Annual Report for Period: 02/2011 - 01/2012
Submitted on: 12/07/2011
Principal Investigator: Fahey, Timothy J.
Award ID: 1114804
Organization: Cornell University
Submitted By:
Fahey, Timothy - Principal Investigator
Title:
Long-Term Ecological Research at the Hubbard Brook Experimental Forest

Project Participants

Senior Personnel

Name: Fahey, Timothy
Worked for more than 160 Hours: Yes
Contribution to Project:
As a PI, I provide overall project management and coordination. I also conduct research on forest productivity and nutrient cycling.

Name: Driscoll, Charles
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Yanai, Ruth
Worked for more than 160 Hours: Yes
Contribution to Project:
Ruth coordinates the MELNHE project (Multiple Element Limitation in Northern Hardwood Ecosystems). This year, we began applications of N, P, and Ca in stands of different ages at Hubbard Brook, Jeffers Brook, and Bartlett Experimental Forests. Ruth is also working with Mark Green, John Campbell, and others on Quantifying Uncertainty in Ecosystem Studies (QUEST).

Name: Green, Mark
Worked for more than 160 Hours: Yes
Contribution to Project:
Mark Green is an Assistant Professor, Plymouth State University.
Mark was the lead scientist on the ROA supplement project. He decided on observation methods and coordinated the graduate students who deployed sensors on the forest plots. Also collaborated with Ruth on her project addressing multi-element nutrient limitation of northern hardwoods. An NSF ROA supplement to her grant has allowed our team add soil moisture monitoring and to purchase wollastonite.

Name: Pruyn, Michelle
Worked for more than 160 Hours: No
Contribution to Project:
Michele Pruyn is an Assistant Professor, Plymouth State University.
Michele is a sapflow expert, and thus advised Jordan on the sapflow deployment.

Name: Groffman, Peter
Worked for more than 160 Hours: Yes
Contribution to Project:
As a co-principal investigator, Peter was responsible for lnog-term measurements of microbial biomass and activity and with ancillary funding, led work on winter climate change and nitrogen gas fluxes.

Name: McGuire, Kevin
Worked for more than 160 Hours: Yes
Contribution to Project:
Kevin manages subaward, and he is primary advisor to M.S. student on project.

Name: Bailey, Scott

Worked for more than 160 Hours: Yes

Contribution to Project:

As Co-PI, Scott is responsible for field coordination.

Name: Likens, Gene

Worked for more than 160 Hours: Yes

Contribution to Project:

Overall project supervision, ecosystem and biogeochemical research on precipitation, forest and stream ecosystems of the Hubbard Brook Valley.

Name: Mitchell, Myron

Worked for more than 160 Hours: Yes

Contribution to Project:

Major focus is on the evaluation of the sulfur budgets of the watersheds at Hubbard Brook. The approaches include the use of archived samples for examining long-term changes in the sulfur and oxygen isotopic values of both precipitation and stream water. Recent work has also analyzed the interactions between climatic factors (especially as affecting stream discharge) and atmospheric deposition in affecting stream responses for both sulfate concentrations and flux.

Name: Ratliff, Tera

Worked for more than 160 Hours: Yes

Contribution to Project:

Tera Ratliff is a graduate student at Miami University studying nutrient limitation of microbial activity.

Name: Fisk, Melany

Worked for more than 160 Hours: Yes

Contribution to Project:

Melany Fisk's research focuses on nutrient cycling and soil organisms. She is involved in studies of winter climate and snowpack controls of carbon and nitrogen processing, and of plant-microbe processes that mediate interactions among different nutrients (calcium, nitrogen, phosphorus).

Name: Johnson, Chris

Worked for more than 160 Hours: Yes

Contribution to Project:

Supervised research on soil biogeochemistry and trace metals.

Name: Rodenhouse, Nicholas

Worked for more than 160 Hours: Yes

Contribution to Project:

Coordinated collection of valley-wide, long-term data on heterotroph populations, including bird distribution and abundance, moose herbivory in relation to vegetation and bird populations, and arthropod populations across the climate gradient.

Name: Battles, John

Worked for more than 160 Hours: Yes

Contribution to Project:

John is a professor of forest ecology at UC Berkeley and a senior scientist in charge of the tree population and vegetation dynamics component at Hubbard Brook LTER.

Post-doc

Graduate Student

Name: Bae, Kikang

Worked for more than 160 Hours: Yes

Contribution to Project:

Kikang is a PhD student in the Department of Forest and Natural Resources at ESF. She has been investigating soil respiration at Hubbard Brook, Jeffers Brook, and Bartlett, as part of the N & P manipulation study.

Name: Christ, Jordan

Worked for more than 160 Hours: Yes

Contribution to Project:

Jordan Christ is an M.S. Student, Plymouth State University.
Jordan was the team sapflow technician, responsible for building sensors and deploying the sapflow equipment (Campbell data loggers, multiplexors, batteries, and solar panels). He deployed the sensors on the forest plots in June and removed them in October.

Name: Molloy, Joseph

Worked for more than 160 Hours: Yes

Contribution to Project:

Joseph Molloy is an M.S. Student, Plymouth State University.
Joe was responsible for installing soil moisture probes on the plots and helping organize the application of wollastonite (CaSiO3) on the treatment plots.

Name: Gillin, Cody

Worked for more than 160 Hours: Yes

Contribution to Project:

Cody is an M.S. student at Virginia Tech developing a predictive model of hydropedological unit spatial variation.

Name: Kang, Phil-Goo

Worked for more than 160 Hours: Yes

Contribution to Project:

As part of his Ph.D. research, Phil-Goo is analyzing the DOM (dissolved organ matter) dynamics of selected watersheds at the HBEF. His work is characterizing the lability of various DOM fractions including DOC (Dissolved organic carbon), DON (Dissolved organic nitrogen) and DOS (Dissolved organic sulfur. He is also evaluating the stoichiometric relationships among C, N and S solutes.

Name: Goswami, Shinjini

Worked for more than 160 Hours: Yes

Contribution to Project:

Shinjini Goswami is a graduate student at Miami University studying nitrogen and phosphorus limitation in forests.

Name: Auwae, Russell

Worked for more than 160 Hours: Yes

Contribution to Project:

Russell Auwae is a graduate student at Miami University studying snowpack effects on microbial processes.

Name: Neugarten, Rachel

Worked for more than 160 Hours: Yes

Contribution to Project:

Rachel was hired as a field technician through Tim Fahey (Cornell). She mapped and cored trees in the demography plots, resurveyed vegetation in Watersheds 1, and surveyed the 'Birdlines' tagged tree inventory. She also helped with the valley-wide moose density survey and data entry/quality control.

Name: Solmonoff van Doorn, Natalie

Worked for more than 160 Hours: Yes

Contribution to Project:

Natalie is a PhD student advised by John Battles at UC Berkeley. She completed her PhD data collection (mapping and coring) quantifying neighborhood tree dynamics in Hubbard Brook Valley and helped survey beech saplings for frost damage.

Name: Fashu-Kanu, Samuel

Worked for more than 160 Hours: Yes

Contribution to Project:

Samuel Fashu-Kanu is a Ph.D student with Driscoll in Dept. of Civil Engineering at Syracuse University. He is evaluating soil solution response to soil freezing events.

Name: Pourmokhtarian, Afshin

Worked for more than 160 Hours: Yes

Contribution to Project:

Afshin Pourmokhtarian is a Ph.D. student with Charles Driscoll in the Department of Civil and Environmental Engineering at Syracuse University. He is working on climate change effects on soil and stream chemistry.

Name: Werner, Samuel

Worked for more than 160 Hours: Yes

Contribution to Project:

Samuel Werner is a M.S. student with Charles Driscoll in the Department of Civil and Environmental Engineering at Syracuse University. He is working on soil-stream atmosphere dynamics.

Undergraduate Student

Name: Mikolaj, Zack

Worked for more than 160 Hours: Yes

Contribution to Project:

Zack Mikolaj was an undergraduate at Miami University studying soil phosphorus and microbial communities.

Name: Geyser, Zach

Worked for more than 160 Hours: Yes

Contribution to Project:

Zach Geyser was an undergraduate at Miami University studying litter decomposition.

Name: Reidy, Matt

Worked for more than 160 Hours: Yes

Contribution to Project:

Matt Reidy was an undergraduate at Miami University studying fungal decomposer communities in leaf litter.

Name: Hebert, Simon

Worked for more than 160 Hours: Yes

Contribution to Project:

Carried out field sampling at Hubbard Brook and in the White Mountain National Forest.

Name: Adams, Julia

Worked for more than 160 Hours: Yes

Contribution to Project:

Sorted litter samples to identify and count seeds of mast-bearing trees, weighed malaise trap samples; assisted with data entry and verification.

Name: Williams, Dana

Worked for more than 160 Hours: Yes

Contribution to Project:

Sorted litter samples to identify and count seeds of mast-bearing trees, weighed malaise trap samples; assisted with data entry and verification.

Name: Tate, Allen

Worked for more than 160 Hours: Yes

Contribution to Project:

Quantified moose browse and pellets, vegetation density, shrub structural characteristics, and insect abundance on the valley-wide plots.

Name: Manning, Brett

Worked for more than 160 Hours: Yes

Contribution to Project:

Assisted with arthropod field experiments, sampling and sorting.

Name: Stewart, Danielle

Worked for more than 160 Hours: Yes

Contribution to Project:

Danielle is a UC Berkeley undergraduate student who worked as field technician on the Hubbard Brook 'vegetation crew.' She mapped and cored trees in the demography plots, resurveyed vegetation in Watershed 1, and surveyed the 'Birdlines' tagged tree inventory. Other projects included an orchid survey, valley-wide moose density survey, a browsing study. In addition, she entered data into a database and performed quality control checks.

Name: Starrs, Carlin

Worked for more than 160 Hours: Yes

Contribution to Project:

Carlin is a UC Berkeley undergraduate student who worked as field technician on the Hubbard Brook 'vegetation crew.' She mapped and cored trees in the demography plots, resurveyed vegetation in Watersheds 1 and 4, and surveyed the 'Birdlines' tagged tree inventory. Other projects included an orchid survey, valley-wide moose density survey, a browsing study, and a white pine and red oak seedling transects. In addition she completed a hemlock woody adelgid survey around Mirror Lake and entered data into a database and performed quality control checks.

Name: Saul, Jack

Worked for more than 160 Hours: Yes

Contribution to Project:

Jack is a student at Williams College who worked as field technician on the Hubbard Brook 'vegetation crew.' He mapped and cored trees in the demography plots, resurveyed vegetation in Watersheds 1 and 4, and surveyed the 'Birdlines' tagged tree inventory. He also helped with the valley-wide moose density survey, orchid surveys, data entry/quality control.

