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Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Timothy J Fahey

Accomplishments

* What are the major goals of the 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 HBR 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, modeling and quantitative analysis, 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. In our current LTER funding cycle we focus 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.

Long-term collection of precipitation and surface water for complete chemical characterization has been maintained continuously since the 1960s. Knowledge of baseline conditions is critical for evaluating quantitatively the effect of human activities on environmental conditions, such as the impact of acid deposition. Efforts to restore ecosystems to prior, "pristine" condition require restoration targets, often based on some presumed or unknown baseline condition. Our biogeochemical monitoring program is designed to provide this baseline. Similarly, we quantify the hydrologic budget of a suite of small watersheds that allows us to detect global change effects on hydrologic fluxes with extremely high sensitivity. We also maintain a comprehensive, long-term monitoring program on forest vegetation composition, biomass, productivity and chemistry and the population trends of a suite of heterotrophic organisms, focused on passerine birds and their food web. These surveys indicate local and global phenomena shaping trends and a baseline for development of deeper theoretical understanding of ecological interactions.

Experimental manipulations on the experimental watersheds at Hubbard Brook have advanced both science and management of landscapes. Our most prominent ongoing experiments quantify ecosystem recovery from forest harvests and ecosystem responses to restoration of pristine conditions of soil base saturation. A variety of plot-scale experiments and manipulations provides additional process-based understanding of ecosystem function in northern hardwood forest ecosystems. We synthesize the work at Hubbard Brook using simulation models, model-data fusion and uncertainty analysis to improve understanding of ecosystem dynamics at various spatial and temporal scales. Our dynamic hydrochemical models are useful tools for understanding and predicting the interactive effects of climate change, atmospheric CO2, and atmospheric deposition on the hydrology and water quality of forested watersheds. Evaluation of uncertainty in ecosystem dynamics has been limited by the complexity of ecosystem data sets and processes, but new computational tools provide the means to improve this situation. A major ongoing activity in the HBR-LTER project has been to advance error analysis in biogeochemical budgets.

The HBR LTER project has an active program of outreach and education activities coordinated through the Hubbard Brook Research Foundation. Long-term research should play a crucial role in addressing grand challenges in environmental stewardship at local and national scales. The HBR LTER takes this responsibility very seriously. We attempt to inform policy decisions through our Science Links program. We also promote outreach to regional ecosystem stakeholders through the Hubbard Brook Roundtable. The project also takes very seriously its responsibilities for the training and development of scientists and educators. Most of these activities also are coordinated through the auspices of the Hubbard Brook Research Foundation.

* What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?

Major Activities:

MONITORING CLIMATE, BIOGEOCHEMISTRY AND BIOTIC COMMUNITIES: We have completed the build-out of our environmental sensor network, including digital sensors for meteorological variables streamflow in nine

experimental catchments. We are now streaming these data to a real-time display creating the potential for identifying key sampling event campaigns.

We continue to monitor long-term changes in key solutes in streamwater. This long-term record has provided the basis for evaluating the mechanisms driving N retention in forest catchments at Hubbard Brook and throughout North America. Similarly, temporal patterns in dissolved organic carbon at Hubbard Brook and across the region challenge previous ideas on DOC generation in forested catchments.

Long-term monitoring of selected components of the biotic community is carried out at the small catchment and large landscape scale. In particular monitoring of bird communities and their key food sources (Lepidopteran larvae) is conducted in a 50 ha permanent mapped plot and in a large network of small plots across the 3,000 ha landscape of Hubbard Brook. Coincident monitoring of vegetation, seed production, and small mammal populations provides insights into the green food web.

LANDSCAPE STUDIES. An organizing theme of the current LTER funding cycle at HBR is improving the conceptual basis for understanding the interactions of soils, hydrology, vegetation, heterotrophic activity and biogeochemical cycles across the complex landscape. The hydrogeochemical template underlying these landscapes plays a key role in sorting biotic communities and driving ecosystem processes. During the past year we have investigated landscape-scale variation in N cycling, partially driven by differences in winter climate. Using a combination of isotopic tracers and chamber measurements we have examined the effect of elevation on N cycle processes. These processes play a key role in regulating soil N availability and N nutrition of vegetation; and annual variation in foliar N seems to dominate bottom up control on lepidoteran larvae. We compared the growth and survival of these larvae across the elevation gradient as the key link between ecosystem N cycling and the demography of insect-gleaning bird species.

Landscape attributes also play a central role in maintaining intraspecific genetic and phenotypic diversity by mediating the effects of drift and setting the template for adaptive and plastic divergence. These landscape components are known to influence genetic structure in stream species differentially, but, to our knowledge, no study has compared their effects on genetic and phenotypic divergence. We examined the relative effects of the stream network and terrestrial matrix on genetic and phenotypic divergence in two stream salamanders, *Gyrinophilus porphyriticus* and *Eurycea bislineata.*

We are completing a spatial analysis of moose herbivory, vegetation structure, and understory bird populations at the valley-wide spatial scale. This research is the first to quantify the contribution of moose herbivory to the maintenance of biodiversity in a northern hardwood forest. They report that moose browsing has significantly affected shrub structure and that these structural changes in turn affect the understory nesting substrate for birds.

BIOGEOCHEMICAL MEASUREMENTS AND EXPERIMENTS: We are conducting a long-term manipulation of soil nutrient availability to evaluate the independent and interactive effects of N, P and Ca on northern hardwood forest ecosystem dynamics. Following two years of comprehensive, pre-treatment measurements we began nutrient additions in 2011; thus, in 2013 we completed the third year of treatment. Measurements of tree nutrition, growth, water use, and C allocation are conducted in concert with soil measurements and modeling.

Despite a long history of soil measurements at Hubbard Brook, limited characterization of soil organic matter has been conducted. Patterns in the biomolecular composition of soil organic matter and hot-water extractable organic matter were examined by using a molecular mixing model to estimate the content of carbohydrates, protein, lipids, and lignin. The molecular mixing model uses elemental analysis (C,H,N) and ^{13}C nuclear magnetic resonance spectroscopy with cross-polarization and magic-angle spinning data to estimate the percentage of total carbon in the various classes of biomolecules. Terrestrial soil is a large reservoir of atmospherically deposited mercury. However, few studies have evaluated the accumulation of mercury in terrestrial ecosystems in the northeastern United States, a region which is sensitive to atmospheric mercury deposition. Mercury and organic matter were characterized in soil profiles from 139 sampling sites for five sub-regions across the northeastern United States.

MODELING AND SYNTHESIS: We utilize a suite of models to develop and explore hypotheses about ecosystem dynamics at Hubbard Brook and across larger scales. We also have been actively synthesizing information on key biotic populations and ecological processes by combining observation from Hubbard Brook with regional data sets. In the past year we utilized the simulation model PnET-BGC and downscaled climate change projections. Bias correction-spatial disaggregation (Grid-based) and asynchronous regional regression model (station-based) statistical downscaling techniques were compared to project biogeochemical responses to changing climate at the HBEF. Future climate projections were developed from monthly output of two atmosphere-ocean general circulation models (HadCM3, PCM) driven by A1fi and B1 emission scenarios from the IPCC-AR4. The purpose of the work was to evaluate the impact of downscaling approaches and spatial disaggregation.

