

## Preview of Award 1114804 - Annual Project Report

### Cover

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### 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 CO<sub>2</sub>, 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:**

**BIOGEOCHEMICAL AND CLIMATE MONITORING:** We investigated long-term chemistry trends in streamwater and soil water along an elevation gradient to evaluate the progress of recovery from the effects of acidic deposition at the HBEF. Historic acidic deposition and the acid-sensitive nature of soils have led to chronic acidification of drainage waters in these headwater catchments. Additionally, episodic acidification associated with snowmelt makes spring the most acidic period of the annual cycle. Deposition of sulfate and nitrate has declined throughout the study period due to controls on emissions from electric utilities. The decreased input of strong acid anions has resulted in decreased leaching of base cations from the soil. Fluvial transport of POC and PON were estimated by coupling concentrations with hydrologic measurements from the stream gauging station using a hydrologic model.

Climate change is playing out over the complex and dynamic hydrobiogeological structure of the landscape (i.e., the intertwined patterns of soils, vegetation and hydrologic flowpaths), with a spatially variable history of land-use, and a wide range of current human activities and concurrent environmental changes. We combined data from long-term (50 year) measurements of multiple aspects of climate and ecosystem structure and function to highlight important but poorly studied interactions that could be critical determinants of the responses of plant and animal communities, fluxes of water, element dynamics, and ecosystem services of northern hardwood forest ecosystems.

**BIOGEOCHEMICAL EXPERIMENTS:** We have quantified Ca depletion from watershed-ecosystems at Hubbard Brook owing to acid deposition and forest harvest. In 1999 we initiated a long-term experiment in which we replaced the calcium losses by adding a calcium silicate mineral to Watershed 1, in order to restore available soil Ca to pre-industrial levels through natural weathering. Measurements of ecosystem responses in this experiment have continued and they are complemented by new experiments on Ca, N and P interactions. As the principal macronutrients limiting vegetation productivity, N and P interact in myriad ways that are imperfectly understood yet critical to ecosystem structure and function. Anthropogenic N addition is changing the relative availability of these

nutrients with implications for forest health and production. We initiated a long-term study of Ca x N x P interactions in northern hardwood forest to provide insights into this important issue. In addition, building upon previous research on winter climate change effects on biogeochemical cycles at Hubbard Brook, two major initiatives are in progress. First, a soil warming experiment is being conducted in the northern hardwood forest, designed to disentangle winter and summer effects of soil warming on ecosystem dynamics. Pre-treatment measurements and infrastructure for this experiment (plot establishment, heating cables, environmental sensors, etc.) was implemented during summer and fall 2012 with initiation of treatments planned for field season 2013.

Second, a winter climate gradient study has been established across the elevation gradient in the Hubbard Brook valley. In this study we are using double-isotope ( $^{13}\text{C}$ ,  $^{15}\text{N}$ ) labeled leaf litter to quantify the effects of winter climate on the movement and fate of detrital C and N in northern hardwood forest soils. Addition of labeled litter was conducted in fall 2011 and fall 2012, and sample collection from field plots and isotope analysis are ongoing, including organic matter, soil solutions, soil microbes and key invertebrate populations.