Name: Plattner, Anna

Worked for more than 160 Hours: Yes

Contribution to Project:

Anna is a Cornell University undergraduate student who worked as field technician on the Hubbard Brook 'vegetation crew.' She mapped and cored trees in the demography plots, resurveyed vegetation in Watersheds 1, and surveyed the 'Birdlines' tagged tree inventory. She also helped with the valley-wide moose density survey, orchid surveys, data entry/quality control. At the end of the summer she was working on a senior thesis for Cornell, for which she looked for patterns of sugar maple seedlings in hummocks and hollows.

Name: Syversen, Michael

Worked for more than 160 Hours: Yes

Contribution to Project:

Mike is a Cornell University undergraduate student who worked as field technician on the Hubbard Brook 'vegetation crew. He mapped and cored trees in the demography plots, resurveyed vegetation in Watersheds 1 and 4, and surveyed the 'Birdlines' tagged tree inventory. He also helped with the valley-wide moose density survey, orchid surveys, data entry/quality control, and a sugar maple seedling study.

Name: Kelley, Gaylen

Worked for more than 160 Hours: Yes

Contribution to Project:

Gaylen is a University of Vermont undergraduate student who worked as field technician on the Hubbard Brook 'vegetation crew attends University of Vermont. She mapped and cored trees in the demography plots, resurveyed vegetation in Watersheds 1, and surveyed the 'Birdlines' tagged tree inventory. She also helped with the valley-wide moose density survey and data entry/quality control.

Name: Allen, Isaac

Worked for more than 160 Hours: Yes

Contribution to Project:

Worked on the dynamics of particulate organic carbon and nitrogen in soil water and streamwater.

Technician, Programmer

Name: Shepard, Katherine

Worked for more than 160 Hours: Yes

Contribution to Project:

Katherine was not funded on the LTER grant but worked on related NSF-funded projects.

Name: Buso, Donald

Worked for more than 160 Hours: Yes

Contribution to Project:

Collection of routine water samples in the field; sample analysis; and data management.

Name: Koppers, Mary

Worked for more than 160 Hours: Yes

Contribution to Project:

Mary Margaret Koppers is a technician examining soil chemistry at Syracuse University.

Name: Scull, Kathleen

Worked for more than 160 Hours: Yes

Contribution to Project:

Conducted point-counts of birds and assisted with vegetation sampling during summer 2010.

Name: Coolidge, Tracy

Worked for more than 160 Hours: Yes

Contribution to Project:

Conducted point-counts of birds and assisted with vegetation sampling during summer 2010.

Name: Brooks, Marion

Worked for more than 160 Hours: Yes

Contribution to Project:

Conducted point-counts of birds and assisted with vegetation sampling during summer 2010

Name: Larson, Debra

Worked for more than 160 Hours: Yes

Contribution to Project:

Debra worked as a field technician for John Battles (UC Berkeley). She led the mapping crew in the spruce-fir-birch demography plot. She helped core trees in the demography plots, and surveyed beech saplings for frost damage. In addition, she entered data into a database and performed quality control checks.

Name: Montesdeoca, Mario

Worked for more than 160 Hours: Yes

Contribution to Project:

Mario Montesdeoca supervises laboratory activities at Syracuse University, Department of Civil Engineering.

Name: Brinkley, Jordan

Worked for more than 160 Hours: Yes

Contribution to Project:

Sampling and analysis of soil solution and stream samples.

Name: Heinz, Alexis

Worked for more than 160 Hours: Yes

Contribution to Project:

Alexis provided field assistance in sample collection and laboratory assistance in sample processing and data management.

Name: Wood, Cynthia

Worked for more than 160 Hours: Yes

Contribution to Project:

Cindy provided field assistance in sample collection and lab assistance in sample processing and data management.

Other Participant

Research Experience for Undergraduates

Name: Burns, Margaret

Worked for more than 160 Hours: Yes

Contribution to Project:

Maggie performed a hydrological and geochemical characterization of the C horizon in soil pits placed in the hydrological reference watershed. This was part of a larger study characterizing the hillslope hydropedology in the watershed.

Years of schooling completed: Junior

Home Institution: Other than Research Site

Home Institution if Other: University of Maine

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2011

REU Funding: REU supplement

Name: Tanner, Kari

Worked for more than 160 Hours: Yes

Contribution to Project:

Kari (Christy) measured the presence and severity of beech bark disease in forests growing on soils with widely varying base cation availability. This was part of a larger project investigating the relative importance of different nutrients as forest stands age (Multiple Element Limitation).

Name: Soroka, Alex

Worked for more than 160 Hours: Yes

Contribution to Project:

Alex used water isotopes to characterize the groundwater contribution to streams in the greater Hubbard Brook Valley.

Name: Thatcher, Erik

Worked for more than 160 Hours: Yes

Contribution to Project:

Erik used a laser diffraction technique to characterize soil particle size distribution in soil pits dug as part of a larger study characterizing the hillslope hydropedology in the hydrological reference watershed.

Name: Rosen, Phoebe

Worked for more than 160 Hours: Yes

Contribution to Project:

Phoebe worked on a project assessing the nitrification and δ15N of soil horizons from soil pits dug as part of a larger study characterizing the hillslope hydropedology in the hydrological reference watershed.

Organizational Partners

Other Collaborators or Contacts

Karin Rebel, Utrecht University, Environmental Sciences, The Netherlands
Heidi Asbjornsen, Associate Professor, University of New Hampshire. Ms. Amey Bailey, USDA Forest Service
Dr. Scott Bailey, USDA Forest Service
Dr. Susana Bernal, Princeton University & Center for Advanced Studies CEAB-CSIC, Spain
Dr. John Campbell, USDA Forest Service (supervises technician on water isotope project)
Dr. Jonathan Cole, Cary Institute of Ecosystem Studies
Dr. Daniel Conley, Lund University, Sweden
Dr. Charles Driscoll, Syracuse University
Dr. Stefan Gerber, Princeton University
Dr. Mark Green, Plymouth State University

Dr. Peter Groffman, Cary Institute of Ecosystem Studies
Dr. Lars Hedin, Princeton University
Dr. Chris Johnson, Syracuse University
Dr. Sherri Johnson, Oregon State University
Dr. Kristin Judd, Eastern Michigan University
Dr. James LaBaugh, US Geological Survey, Reston, VA
Dr. David Lindenmayer, Australian National University
Dr. Winsor Lowe, University of Montana
Dr. Kevin McGuire, Virginia Commonwealth
Dr. Myron Mitchell, SUNY-ESF, Syracuse
Dr. Scott Ollinger, University of New Hampshire
Mr. Donald Rosenberry, US Geological Survey
Dr. Paul Schaberg, USDA Forest Service
Dr. Christian Torgersen, USGS, Univ. Washington-Seattle
Dr. Lars Tranvik, Uppsala University
Dr. Dana Warren, NOAA, Seattle, WA
Dr. Tom Winter, US Geological Survey (deceased)
Gretchen Miles, Arcadis
Bernhard Mayer, University of Calgary
Jeffrey Welker, University of alaska
Zhihong Xu, Griffith University, Brisbane, Australia. Collaborating on project involving use of tree rings for climate change detection.
Aimee Bailey, USFS Northern Research Station
Dr. Natalie Cleavitt, Cornell University

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

See the attached file.

Findings:

See the attached file.

Training and Development:

see attached file.

Outreach Activities:

See attacged file.

Journal Publications

Fatemi, FR; Yanai, RD; Hamburg, SP; Vadeboncoeur, MA; Arthur, MA; Briggs, RD; Levine, CR, "Allometric equations for young northern hardwoods: the importance of age-specific equations for estimating aboveground biomass", CANADIAN JOURNAL OF FOREST RESEARCH-REVUE CANADIENNE DE RECHERCHE FORESTIERE, p. 881, vol. 41, (2011). Published, 10.1139/X10-24

Lucash, M.S., R.D. Yanai, Joel D. Blum and B.B. Park., "Foliar nutrient concentrations related to soil sources across a range of sites in the northeastern USA.", Soil Sci. Soc. Am. J, p. , vol. , (2011). Accepted,

Yanai, R.D., M.A. Arthur, M. Acker, and B.B. Park., "Variation in mass and nutrient concentration of leaf litter across years and sites in New Hampshire northern hardwoods.", Can. J. For. Res., p. , vol. , (2011). in revision,

Minick, KJ; Fisk, MC; Groffman, PM, "Calcium and phosphorus interact to reduce mid-growing season net nitrogen mineralization potential in organic horizons in a northern hardwood forest", SOIL BIOLOGY & BIOCHEMISTRY, p. 271, vol. 43, (2011). Published, 10.1016/j.soilbio.2010.10.00

Brooks, P.D., P. Grogan, P.H. Templer, P.M. Groffman, M. ??quist and J. Schimel, "Carbon and nitrogen cycling in snow-covered environments", Geography Compass, p. 682, vol. 5/9, (2011). Published,

Groffman, P.M. and M.C. Fisk., "Phosphate additions have no effect on microbial biomass and activity in a northern hardwood forest.", Soil Biology and Biochemistry, p. 2441, vol. 43, (2011). Published,

Groffman, P.M. and M.C. Fisk., "Calcium constrains plant control over forest ecosystem nitrogen cycling.", Ecology, p. 2035, vol. 92, (2011). Published,

Werner, S.F., C.T. Driscoll,, P.M. Groffman and J.B. Yavitt., "Soil oxygen availability and trace gas dynamics in a northern hardwood forest.", Biogeosciences., p. , vol. , (2011). Submitted,

Mitchell, MJ, "Nitrate dynamics of forested watersheds: spatial and temporal patterns in North America, Europe and Japan", JOURNAL OF FOREST RESEARCH, p. 333, vol. 16, (2011). Published, 10.1007/s10310-011-0278-

Mitchell, MJ; Likens, GE, "Watershed Sulfur Biogeochemistry: Shift from Atmospheric Deposition Dominance to Climatic Regulation", ENVIRONMENTAL SCIENCE & TECHNOLOGY, p. 5267, vol. 45, (2011). Published, 10.1021/es200844

Mitchell, MJ; Lovett, G; Bailey, S; Beall, F; Burns, D; Buso, D; Clair, TA; Courchesne, F; Duchesne, L; Eimers, C; Fernandez, I; Houle, D; Jeffries, DS; Likens, GE; Moran, MD; Rogers, C; Schwede, D; Shanley, J; Weathers, KC; Vet, R, "Comparisons of watershed sulfur budgets in southeast Canada and northeast US: new approaches and implications", BIOGEOCHEMISTRY, p. 181, vol. 103, (2011). Published, 10.1007/s10533-010-9455-

