.

5) Apply emerging visualization and outreach tools to engage educators and the public.

Results/Project outcomes

Website: We have developed a website available at: https://smartforest.org. The two separate websites developed for NESN and Smart Forests (a parallel project), have been combined into a single site: https://smartforests.org/. By doing so, we now have resources to continue past the funding term of the NSRC NESN grant. Collaborators from both of these networks are shown on this site through a site list and interactive map. Links to site research and data are kept up-to-date, and as sites become more active in the network, they develop a landing page to highlight their work with environmental sensors. The site highlights news at collaborating sites, and articles on specific research efforts.

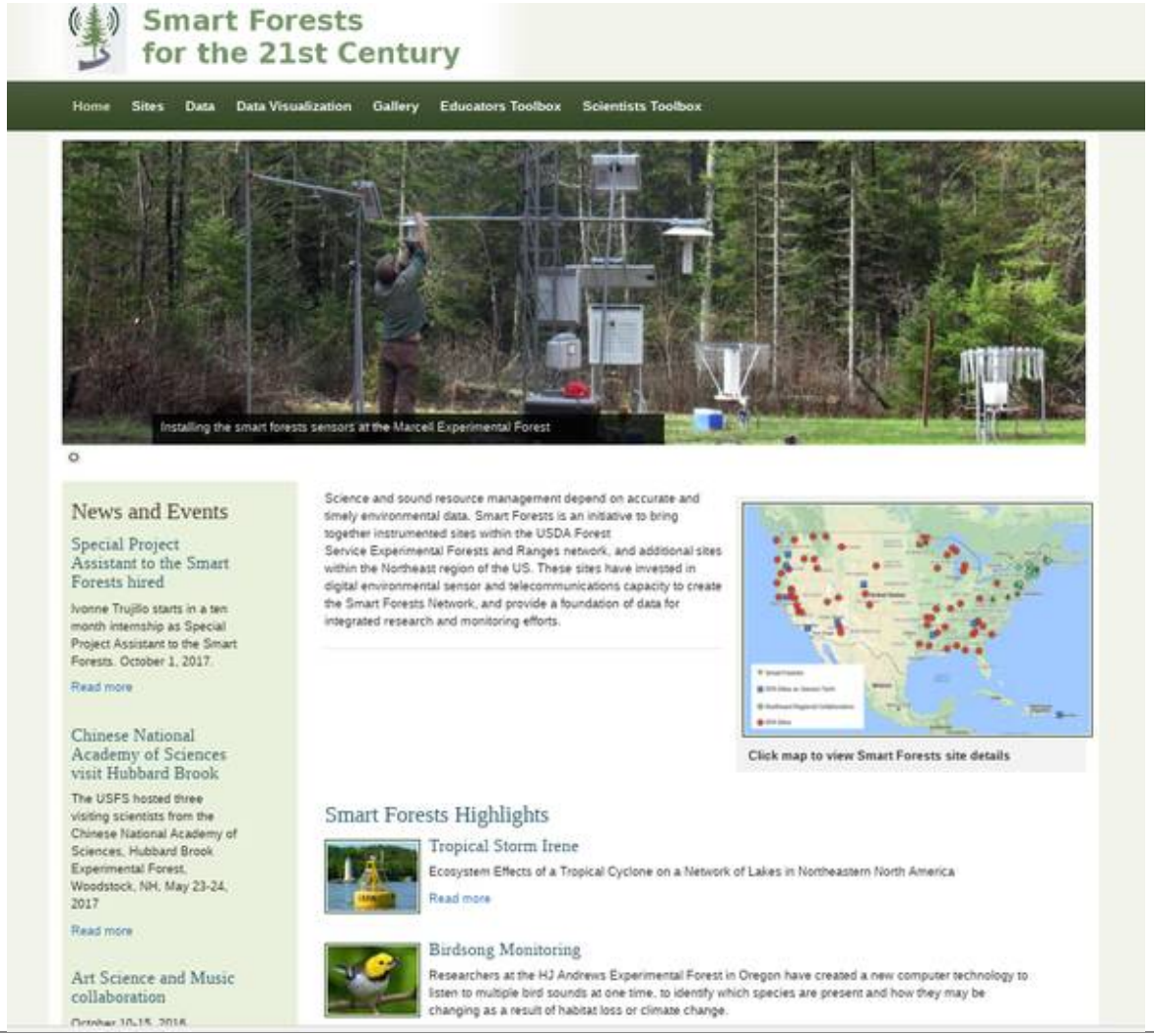
Data Portal: We have used the R shiny package combined with sensor middleware (GCE Toolbox, and custom scripts), to ingest, reformat, and align data from individual sites into a centralized data portal. As new sites develop environmental sensor capabilities, there are opportunities to standardize data formats. These backend tools provide the custom coding that allow sites to participate with their pre-exisiting sensor configurations and file formats.