**LANDSCAPE STUDIES:** The Hubbard Brook valley encompasses a complex landscape typical of the glaciated Appalachian uplands and human-accelerated environmental changes are being played out across this template. 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 this complex landscape. Our strategy is to integrate a suite of surveys and process studies across the Hubbard Brook landscape to evaluate the interactions among these ecosystem elements. These surveys build upon a suite of 450 permanent plots at the Valley-wide scale. Although soils in the Hubbard Brook watersheds have generally been regarded as well-drained, the occurrence of a perched water table and soil saturation exhibits systematic patterns across the typical landscape. This template plays a key role in shaping soil water flow pathways, biogeochemical processes, vegetation dynamics and heterotroph habitats. We surveyed soils and water levels across a series of typical hydopedologic units distributed along the landscape in WS3 at HBR. Finally, we are working primarily at the valley-wide spatial scale to document the spatial and temporal dynamics of heterotroph abundance and to develop mechanistic models for the observed patterns of change. We are focusing specifically on herbivory by moose, avian distribution and abundance, the dynamics of insects in the "green" food web of forest foliage and salamanders as top predators in the "brown" food web of the forest floor. During the 2012 field season we began to collect fine-scale microclimate information (temperature, relative humidity) by using HOBOs placed in stratified random manner throughout the Hubbard Brook Valley. These data will aid understanding how abiotic drivers affect the observed spatial and temporal dynamics of heterotroph populations. We also conducted a spatial analysis of moose herbivory, vegetation structure, and understory bird populations at the valley-wide spatial scale including understory shrub structure at Black-throated Blue Warbler (*Setophaga caerulescens*) nest sites. Finally, we have used long-term spatial data on spring forest phenology, seasonal arthropod phenology and bird arrival times and demography to quantify the extent to which the Black-throated Blue Warbler is adjusting its arrival and breeding schedule to climatic variation.

**MODELING AND QUANTITATIVE ANALYSIS:** We use the biogeochemical

model, PnET-BGC, to evaluate the effects of potential future changes in temperature, precipitation, solar radiation, and atmospheric CO<sub>2</sub> on pools, concentrations, and fluxes of major elements at Hubbard Brook. Future climate projections used to run PnET-BGC were generated specifically for the Hubbard Brook with a statistical technique that downscales climate output from atmosphere-ocean general circulation models. Effects of global climate change will be manifested differently across landscapes with varying biogeographic characteristics. We evaluated ecosystem responses to global change with PnET-BGC across four regional watersheds from NY, VT, NH and ME. We also used the Multiple-element limitation model (MEL) as the theoretical framework for our ongoing experimental studies of biogeochemical interactions in northern hardwood forest. We parameterized and calibrated the MEL model for Hubbard Brook and evaluated N x P interactions through successional forest development. Finally, we combined AmeriFlux data with long-term vegetation phenology data from Hubbard Brook to quantify the impact of a late-spring frost in 2010 on forest carbon budgets in New England.

**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) providing new discoveries on the nature and mechanisms of nutrient limitation in forest ecosystems and its interaction with natural and human-accelerated environmental change; 3) exploring the interactions among hydrogeochemical templates, vegetation structure and dynamics, and key heterotroph populations and habitats at the large landscape scale; and 4) quantifying key components of uncertainty in biogeochemical budgets and evaluating interactions among drivers of long-term ecological changes using simulation models.

**Significant Results:**

**BIOGEOCHEMICAL and CLIMATE MONITORING:** 1) We showed that rapid and relentless dilution of surface water chemistry is occurring in the White Mountains of New Hampshire, following decades of acid deposition. Extrapolating measured linear trends using a unique data set of up to 47 years, suggest that both precipitation and streamwater chemistry in the Hubbard Brook Experimental Forest will approach demineralized water within one to three decades. 2) Stream water pH has increased 0.01 units per yr and the acid neutralizing capacity (ANC) has increased 0.69 microequivalents per L per yr. While the changes in stream water chemistry broadly reflect changes in soil water chemistry, we found variation by landscape position in the magnitude and significance of changes in the chemistry of soil water draining the organic and mineral soil horizons. We also found the trend of recovery from acidification observed in the overall time series is similar to that of the record representing the peak spring snowmelt of each year. Additionally, we found that for both the overall stream chemistry record and for the snowmelt period, the trends showed similar increases in pH, decreases in sulfate, and decreases in nitrate. The similarity between the trends in the overall time series and the snowmelt periods is an important finding that demonstrates the recovery from acidification of drainage waters both during baseflow throughout the year and during the high flows of snowmelt. This finding indicates that episodic acidification associated with snowmelt is declining in severity. 3) Concentrations and fluxes of POC and PON were greatest in waters draining the forest floor and decreased through the mineral soil to streamwater. Concentrations and fluxes of POC and PON varied among the elevation zones, with the highest values in the spruce-fir-birch zone and somewhat lower values in the hardwood zones. Seasonally, concentrations of both POC and PON were higher during the growing season (May-October),