After pilot-testing the lessons will be posted in the middle- and high-school classroom resources section of HBRF???s website (described above). These lessons are promoted at teacher training events throughout the state by HBRF staff and partner instituti, "After pilot-testing the lessons will be posted in the middle- and high-school classroom resources section of HBRF???s website (described above). These lessons are promoted at teacher training events throughout the state by HBRF staff and partner instituti", Biogeochemistry, p. , vol. , (2011). Accepted,

Butler, TJ; Vermeylen, FM; Rury, M; Likens, GE; Lee, B; Bowker, GE; McCluney, L, "Response of ozone and nitrate to stationary source NOx emission reductions in the eastern USA", ATMOSPHERIC ENVIRONMENT, p. 1084, vol. 45, (2011). Published, 10.1016/j.atmosenv.2010.11.04

Lindenmayer, DB; Likens, GE, "Effective monitoring of agriculture", JOURNAL OF ENVIRONMENTAL MONITORING, p. 1559, vol. 13, (2011). Published, 10.1039/c0em00691

Lindenmayer, DB; Likens, GE, "Adaptive monitoring: a new paradigm for long-term research and monitoring", TRENDS IN ECOLOGY & EVOLUTION, p. 482, vol. 24, (2009). Published, 10.1016/j.tree.2009.03.00

Lindenmayer, DB; Hobbs, RJ; Likens, GE; Krebs, CJ; Banks, SC, "Newly discovered landscape traps produce regime shifts in wet forests", PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA, p. 15887, vol. 108, (2011). Published, 10.1073/pnas.111024510

Judd, K. E., G. E. Likens, D. C. Buso and A. S. Bailey., "Minimal response in watershed nitrate export to severe soil frost raises questions about nutrient dynamics in the Hubbard Brook Experimental Forest.", Biogeochemistry, p. , vol. , (2011). Published, 10.1007/s10533-010-9524-4

Lindenmayer, D. B. and G. E. Likens., "Losing the culture of ecology.", Bulletin of the Ecological Society of America 92:245???246., p. 245-246, vol. 92, (2011). Published, 10.1890/0012-9623-92.3.245

Lindenmayer, D. B. and G. E. Likens., "Direct measurement versus surrogate indicator species for evaluating environmental change and biodiversity loss", Ecosystems, p. 47, vol. 14, (2011). Published, 10.1007/s10021-010-9394-6

LaBaugh, J. W., P. T. Harte, A. M. Shapiro, P. A. Hsieh, C. D. Johnson, D. J. Goode, W. W. Wood, D. C. Buso and G. E. Likens., "Physical,

chemical, and isotopic data on groundwater for Mirror Lake, West Thornton, New Hampshire, 1983 to 1997", Open-File Report, USDI U.S. Geological Survey, p. , vol. , (2011). Accepted,

Miles, G. R., M. J. Mitchell, B. Mayer, G. E. Likens and J. Welker., "Long-term analysis of Hubbard Brook stable oxygen isotope ratios of stream water and precipitation sulfate.", Biogeochemistry, p. , vol. , (2011). Accepted,

Rozzi, R., J. J. Armesto, J. R. Guti??rrez, C. B. Anderson, F. Massardo, G. E. Likens, A. Poole, K. Moses, E. Hargrove, A. Mansilla, J. Kennedy, M. F. Willson, K. Jax, C. G. Jones, , J. B. Callicott, and M.T.K. Arroyo., "Integrating ecology and environmental ethics: earth stewardship in the Southern end of the Americas.", BioScience, p. , vol. , (2011). Accepted,

Fisk, MC; Fahey, TJ; Sobieraj, JH; Staniec, AC; Crist, TO, "Rhizosphere disturbance influences fungal colonization and community development on dead fine roots", PLANT AND SOIL, p. 279, vol. 341, (2011). Published, 10.1007/s11104-010-0643-

Fuss, CB; Driscoll, CT; Johnson, CE; Petras, RJ; Fahey, TJ, "Dynamics of oxidized and reduced iron in a northern hardwood forest", BIOGEOCHEMISTRY, p. 103, vol. 104, (2011). Published, 10.1007/s10533-010-9490-

Schwenk, WS; Strong, AM, "Contrasting patterns and combined effects of moose and insect herbivory on striped maple (Acer pensylvanicum)", BASIC AND APPLIED ECOLOGY, p. 64, vol. 12, (2011). Published, 10.1016/j.baae.2010.10.00

Holmes, RT, "Avian population and community processes in forest ecosystems: Long-term research in the Hubbard Brook Experimental Forest", FOREST ECOLOGY AND MANAGEMENT, p. 20, vol. 262, (2011). Published, 10.1016/j.foreco.2010.06.02

Wyman, KE; Rodenhouse, NL; Bank, MS, "MERCURY BIOACCUMULATION, SPECIATION, AND INFLUENCE ON WEB STRUCTURE IN ORB-WEAVING SPIDERS FROM A FORESTED WATERSHED", ENVIRONMENTAL TOXICOLOGY AND CHEMISTRY, p. 1873, vol. 30, (2011). Published, 10.1002/etc.57

Stange, E.E., M.P. Ayres and J.E. Bess., "Concordant population dynamics of Lepidoptera herbivores in a forest ecosystem.", Ecography, p. 772, vol. 34, (2011). Published,

Sofaer, H. R., K. M. Langin, J. Wilson, and T. S. Sillett., "Demography of songbird populations in a rapidly changing world: the importance of long-term studies.", American Biology Teacher, p. 285, vol. 73, (2011). Published,

van Doorn, NS; Battles, JJ; Fahey, TJ; Siccama, TG; Schwarz, PA, "Links between biomass and tree demography in a northern hardwood forest: a decade of stability and change in Hubbard Brook Valley, New Hampshire", CANADIAN JOURNAL OF FOREST RESEARCH-REVUE CANADIENNE DE RECHERCHE FORESTIERE, p. 1369, vol. 41, (2011). Published, 10.1139/X11-06

Cleavitt, NL; Fahey, TJ; Battles, JJ, "Regeneration ecology of sugar maple (Acer saccharum): seedling survival in relation to nutrition, site factors, and damage by insects and pathogens", CANADIAN JOURNAL OF FOREST RESEARCH-REVUE CANADIENNE DE RECHERCHE FORESTIERE, p. 235, vol. 41, (2011). Published, 10.1139/X10-21

Campbell, JL; Driscoll, CT; Pourmokhtarian, A; Hayhoe, K, "Streamflow responses to past and projected future changes in climate at the Hubbard Brook Experimental Forest, New Hampshire, United States", WATER RESOURCES RESEARCH, p. , vol. 47, (2011). Published, 10.1029/2010WR00943

Fahey, TJ; Yavitt, JB; Sherman, RE; Groffman, PM; Fisk, MC; Maerz, JC, "Transport of Carbon and Nitrogen Between Litter and Soil Organic Matter in a Northern Hardwood Forest", ECOSYSTEMS, p. 326, vol. 14, (2011). Published, 10.1007/s10021-011-9414-

Fahey, TJ; Blum, JD, "Litter layers (O-ie) as a calcium source of sugar maple seedlings in a northern hardwood forest", CANADIAN JOURNAL OF FOREST RESEARCH-REVUE CANADIENNE DE RECHERCHE FORESTIERE, p. 898, vol. 41, (2011). Published, 10.1139/X11-02

Fatemi, F,R,, R. D. Yanai, S. P. Hamburg, M. A. Vadeboncoeur, M. A. Arthur, R. D. Briggs, and C. R. Levine, "The Influence of Stand Age on Aboveground Allometry of Northern Hardwood Tree Species.", Canadian Journal of Forest Research, p. 1, vol. 41, (2011). Published,

Raciti, S.M., T.J. Fahey, C.T. Driscoll, F.J. Carranti, D.R. Foster, P.S. Gwyther, B.R. Hall, S.P. Hamburg, J.C. Jenkins, J.P. Jenkins, C. Neill, S.V. Ollinger, B.W. Peery, E. Quigley, R.E. Sherman, R.Q. Thomas, M.A. Vadeboncoeur, D.A. Weinstein, G. Wilso, "Local Scale Carbon Budgets and Mitigation Opportunities for the Northeastern United States.", BioScience, p. , vol. , (2011). Accepted,

Vadeboncoeur, M.A., S.P. Hamburg, C.V. Cogbill and W.Y. Sugimura, "A comparison of presettlement and modern forest composition in central New Hampshire", Canadian Journal of Forest Research, p. , vol. , (2011). Accepted,

Books or Other One-time Publications

Likens, G. E. and T. J. Butler., "Acid rain.", (2011). Book, Published
Collection: Encyclopaedia Britannica.
Bibliography: http://www.britannica.com/EBchecked/topic/3761/acid-rain

Pardo LH, Driscoll CT, Goodale CL., "Introduction.", (2011). Gen. Tech. Rep., Published
Editor(s): L.H. Pardo, M.J. Robin-Abbott, C.T. Driscoll.
Collection: Assessment of Nitrogen Deposition Effects and Empirical Critical Loads of Nitrogen for Ecoregions of the United States.
Bibliography: U.S. Department of Agriculture, Forest Service, Northern Research Station, Gen. Tech. Rep. NRS-80. Newtown Square, PA, pp. 1-7.

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Editor(s): L.H. Pardo, M.J. Robin-Abbott, C.T. Driscoll.
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Bibliography: Department of Agriculture, Forest Service, Northern Research Station, Gen. Tech. Rep. NRS-80. Newtown Square, PA, pp. 229-284.

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Bibliography: XXV IUGG General Assembly: Earth on the Edge: Science for a Sustainable Planet Melbourne, Australia.

Web/Internet Site

URL(s):
http://www.hubbardbrook.org/
Description:
This site provide descriptions of the current research projects at HBR as well as Long-term research. This page is updated frequently to reflect changes in the development and scope of current research.

Other Specific Products

Product Type:
Teaching aids
Product Description:

A practice exam centered on Hubbard Brook data and designed to support the preparation of students for the New England Common Assessment Program exams have been completed at the request of Littleton High School, one of our partner schools. These exams use HBES data to support the teaching of science inquiry skills. It is currently being pilot-tested and will be posted along with the two previously completed practice exams on HBRF?s educational resources website.

Sharing Information:

These practice exams have been distributed to teachers throughout the state through workshops held at the New Hampshire Science Teachers? Association semi-annual meetings, as well as through our informal network of teachers.

Product Type:

Teaching aids

Product Description:

Five high-school science lessons focusing on Hubbard Brook research and using data generated by the study were developed by the teachers participating in our summer Research Experience for Teachers program. They are currently being pilot tested.

Sharing Information:

After pilot-testing the lessons will be posted in the middle- and high-school classroom resources section of HBRF?s website (described above). These lessons are promoted at teacher training events throughout the state by HBRF staff and partner institutions such as the New Hampshire Education and Environment Team and the New Hampshire Science Teachers? Association.