Simulation model approaches also may be useful for providing scenarios of soil C stocks under global change. Carbon sequestration in forest biomass and soils may help decrease regional carbon footprints and mitigate future climate change. The efficacy of these practices must be verified by monitoring and by approved calculation methods (i.e., models) to be credible in carbon markets. Two widely-used soil organic matter models – CENTURY and RothC – were used to project changes in soil organic carbon pools after clear-cutting disturbance, as well as under a range of future climate and atmospheric carbon dioxide (CO_2) scenarios.

Our valley-wide surveys of bird distribution and abundance also are informing new modeling approaches. For example, our data were used to compare multi-species machine learning algorithms with the goal of improving the prediction of rare species.

They showed that simultaneous prediction of multiple species can improve predictions of single rare species when interactions among species drive distributions directly (e.g., via facilitation, competition) and where these species co-occur in similar habitats. Such multi-species prediction remains a promising avenue for species distribution modeling.

Regional patterns of change in the C and N cycles of rivers were evaluated in major synthesis efforts. The interaction between human activities and watershed geology is accelerating long-term changes in the carbon cycle of rivers. We evaluated changes in bicarbonate alkalinity, a product of chemical weathering, and tested for long-term trends at 97 sites in the eastern United States draining over 260,000 km^2. Also, to examine whether nitrogen concentrations in streams of forested reference catchments were changing over time or responding to changing climate, we synthesized data collected over 12 to 36 years from 22 catchments at seven USDA Forest Service Experimental Forests that span the USA. These synthesis efforts provide crucial information both for hypothesis testing and to inform debates on environmental policies.

Specific Objectives:

Our specific objectives include 1) maintaining long-term measurements of climate, hydrology, vegetation, soils, solution chemistry and heterotroph populations across the site; 2) exploring the interactions among hydrogeochemical templates, vegetation structure and dynamics, and key heterotroph populations and habitats at the large landscape scale; 3) providing new discovers on the nature and mechanisms of nutrient limitation in forest ecosystems and its interaction with natural and human-accelerated environmental change; and 4) synthesizing biogeochemical and ecological knowledge u sing simulation models and regional surveys.

Significant Results:

MONITORING CLIMATE, BIOGEOCHEMISTRY AND BIOTIC COMMUNITIES: Since 1992 biomass accumulation in the HBR forest has been negligible or even negative, yet streamwater export of dissolved inorganic nitrogen has decreased from ~4 kg N ha^{-1} y^{-1} to ~1 kg N ha^{-1} y^{-1}, despite chronically elevated atmospheric nitrogen deposition (~7 kg N ha^{-1} y^{-1}) and predictions of nitrogen saturation. We showed that the ecosystem has shifted to a net nitrogen sink, either storing or denitrifying ~8 kg N ha^{-1} y^{-1}.

Atmospheric deposition of sulfate and nitrate has declined throughout the study period (1982-2012) due to emissions controls, slowing losses of base cations from soil. Streamwater pH has increased at a rate of 0.01 units y^{-1} and the ANC has gained 0.69 µeq L^{-1} y^{-1}. Streamwater during the snowmelt period had gains in ANC and pH very similar to the overall record, with closely related steady decreases in sulfate. The similarity between the overall time series and that of the snowmelt period demonstrates the recovery from chronic acidification of drainage waters during baseflow is coincident with abatement of snowmelt acidification.

LANDSCAPE STUDIES: Earlier work has suggested that climate change may be contributing to the unexpected, strong retention of N in Hubbard Brook watersheds. We evaluated effects of climate variation, both spatial and temporal, on soil N cycling. High elevation plots consistently had higher rates of both in situ and potential net mineralization and nitrification than low elevation plots (Fig. 1). These results suggest that climate warming has decreased N supply in the northern hardwood forests at Hubbard Brook. This idea is supported by analysis of historical data that shows declines in soil inorganic N pools and supply via mineralization and nitrification over the past four decades (Fig. 2).

Spatial patterns of genetic and phenotypic divergence were uncorrelated in two species of salamander. Genetic divergence increased with absolute geographic distance between sites. In contrast, phenotypic divergence was unrelated to absolute geographic distance, but related to relative stream vs. overland distances. The results also show that small differences in life history traits (e.g., adult terrestriality) can produce large differences in patterns of intraspecific divergence, even in closely related species and in the same landscape.

We are testing the hypothesis that inter-annual variation in foliar N content can generate the large fluctuations in caterpillar abundance observed in the HBEF. This research evaluates the degree to which the nitrogen content of leaves affects 1) the per-capita change in caterpillar abundance on four common woody plant species, 2) the body size (and thus fecundity) of adult moths, and 3) the larval growth rates of common Lepidoptera species. Body size and larval growth rates are significantly affected by foliar nitrogen content, which is itself a function of climatic conditions.

Evaluating the role of the geohydrologic template in driving landscape scale patterns depends first upon quantifying that template. Although soils at Hubbard Brook have been regarded as well drained, the occurrence of a perched water table and soil saturation exhibits systematic patterns across the landscape. Empirical cumulative density functions (Fig. 3, bottom panels) show the probability that a water table exists at a given percentage of the total depth of a soil profile along the landscape gradient.

BIOGEOCHEMICAL MEASUREMENTS AND EXPERIMENTS: We evaluated relationships among site fertility and tree carbon allocation for pre-treatment data from our extensive nutrient addition experiment. Belowground C allocation was lowest at the most fertile site (Fig. 4). During the growing season, soil respiration was low where net N mineralization and net nitrification were high across thirteen stands.

Studies of wood removal in headwater streams revealed unexpected patterns. The mean size of stream substrates and the amount of riffle habitat increased following wood removal, but substrate and habitat responses were weaker in the wood addition site. Summer nitrate uptake velocities increased in the wood removal treatments relative to the reference and wood addition treatments, possibly because wood removal increased the availability of stable substrates for periphyton growth, therefore increasing nitrate demand in these streams.

Carbohydrate content of surface soil horizons decreased from about 50% of the carbon in recent litter to approximately 35% in the bottom of the humus layer. Lipids accounted for about 18% of carbon in recent litter and increased to 40% in the lower humus layers. The hot water extractable organic matter fraction of soil organic matter was dominated by carbohydrates (40-70% of C). Carbohydrates and lipids in hot water extractable organic matter exhibited depth patterns that were the opposite of the soil organic matter.

Across a regional survey, significant relationships were not observed between current net atmospheric mercury deposition and soil mercury concentrations or pools. Soil mercury appears to be preserved relative to organic carbon (OC) and/or nitrogen (N) in the soil matrix, as a significant negative relationship was observed between the ratios of mercury to organic carbon (Hg/OC) and organic carbon to nitrogen (OC/N) ($r = 0.54$, $p < 0.0001$). The mean residence time for soil mercury was estimated to be 1,800 years.