with peak concentrations during the mid to end of the summer. This pattern coincided with a larger flux of particulate materials during the growing season than the non-growing season. 4) We found that climate alone cannot explain the occurrence of a dramatic greater than 90 percent drop in watershed nitrate export over the past 46 years, despite longer growing seasons and higher soil temperatures. The strongest climate influence was an increase in soil temperature accompanied by a shift in paths of soil water flow within the watershed, but this effect explained, at best, only about 40 percent of the nitrate decline. In contrast, at least 50-60 percent of the observed change in the N export could be explained by the long-lasting effect of forest cutting in the early 1900s on the N cycle of the soil and vegetation pools. 5) Long-term monitoring within the Hubbard Brook Valley also revealed changes in many climate and limnological variables known to affect the structure and function of aquatic ecosystems. Mean annual temperatures in two headwater streams on south-facing slopes of the Hubbard Brook Valley declined about 2 degrees C from 1966 to 1983, and then showed a small (about 1 degree C) and variable increase thereafter.

**BIOGEOCHEMICAL EXPERIMENTS:** 1) An unexpected outcome of our Ca amendment on W1 was a change in watershed hydrology; annual evapotranspiration increased by 25 percent, 18 percent, and 19 percent, respectively, for the three years following treatment before returning to pretreatment levels (Fig. 1). 2) Most recently, we have quantified the long-term responses of forest biomass and aboveground net primary production (ANPP) to the W1 treatment. Our earlier reports tentatively linking soil base cation depletion with the observation that biomass accumulation had unexpectedly ceased in the biogeochemical reference watershed at Hubbard Brook (WS6) appear to be borne out by this experiment. In particular, the trajectory of biomass accumulation has been strikingly altered by the Ca addition to WS1 (Fig. 2). The principal cause of this response is increased growth of the dominant trees. 3) Pre-treatment data from our N x P experiment indicate a strong relationship between soil N availability and total soil respiration (TSR) across the thirteen sites (Fig. 3). Similarly, total belowground carbon allocation (TBCA) decreased significantly with increasing soil N availability. In contrast, despite a four-fold range in soil P availability across the sites, no relationship with TSR and TBCA were observed.

**LANDSCAPE STUDIES:** 1) Empirical cumulative density functions (Fig. 4, 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. These ECDFs were constructed using one year of 10-minute water-level data from wells. These water table data illustrate the sequence of soil drainage characteristics across a typical hillslope and the consequent interactions with soil profile development. 2) In the area of landscape studies of heterotrophs, we showed that arrival of black-throated blue warblers was weakly matched to spring leafout dates, but that birds became more closely synchronized to local phenology in their initiation of clutches. Food abundance during the egg formation period explained 15 percent of the variation in clutch initiation dates after accounting for the effects of spring phenology. The average honological plasticity displayed by the population resulted in the highest reproductive output; thus, adaptive plasticity is presently maintaining a honological match in this system.

**MODELING and QUANTITATIVE ANALYSIS:** 1) PnET-BGC simulations under future climate change show a shift in hydrology characterized by later snowpack

