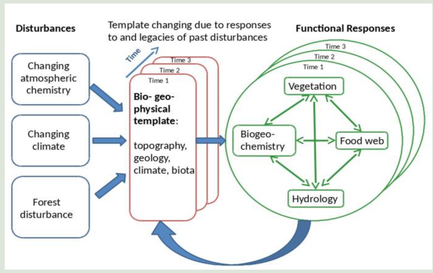
# Long-Term Ecological Research
## at the Hubbard Brook Experimental Forest

## Overview

The overall goal of the Hubbard Brook LTER program is to improve understanding of the response of structure and function of the Northern Forest ecosystem to natural and anthropogenic disturbances. Hubbard Brook serves as a central hub for basic research and ecosystem monitoring, as well as for a suite of educational, policy and outreach activities in the Northern Forest region.

We have organized our research around three types of disturbance: 1) disturbance resulting directly or indirectly from regional climatic change; 2) disturbances associated with air pollution; and 3) disturbances related to tree mortality and land use change (see 'science themes' below). Our activities include: 1) collection, management and analysis of long-term data sets; 2) small-watershed- and plot-scale manipulation experiments; 3) ecological process studies on hydrology, soil, vegetation, soil microbes and other heterotrophs; 4) cross-site surveys and experiments across the Northern Forest region; 5) development and application of ecosystem models; and 6) educational, outreach and natural resource management projects coordinated by the Hubbard Brook Research Foundation (HBRF; see 'education' and 'outreach' below).




Conceptual model of HBR LTER. The biogeophysical template of HBR is formed by inherent "state factors" (topography, parent material, climate, biota), changing through time and controlling the functional responses of hydrology, vegetation, food webs and biogeochemistry. The biogeophysical template is also influenced by disturbances, including air pollution, climate change and forest disturbance (e.g., cutting) which are the focused research themes.

## Recent Publication Highlights

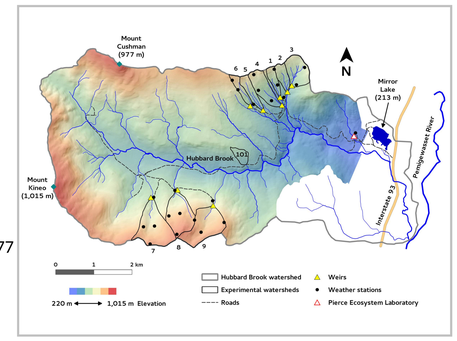
**Influence of Landscape Position and Transient Water Table on Soil Development and Carbon Distribution in a Steep, Headwater Catchment** (2014) Bailey, SW, PA Brousseau, KJ McGuire, & DS Ross. Geoderma 226-227: 279-289

**Restoring soil calcium reverses forest decline** (2014) Battles, JJ, TJ Fahey, CT Driscoll, JD Blum, & CE Johnson. Environ. Sci. Technol. Lett. 1:15-19

**U.S. power plant carbon standards and clean air co-benefits** (2015) Driscoll, CT, KF Lambert, D Burtraw, JJ Buonocore, SB Reid, & H Fakhraei. Nature Climate Change 5:535-540

**Winter climate change affects growing season soil microbial biomass and activity in northern hardwood forests** (2014) Durán, J, JL Morse, PM Groffman, JL Campbell, LM Christenson, CT Driscoll, TJ Fahey, MC Fisk, MJ Mitchell, & PH Templer. Global Change Biology 20:3568-3577

**The promise and peril of intensive-site-based ecological research: Insights from the Hubbard Brook ecosystem study** (2015) Fahey, TJ, PH Templer, BT Anderson, JJ Battles, JL Campbell, CT Driscoll, AJ Fusco, MB Green, KAS Kassam, NL Rodenhouse, L. Rustad, PG Schaberg, & MA Vadeboncoeur. Ecology 96(4):885-901




**Decreased water flowing from a forest amended with calcium silicate (2013)** Green, MB, AS Bailey, SW Bailey, JJ Battles, JL Campbell, CT Driscoll, C Eagar, L Lepine, GE Likens, SV Ollinger, & PG Schaberg. PNAS 110(15):5999-6003

**From missing source to missing sink: Long-term nitrogen dynamics of the northern hardwood forest** (2013) Yanai, RD, MA Vadeboncoeur, S Hamburg, MA Arthur, C Fuss, PM Groffman, TG Siccama, & CT Driscoll. Environ. Sci. Technol. 47:11440-11448

## Science Themes

### Forest Disturbance

Although Northern Forest ecosystems in the past were subjected to a variety of natural disturbances, we have observed recently, and can anticipate in the future, an unprecedented combination of disturbances including intensified forest harvest, exotic pests and diseases, and climatic phenomena (see photos right). These multiple and compounding disturbances challenge traditional concepts of forest ecosystem development and demand a more encompassing model that incorporates their spatial and temporal components.