We added a calcium silicate mineral to a paired watershed at the HBEF, in an amount designed to gradually replace the estimated amount of calcium lost as a result of human activity in the 20th century (due primarily to acid deposition). The experimental restoration resulted in a recovery of tree biomass increment. The improved calcium nutrition also promoted higher aboveground net primary production and increased the photosynthetic surface area in the treated watershed relative to the reference watershed (Fig. 5).

MODELING and SYNTHESIS: Four climate change scenarios were used to simulate future changes in soil organic carbon pools using two soil C models. Climate-change simulations predicted increases in soil organic carbon by as much as 7% at the end of this century, partially offsetting future carbon dioxide emissions. This sequestration was the product of enhanced forest productivity, and associated litter input to the soil, due to increased temperature, precipitation and carbon dioxide. The simulations also suggested that considerable losses of soil organic carbon (8% - 30%) could occur if forest vegetation at HBEF does not respond to changes in climate and carbon dioxide levels.

We evaluated the sensitivity of key hydrologic parameters to climate change under two different downscaling approaches. The choice of downscaling approach had a major impact on projections of soil moisture and streamflow under future climate conditions due to the effectiveness in mimicking observed precipitation quantity and temporal patterns. The climate and streamflow change signals indicated that the current snowmelt-driven flow regime with elevated discharge in April will likely shift to a flow regime dominated by sustained large winter streamflows.

Key outcomes or Other achievements:

During July 2013 the National Science Foundation conducted an external, peer review of our LTER research program. The review was extremely valuable in stimulating further integration of the overall study, recommending particular areas for improvement and providing additional direction for information management activities. See below.

STATUS OF HBR DATA HOLDINGS: During the past year, a strong focus has been placed on improving the availability and standardization of HBR data packages. This effort has centered on the following three efforts: 1) *Upgrades to existing data packages:* To meet the requirements of the centralized LTER PASTA information system, the HBR data packages have been updated to incorporate numerous new requirements for standardized metadata. During this process, we have also updated metadata content were necessary to reflect updates to personnel/publications/methods, and have added new data to ongoing data packages. All data are openly available on the http://hubbardbrook.org website. All of our data packages have been evaluated through the PASTA web services, and those that are complete have been uploaded to the PASTA staging area (~75% of the HBR data packages are now PASTA compliant). The HBR community values the LTER policy, which allows the collection of user identity with downloads; datasets will be uploaded to the live PASTA server when this capability has been fully implemented (at the current time, data uploaded to PASTA, and requiring user authentication, is available only to LTER members). 2) *Development of new data packages:* A 'Project' database is under development, to ensure that all data is identified and tracked. This is being done in coordination with the Research Approval Committee (RAC). During this past year, we have identified a number of new datasets to add to our data collection, and 15 of those have recently been completed and made available; another 30 are under development. 3) *Implementation of metadata database*. We are in the process of migrating HBR metadata content to a PostgreSQL implementation of the metabase schema. This ongoing effort (targeting completion in 2014), migrates the content of individually maintained EML metadata files to a database. By using the metabase schema, in use by other LTER sites, and following the successful PostgreSQL implementation by the MCR/SBC, we are able to leverage numerous resources available within the LTER community (knowledge base, software tools, etc).

WEBSITE (http://hubbardbrook.org): The website for HBR is hosted on a server at the University of NH and managed by the HBR-IM. The physical location of this server is at the Research Computing and Instrumentation (RCI) Center, in a climate controlled environment, with emergency power. A service level agreement (SLA) between the Earth

Systems Research Center and RCI provides system administration, upgrades, backups, helpdesk support, and expertise for special projects as needed.

Ongoing updates are made to researcher profiles, research highlights, and the HBR bibliography. A number of improvements have been made to http://hubbardbrook.org this past year. Although this is an ongoing process, some of the improvements to date include refreshing the page style, improving access by mobile devices, reviewing and improving website and database security, and updating database access to accommodate PASTA requirements.

SENSOR NETWORK: HBR Information management provides support for the environmental sensor network at the site; digital sensors are installed to monitor streamflow (stage height) from 9 small watersheds in the Hubbard Brook valley, and meteorological data at 25 stations throughout Hubbard Brook, and in a number of project-level sensor networks. Maintenance and operation of the sensors is done by Forest Service staff, and the HBR-IM works closely with that team on the implementation and operation of data processing and quality control. The build-out of the sensor network is an ongoing process which started in 2008. For more than a year, we have been providing streaming meteorological, hydrological and web cam sensor data to a local, real-time display, in which provisional data can be viewed by both the research and education communities. On this interactive webpage, the user can select sensors to display, pan/zoom, and hover to view values. The HBR community uses this interface to realtime data to respond to events, and has provided valuable input for the development of this system to access sensor data in real time. In the near-term, we will be completing our implementation of a GCEdata Toolbox (developed by GCE-LTER) to provide high-level quality controlled data products for the research community. Both HBR-IM and USFS staff have attended training on the GCEdata Toolbox, which has been offered through the LTER.

* What opportunities for training and professional development has the project provided?

The Hubbard Brook LTER project takes very seriously its responsibilities for the training and development of scientists and educators. Most of these activities also 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. We conduct a REU site program, entitled "Investigating and Communicating Change in Ecosystems", hosting 9 undergraduate students. Students are paired with researchers and develop and conduct 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.

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. The field trip serves to promote our data-centered teaching aids and acquaint the teachers in the state with the site as an educational resource. We also partner with the New Hampshire Education and Environment Team (NHEET)

to provide teacher workshops focusing on science process skills, including a state-wide Math-Science Partnership which works with 2 school districts in the state with the aim of integrating their science education from grades K-8. In addition, in 2013 we hosted one new teacher for a summer research experience (RET), primarily supported by a supplement to this LTER grant, as well as two returning teachers who worked on further development of science-process skill related teaching resources.

3. **School partnerships**: We are active with a number of local schools and school districts. Through our RET program we have developed close working relationships with Lin-Wood School (grades 6-12), Kennett Middle School (grades 6-12), and Bartlett Middle School (grades 6-12), and Newfound Regional High School (9-12), all of which are fairly close to the site and have had one or more teachers engaged with us for multiple years. In addition we work with Plymouth Elementary (grades 6-8), Bethlehem Elementary (4-6), Littleton High School (9-12), and Plymouth Regional High School (9-12 on an as-requested basis. Together these represent the 5 school districts closest to Hubbard Brook. In addition, we provide tours to other schools as requested.

   The Hubbard Brook Research Foundation is 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. The main activity of the group in 2013 was the Math-Science Partnership program, described above. 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.

* How have the results been disseminated to communities of interest?

In addition to publishing extensively in peer-review journals, the HBR LTER project has an active program of outreach activities also coordinated through the Hubbard Brook Research Foundation. The HBRF has long been recognized as a leader in public policy outreach with its Science Links program. In 2013 we joined forces with three other northeastern LTER sites (PIE, HFR, and BES), as well as the Cary Institute for Ecosystem Studies, Syracuse University, and the University of New Hampshire to create the Science Policy Exchange. The purpose of the exchange is to increase the impact of long-term ecological research on policy and conservation in promoting environmental stewardship and human well-being. The hope is that by joining efforts the group will be better able to sustain dialog with policymakers as well as be able to bring a broader array of policy-relevant science to policy discussions. Initial projects being undertaken include regional land-use change, forest birds, and recovery from air pollution.