Product Type:

Internet site

Product Description:

Multiple Element Limitation in Northern Hardwood Ecosystems (MELNHE) project are studying N and P acquisition and limitation through a series of nutrient manipulations in northern hardwood forests. This project is supported by the National Science Foundation, and builds upon the Northern Hardwood Forest Calcium Cycling Project, which established our sites at Bartlett. The project is also affectionately called the Shoestring Project, for the continued effort prior to continued funding.

Sharing Information:

http://www.esf.edu/melnhe/

Product Type:

Internet site

Product Description:

Quantifying Uncertainty in Ecosystem Studies (QUEST): Ecosystem nutrient budgets often report values for pools and fluxes without any indication of uncertainty, which makes it difficult to evaluate the significance of findings or make comparisons across systems. QUEST is a research network that has evolved around the idea that uncertainty analysis should be an accepted and expected practice in the construction of ecosystem budgets.

Right now we are conducting a cross-site comparison of input-output budgets in several watersheds throughout the US.

Sharing Information:

http://www.quantifyinguncertainty.org/

Product Type:

Teaching aids

Product Description:

Migratory Bird Center's "Bridging the American's program.

Sharing Information:

This program was brought to secondary school students in Plymouth, New Hampshire by T.S. Sillett with Jackie Wilson (Hubbard Brook Research Foundation), Susan Bradfield and Mary Deinlein (SMBC).

Product Type:

web site: Bird population and community studies at HBEF

Product Description:

http://www.hubbardbrook.org/research/animals/bird/holmes-intro03.htm

Sharing Information:

Available to researchers, students, teachers via the HBR website.

Contributions

Contributions within Discipline:

Research in the Hubbard Brook LTER program seeks a better basic understanding of the discipline of ecosystem biology, especially biogeochemistry and energy flow. Our long-term measurements of a suite of large-scale experiments has contributed to refined understanding of the interactions between ecological processes and biogeochemical cycles. A suite of simulation modeling studies allows us to synthesize understanding at regional scales and in future scenarios of environmental change. Our studies of energy flow through the complex herbivore and detrital food webs integrates knowledge across sub-disciplinary lines including vegetation dynamics, microbial ecology and heterotrophy population dynamics.

Contributions to Other Disciplines:

Beyond the core disciplines of ecosystem biology and biogeochemistry, the HBR LTER Program contributes to allied research disciplines in the physical and biological sciences. Our work attracts the interest of geochemists and physical hydrologists as well as that of molecular and cell biologists. The continuity of standardized and well-documented data collection is a hallmark of the HBR LTER; this aspect of the long-term studies at our site provides an internationally recognized benchmark for many disciplines of field-oriented research.

Contributions to Human Resource Development:

The Hubbard Brook LTER Project makes an active effort to develop human resources at many stages of development, from K-12 through post-doctoral. Through our educational and research activities numerous students and technicians have advanced their capacity for addressing the environmental problems that face 21st Century society. A continuous stream of researchers has been nurtured in the HBR LTER, eventually to reach prominent positions in academic, governmental and private sector institutions. We have encouraged the participation of females and minorities in our project through recruitment at our participating Universities and throughout the world.

Contributions to Resources for Research and Education:

Building upon its tradition of contributing to public education and policy development, the Hubbard Brook LTER project has developed two principal outreach and educational programs: the Science Links and Environmental Literacy programs. Science Links is designed to communicate scientific results to policy makers and the general public in areas such as acid rain, nitrogen deposition and mercury pollution. By providing politically-neutral scientific appraisals of the state of research on these topics, Science Links performs a public service that is not easily accomplished either by government agencies or by environmental NGO's. The Environmental Literacy program is a cooperative effort with the USDA Forest Service to train K-12 teachers in northeastern states in the fundamentals of forest ecology. The Forest in Every Classroom initiative is achieving this goal through teacher training workshops and curriculum development.

Contributions Beyond Science and Engineering:

Society is confronted with difficult choices about the degree of pollution abatement that is necessary to achieve desirable outcomes in terms of environmental quality. The long-term data sets from HBR-LTER provide among the best objective information available on which to base judgments about the threats of pollution to forest health, soil and water quality, and about the effectiveness of pollution abatement efforts in reducing those threats. Temporal trends can be evaluated against the backdrop of natural variation in reference and manipulated catchments, providing both parameter values and validation data for predictive models. Cost-effective environmental protection depends upon using these models to project the benefits of particular pollution abatement strategies. Hubbard Brook is a cornerstone of such efforts.

Conference Proceedings

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Organizational Partners

Any Conference

2011 LTER AT HBR ANNUAL REPORT

Project Activities and Findings

The research project, Long-Term Ecological Research at Hubbard Brook Experimental Forest (HBR-LTER) continues to advance the overall goal of improving understanding of the response of northern forest ecosystems to natural and anthropogenic disturbances. The HBEF serves as a hub for ongoing forest ecosystem research in the northeastern region where a suite of natural and anthropogenic disturbance agents is resulting in an unprecedented pace of change in ecosystem structure and function. Through an integrated suite of long-term monitoring, experimental manipulations, simulation modeling and regionalization, and public outreach and education activities, the HBR-LTER is providing both fundamental insights about forest ecosystem dynamics and applications to help guide policy and management responses concerning human-accelerated environmental change. This Annual Report of the HBR-LTER describes recent progress towards our objective of quantifying the response of ecosystem structure and function to three classes of disturbance: air pollution and atmospheric deposition, forest pulse events and land use change, and regional climate change. In our most recent proposal to the NSF we describe our conceptualization of forest ecosystem dynamics in recognition of landscape scale patterns and processes. New studies have been initiated or are planned to improve theoretical understanding of the dependence and interconnections of ecological, hydrologic, and biogeochemical phenomena within and across various landscape scales. In the present Annual Report some of the early results from these new studies are described. We organize our Activities and Findings around nine key research activities.

1. **Long-term biogeochemical monitoring.** The routine monitoring of precipitation and stream chemistry is a cornerstore of our long-term studies of forest biogeochemistry at HBR. We continued routine, weekly collections of precipitation and stream water from gauged watersheds in the HBR. The stream collection sites in HBR are Watersheds (W) 1, 2, 3, 4, 5, 6, 9, and the main stem of the Hubbard Brook. Our routine, weekly bulk precipitation sites are located at the base of the Hubbard Brook Valley at the R.S. Pierce Ecosystem Laboratory at 252-m elevation), on the south-facing slopes at RG-11 (at W6 at 550-m elevation) and on the north-facing slopes at RG-23 (at W9 at 770 m elevation). We retained one auxiliary precipitation site at RG-1 (at W1 at 525-m elevation) to use in the rare event of contamination or loss of the primary RG-11 bulk precipitation sample. Paired RG-1 and RG-11 data showed no statistically significant differences between the chemistry at either site. The analyses routinely performed are for concentrations of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, NH_4^{+}, pH, SO_4^{2-}, NO_3^{-}, Cl^{-}, PO_4^{3-}, and for dissolved Si. We measure pH, acid-neutralizing capacity (ANC), dissolved inorganic carbon (DIC), and electrical conductivity on all samples at the R.S. Pierce Ecosystem Laboratory immediately after collection at HBR. Filtered sub-samples from selected watersheds and precipitation collection sites are sent to the laboratory for analysis of monomeric aluminum, total dissolved nitrogen (TDN), and dissolved organic carbon (DOC). Also, routine weekly samples from W3, W6, W9, the main Hubbard Brook and RG-11 continue to be collected for oxygen, hydrogen and nitrogen isotopes in cooperation with the USFS.

We continued to collect year-round, hourly water temperature data from the reference W6 stream and from Mirror lake (from a centrally-located buoy, at 0.10-m depth), using programmable micro-thermistors (Onset Computer Corp. TidBits ©). These fine-scale thermal data provide an accurate, long-term, continuous record, and confirm the precision and accuracy of our regular weekly measurements of water temperature taken at the time of sampling. Long-term temperature data from HBR have been used in a synoptic paper (Kaushal et al. 2010), and in an analysis of streamwater temperature trends and ice-cover duration at Mirror Lake (Likens 2011). In December 2010 we installed 9 additional sensors (Onset Hobo © 2-channel recording thermistors) at all 9 gauged HBR watersheds.

With few exceptions, we continue to collect stream and precipitation samples on a weekly basis. We continue to sample from W1, W6, W9, the main Hubbard Brook, and Mirror Lake West Inlet during periods of elevated flow, using automated ISCO samplers when appropriate, and hand samples when temperatures prevent the use of battery-driven pumps. These sites represent the range of hydrologic and chemical conditions across the Hubbard Brook Valley, including highly acidic, surface waters and more buffered, groundwater-fed streams.

Long-term datasets such as those described above offer invaluable information to measure the effects of global change on water resources and provide essential knowledge to develop management practices to remediate human-induced alterations of natural conditions. For example, we synthesized stream nitrate and ammonium data collected over 12 to 37 yrs in 23 forested basins of 7 USFS Experimental Forest Research sites occurring across a gradient of atmospheric deposition and climatic conditions. Basins were chosen based in the absence of anthropogenic disturbances in the last 60 yrs other than atmospheric deposition. However, some of them have been exposed to natural disturbances over the study. Results show contrasting trends among reference basins and similar responses to natural disturbances. For instance, between 1987 and 2007 stream nitrate concentration decreased in HJ Andrews (OR) and HBR, and increased in Coweeta (NC), although atmospheric deposition tended to decrease in all 3 sites and streamflow did not change significantly. On the other hand, nitrate concentrations generally increased after natural disturbances but with varying response times and magnitudes.

2. **Analysis of uncertainty in forest ecosystem studies.** Nutrient budgets for forested ecosystems have rarely included error analysis, in spite of the importance of uncertainty to interpretation and extrapolation of the results. We have made recent progress in quantifying uncertainty in biomass, soils, hydrologic inputs and outputs, and biogeochemistry at HBR. Uncertainty derives from natural spatial and temporal variation and also from knowledge uncertainty in measurement and models. For example, when estimating forest biomass, researchers commonly report sampling uncertainty but rarely propagate the uncertainty in the allometric equations used to estimate tree biomass, much less the uncertainty in the selection of which allometric equations to use. Change over time may have less uncertainty than a single measurement, if the measures are consistently biased, as by the use of inaccurate allometric equations or soil sampling techniques.

Estimating uncertainty in the nutrient contents of forest biomass is daunting because of the complexity of the calculations. In the case of the HBR budget for Watershed 6 (W6) in 1965, there were 3987 trees in the inventory, biomass equations for 5 tree species and 5 tissue types and tissue chemistry for 6 tree species and 7 tissue types. Fortunately, because both the biomass equations and the tissue chemistry are based on multiple trees, there is a clear basis for describing the uncertainty in all the equations and parameters in the calculation. This uncertainty can be propagated through thousands of calculations without challenging the capacity of modern desktop computers.