While continuing to monitor key ecosystem features, we have initiated a forest fertilization experiment, regional surveys, plot experiments, development of global circulation model algorithm and model applications of ice storm disturbance (see photos right); and are using remote sensing and modeling to scale up our local investigations to the Northern Forest region.

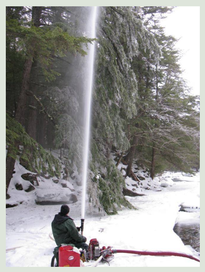
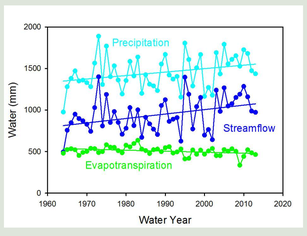
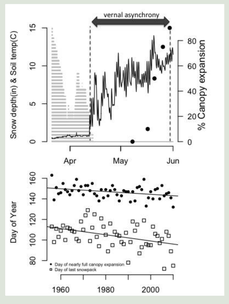




Photo of a blowdown event (June 2012; above). Plans are underway for an ice storm experiment during winter 2016. Photos are from a pilot experiment of the ice storm treatment (right).




Time series plot of annual water balance of an experimental watershed (left). Shown are long-term increases in precipitation and decreases in evapotranspiration resulting in increases in stream discharge. Also shown (right) is the "vernal asynchrony" - the spring period between loss of snowpack and canopy closure, which is characterized by a marked increase in soil temperature. Long term measurements show that the vernal asynchrony is increasing over time.

### Changing Climate

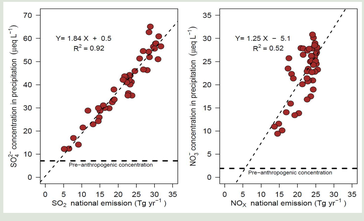
The Hubbard Brook (HBR) ecosystem is positioned between the broadleaf deciduous and evergreen needleleaf biomes, an ecotone that is sensitive to climate change. The HBR water balance has been significantly altered by large, long-term increases in annual precipitation, decreases in evapotranspiration, and declining duration of snow and lake ice cover.

In the HBR LTER we also explore: winter climate effects through snowpack manipulations and gradient studies; ecosystem responses to gradually changing climate drivers; and apply downscaled global circulation model inputs to hydrochemical simulation models to project future climate change effects.

### Air Pollution

Forest ecosystems downwind of industrialized regions are exposed to high levels of chronic air pollution. Our research includes long-term measurements of sulfur, nitrogen and mercury deposition, and their effects on ecosystem structure and function. Observations of acid rain at HBR played a role in the development of policies controlling sulfur and nitrogen oxide emissions.

Monitoring the recovery of ecosystems at HBR to ongoing and anticipated emission controls provides input on the effects of air quality management. Coordinated ecosystem monitoring, experimental manipulation involving calcium silicate addition, and modeling are being used to address hypotheses about the future response and recovery of the Northern Forest to acidic deposition and nitrogen saturation.



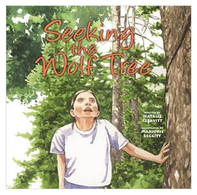

Strong relationships are evident between national emissions of sulfur dioxide and nitrogen oxides and sulfate and nitrate in bulk deposition, respectively (left). Concentrations in precipitation are decreasing and approaching pre-industrial levels. A calcium silicate (wollastonite) addition experiment was initiated in 1999 in Watershed 1 to examine the effects of replacing the available soil calcium depleted from acid deposition (right). Large increases in regeneration success and in tree growth and health of sugar maple have been observed following calcium addition. The largest responses were in the mid and high elevation zones because soils there were more depleted in calcium than in low elevation, richer sites.