The Hubbard Brook Research Foundation hosts a dynamic website with teaching resources developed with support of the LTER Schoolyard program and the USDA-Forest Service. It contains data activities developed by our RET teachers, mock-NECAP exams developed with our partner schools, and teaching guides on acid rain and migratory birds. Contents of the

website are promoted at state-wide and regional science teacher conferences and through our various partnerships with teacher professional development organizations.

* What do you plan to do during the next reporting period to accomplish the goals?

We plan to continue our long-term activities in ecosystem monitoring, biogeochemical experiments, landscape studies, modeling and quantitative analysis, data management, education and outreach during the next reporting period.

Supporting Files

	Filename	Description	Uploaded By	Uploaded On
(Download)	2013 Annual Report FIGURE file.pdf	Figures 1-5 as referred to in the ACCOMPLISHMENT section.	Timothy Fahey	01/29/2014

NOTE: FIGURES are at end of document

Products

Journals

- Balaria, A., and C.E. Johnson. (2013). Compositional characterization of soil organic matter and hot-water extractable organic matter in organic horizons using a molecular mixing model. *J. Soils Sediments*. 13 1032.

  Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

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- Fisk, M.C., T.J. Ratliff, S. Goswami, and R.D. Yanai (2013). Synergistic soil response to nitrogen plus phosphorus fertilization in hardwood forests. *Biogeochemistry*. .

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- Lindenmayer, D. B., D. Blair, L. McBurney, S. C. Banks, J. Stein, R. Hobbs, G. E. Likens and J. Franklin. (2013). Principles and practices for Biodiversity Conservation and Restoration Forestry – a 30 year case study on Victorian montane ash forests and the critically endangered Leadbeater’s Possum. *Australian Zoologist*. .

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  Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; ISBN: 978-1-62748-381-0

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; OTHER: Global Institute of Sustainable Forestry, Research Paper 013.

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes ; OTHER:

Thesis/Dissertations

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  Acknowledgment of Federal Support = Yes

- Dib, A.. *Simulating Effects of a Changing Climate and Higher CO2 Emissions on Soil Carbon Pools at the Hubbard Brook Experimental Forest Using CENTURY and RothC. M.S. Thesis*. (2013). Syracuse University.

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- Pourmokhtarian, A.. *Biogeochemical Modeling of the Response of Forest Watersheds in 77 the Northeastern U.S. to Future Climate Change. Ph.D. Thesis*. (2013). Syracuse University.

  Acknowledgment of Federal Support = Yes

- McDonald, Michael. *Effects of moose herbivory on understory vegetation and bird populations. Masters of Science, The Rubenstein School of Environment and Natural Resources*. (2013). University of Vermont.

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Conference Papers and Presentations

- John J. Battles and Robert A. York (2013). *Can a general theory of forest structure and dynamics based on metabolic scaling laws provide insights to forest managers?*. Annual meeting of the Ecological Society of America. Minneapolis, MN.

  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Campbell, J., R. Yanai, M. Green, G. E. Likens, D. Buso, C. See and B. Barr. (2013). *Quantifying Uncertainty in the Net Hydrologic Flux of Calcium at the Hubbard Brook Experimental Forest, New Hampshire, USA*. Amer. Geophys. Union Meeting. San Francisco, CA.

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Diggs, Franklin, R.D. Yanai, and Thomas Horton (2012). *Mycorrhizal guilds decline similarly with depth in two northern hardwood forests.*. Ecological Society of America Annual Meeting. Minneapolis, MN.

  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

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  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Yanai, R.D., K. Bae, C.R. Levine, P. Lilly, M.A. Vadeboncoeur, F.R. Fatemi, J.D. Blum, M. Arthur, Steven Hamburg. (2013). *Nutrient Budgets in Successional Northern Hardwood Forests: Uncertainty in soil, root, and tree concentrations and pools.*. American Geophysical Union Fall Meeting. San Francisco, CA.

  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Rodenhouse, N.L. (2013). *Assessing the sensitivity of migratory songbirds to climate change*. New England Natural History Conference. Springfield, MA.

  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Betts, M.G. (2013). *Why do species occur where they do? An examination of land-use, climatic and behavioral drivers of animal distributions*. Invited seminar, University of Illinois, Dept. of Natural Resources and Environmental Sciences. Illinois.

  Status = PUBLISHED; Acknowledgement of Federal Support = No

- Betts, M.G. (2012). *On species distributions*. Invited seminar, Portland State University Dept. of Biology. Portland, WA.

  Status = OTHER; Acknowledgement of Federal Support = No

- Betts, M.G. (2012). *Toward a behavioral global ecology*. Invited seminar, Texas Tech University. Lubbock, Texas.

  Status = OTHER; Acknowledgement of Federal Support = No

- Frey, S.J.K, Rodenhouse, N.L., Sillett, S., Holmes, R.T., and Betts, M.G. (2012). *Ups and downs: Long-term songbird population trends across an elevational gradient in the Hubbard Brook Experimental Forest, NH*. Ecological Society of America Conference. Portland Oregon.

  Status = OTHER; Acknowledgement of Federal Support = Yes

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  Status = OTHER; Acknowledgement of Federal Support = Yes

- Hallworth, M. T., T. S. Sillett, S. Van Wilgenburg, K. Hobson and P. P. Marra. (2013). *Range-wide migratory connectivity revealed by archival light-level geolocators*. Annual Cooperators' Meeting, Hubbard Brook Ecosystem Study. North Woodstock, NH.

  Status = OTHER; Acknowledgement of Federal Support = Yes

- Holmes, R.T. (2013). *Ups and downs: bird population trends across the Hubbard Brook valley*. Annual Cooperators' Meeting, Hubbard Brook Ecosystem Study. North Woodstock, NH.

  Status = OTHER; Acknowledgement of Federal Support = Yes

- Illan, J.G, Thomas C.D, Betts M.G. (2012). *On the influence of climate change on bird distributions: Will the predictions come true?*. Department of Biology Workshop. The University of York. York, United Kingdom.

Status = OTHER; Acknowledgement of Federal Support = No

- Kaiser, S.A. T.S. Sillett, M.S. Webster. (2013). *Habitat-specific reproductive strategies in response to food supplementation increase male fitness in a songbird*. One Hundred and Thirty-first Meeting of the American Ornithologists' Union. Chicago, IL.

  Status = OTHER; Acknowledgement of Federal Support = Yes

- Lany, N.K., M.P. Ayres, E. Stange, T.S. Sillett, N.L. Rodenhouse, R.T. Holmes (2013). *Spring leaf phenology, insect abundance, and the timing of breeding by the Black-throated Blue Warbler*. New England Natural History Conference. Springfield, MA.

  Status = OTHER; Acknowledgement of Federal Support = Yes

- Lany, N.K., M.P. Ayres. (2013). *Temperature and the balance of top-down and bottom-up interactions in a temperate hardwood forest.*. Seminar, Swedish University of Agricultural Sciences. Uppsala, Sweden.