RealTime Ecosystem Modeling: This task involved establishing the harvest of NOAA gridded forecast data from the NCEP-NAM 5km (now 3km) model to provide the drivers for PnET. These data were also of interest to the NH-EPSCoR research community, and we were able to get additional funds from that project to support this effort. We included the EPSCoR research team in identifying non-PnET-related data products that would be of interest to their community, and have added those to the list of data harvested and archived. The archive of these data began on May 1 2013, and has run seamlessly since then, with all data archived and available through EPSCoR cyberinfrastructure resources. Major outcome from this effort is the realtime PnET Productivity product available in an interactive map online http://earthatlas.sr.unh.edu, and a publication from the EPSCoR team that used spring ecosystem warmup trends provided by this archive.

Winter-Spring Transition Study: With efforts at the site level (Hubbard Brook) and state level (NH-EPSCoR) we continue to evaluate patterns in spring and fall ecosystem transitions. Our intial insights have been incorporated into one NSF proposal (not funded) and we have provided input data for a state-wide EPSCoR sensor synthesis project. We continue now with the analyis of temperature trends during these critical shoulder periods at individual sites, and at spatially disctributed sites withing the NESN/SmartForests network. A recent initiative (with continued funding), is the evaluation and deployment of affordable dendrometer instruments for closely tracking tree growth during these transitional periods.