To illustrate, we used a Monte Carlo approach, in which the entire calculation of biomass is repeated many times using random sampling of values for nutrient concentrations and biomass equations defined by the statistical distribution of the sampled trees. Figure 1 shows the results of 100 such calculations applied to stand inventory from W6 in 1965. The distribution of the results can be analyzed to describe the uncertainty in the calculations: the mean is 611 kg N ha^{-1}, close to that reported by Bormann et al (1977), and the uncertainty, which has never before been estimated, shows a 95% confidence interval ranging from 562 to 670 kg N ha^{-1} (Figure 2).

Figure 1. Uncertainty in the N contents of biomass at the Hubbard Brook Experimental Forest, reflecting both uncertainty in allometric equations and in tissue N concentrations. Monte Carlo results of N in biomass in 1965 for 100 iterations.

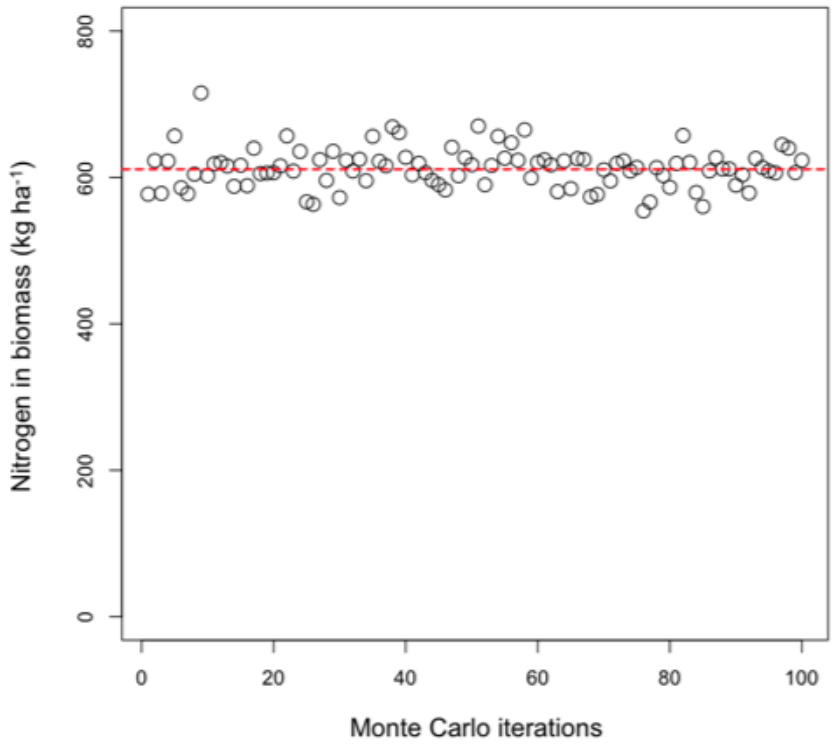
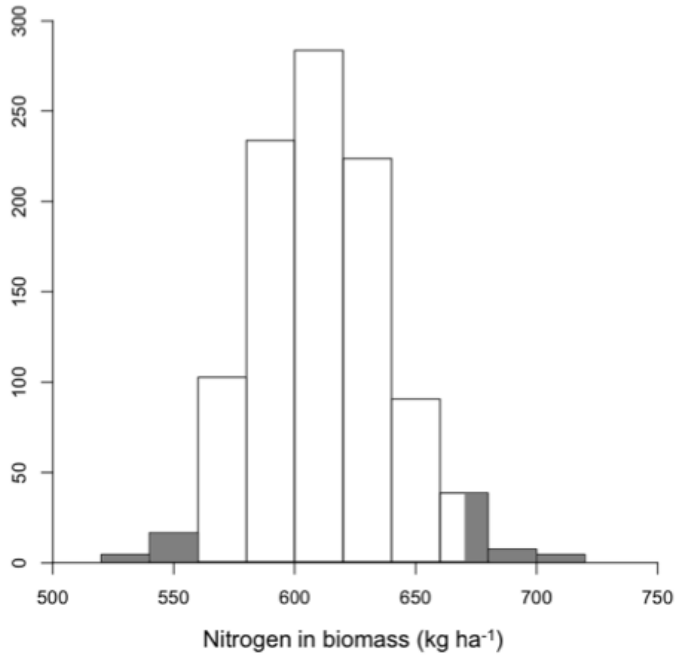


Figure 2. Frequency distribution of 1000 iterations, showing the 95% confidence interval in white.



The assignment of uncertainty to our long-term biogeochemical data is a complex and important effort. To establish the uncertainty of solute export or import requires an understanding of the error found in the solute analyses and the water fluxes. Our calculations suggest that the uncertainty in our streamwater and precipitation solute and water fluxes at HBR is additive and in the range of 5 to 10% together. Base cation exports and imports may have an uncertainty of <5%, while solutes with extremely low concentrations (e.g. ammonium and phosphorus) may be as high as 25%. During our studies, the number of solute analyses that are less than the method of detection have increased significantly. In fact, some solute fluxes have exhibited more or less uncertainty over time because of improvements in analytical methodology or because of decreases in concentration.

Long-term elemental budgets for watersheds at the HBR have provided new insight into the integration of biogeochemistry and ecology. These budgets have shown how forest disturbance from timber harvest, acid deposition, and climate disturbance (e.g. ice storms) alters the elemental dynamics of forested ecosystems. The element budgets have been analyzed, knowing that inherent uncertainties exist and their approximate magnitudes, however detailed propagation of uncertainty through the inputs, outputs, and net hydrologic flux has not been attempted. We are now attempting to analyze uncertainty in multiple element budgets at HBR to identify the major sources of uncertainty in each input-output budget and how those sources of uncertainty have changed with time. Preliminary results for nitrate in W6 show consistent uncertainty throughout the record, arising from consistent monitoring practices.

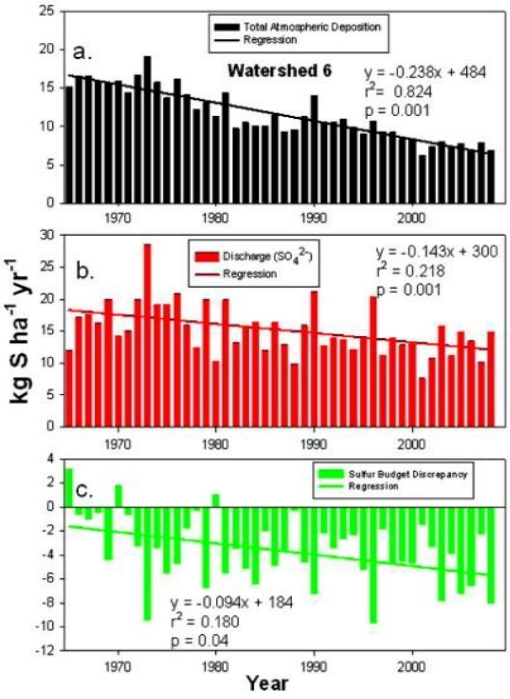
3. **Hydrogeochemical responses to global change.** Dynamic hydrochemical models are a useful tool to understand and predict the interactive effects of climate change, atmospheric CO_2, and atmospheric deposition on the hydrology and water quality of forested watersheds. We used the biogeochemical model, PnET-BGC, to evaluate the effects of potential future changes in temperature, precipitation, solar radiation and atmospheric CO_2 on pools, concentrations, and fluxes of major elements at the HBR. Future climate projections used as model input were generated specifically for the HBR with a statistical technique that downscales atmosphere-ocean general circulation model output to the temporal and spatial resolution of the observations. These climate projections indicate that over the 21st. century, average air temperature will increase at the site by 1.7 to 6.5 °C with simultaneous increases in annual average precipitation ranging from 4 to 32 cm above the long term mean (1970-2000). PnET-BGC simulations under future climate change show a shift in hydrology characterized by later snow pack development, earlier spring discharge (snowmelt), greater evapotranspiration, and a slight increase in annual water yield (associated with CO_2 effects). Model results show under elevated temperature, net soil nitrogen mineralization and nitrification markedly increase, resulting in elevated loss of NO_3^- and acidification of soil and streamwater and altering the quality of water draining from forested watersheds. Invoking a CO_2 fertilization effect mitigates the projections of elevated NO_3^- loss.

4. **Landscape patterns of soil gases.** The production and consumption of the greenhouse gases, carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), are controlled by redox reactions in soils. Together with oxygen (O_2), seasonal and spatial dynamics of these atmospheric gases can serve as robust indicators of soil redox status, respiration rates, and nitrogen cycling. We examined landscape patterns of soil oxygen and greenhouse gas dynamics in Watershed 3. We analyzed depth profiles of soil O_2, CO_2, N_2O, and CH_4 approximately bimonthly for one year. Soil gas depth profiles were obtained from several different soil types encompassing a range of topographic positions, drainage classes, and organic matter content. Soil O_2 was a good predictor of greenhouse gas concentrations. Unsaturated soils always had O_2 concentrations > 18%, while saturated soils had O_2 ranging from 0 to 18%. For unsaturated soils, changes in CO_2 were nearly stoichiometric with O_2. High concentrations of CH_4 (> 10 µL/L) were typically associated with saturated soils; CH_4 was typically below atmospheric concentrations (< 1.8 µL/L) in unsaturated soils. High concentrations of N_2O (> 5,000 nL/L) were found only in well-aerated soils after summer rainfall events and in marginally-anoxic soils; N_2O was consumed (< 200 nL/L) under anoxic conditions. The production and consumption of greenhouse gases were linked to functionally distinct biogeochemical zones of variable redox conditions (hotspots), which exhibit dynamic temporal patterns of redox fluctuations (hot moments). These soil redox hot phenomena were temporally driven by climate and spatially organized by soil type (reflective of topographic position) further constrained by subsurface hydrology.

5. **Watershed-level responses to calcium silicate treatment.** Despite decreases in acidic atmospheric deposition, many base-poor watersheds in the northeastern U.S. have remained acidic, with some exhibiting chronically low pH and acid neutralizing capacity (ANC) in surface water. Watershed 1 (W1) was experimentally treated with calcium silicate ($CaSiO_3$; wollastonite) in October 1999 to assess the role of calcium (Ca) supply in the structure and function of base-poor forest ecosystems. During the past decade wollastonite addition significantly increased the concentrations and fluxes of Ca, dissolved Si, and ANC and decreased the concentrations and fluxes of inorganic-monomeric Al (Al_i) and hydrogen ion (H^+) in both soil solution and stream water in all sub-watersheds of W1. The magnitude of changes in these concentrations and fluxes generally decreased with increasing soil depth, since most of the Ca derived from the dissolution of the added wollastonite remained in upper soil horizons during the study period. Approximately 2% of the added Ca and 7% of the added Si were exported from W1 in streamwater in the first six years after treatment. The extent of stream export of added Ca and Si was greatest in the high-elevation spruce-fir-birch sub-watershed, probably due to its shallow soil depth. Watershed-scale Ca amendment with wollastonite appears to be an effective approach to mitigating effects of acidic deposition. Not only does it appear to alleviate acidification stress to forest vegetation, but also it provides for the long-term supply of ANC to acid-impacted rivers and lakes downstream.