  Status = OTHER; Acknowledgement of Federal Support = No

- Miller, C. M., H. Merrill, N.L. Rodenhouse, S. Kaiser, L. Neitmann. (2013). *Humans vs. digital recorders: alternative methods for surveying birds*. Annual Cooperators' Meeting, Hubbard Brook Ecosystem Study. North Woodstock, NH..

  Status = OTHER; Acknowledgement of Federal Support = Yes

- Muniz, A., and S.A. Kaiser. (2013). *Spatial and temporal variation in nest predation rates of a migratory songbird across an elevation gradient*. 20th Annual Conference of The Wildlife Society. Milwaukee, WI.

  Status = OTHER; Acknowledgement of Federal Support = Yes

Other Publications

- Driscoll, C.T. (2013). *Ecological effects of acidic deposition*. Reference Module in Earth Systems and Environmental Sciences.

  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Driscoll, C.T., P.M. Groffman, J.M. Blair, A.E. Lugo, C.M. Laney, and D.P.C. Peters. (2013). *Cross-site comparisons of precipitation and surface water chemistry*. In Long-Term Trends in Ecological Systems: A Basis For Understanding Responses to Global Change. USDA Agricultural Research Service Publication, Washington, DC..

  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- LaBaugh, J. W., P. T. Harte, A. M. Shapiro, P. A. Hsieh, C. D. Johnson, D. J. Goode, W. W. Wood, D. C. Buso, G. E. Likens and T. C. Winter. (2013). *Physical, chemical, and isotopic data from groundwater in the watershed of Mirror Lake, and in the vicinity of Hubbard Brook, near West Thornton, New Hampshire, 1983 to 1997*. U.S. Geological Survey Open-File Report 2013-1087. 147 pp. http://pubs.usgs.gov/of/2013/1087/.

  Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Technologies or Techniques

- Nothing to report.

Patents

Nothing to report.

Inventions

Nothing to report.

Licenses

Nothing to report.

Websites

Title:
Multiple Element Limitation in Northern Hardwood Ecosystems
URL:
http://www.esf.edu/MELNHE
Description:

Stands at this site are among those under observation in MELNHE's nutrient manipulation studies.

Title:
Quantifying Uncertainty in Ecosystem Studies
URL:
http://quantifyinguncertainty.org
Description:

Some of our work appears on the QUEST website as case studies, and as input in developing best practices.

Title:
Education Programs at Hubbard Brook

URL:
http://hubbardbrookfoundation.org/education-programs-at-hubbard-brook-an-overview/
Description:

An overview of education and outreach activities at Hubbard Brook as facilitated by The Hubbard Brook Research Foundation.

Title:
Hubbard Brook Ecosystem Study
URL:
http://www.hubbardbrook.org
Description:

The Hubbard Brook Ecosystem Study (HBES) pioneered the small watershed technique as a method of studying ecosystem processes.

This long-term ecological research is conducted within the Hubbard Brook Experimental Forest (HBEF), a 3,160 hectare reserve in the White Mountain National Forest, New Hampshire, owned/managed by the USDA Forest Service Northern Research Station.

On-site research has produced some of the most extensive and longest continuous data bases on the hydrology, biology, geology and chemistry of a forest and its associated aquatic ecosystems.

Title:
Effect of Climate Change on Black-throated Blue Warblers
URL:
http://nationalzoo.si.edu/scbi/migratorybirds/blog/default.cfm?id=13
Description:

A description of our research on the effects of climate change on Black-throated Blue Warblers

Title:
What Limits the Reproductive Success of Migratory Birds
URL:
http://rydberg.biology.colostate.edu/langink/HubbardBrook
Description:

An educational activity for high school students that uses our data on the reproductive success of a migratory songbird.

Title:
What Limits the Reproductive Success of Migratory Birds? An online population ecology module
URL:

http://hubbardbrookfoundation.org/what-limits-the-reproductive-success-of-migratory-birds/

Description:

An educational activity for high school students that uses our data on the reproductive success of a migratory songbird.

Title:

Science Links program of the Hubbard Brook Research Foundation

URL:

http://hubbardbrookfoundation.org/12-2/

Description:

The Science Links program was developed by the Hubbard Brook Research Foundation to help bridge the gap between science and public policy.

HBRF has completed four Science Links reports:

Carbon and Communities

Acid Rain Revisited

Mercury Matters

Nitrogen Pollution: From the Sources to the Sea

Other Products

Product Type:

Databases

Description:

Available on the Hubbard Brook Ecosystem Study website for data searches

http://www.hubbardbrook.org/data/dataset_search.php

http://www.dartmouth.edu/~estange/mothbd.htm

Other:

Participants

Research Experience for Undergraduates (REU) funding

Form of REU funding support:

REU supplement

How many REU applications were received during this reporting period?

72

How many REU applicants were selected and agreed to participate during this reporting period?

9

REU Comments:

these students are included in the list of participants below.

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Cynthia Wood	Non-Student Research Assistant	1
Alexis Kristan Heinz	Technician	2
John J Battles	Co-Investigator	2
Natalie L Cleavitt	Other Professional	6
Steve J Harshman	Undergraduate Student	3
Liana Acevedo-Siaca	Undergraduate Student	2
Benjamin S Feinson	Undergraduate Student	2
Noah Shephard	Undergraduate Student	3
Jill Hautaniemi	Research Experience for Undergraduates (REU) Participant	2
Shannon Healy	Research Experience for Undergraduates (REU) Participant	1
Kevin J McGuire	Co-Investigator	2
Scott W Bailey	Co-Investigator	3
Cody P Gillin	Graduate Student (research assistant)	6
John P Gannon	Graduate Student (research assistant)	10
Melany Fisk	Co-Investigator	3
Hannah Babel	Undergraduate Student	1
Austin McDonald	Undergraduate Student	2
Erin Collin	Undergraduate Student	1
Shinjini Goswami	Graduate Student (research assistant)	6
Owen Patterson	Graduate Student (research assistant)	6
Tera Ratliff	Technician	12
Rick Biche	K-12 Teacher	1
Joe Yahna	K-12 Teacher	1
Andrew Richardson	Co-Investigator	1
Trevor Keenan	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Donald Aubrecht	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Min Lee	Undergraduate Student	3

Name	Most Senior Project Role	Nearest Person Month Worked
Peter Mark Groffman	Co-Investigator	1
Jorge Duran	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Lisa Martel	Technician	4
Kate Shepard	Technician	2
Amanda Irish	Technician	1
Dana M Williams	Undergraduate Student	1
Catherine McCandless	Undergraduate Student	1
Donald C Buso	Technician	10
Gene E Likens	Co-Investigator	0
AnnaMarie V Saenger	Undergraduate Student	3
Joshua A Grant	Undergraduate Student	3
Nathaniel Hernandez	Undergraduate Student	2
Nina Lany	Graduate Student (research assistant)	4
Clarice` Bayer	Graduate Student (research assistant)	4
Sarah J.K. Hadley	Graduate Student (research assistant)	1
Charles T Driscoll	Co PD/PI	2
Michael Rice	Technician	12
Afshin Pourmokhtarian	Graduate Student (research assistant)	1
Colin Fuss	Graduate Student (research assistant)	3
Mary Margaret Koppers	Technician	6
Mario Montesdeoca	Technician	2
Isaac Allen	Technician	1
Gabrielle Ard	Technician	1
Shuai Shao	Non-Student Research Assistant	1
Chris Johnson	Co-Investigator	2
Kelsey Jardine	Undergraduate Student	2
Katelyn Tamargo	Undergraduate Student	2
Alain Dib	Graduate Student (research assistant)	3
Zaixing Zhou	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Mary Martin	Other Professional	7
Kristi Donahue	Other	1
Nicholas Dowhaniuk	Undergraduate Student	1
Edward Donovan	Undergraduate Student	1
Sarah Geromini	Undergraduate Student	1
Ryan Kolmeister	Undergraduate Student	1