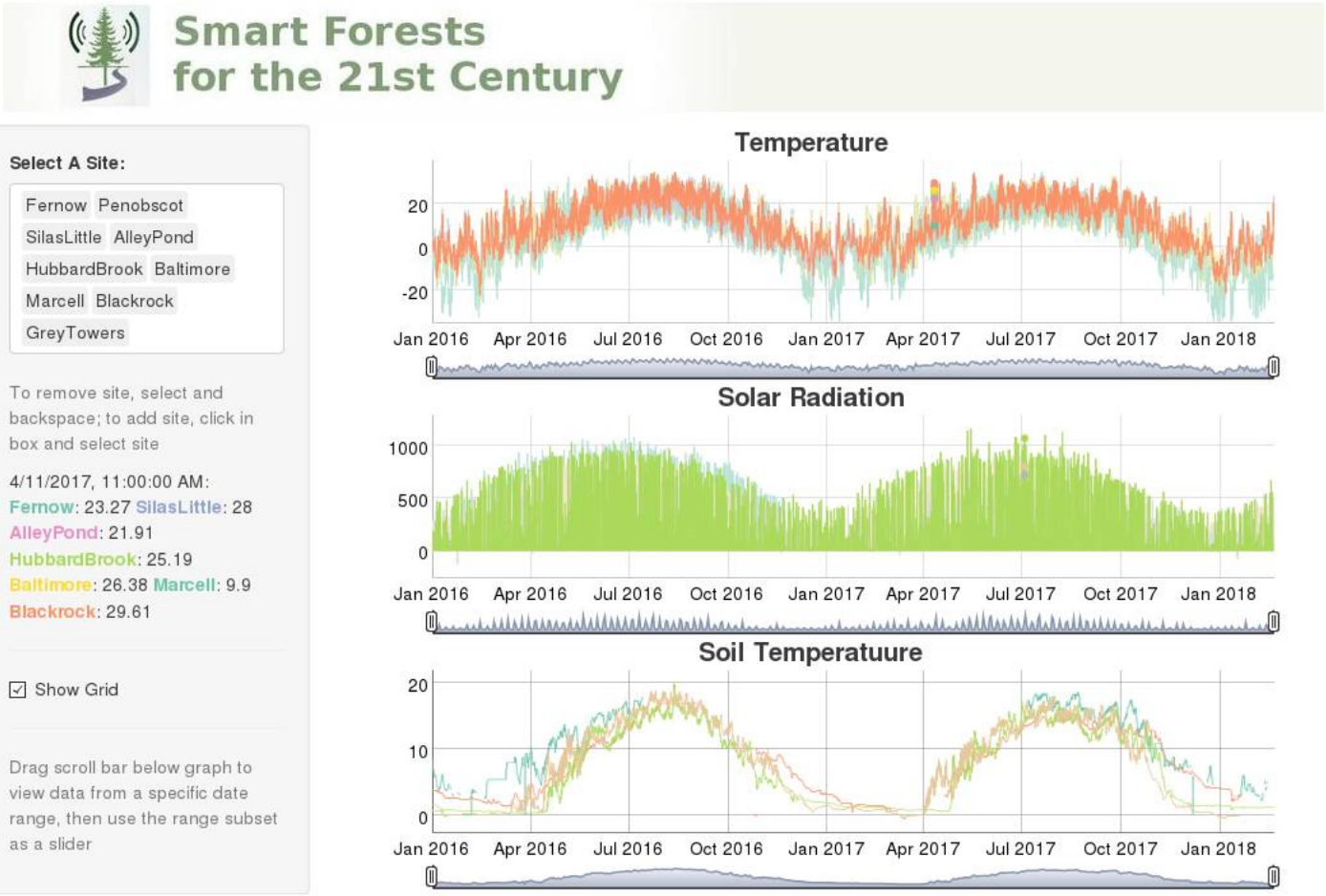
Visualization and Outreach Tools: Our ongoing efforts on the Waterviz project (funded in part by this grant) has generated considerable interest in the public and educational community, and provided the basis for a funded NSF EAGER grant on ”The Confluence of Art, Music and Science at Long Term Ecological Research Sites”. In addition, we have worked extensively with Global Lake Ecological Observatory Network (GLEON) from Lake Sunapee, NH as a pilot site (www.lakesunapee.org; www.gleon.org) and with the development of LakeObserver and its visualization tools (www.lakeobserver), and lake analyzer (rlakeanalyzer) as tests of concept for integrating lake ecosystem data with forest sensor data.