development, earlier spring discharge (snowmelt), greater evapotranspiration, and a slight increase in annual water yield (associated with carbon dioxide effects on vegetation). Model results indicate that under elevated temperature, net soil nitrogen mineralization and nitrification markedly increase, resulting in acidification of soil and stream water, thereby altering the quality of water draining from forested watersheds. Invoking a carbon dioxide fertilization effect on vegetation under climate change substantially mitigates watershed nitrogen loss. 2) Climate projections indicate that over the 21st century, average air temperature will increase at all sites with simultaneous increases in annual average precipitation. Model results show that under elevated temperature, net soil nitrogen mineralization and nitrification markedly increase, resulting in acidification of soil and streamwater, although the extent varies with site land disturbance history and cumulative inputs of atmospheric nitrogen deposition that vary regionally. 3) Our calculations suggest that the uncertainty in our streamwater and precipitation solute and water fluxes at HBEF is additive and in the range of 5 to 10 percent. Base cation exports and imports have an uncertainty of less than 5 percent, while solutes with extremely low concentrations (e.g. ammonium and phosphorus) may be as high as 25 percent. Over the period of our studies, the numbers of solute analyses that are less than the method of detection have increased significantly. 4) We combined AmeriFlux data with long-term vegetation phenology data from Hubbard Brook to quantify the impact of a late-spring frost in 2010 on forest carbon budgets in New England.

Key outcomes or  
Other achievements:

July 2012 marked the transition of Hubbard Brook Information Management from the US-Forest Service to an LTER-funded position. The current HBR-Information Manager (IM) has worked closely with the previous USDA-FS IM to identify immediate and long-term needs for information management at the HBR. The LNO-supported EML mentoring program has been used extensively in the past few months by the new IM.

**STATUS OF HBR DATA HOLDINGS:** Prior to the establishment of new EML features (Ave essential) and the PASTA evaluation tests, the HBR data holdings were all compliant with the EML 2.0 schema, and were at the highest level of completion (level 5). With new standards for LTER datasets forthcoming, we have evaluated all of the HBR data packages through PASTA web services. This LNO tool has been very helpful in determining the current status of our data packages – the xml output report from this evaluation service has been parsed to generate detailed and summary reports, at different levels of data aggregation, to communicate HBR data package status to the HBR community, and to inform the process of prioritizing our efforts in bringing our data packages up to the next level. Dataset compliance with the individual tests varies, and current efforts are underway to address these issues. A new release of HBR EML is forthcoming, and incorporates the upgrade to EML 2.1, as well as code modifications to our website code, allowing access to data tables via PASTA. The LNO Data Access Server (DAS) has just come to the attention of the HBR-IM, and further code modifications will be made to our local data access code to make use of this service. Through the LNO-DAS, we will have access to a log of data download connections to the HBR website via the LNO metacat and PASTA data portals.

Many data packages have been updated over the past few months (about 75 percent of active datasets), including all of the long-term stream and precipitation chemistry, Mirror Lake datasets, many of the USFS long-term meteorological and hydrological data, and a number of ongoing datasets from HBR PIs. In most

cases, these recent updates include data up to 2010 or 2011. A number of these will be updated to reflect 2012 calendar year during the first quarter of 2013. Data have been updated on both ClimDB and HydroDB through 2011.

At the current time, HBR metadata is maintained in individual xml files. We are in the early stages of migrating that content to a database (extraction of information from xml via xslt to generate database-ready tabular datafiles). This effort will also move us forward in the establishment of a project database, and we plan to concentrate on the project-level tables initially, since this will provide better access to this information for both the IM, Research Advisory Committee, and the HBR Site Manager.

**WEBSITE (<http://hubbardbrook.org>):** The website for HBR 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.

Updates to non-data website content have focused on researcher profiles, updating the HBR bibliography (both on our site webpages and in the LNO Bibliography database), and developing web pages to highlight current research at HBR.