## Education

### Schoolyard LTER

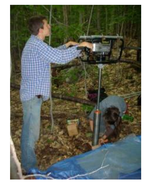
Hubbard Brook's school-yard LTER program targets middle- and high-school teachers with professional development, development of teaching resources, and school partnerships. Teacher professional development occurs through a Research Experience for Teachers (RET) program, and partnerships, including Project Learning Tree, Project WET, Project WILD, GLOBE, the USDA-Forest Service, and the New Hampshire Science Teachers' Association. Teaching resources focus on utilizing the long-term datasets from the site to support the teaching of science process skills.

In 2015, Hubbard Brook joins the LTER Schoolyard Book Series with the publication of *Seeking the Wolf Tree*.




### Research Experience for Undergraduates (REU)

Hubbard Brook hosts 8-10 REU students each summer through a program entitled "Investigating and Communicating Change in Ecosystems." The REU program emphasizes the *societal relevance of research on ecology and the changing environment* through research overseen by teams of scientist-mentors and science communication activities overseen by outreach mentors.

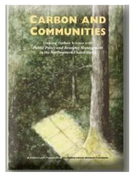


Students choose from projects distributed among four research themes (animal ecology, biogeochemistry, hydrology and soils, and forest vegetation and carbon cycling) that are representative of, and integrated within, the ecosystem science of the Hubbard Brook LTER site. Each student also participates in a weekly science communication workshop that emphasizes the interface between ecological research and the broader society through the use of case studies, interactions with professionals working with NGOs, management agencies and educational institutions, and writing and speaking activities designed to emphasize the skills necessary for communicating to broad audiences. The program is run jointly by Plymouth State University and the Hubbard Brook Research Foundation.

## Outreach and Engagement

### Science Links

Together with experts from other institutions, LTER scientists translate scientific information from Hubbard Brook and related research for policymakers at regional and national levels. The most recent project, *Carbon and Communities*, analyzed carbon budgets and mitigation strategies on a county scale for 9 counties in the Northeast representing a spectrum of land-uses (Raciti et al. 2012). This work included colleagues from the BES, HFR and PIE LTER sites. The next Science Links projects, on migratory birds and winter climate change, are under development.




### Science Policy Exchange

In 2012, the Hubbard Brook Research Foundation helped launch the Science Policy Exchange (SPE), a collaborative of six research institutions and four LTER sites dedicated to increasing the influence of science on environmental policy, conservation, and natural resource management. A current project, entitled *Co-benefits of Carbon Standards*, quantifies and communicates the environmental and human health benefits of reducing carbon emissions from power plants. Recent progress includes two public reports in 2014, a journal article (Driscoll et al. 2015), targeted outreach to federal and state policy makers, and broad media coverage, including the *New York Times*, *Washington Post and NPR*. Additional SPE work focuses on 1) synthesizing and sharing data related to the ecological and economic impacts of forest pests and pathogens and 2) assessing "green infrastructure" designs that address stormwater runoff and water pollution, among other environmental issues (report published by SPE in 2015).

### Forest Science Dialogues: Building a model of Public Engagement with Science (PES) at a LTER site

In 2014, the Hubbard Brook Research Foundation initiated Forest Science Dialogues, a pilot project to develop and test mechanisms for dialogue-based engagement between ecosystem scientists and local citizens in the northeastern US, with a focus on the rural region surrounding HBR. Elements of this project include:

- Hubbard Brook Roundtables; Facilitated dialogue sessions involving scientists and community members, decision makers, and leaders from various stakeholder groups and networks.
- A needs assessment process involving a roundtable with network and community gatekeepers and a systematic review of social science literature to identify priority topics for engagement.
- Public engagement workshops and training sessions for Hubbard Brook scientists and Hubbard Brook Research Foundation staff.
- An ongoing external evaluation led by RMC Research Corp.

The goals of the project are: 1) To open new channels of two-way communication and new opportunities for interaction and collaboration among scientists and public audiences; 2) To develop and test mechanisms of Public Engagement with Science (PES) in the context of site-based ecosystem research; 3) To build the capacity of members of the Hubbard Brook Ecosystem Study to listen to and engage with local citizens.

## Acknowledgments

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