Name	Most Senior Project Role	Nearest Person Month Worked
Alison Magill	Other	4
Thadeus Hatch	Other	1
Geoff Wilson	Other Professional	12
Jackie Wilson	Other Professional	6
Aubrey Tyler	Research Experience for Undergraduates (REU) Participant	3
Seth Lutter	Research Experience for Undergraduates (REU) Participant	3
Sam Gersie	Research Experience for Undergraduates (REU) Participant	3
Carly Ellis	Research Experience for Undergraduates (REU) Participant	3
Tim Campbell	Research Experience for Undergraduates (REU) Participant	3
Russell Callahan	Research Experience for Undergraduates (REU) Participant	3
Liza Testley	Research Experience for Undergraduates (REU) Participant	3
Sean Littlefield	K-12 Teacher	1
Peter Dumont	K-12 Teacher	1
Nicholas Rodenhouse	Co-Investigator	2
Ruth Yanai	Co-Investigator	2
Heather Engelman	Technician	1
William O'Neill	Technician	1
Brannon Barr	Graduate Student (research assistant)	1
Yi Dong	Graduate Student (research assistant)	2
Kikang Bae	Graduate Student (research assistant)	0
Myron James Mitchell	Co-Investigator	1
Tamir Puntsag	Graduate Student (research assistant)	4
Joel D Blum	Co-Investigator	1
John L Campbell	Other Professional	4
Pamela Templer	Other Professional	1
Michele Lynn Pruyn	Co-Investigator	2
Timothy J Fahey	PD/PI	1
Hongzhang Kang	Non-Student Research Assistant	1
Gary Lovett	Other Professional	1
Jennifer L Morse	Postdoctoral (scholar, fellow or other postdoctoral position)	6

What other organizations have been involved as partners?

Name	Location
Hubbard Brook Research Foundation	Woodstock, NY
Plymouth State University	New Hampshire

Have other collaborators or contacts been involved? Y

Impacts

What is the impact on the development of the principal discipline(s) of the project?

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.

What is the impact on 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.

What is the impact on the development of human resources?

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.

What is the impact on physical resources that form infrastructure?

During the past year we improved the physical infrastructure at HBR in two ways: 1) we expanded our realtime environmental sensor network, and 2) we expanded the capacity of our physical sample archive.

What is the impact on institutional resources that form infrastructure?

Nothing to report.

What is the impact on information resources that form infrastructure?

The website for Hubbard Brook (http://hubbardbrook.org) is now hosted on a server at the University of NH, providing local control of the system to the HBR-IM. The physical location of this server is at the Research Computing and Instrumentation (RCI) Center, in a climate controlled environment, with emergency power. RCI provides system administration, upgrades, backups, helpdesk support, and expertise for special projects as needed. Changes to the website now take place on a separate development server, providing a platform for developing/testing new datasets, metadata, changes in webpage functionality, etc. A mirror of this webserver will be established at the LNO, providing offsite redundancy, and failover capability.

What is the impact on technology transfer?

Nothing to report.

What is the impact on society beyond science and technology?

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.

Changes

Changes in approach and reason for change

Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them

Nothing to report.

Changes that have a significant impact on expenditures

Nothing to report.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.

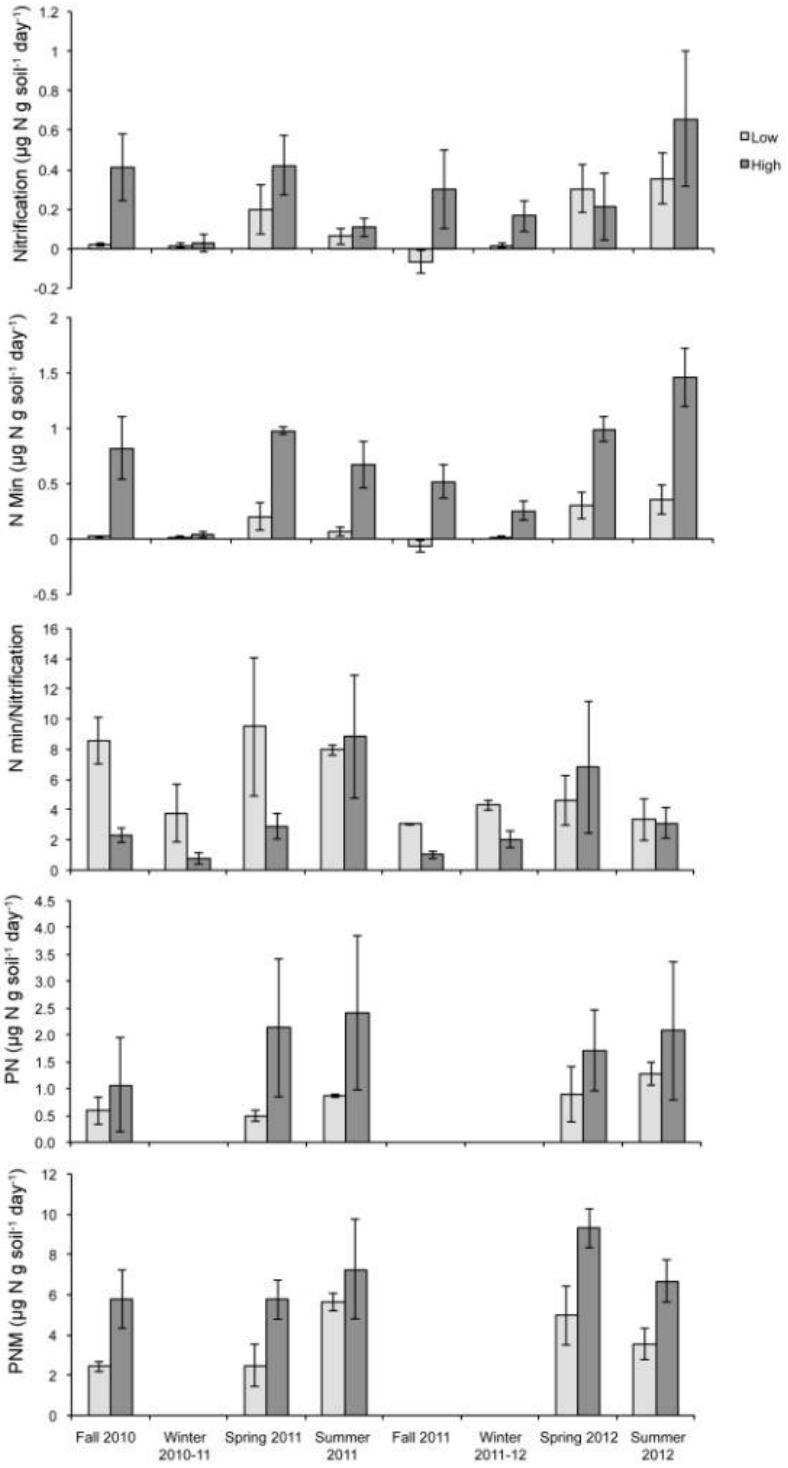

Figure 1. From top to bottom: In situ net nitrification, in situ net N mineralization, the ratio of in situ mineralization to nitrification, potential net nitrification (PN) and potential net N mineralization (PNM) in three high elevation and three low elevation plots at the Hubbard Brook Experimental Forest at 5 – 8 sample dates between fall 2010 and summer 2012.