6. **Watershed sulfur dynamics: local and regional patterns**. Atmospheric sulfur (S) emissions peaked in 1994 followed by a dramatic decrease that resulted in marked declines in sulfate (SO_4^{2-}) concentrations in precipitation and many surface waters of eastern North America. These changes in S biogeochemistry have important implications with respect to the mobilization of toxic and nutrient cations and the acidification of watersheds. We used the continuous long-term record for Watersheds 1, 3, 5 and 6 (37 to 44 yrs from 1965 through 2008) of SO_4^{2-} concentrations and fluxes to show that the annual discrepancies in SO_4^{2-} flux in drainage waters minus total atmospheric S deposition have become significantly ($p<0.001$) more negative, indicating the increasing importance of the release of S from internal sources with time (Fig. 3). We found that watershed wetness was highly significant ($p<0.001$) and explained 57 ($n=157$) % of the annual variation for the combined results for Watersheds 1, 3, 5 and 6. We discovered that the biogeochemical control of annual SO_4^{2-} export in stream water of forested watersheds has shifted from atmospheric S deposition to climatic factors by affecting hydrologic conditions.

Figure 3. Annual calendar-year sulfur budgets for watershed 6 at the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire from 1966 through 2008. (a) Total deposition is the sum of bulk precipitation measurements as well as dry deposition estimates using CASTNET measurements as developed elsewhere.(15) (b) Annual discharge of inorganic SO42-. (c) The sulfur budget discrepancy is the difference between total deposition and discharge of inorganic SO42-. Regression lines and associated statistics are provided (*n* = 44).



In wider context, within southeastern Canada and northeastern USA, a peak in SO_4^{2-} concentration has been reported for some streams following periods of substantial catchment drying during the summer months (Ontario, Canada; VT, NH and NY). However, it is currently unclear if a SO_4^{2-} response to seasonal drying is widespread across the broader region, or to what extent the level of response varies among catchments. Sulfate response to seasonal drying was compared across 20 catchments from 11 locations across southeastern Canada (ON, QC and NS) and northeastern USA (NH, NY, VT, WV, ME). Using long-term monitoring data of stream discharge and chemistry, the number of days for each month of the dry season (#d) when discharge (Q) was below a threshold level (25th percentile; Q25) was calculated for each catchment to give a measure of 'seasonal dryness' (#d Q < Q25). A SO_4^{2-} response score (rs) was then calculated for each catchment based on linear regression analysis of #d Q < Q25 versus either the annual SO_4^{2-} concentration, or the residual of annual SO_4^{2-} concentration as a function of time (yr). The final rs values for each catchment provided an estimate of the proportion of variation in annual SO_4^{2-} concentration that could be explained by seasonal drying (possible rs range = 0 – 1). The SO_4^{2-} response scores were positively related to percent wetland area (w) (rs = 1.000 – 0.978e-0.054*w, r^2 = 0.44) and percent saturated area (sat) (rs = 0.481 – 0.488e – 0.101*sat, r^2 = 0.54) indicating that wetlands/saturated areas were an important driver of regional variation in the SO_4^{2-} response to seasonal drying. Results suggested that any shift toward drier summers as a result of climate change could impact SO_4^{2-} dynamics in a large number of catchments throughout the region.

7. **Biogeochemical interactions among calcium, nitrogen and phosphorus.** The complex interactions among three key nutrient elements remain poorly understood. Changes in availability of Ca and N owing to human activity could interact in a variety of ways with P availability to influence forest ecosystem dynamics. We are conducting experimental manipulations of these three nutrients at various temporal and spatial scales and measuring responses of soil microbes, mycorrhizae and tree growth and nutrition to these manipulations.

We established field plots and plant-free laboratory mesocosms with P and Ca additions to test the hypotheses that 1) microbial biomass and activity are limited by P in the northern hardwood forest soils at HBR; 2) elevated Ca increases inherent P availability and therefore reduces any effects of added P and 3) P effects are more marked in the more carbon (C) rich Oie compared to the Oa horizon. Treatments included P addition (50 kg P ha^{-1}), Ca addition (850 kg Ca ha^{-1}) and Ca + P addition (850 kg Ca ha^{-1} and 50 kg P ha^{-1}). The P treatments increased resin-available P levels and reduced phosphatase activity, but had no effect on microbial biomass C, microbial respiration, C metabolizing enzymes, potential net N mineralization and nitrification in the Oie or Oa horizon of either field plots or plant free mesocosms, in either the presence or absence of added Ca. Total, prokaryote, and eukaryote PLFA were reduced by P addition, possibly due to reductions in mycorrhizal fungal biomass. These results suggest that increased N deposition and acidification have not created P limitation of microbial biomass and activity in these soils.

Forest ecosystem N cycling is a critical controller of the ability of forests to prevent the movement of reactive N to receiving waters and the atmosphere and to sequester elevated levels of atmospheric carbon dioxide (CO2). We showed that Ca constrains the ability of northern hardwood forest trees to control the availability and loss of N. We evaluated soil N-cycling response to Ca additions in the presence and absence of plants and observed that when plants were present, Ca additions “tightened” the ecosystem N cycle (Fig. 4), with decreases in inorganic N levels, potential net N mineralization rates, microbial biomass N content, and denitrification potential. In the absence of plants, Ca additions induced marked increases in nitrification (the key process controlling ecosystem N losses) and inorganic N levels (Fig. 5). The observed “tightening” of the N cycle when Ca was added in the presence of plants suggests that the capacity of forests to absorb elevated levels of atmospheric N and CO2 is fundamentally constrained by base cations, which have been depleted in many areas of the globe by acid rain and forest harvesting.

Figure 4. Potential (A) net N mineralization and (B) net nitrification in field plots sampled seven times after treatments were applied over two years (October 2006 and May, July, and October of 2007 and 2008), and total net (C) N mineralization and (D) nitrification over a two-year incubation in plant-free mesocosms. Bars with different lowercase superscript letters are significantly different at P < 0.05. Data are means + SE.

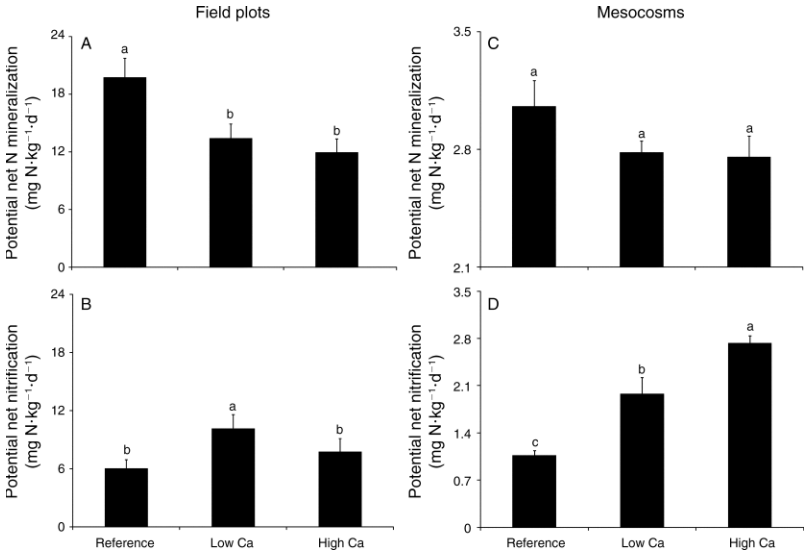
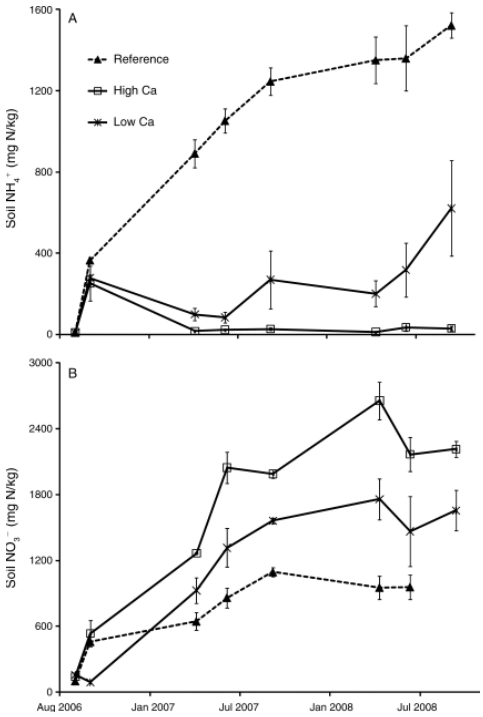
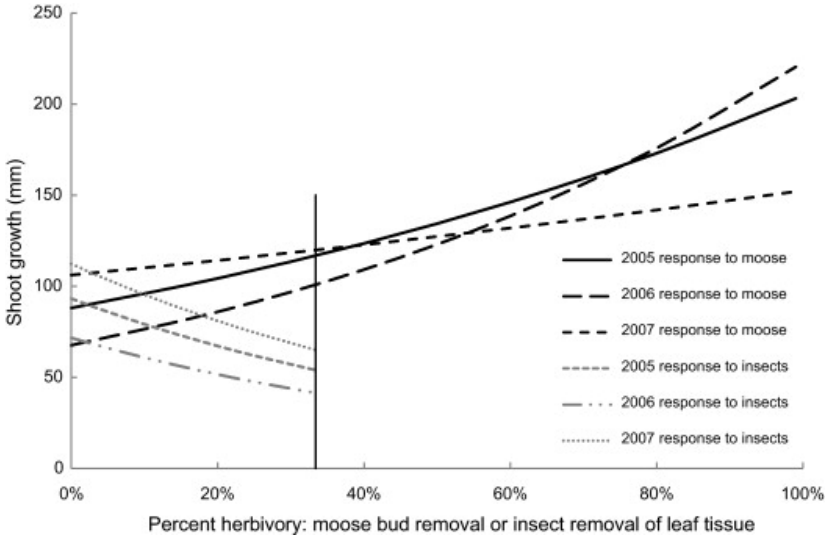


Figure 5. Soil concentration of (A) NH_4^+ and (B) NO_3^- in field plots sampled in May (pre-treatment) and October 2006 and in May, July, and October of 2007 and 2008 at the Hubbard Brook Experimental Forest, White Mountain National Forest, New Hampshire, USA. Treatments were initiated in summer 2006. There were no significant differences (P = 0.27) in soil NH_4^+ levels in field plots in May 2006, but treatment effects were significant (P < 0.001) over all subsequent sample dates, with no interaction between treatment and sample date. Post hoc analysis showed significant (P < 0.05) differences in soil NH_4^+ levels between reference, low-Ca, and high-Ca treatments in the field plots. There were no significant differences in NO_3^- levels either before or after treatments were applied. Data are means ± SE.