Website



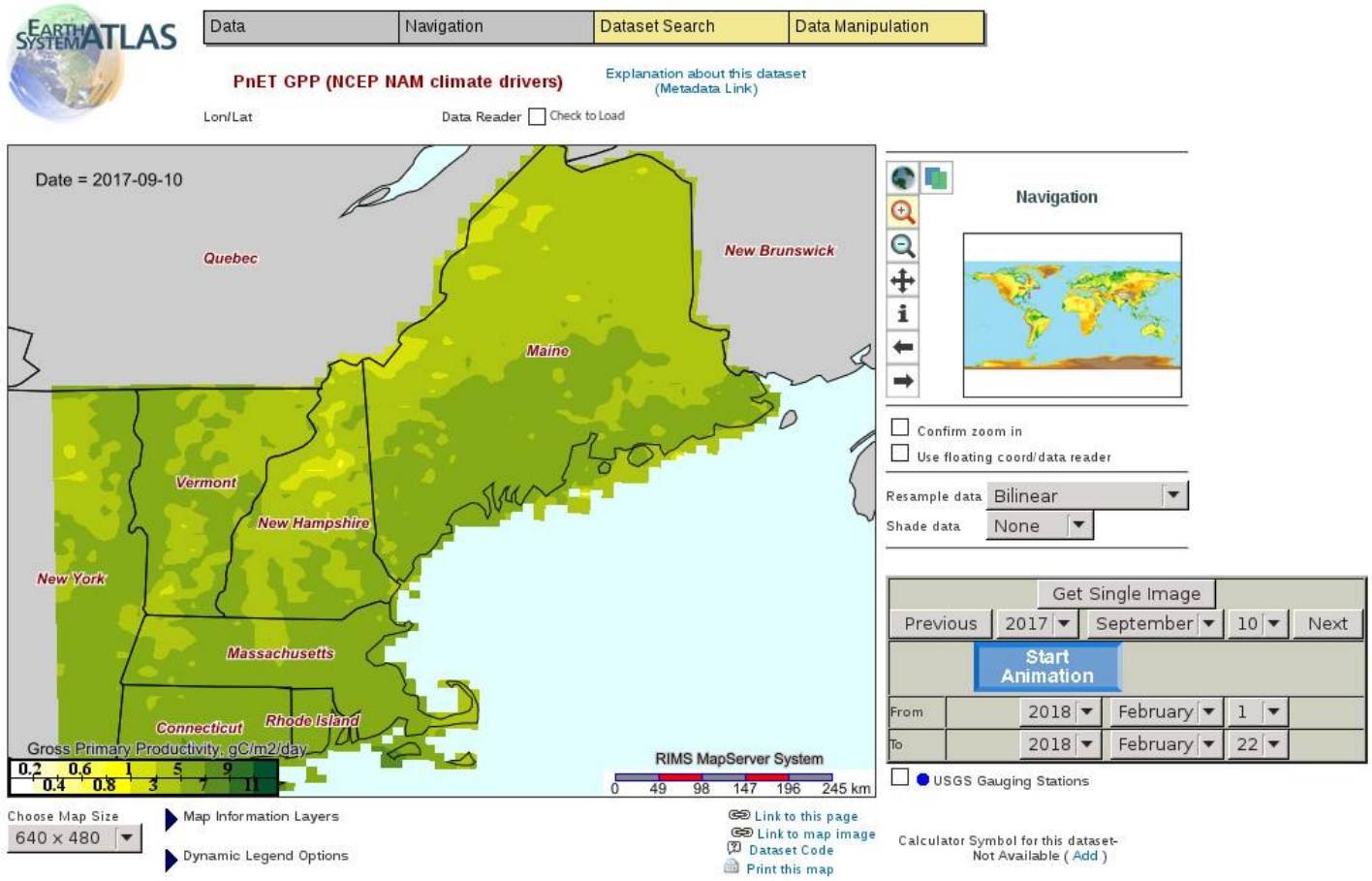
The website content developed for this project has been integrated into the overarching Smart Forests website. By combining these two communities of environmental sensor users, we are able to serve more data through a single data portal, eliminate redundancy between sites, and combine our efforts with a larger network with a longer funding timeline https://smartforests.org

Data Portal



A data portal has been developed to serve both the original Smart Forests (with USDA Forest Service focus), and the sites identified in this grant. Using the R Shiny package, we are able to view data across multiple sites, providing a user interface that allows custom views of multiple sites/variables/timespans. https://smartforests.org

Realtime Modeling of Productivity



The NOAA NCEP NAM 3km forecast model output is obtained and archived daily. Of the 800 variables available, we archive ~20 variables (both hourly and daily products). This subset serves NH-EPSCOR data users, and the realtime PnET ecosystem modeling goal of this proposal. Snapshots and animations of all variables, plus PnET calculated gross primary productivity are available through http://earthatlas.sr.unh.edu