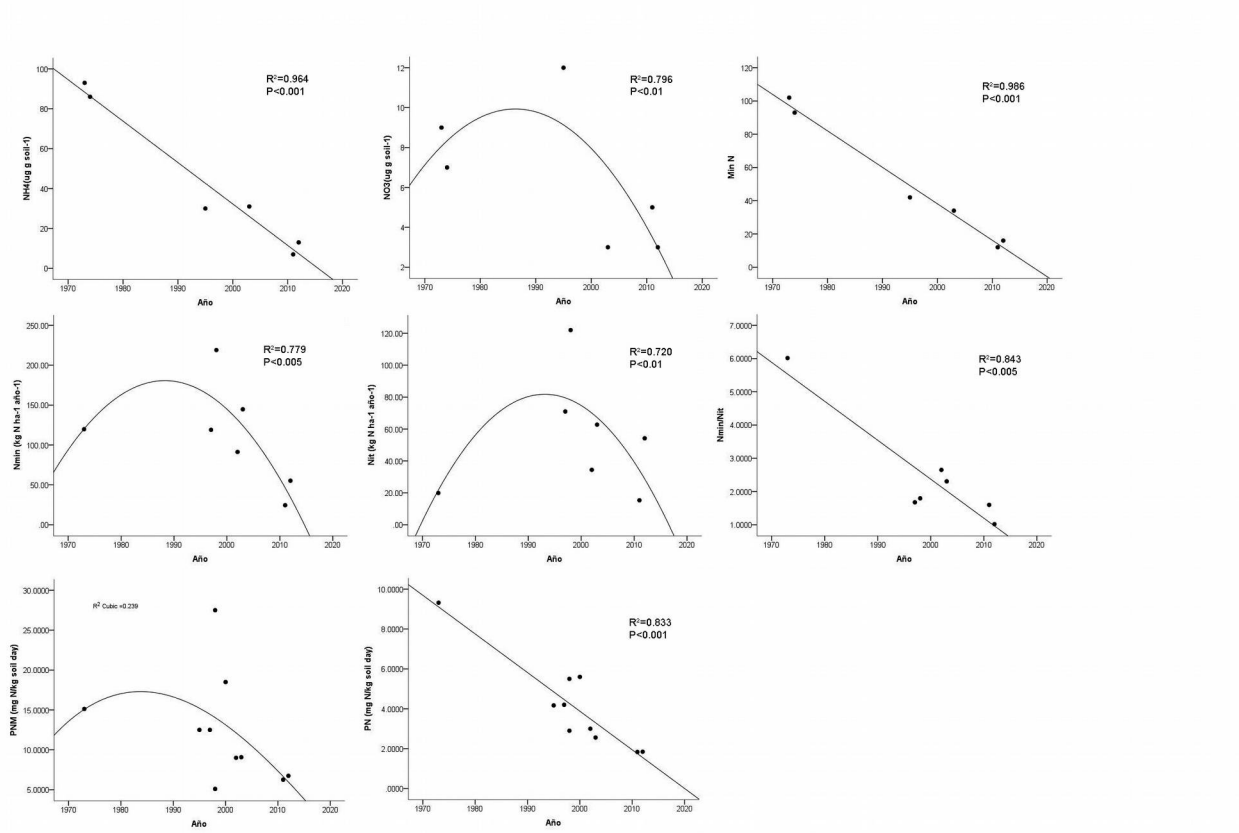

Figure 2. Changes in soil nitrogen cycle variables over four decades at the Hubbard Brook Experimental Forest. Top row – soil ammonium, nitrate and total inorganic N pools. Middle row in situ net N mineralization, in situ net nitrification and the ratio of in situ mineralization to nitrification. Bottom row – potential net N mineralization and nitrification.

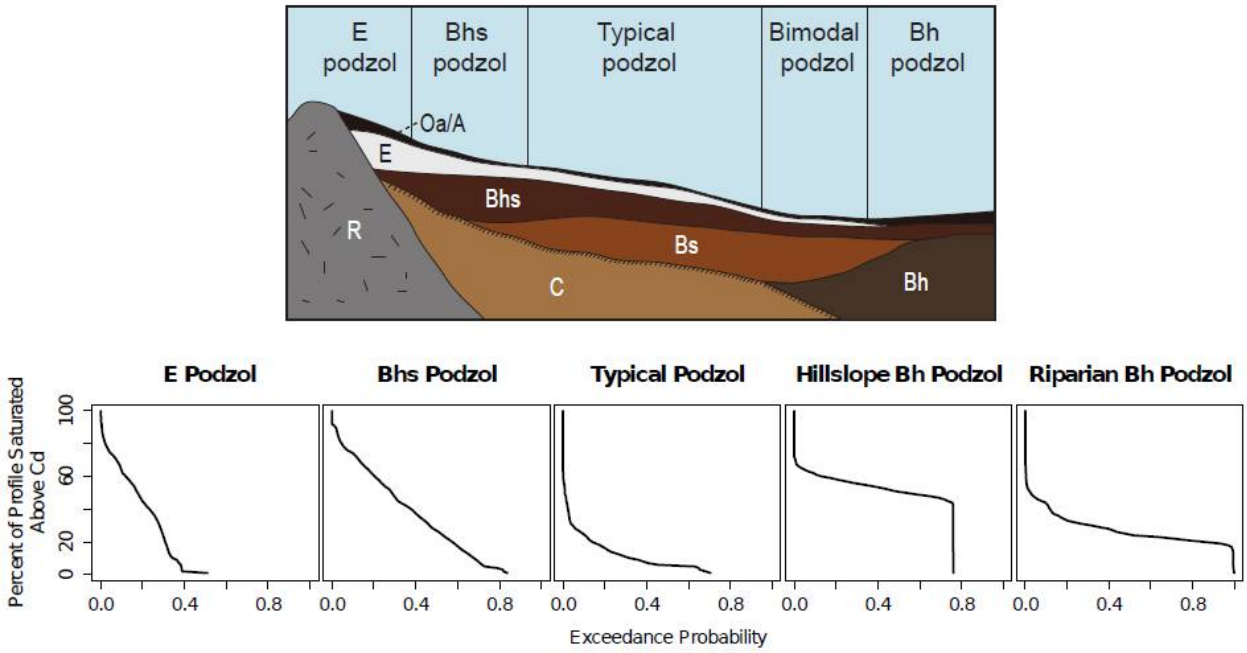

Figure 3. Conceptual diagram (top) showing soil horizonation along a typical Hydropedological Unit (HPU) sequence. Empirical cumulative density functions (ECDFs, bottom) show the probability a water table exists at a given percentage of the total depth of a soil profile along the transect. Soil profiles in this figure are considered to begin at the Cd horizon and extend to the surface. ECDFs were constructed from 1 year of 10-minute water level data from a well in each of the HPUs along the sequence.