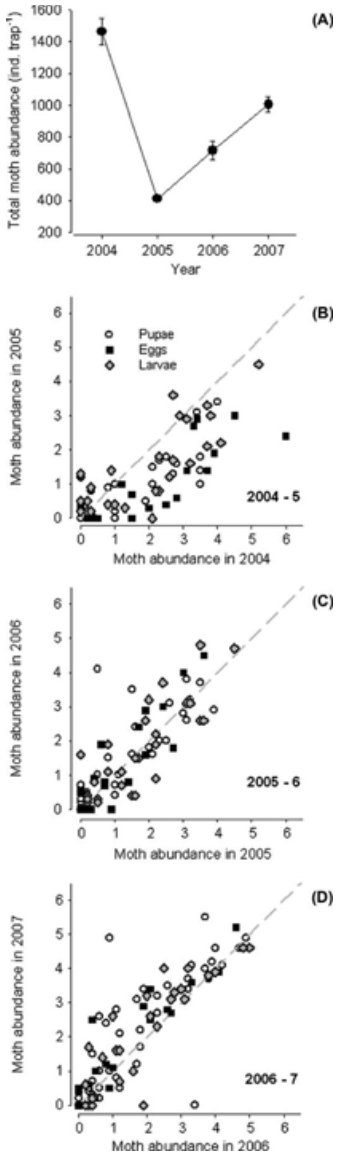
8. **Interactions among heterotrophs: arthropods, birds and moose.** Our studies of the herbivore food web in northern hardwood forest ecosystems build upon our developing conceptual model of landscape-scale patterns and processes. Our research on arthropod dynamics explores the processes that generate interannual population fluctuations in Lepidoptera that are the forest's major herbivores and a critical and dynamic part of the forest food web (Fig.6). This work addresses the paradox that Lepidoptera larvae are more abundant in northern hardwoods forest where it is cooler, despite year-to-year trends indicating that warmer weather favors population growth. Top-down (predators and parasitoids) and bottom up (beginning with nitrogen availability in the soil) factors and processes may interact to create this pattern, and these may be altered significantly by climate change. We have found that Lepidoptera larvae at Hubbard Brook routinely experience temperatures far below their thermal optima, although these optima do vary among species, such that higher temperatures increase larval growth rate. Foliar nitrogen has varied up to 1.5-fold over seventeen years of observation and shows similar variation along an elevation (climate) gradient; the pattern of increasing foliar nitrogen at higher elevations correlates with increased soil moisture and soil nutrient mobility in these cooler areas. Insect bioassays show that this observed decrease in foliar nitrogen in lower elevation leaves significantly decreases the growth rates of leaf feeding Lepidoptera, increases larval mortality, and increases the number of days required to complete the larval period. Field studies also show that attack rates on caterpillars by birds and the movement rates of parasitoids are negatively related to temperature, such that at warmer temperatures caterpillars may experience greater top-down control by predators and parasitoids. Thus, an increase in forest defoliator growth rates at higher temperatures may be offset or even outweighed by a decrease in food quality or an increase in predation by natural enemies at higher temperatures. We plan to expand arthropod sampling throughout the Hubbard Brook valley such that it can be synthesized with remote sensing data, allowing us to predict secondary productivity across the landscape.

Figure 6. Shoot growth (leader) of striped maple saplings (*n* = 135 per year) as a function of herbivory (percent removal of leaf tissue by insects and buds removed by moose). Vertical line represents the maximum insect herbivory observation during the study (33%). Moose browse curves are based on median insect herbivory (3.8%), insect herbivory curves are based on median moose browse (0%), and all curves are based on median light availability.



The effects of moose herbivory on understory vegetation and bird populations is being carried out through a spatial analysis of moose herbivory, vegetation structure, and understory bird populations at valley-wide spatial scale. The goal of this project is to quantify the contribution of moose herbivory to the maintenance of biodiversity in northeastern forests. In addition to valley-wide surveys of herbivory, understory shrub structure at Black-throated Blue Warbler (*Setophaga caerulesens*) nest sites was surveyed in 2011. We found that moose browse significantly affected shrub structure (Fig. 7) and that these structural changes affected the understory nesting substrate for birds. These effects were quantified using paired plot analyses, whereby nest sites were compared to reference (non-nest) sites.

Figure 7. Annual moth captures from six black light traps deployed at three sites in the White Mountains of New Hampshire, USA. Panel A: total moth abundance, with error bars representing SE of site means. Panels B-D: comparisons between consecutive years, with moth abundance is expressed in units of Ln(moths×trap^{-1}×yr^{-1}+1). Points represent species, with different symbols denoting differences in overwintering life stage (one example of how population dynamics within the assemblage might be structured). Points above or below the line of equality indicate population growth rates that were positive or negative, respectively.

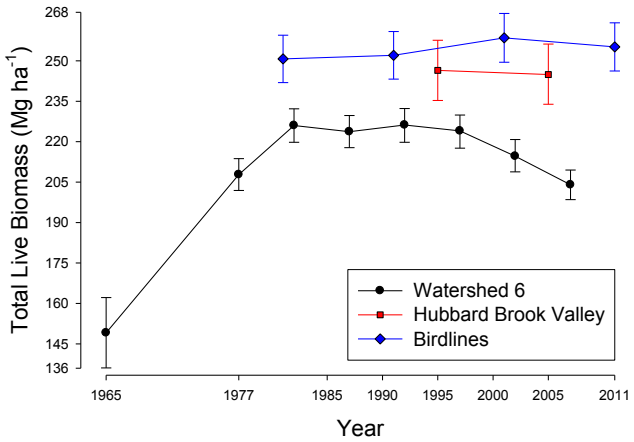


A survey of bird abundance and distribution at valley-wide scale was again carried out (for the ninth year) in 2011. We are evaluating the effects of habitat structure, elevation, climate, and presence of congeners on the distribution of Red-eyed (*Vireo olivaceus*) and Blue-headed (*Vireo solitarius*) vireos within the HBR. In 2011, we conducted playback experiments with the goal of quantifying the presence, strength and effects of the interactions between Red-eyed Vireos and Blue-headed Vireos. This study will elucidate the ecological mechanisms that shape the spatial distributions of bird species with similar ecology.

We also continued our study of trends in bird occupancy and distribution across environmental gradients using valley-wide data from the HBR. We are quantifying long-term trends and altitudinal range shifts of birds within the HBR using the occupancy modeling approach. We are also examining the assumptions of climate-envelope models. Last, exploring the potential of Lidar measurements to link forest structure and composition with bird species richness.

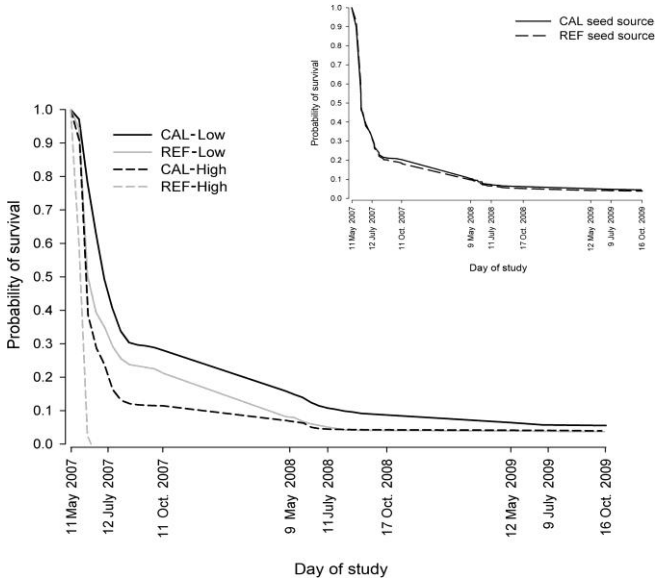
9. **Forest vegetation dynamics.** We continue to seek a better understanding of the patterns and causes of long-term changes in forest vegetation at HBR. As illustrated in Fig. 8 the biomass of the HBR forest has remained either flat or declining over the past 30 years, depending upon site and scale of observation. We are analyzing the role of particular species and demographic processes contributing to this unexpected pattern (i.e., most long-term forest surveys and models project continued biomass accumulation beyond forest age 100 yrs in northern hardwoods). Coincident declines in all three dominant hardwood species (sugar maple, yellow birch and American beech) is occurring in many landscape positions across HBR. Building upon existing experiments and permanent plot studies we are quantifying demographic processes explaining these long-term trends.

Figure 8. Trends in live tree biomass for forests in Hubbard Brook Valley.



For example, the possible regeneration failure of sugar maple (Acer saccharum Marsh.) as part of their decline has been not well explored using field studies. We sought to clarify the roles of maternal effects and dynamics of early-season survival in contributing to the previously documented pattern of larger seedlings and higher seedling densities on a Ca-treated watershed (W1) at HBR. We used a reciprocal seed planting experiment at four sites, two sites per watershed blocked by elevation. Regardless of maternity, sugar maple seedlings planted in W1 had higher survival than seedlings in the reference watershed (Fig. 9). However, this advantage was not as clearly linked to the Ca amendment as in our previous work, probably, in part, because Ca availability has decreased over time. Maternal effects on seed chemistry and some seedling traits were detected, but these were not strong determinants of survival. The strength of Ca addition effects on sugar maple regeneration from seed depends on initial soil characteristics, application amounts, and interactions of the amendment with other factors such as leaf litter accumulation, weather, and pathogens.

Figure 9. Survivorship curves for the first 3 years of life for sugar maple (*Acer saccharum*) seedlings of the 2007 cohort at four sites differing in soil Ca status and elevation. Plots within each site were reciprocally planted with seed from CAL and REF within elevation (inset). CAL and REF are abbreviations for Ca added and reference watersheds, respectively. Low and High refer to the elevation classes. At REF-High, all seedlings were dead by the fourth observation time.