Dendrometer Test Suite

a

b

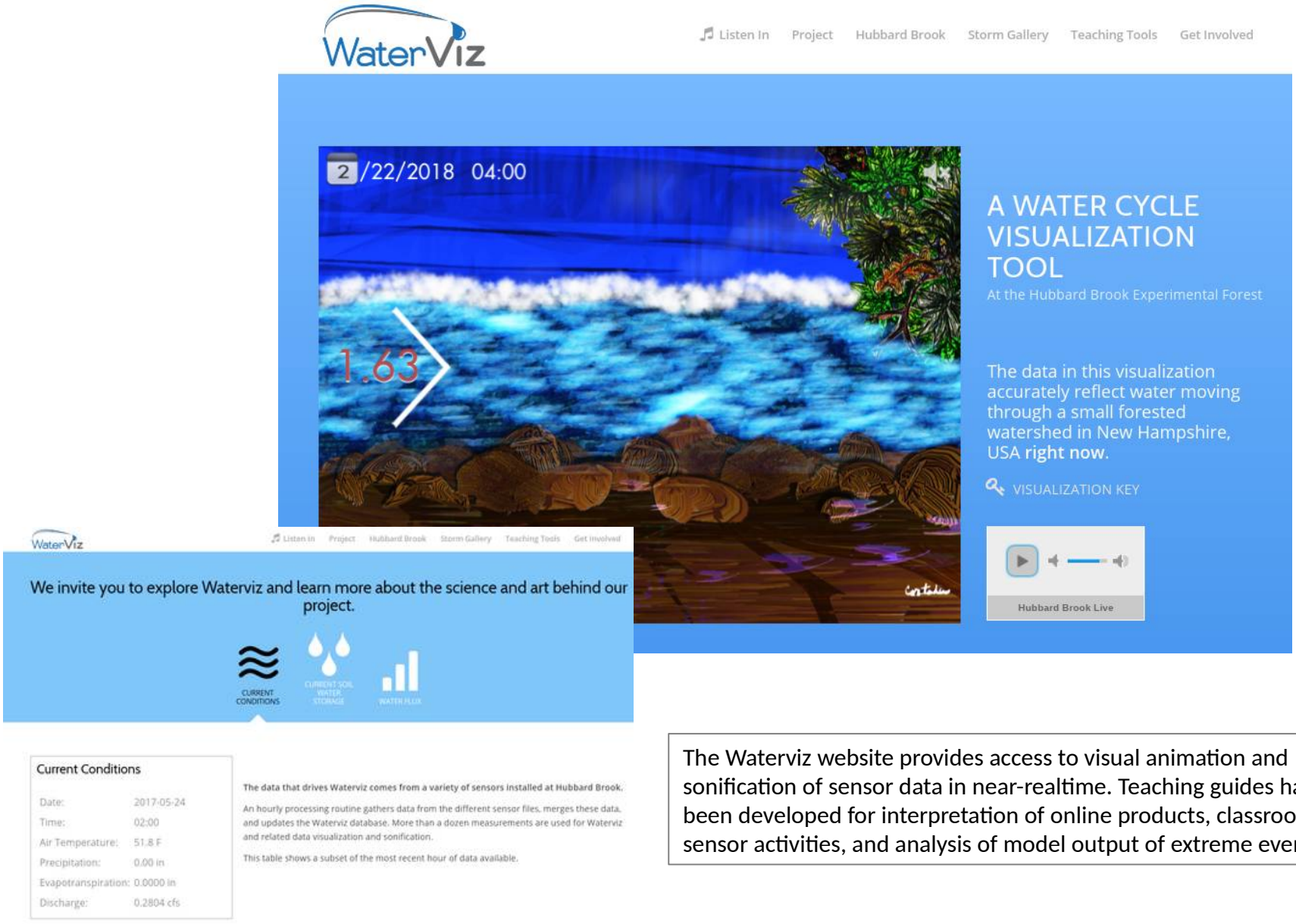
c

d

Project collaborators have developed a test suite of instrumentation to address tree growth, with an emphasis on improving temporal resolution, deployment numbers, and cost. Through coincident deployment of commercial instruments and lower cost site-developed instrumentation, these instruments are currently in the bench-test mode, and will be deployed in 2018 through funding from US Forest Service Smart Forests.

a) Blackrock Forest point dendrometer, b) Edaphic Systems point dendrometer, c) Environmental Monitoring Systems band dendrometer, d) data from instument shown in a.