**SENSOR NETWORK: *Infrastructure*** – Increasing realtime sensor capacity at HBR has been an ongoing process for several years. We continuously monitor streamflow (stage height) from 9 small watersheds in the Hubbard Brook valley, and meteorological data at 25 stations throughout Hubbard Brook. At all gaging stations we collect analog data on paper charts, and over the past several years, have co-located electronic sensors that perform the same function, reporting data every fifteen minutes. Similarly, electronic sensors have been co-located at a subset of the meteorological stations, collecting temperature, precipitation, and relative humidity. All power at non-headquarter (HQ) sites is supplied by solar. Electronic sensor data is stored on dataloggers, and pushed hourly to HBR HQ via 900 MHz radios. During the summer of 2012, additional sensors were added to begin monitoring stream temperature and conductivity at all watersheds on the same fifteen minute interval. This fall, electronic sensors were installed at six new soil climate sites, monitoring soil temperature and soil moisture. Additional webcams have been installed throughout the valley, and are used to monitor phenology (leaf on and leaf off) and days of ice cover on Mirror Lake.

We are in the process of testing Wi-Fi radios (2.4 GHz and 5.8 GHz), which would increase our data transmission capacity and speed. Although this is a slightly longer-term goal, a system such as that could enable real-time streaming of video and audio environmental sensors. At the current time, 5 repeaters have been installed throughout the valley, to accommodate the line of site requirements for the 900MHz radio network.

***Sensor Quality Control and realtime display*** – With many sensors in place by 2012, and daily operation (power, communication, etc.) running smoothly, the HBR initiated an effort to implement in-line quality control, and streaming of

real-time data to the web. This effort has involved the development of custom code (primarily in R) to ingest data from the staging area, evaluate preliminary QC status, and generate flagged output for archive and visualization. The initial QC checks have varied by sensor type, but include such checks as min/max limits, incremental step-size, and comparisons with historical data. For the latter, the 50 year daily min/max data were used to generate statistics for each day of the year, for each station. As incoming data is received, a series of QC checks are performed, a flag column is generated and populated with QC status. We are currently in the process of migrating this processing workflow to the LTER GCE Data Toolbox. This program provides the capability of incorporating metadata and processing documentation into the workflow, which is critical to reach the point where we can generate data products from these sensors that can be shared with the broader scientific community. HBR-IM recently attended the GCEdata Toolbox and Metabase training at UGA, and is working with the USDA-FS team at HBR to develop and implement the required workflows.

In early 2012, we began to push 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. The sensor data webpage reads from csv files, and generates a near-realtime display (about 1-2hr delay). On this interactive webpage, the user can select sensors to display, pan/zoom, and hover to view values. Only quick-look data (graphs) are available on the site pending full implementation of QC evaluation/flagging, metadata, and processing history documentation.

**\* 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 received funding for our REU site program, entitled "Investigating and Communicating Change in Ecosystems", and will begin the first cohort in the summer of 2013. In 2012 we continued to offer an REU experience for as many undergraduates as possible, using a combination of LTER and USDA-Forest Service funds, and hosted four undergraduates from around the country. The students were paired with 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.

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:

**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/>

**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 2012 we hosted three new teachers 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.

**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), 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), Plymouth Regional High School (9-12), and Newfound High School 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 2012 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. We regularly present research findings at forums for general and professional audiences, conduct field trips for general public and school audiences at the site and discuss research findings with reporters and policymakers. More specifically, we examined the efforts of five Long Term Ecological Research Network sites to enhance policy, management, and conservation decisions for forest ecosystems. In these case studies, we explored the approaches used to inform policy on atmospheric deposition, public land management, land conservation, and urban forestry, including decision maker engagement and integration of local knowledge, application of models to analyze the potential consequences of policy and management decisions, and adaptive management to generate new knowledge and incorporate it into decision making. Efforts to enhance the role of long-term research in informing major environmental challenges would benefit from the development of metrics to evaluate impact; stronger partnerships among research sites, professional societies, decision makers, and journalists; and greater investment in efforts to develop, test, and expand practice-based experiments at the interface of science and society. This synthesis was another in the long-running series of policy outreach efforts of the HBR LTER project coordinated in the Science Links program.