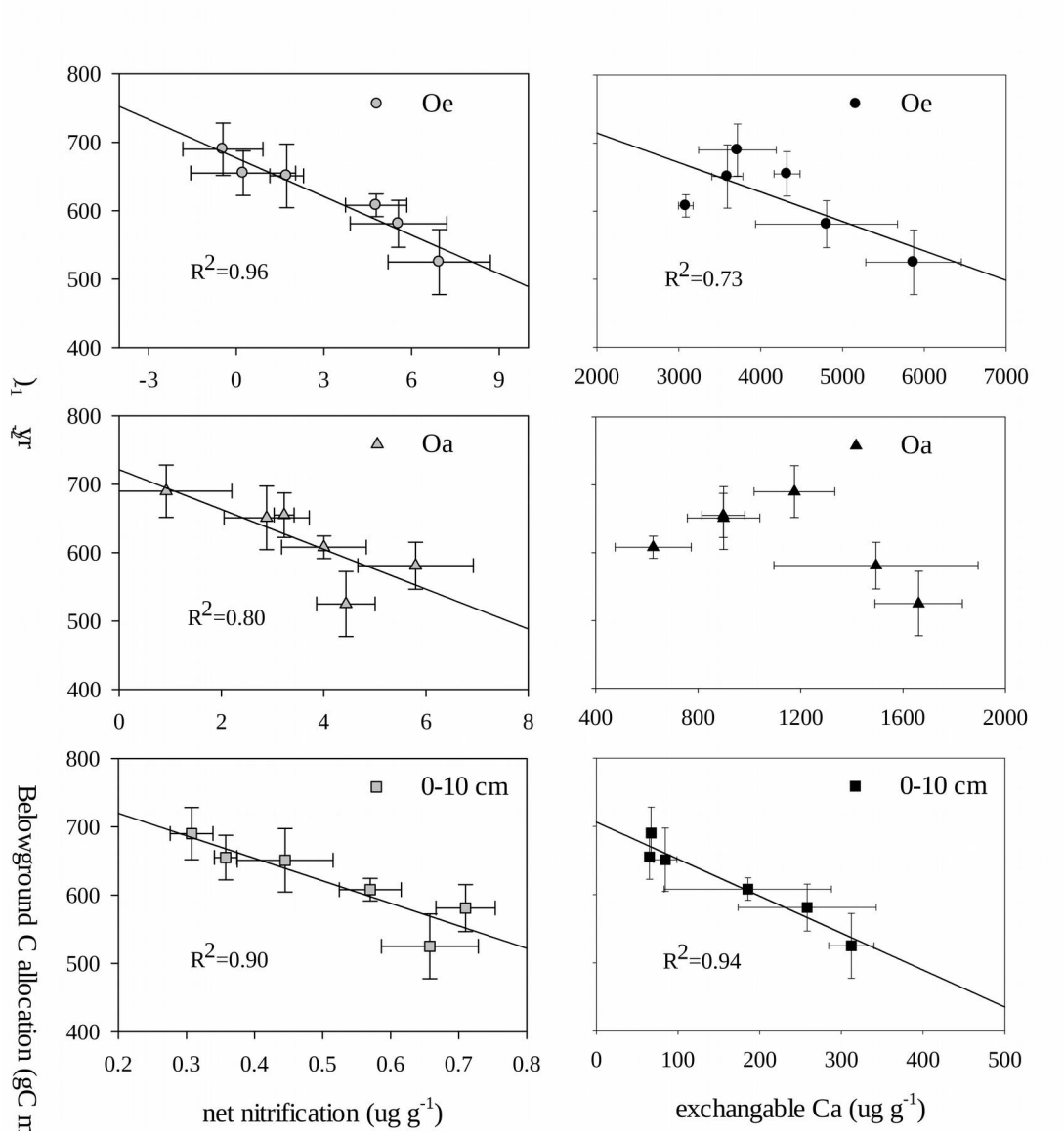

Figure 4. Relationship between belowground C allocation and N and Ca availability in the 6 intensive stands at Bartlett, Hubbard Brook, and Jeffers Brook. Data are displayed for three soil horizons; Oe, Oa, and 0 – 10 cm in the mineral soil. Points represent the mean and bars the standard error of the mean (n = 4 plots per stand) and lines show relationships significant at α= 0.05.

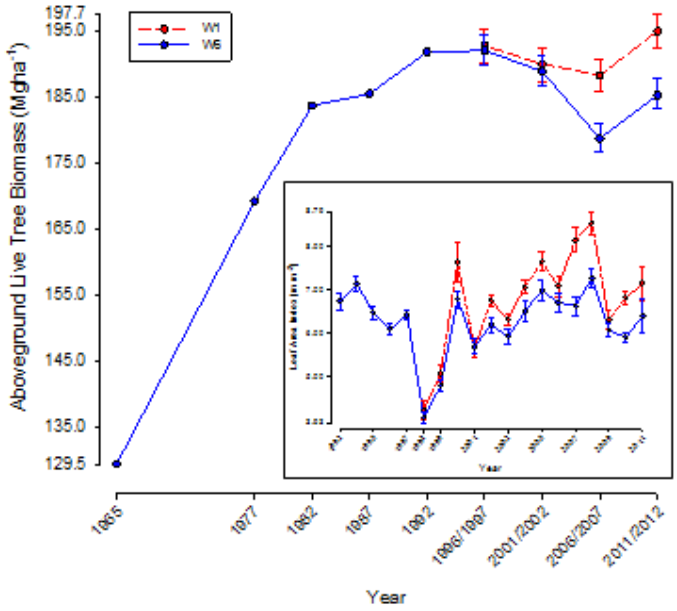

Figure 5: Trends in aboveground live tree biomass and leaf area index in the reference watershed (WS6) and the Ca-treated watershed (WS1) in Hubbard Brook Experimental Forest, New Hampshire. Aboveground live tree biomass (trees ≥ 2 cm in diameter at breast height, 1.37 m) from 1965 to 2012 for WS6 and from 1996 to 2011 for WS1. Means and 95% confidence intervals calculated using Monte Carlo error propagation to account for allometric errors. For 1965 and 1977 (†), different methods were used to estimate uncertainty. See the Supporting Information for details. Inserted figure: Leaf area index from 1993 to 2011 for WS6 and from 1998 to 2011 for WS1. Means are plotted with 95% confidence intervals.