Water Cycle Visualization and Sonification



The Waterviz website provides access to visual animation and sonification of sensor data in near-realtime. Teaching guides have been developed for interpretation of online products, classroom DIY sensor activities, and analysis of model output of extreme events.

Implications and applications in the Northern Forest region

This project involved a number of sensor-enabled sites within the northeast, establishing a network and website platform to aggregate resources and data into a single-point-of-entry portal. To accommodate sites with pre-exisiting sensor data streams, we used existing middelware software, combined with custom coding, to ingest, reformat, and align data into a centralized data portal. This effort continues under funding from the USDA Forest Service Smart Forests program.

We have established a goal of improving access to dendrometer data (typically read monthly, at best), by evaluating and deploying automated dendrometers (under continued funding through USDA Forest Service). Our goal with the deployment of these sensors is to further explore vegetation responses during the winter-spring transition period.

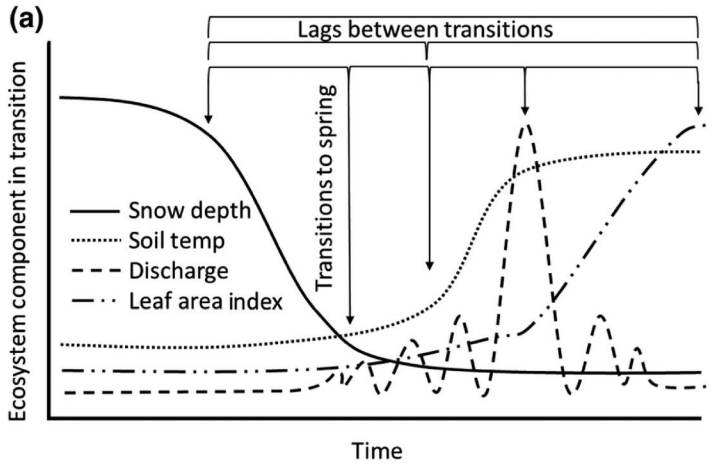
This grant has supported the development of Waterviz for Hubbard Brook: A new water cycle visualization and sonification tool: https://waterviz.org/ The Waterviz uses real time data, in this case from the Hubbard Brook Experimental Forest, to drive an online data visualization and sonification tool of the water cycle in a small headwater catchment in New England. The Waterviz has generated considerable interest in the public and educational community, and has allowed us to obtain an NSF EAGER grant on ”The Confluence of Art, Music and Science at Long Term Ecological Research Sites”.

Future directions

- The network of environmental sensor research sites established under this funding, continues now as part of the Smart Forests sensor network. Although Smart Forests sites are located throughout the US, initial funding from the Forest Service for this network has been focused on the northeastern US.

- The work of Groffman et al. (2012) and Constosta et al (2017) have set the stage and extended investigations into vernal asynchrony. The sensor network within this project is ideally poised to further investigate this phenomenon over the northeast region. With additional detail to be provided by dendrometer instrumentation, and network-wide phenology cameras, we continue to explore the ecological impacts of vernal asynchrony in more detail (funding provided by USFS Smart Forests).

- With USFS Smart Forests funding continuing beyond the extent of this NSRC grant, we will be able to maintain our website resources and continue to incorporate data into our single point of entry data portal.



Conceptual diagram of ecological changes during the 'vernal window' from Contosta et al. (2017).

Project collaborators displayed with USDA Forest Service Smart Forests sites, and full network of Experimental Forests.

Groffman et al. 2012. “Long-Term Integrated Studies Show Complex And Surprising Effects Of Climate Change In The Northern Hardwood Forest”. BioScience 62(12): 1056 - 1066. http://www.bioone.org/doi/abs/10.1525/bio.2012.62.12.7.