In 2012 we began a major effort in outreach to regional "ecosystem stakeholders", defined loosely as people in the

region with a strong economic or social interest in the ecosystem services of the northern hardwood forest. We used a forum we call the Hubbard Brook Roundtable, where stakeholders and scientists discuss areas of concern as they relate to the most current scientific understanding of the ecosystem. The 2012 meeting was centered on the changing winter climate and involved stakeholders such as maple syrup producers, foresters, ski area snowmakers, representatives from recreational organizations, and managers from state and federal management agencies.

A couple of different outlets that were used to disseminate research activities to the public:

Media outlet: New Hampshire Public Television (NHPTV). 2012. Saving Songbirds. A "Windows to the Wild" special program. New Hampshire Public Television, Durham, NH. [This program featured our research in avian ecology at Hubbard Brook]

White paper led to an op-ed piece in the Boston Globe ([http://articles.boston.com/2012-10-14/magazine/34402630\\_1\\_climate-change-natural-snow-ski-area-operators](http://articles.boston.com/2012-10-14/magazine/34402630_1_climate-change-natural-snow-ski-area-operators)).

### \* 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
1114804 Supporting Figure File 2012 Report.pdf	Figures for Annual Report for Award 1114804 (referred to in text)	Timothy Fahey	01/24/2013

### Products

#### Journals

Bernal, Susana; Hedin, Lars O.; Likens, Gene E.; Gerber, Stefan; Buso, Don C. (2/28/12). Complex response of the forest nitrogen cycle to climate change. *PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA*. 109 (9), 3406-3411.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Driscoll, Charles T.; Lambert, Kathleen F.; Chapin, F. Stuart, III; Nowak, David J.; Spies, Thomas A.; Swanson, Frederick J.; Kittredge, David B.; Hart, Clarisse M. (4/1/12). Science and Society: The Role of Long-Term Studies in Environmental Stewardship. *BIOSCIENCE*. 62 (4), 354-366.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Cho, Youngil; Driscoll, Charles T.; Johnson, Chris E.; Blum, Joel D.; Fahey, Timothy J. (4/1/12). Watershed-Level Responses to Calcium Silicate Treatment in a Northern Hardwood Forest. *ECOSYSTEMS*. 15 (3), 416-434.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Blum, Joel D.; Hamburg, Steven P.; Yanai, Ruth D.; Arthur, Mary A. (7/1/12). Determination of foliar Ca/Sr discrimination factors for six tree species and implications for Ca sources in northern hardwood forests. *PLANT AND SOIL*. 356 (1-2), 303-314.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Hufkens, Koen; Friedl, Mark A.; Keenan, Trevor F.; Sonnentag, Oliver; Bailey, Amey; O'Keefe, John; Richardson, Andrew D. (7/1/12). Ecological impacts of a widespread frost event following early spring leaf-out. *GLOBAL CHANGE BIOLOGY*. 18 (7), 2365-2377.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Kang, Phil-Goo; Mayer, Bernhard; Mitchell, Myron J. (1/1/12). Comparison of sample preparation methods for stable isotope analysis of dissolved sulphate in forested watersheds. *ISOTOPES IN ENVIRONMENTAL AND HEALTH STUDIES*. 48 (3), 410-420.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Knapp, Alan K.; Smith, Melinda D.; Hobbie, Sarah E.; Collins, Scott L.; Fahey, Timothy J.; Hansen, Gretchen J. A.; Landis, Douglas A.; La Pierre, Kimberly J.; Melillo, Jerry M.; Seastedt, Timothy R.; Shaver, Gaius R.; Webster, Jackson R. (4/1/12). Past, Present, and Future Roles of Long-Term Experiments in the LTER Network. *BIOSCIENCE*. 62 (4), 377-389.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes

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Lowe, Winsor H.; McPeck, Mark A.; Likens, Gene E.; Cosentino, Bradley J. (5/1/12). Decoupling of genetic and phenotypic divergence in a headwater landscape. *MOLECULAR ECOLOGY*. 21 (10), 2399-2409.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes