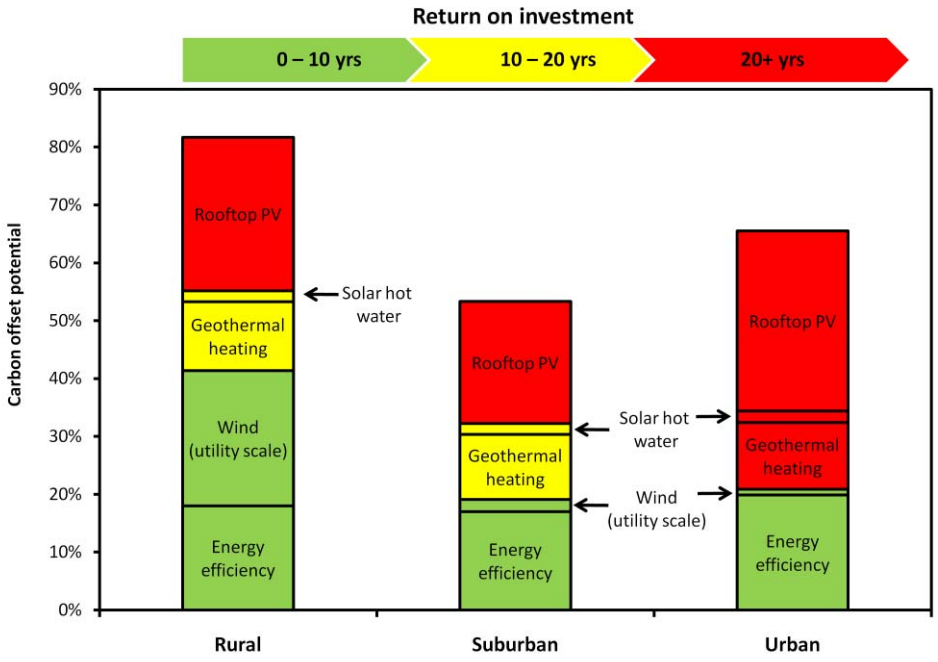


10. **<u>Integrating science and policy</u>.** We have taken a proactive approach to advancing the integration of science and policy in the HBR. Scientists, related professionals and the public have for decades called for greater interaction among scientists, policymakers and the media to address contemporary environmental challenges. Practical examples of effective “real-world” programs to catalyze interactions and provide relevant science are few. Existing successful models however can be used to develop and expand the work of integrating, synthesizing and communicating ecosystem science for environmental policy and natural resource management. We have summarized the structure and strategies used in the HBR *Science Links* program, now

in its tenth year as a successful boundary spanning organization. We detail project activities and results, and share lessons and challenges for the further advancement of *Science Links* and other efforts to bridge the science and policy divide. Further, we suggest the need for increased emphasis in boundary spanning programs as part of publicly funded research initiatives and as legitimate scholarly endeavors that support the scaled co-production of knowledge and harness scientific research to support informed policy and environmental management.

The most recent specific contribution of HBR Science Links was to provide local-scale relevant insights into the problem of mitigating C emissions. Economic and political realities present challenges for implementing an aggressive climate change abatement program in the United States. A high efficiency approach will be essential. We compared carbon budgets and evaluated carbon mitigation potential for nine counties across the northeastern United States that represent a range of biophysical, demographic and socioeconomic conditions. Most counties are net sources of CO_2 to the atmosphere, with the exception of rural forested counties where sequestration in vegetation and soils exceed emissions. Protecting forests will ensure that the region's largest CO_2 sink does not become a source of emissions. For rural counties, afforestation, sustainable fuelwood harvest for bioenergy, and utility-scale wind power could provide the largest and most cost-effective mitigation opportunities among those evaluated (Fig. 10). For urban and suburban counties, energy efficiency measures and energy saving technologies would be most cost-effective. By implementing locally tailored management and technology options large reductions in CO_2 emissions could be achieved at relatively low costs.

Figure 10. Return on investment for technological mitigation opportunities for rural (< 100/km^2), suburban, and urban counties (Baltimore City). The height of each bar indicates the mean carbon offset potential as a percentage of current emissions. The color indicates the expected payback period, with payback periods increasing from bottom to top. Note that several land-intensive mitigation strategies (including biofuels and afforestation) are not represented in this chart, but could provide substantial carbon offsets in rural counties.



Project Training and Development

The Hubbard Brook LTER project takes very seriously its responsibilities for the training and development of scientists and educators. Most of these activities are coordinated through the auspices of the Hubbard Brook Research Foundation, a non-profit, "friends" group associated with the HBR LTER. At the undergraduate level we provide a structured program of activities in the form of tours, lectures and research mentoring. The students actively participate in annual meetings of the Hubbard Brook Ecosystem Study and in regular (usually weekly) project meetings of sub-groups in the HBR-LTER. Many students undertake individualized research projects, although in the past year we suffered a funding hiatus of our LTER-REU site project. Nevertheless, we continued to offer a cohort experience for as many undergraduates as possible, using a combination of LTER, Hubbard Brook Consortium, and USDA-Forest Service funds. Five undergraduates from around the country were paired with Hubbard Brook researchers and developed and conducted independent research projects on topics representing the range of research at the Hubbard Brook LTER. These students also interacted with teachers in our RET program, graduate students, other undergraduates serving on field crews, and a spectrum of Hubbard Brook scientists at weekly Science Night dinner/talks. A renewal grant for our site program, which ran from 2008-2010, was submitted again in 2011 and would add 8 more students to the cohort.

Likewise, graduate students are provided with formal and informal opportunities for training and development. Most students present oral talks at the Annual Meetings of the HBES and a formalized evaluation is provided. Graduate students work closely with their research advisors and with senior research staff in the HBES in the development and conduct of their research. They are also provided opportunities to mentor undergraduate students and to lead tours of their research sites for visiting scientists. The success of our project in graduate student mentoring and training is clearly reflected in our strong record for placing students into academic and other research positions.

The HBR LTER project actively participates in training and development of K-12 teachers, in part with supplementary funding from NSF-RETs as well as independent programs in conjunction with HBRF and USDA Forest Service staff. In the past year K-12 teachers have participated directly in our ongoing research on heterotrophs, vegetation dynamics and forest nutrient manipulations. They have worked with our field crew and participated in project

planning meetings to gain a better understanding of the scientific research process. Our work with the K-12 audiences is organized by HBRF through the Environmental Literacy Program (ELP). ELP is a joint project of the HBRF and the USDA Forest Service Northern Research Station to use ecological knowledge to promote informed decision-making for a sustainable future. It is funded through both the USDA-Forest Service and the LTER Schoolyard program. ELP focuses on middle- and high school teachers and their students through the following three programs:

1. **Inquiry lessons and teaching guides:** A central aim of our ELP program is to provide HBES data to teachers in a format which supports their efforts at building science-process skills, as well as content knowledge, in their students. To this end we have worked with teachers and scientists to develop teaching aids that emphasize the evaluation of data as well as the thought processes that lead to the questions behind the research. These resources are supported by teacher workshops and on-going interactions with HBRF staff. Current offerings can be found at: http://hubbardbrookfoundation.org/environmental-literacy-program/

2. **Teacher training:** We continue to hold or present at teacher workshops, and are active cooperators with the New Hampshire Science Teachers' Association, with whom we hosted a full-day field trip at their semi-annual meeting. Both the field trip and subsequent workshop presentations emphasize the growing number of data-centered activities designed for classroom use, in addition to science content from the Hubbard Brook project. We also partner with the New Hampshire Education and Environment Team (NHEET) to provide teacher workshops focusing on science process skills, hosting a full-day workshop with them in March, 2011, and subsequently obtaining a state-wide Math-Science Partnership grant to continue this work. In addition, in 2011 we hosted four teachers for a summer research experience (RET), partially supported by a supplement to this LTER grant. RET teachers conducted mentored research and helped develop data-activities for our data-lessons program.

3. **School partnerships:** We are currently actively involved with six schools in the region, in addition to the schools which visit us for tours (described below). Our regional partner schools are: LinWood School (grades 6-12), Plymouth Elementary (grades 6-8), Bethlehem Elementary (4-6), Littleton High School (9-12), and Plymouth Regional High School (9-12). Together these represent the 4 school districts closest to Hubbard Brook.

The HBRF is also a member of the New Hampshire Education and Environment Team (NHEET), which is a collaboration of organizations working to support science education in the state. Additional members include the GLOBE Program, Project HOME, Project Learning Tree, Project WET at NH Department of Environmental Services, Projects WILD and Aquatic WILD at NH Fish and Game Department, and the USDA Forest Service. The focus of the group is supporting the teaching of science process skills. In 2011 we hosted a workshop utilizing Hubbard Brook's phenology record to strengthen teachers' skills in manipulating, graphing, and analyzing data. Additionally, HBRF and USDA Forest Service staff give elementary and secondary school tours of the site upon request. Six schools, in addition to our regular school partnership schools, visited Hubbard Brook in the past year.

Outreach Activities

The HBR-LTER is strongly committed to the goal of raising public understanding of science and contributing to the implementation of sound public policy based on that science. Most of our efforts in public outreach are coordinated through the HBRF (as described under Training and Development). The flagship program of our public outreach is ScienceLinks, an ongoing project funded through a variety of grants to make accessible to public policy-makers the scientific results of the HBR-LTER and other regional environmental science research. To date we have completed five major Science Links projects on topics ranging from acid rain to environmental monitoring. In each project a team of experts is convened to develop topical overviews and summaries on the topic, usually synthesizing the state of the science; a technical article is written for a broad audience journal (usually BioScience); non-technical briefing reports and summaries are prepared for distribution to policymakers and public agencies; and press releases and information sessions are conducted for the appropriate public audiences (e.g., Congressional staffers).

Our most recent Science Links project is nearing completion. Entitled, "Carbon and Communities," this project seeks to inform local institutions in northeastern United States on the carbon dioxide emission mitigation opportunities with particular focus on land-based activities. We completed a quantitative analysis of the costs and potential for CO_2 emission reductions in nine representative counties across the region, including those surrounding four NSF-LTER

sites (HBR, BES, HFR, PIE). We produced a publically-accessible outreach document for distribution to various local audiences around the region which we are accessing with the cooperation of USEPA Environmental Finance Center, Syracuse, NY. A technical summary of our findings is forthcoming in BioScience (January 2012), as described under "Activities and Findings."

We have also taken a lead role in developing a general overview article for BioScience evaluating approaches for the public outreach of scientific results from the broader NSF-LTER Network (Driscoll et al., in press).

Presentation of research findings for general and professional audiences: In addition to tours conducted at Hubbard Brook (described below), we have presented research findings to general and professional audiences throughout 2011. Organizations included: the New Hampshire Arborists Association, the New Hampshire Maple Producer's Association, the New Hampshire Science Teachers' Association, the Pakistani Educational Leadership Institute (hosted by Plymouth State University), and Hubbard Brook Research Foundation-sponsored events.

On-site tours: The HBR-LTER provides educational tours of the research site on a frequent basis throughout the academic year. Undergraduate partner schools bring at least one class per year to the site and provide the Hubbard Brook staff with syllabi and written statements describing how the site visit is incorporated into the course curriculum. These schools include: Plymouth State University, the University of New Hampshire, Colby-Sawyer College, Boston University, Cornell University, Wellesley College, and Dartmouth College. Secondary school tours are offered to our ELP partner schools (described under "Training and Development") and other schools where our teaching resources are being used in the classroom.