Contosta et al. (2017), A longer vernal window: the role of winter coldness and snowpack in driving spring transitions and lags. Glob Change Biol, 23: 1610–1625. doi:10.1111/gcb.13517

List of Products

Presentations:

Rustad, L.E. and NESN Team, "Development of Real-Time Environmental Sensor Technology and Applications for the Northeast: A Proposal from the NERC Northeastern Environmental Sensor Working Group (NESN)", NERC BiAnnual Meetings, Saratoga Springs, March 20, 2013.

Rustad, L.E., "Waterviz for Hubbard Brook: A New Water Cycle Visualization Tool", New Hampshire Water Conference, Plymouth, NH, March 21, 2014.

Campbell. J.L., **Rustad**, L.E., Adams, M.B., Brissette, J.C., Hollinger, D.Y., Kabrick, J.M., Kolka, R.K., **Martin**, M.E., Schuler, T.M., and Sebestyen, S.D. "Environmental sensor applications at experimental forests: The Smart Forest Network", Ecological Society of America Annual Meeting, Sacramento, CA, August 12, 2014.

Rustad, L.E., Campbell. J.L., Adams, M.B., Brissette, J.C., Hollinger, D.Y., Kabrick, J.M., Kolka, R.K., **Martin,** M.E., Schuler, T.M., and Sebestyen, S.D. "Environmental sensor applications at experimental forests: The Smart Forest Network", Soil Science Society of America Annual Meetings, Long Beach, CA , November 2, 2014.

Rustad, L.E. "Linking Science, Art, and Music to Communicate to Communicate Conservation", Duke University, November 14, 2014.

Ewing, H.A., K.C. **Weathers**, K.Chiu, B.B. Chrobot, J.D. Mihalko, and M.A. Borre. 2015. Lake Observer: A mobile app for crowdsourcing lake- and water-related data across the globe. 58th Annual Conference on Great Lakes Research, Burlington, VT., 25-29 May 2015.

Weathers, K.C., H.A. Ewing, J. Klug, and M.A. Borre. 2015. . Embracing the role of citizen science in the Global Lake Ecological Observatory Network. 58th Annual Conference on Great Lakes Research, Burlington, VT., 25-29 May 2015.

Rustad, L.E. "The Waterviz for Hubbard Brook: A New Water Cycle Visualization Tool." Hubbard Brook Summer Research Experience for Undergraduates (REU) program, Hubbard Brook, NH, August 5, 2015.

Rustad, L.E. "The Waterviz". Mount Washington Observatory Summer Science Series, North Conway, NH, August 19, 2015.

Campbell. J.L., **Rustad**, L.E., Adams, M.B., Brissette, J.C., Hollinger, D.Y., Kabrick, J.M., Kolka, R.K., **Martin**, M.E., Schuler, T.M., and Sebestyen, S.D. "Environmental sensor applications at experimental forests: The Smart Forest Network", NSF LTER All Scientists Meeting, Estes Park, CO, September 2, 2015

Rustad, L.E. "The Waterviz: A New Way to Envision Wild Water from the Hubbard Brook Experimental Forest, New Hampshire." Festival of the Wild Water, Vallejo, CA, October 17, 2015. **Keynote Speaker**

Rustad, L.E, X. Cortada, M.Quinn, and M. **Martin**, "Waterviz for Hubbard Brook: A New Water Cycle Visualization and Sonification Tool." EPSCoR National Meeting, Portsmouth, NH, November 2, 2015.

Rustad, L.E. and the Waterviz Team. "The Confluence of Art, Music and Science at Long Term Ecological Research Sites." Hubbard Brook Experimental Forest Annual Cooperators Meeting, HBEF, NH, July 11-15, 2016.

Rustad, L.E. and Waterviz Team, "The Waterviz: The Confluence of Art, Music and Science at Long Term Ecological Research Sites." Soil Science Society of America Annual Meetings, Session on "The Beauty of Soils," Minneapolis, MN, November 16, 2016.

Rustad, L.E., X. Cortada, M. Quinn, and M. **Martin**, "Waterviz for Hubbard Brook: A New Water Cycle Visualization and Sonification Tool", Ecological Society of America, Portland, OR, August 7-11, 2017. [Published Abstract]

Rustad, L.E., M. **Martin**, S. Garlick. "The Waterviz for Hubbard Brook: What's Next?" 54th Annual Hubbard Brook Cooperators Meeting, Woodstock, NH, July 12-13, 2017.

Rustad, Lindsey, Xavier Cortada, Marty Quinn, and Mary **Martin**, "Waterviz for Hubbard Brook: A New Water Cycle Visualization and Sonification Tool", Invited talk at Ecological Society of America Annual Meetings, August 8, 2017, Portland, Oregon.

Rustad, L.E., M. **Martin**, X. Cortada, S. Garlick, M. Casey, M.B. Green. "The Waterviz: The Confluence of Science, Art and Music Illuminates Pattern and Process in Water Cycle Data." American Geophysical Union Annual Meetings, New Orleans, LA, December 11-15, 2017

Outreach:

Waterviz for Teachers. Hubbard Brook Experimental Forest, Woodstock, NH, January 5, 2017.

Publications:

Rustad, L.E. WaterViz for Hubbard Brook: A New Water Cycle Visualization and Sonification Tool. LTER Databits, Information ManagementNewletter of the LTER Network, December 2015 Online Issue https://lternet.edu/wp-content/uploads/2017/12/2014-fall-lter-databits.pdf

Rustad, L.E., X. Cortada, M. Quinn, and T. Hallett. The Waterviz for Hubbard Brook: The Confluence of Science, Art and Music at Long Term Ecological Research Sites. Chapter In: Field to Palette: Dialogues on Soil and Art in a time of Planetary Change, editors: Alexandra R. Toland, Jay S. Noller, Gerd Wessolek, Boca Raton: CRC Press 2018.

Aaron M. Ellison, Carri J. LeRoy, Kim J. Landsbergen, and Emily Bosanquet, David Buckley Borden, Paul CaraDonna, Katherine Cheney, Rob Crystal-Ornelas, Ardis DeFreece, Lissy Goralnik, Ellie Irons, Mary **Martin**, Bethann Garramon Merkle, Karri E.B. O'Connell, Clint Penick, Lindsey **Rustad**, Mark Schulze, Nickolas M. Waser, and Lynda Wysong. 2018. Art/Science Collaborations: New Explorations of Ecological , Systems, Values, and their Feedbacks. Ecological Society of America Bulletin, in press.

Contosta, A. R., Adolph, A., Burchsted, D., Burakowski, E., Green, M., Guerra, D., Albert, M., Dibb, J., **Martin**, M., McDowell, W. H., Routhier, M., Wake, C., Whitaker, R. and Wollheim, W. (2017), A longer vernal window: the role of winter coldness and snowpack in driving spring transitions and lags. Glob Change Biol, 23: 1610–1625. doi:10.1111/gcb.13517

Proposals:

NESN related work has contributed to the following research proposals:

National Science Foundation EAGER: The Confluence of Art, Music and Science at Long Term Ecological Study Sites, Lead PI: Mary Martin; CoI: Lindsey Rustad (based on Waterviz and sensor work: funded $300,000 for two years)

National Science Foundation: Research Coordination Network: ArtSciConverge: Integrating the arts and humanities with long-term ecological research. Lead PI: MaryBeth Leigh, UAF; Senior Personnel: Lindsey Rustad ($500,000 for five years)

Collaborative research: Climate change and nitrogen oligotrophication in the northern hardwood forest. Lead PI: Peter Groffman, CIES; Senior Personnel: Lindsey Rustad (not funded).

Websites:

Smart Forests website: https://smartforests.org
Waterviz website: https://waterviz.org