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

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1186/2192-1709-1-11

Groffman, P.M., L.E. Rustad, P.H. Templer, J.L. Campbell, L.M. Christenson, N.K. Lany, A.M. Soggi, M.A. Vadeboncoeur, P.G. Schaberg, G.F. Wilson, C.T. Driscoll, T.J. Fahey, M.C. Fisk, C.L. Goodale, M.B. Green, S.P. Hamburg, C.E. Johnson, M.J. Mitchell, J. (12/12/12). Long-Term Integrated Studies Show Complex and Surprising Effects of Climate Change in the Northern Hardwood Forest. *BioScience*. 52 1056-1066.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1525/bio.2012.62.12.7

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s10584-012-0517-2

Kerr, J. G., M. C. Eimers, I. F. Creed, M. B. Adams, F. Beall, D. Burns, J. L. Campbell, S. F. Christopher, T. A. Clair, F. Courchesne, L. Duchesne, I. Fernandez, D. Houle, D. S. Jeffries, G. E. Likens, M. J. Mitchell, J. Shanley and H. Yao. (1/2/12). The effect of seasonal drying on sulphate dynamics in streams across southeastern Canada and the northeastern USA.. *Biogeochemistry*. 111 393-409.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s10533-011-9664-1.

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s10021-012-9627-y

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1111/j.1442-9993.2011.02351.x

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1177/0309133312440216

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1029/2011WR011228

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, and more (12/3/12). Local-scale Carbon Budgets and Mitigation Opportunities for the Northeastern United States.. *BioScience*. 61 (1), 23-28.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1525/bio.2012.62.1.7

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1890/12-0751.1

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: <http://dx.doi.org/10.5849/jof.11-087>

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Status = PUBLISHED; Acknowledgment of Federal Support = Yes

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

Lin, Teng-Chiu; Hamburg, Steven P.; Lin, Kuo-Chuan; Wang, Lih-Jih; Chang, Chung-Te; Hsia, Yue-Joe; Vadeboncoeur, Matthew A.; McMullen, Cathy M. Mabry; Liu, Chiung-Pin (1/1/11). Typhoon Disturbance and Forest Dynamics: Lessons from a Northwest Pacific Subtropical Forest. *ECOSYSTEMS*. 14 (1), 127-143.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes

Likens, Gene E.; (1/1/11). Limnological measures related to climate change in the Hubbard Brook Valley, USA. *INLAND WATERS*. 1 (2), 93-99.

Status = PUBLISHED; Acknowledgment of Federal Support = Yes

## Books

### Book Chapters

Likens, G. E., T. J. Butler and M. A. Rury. (2012). Acid rain. *Encyclopedia of Global Studies*. Anheier, H.K., Juergensmeyer, M.. Sage Publications. Los Angeles, CA. 17.

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

### Thesis/Dissertations

Werner, S.. *Landscape patterns of soil oxygen availability and trace gas dynamics in a northern hardwood forest*. (5/31/11). Syracuse University.

Acknowledgment of Federal Support = Yes

### Conference Papers and Presentations

Yanai, Ruth, Carrie R. Levine, Mark B. Green, John L. Campbell, Matthew A. Vadeboncoeur, Steve Hamburg. (9/9/12). *Is the missing nitrogen source (or sink) at Hubbard Brook statistically significant? Quantifying Uncertainty in Ecosystem Studies (QUEST)*. Long Term Ecological Research All Scientists Meeting. Estes Park, CO.

Status = OTHER; Acknowledgement of Federal Support = Yes

Craig See, C., R. Yanai, J. Campbell, D. Moore, G. Likens, E. Matsuzaki. (9/9/12). *A proposed cross-site comparison of missing data in long-term hydrologic datasets*. Long Term Ecological Research All Scientists Meeting. Estes Park, CO.

Status = OTHER; Acknowledgement of Federal Support = Yes

Bae, K., R. Yanai, and T. Fahey. (9/9/12). *No fertilization effects on soil respiration and root respiration in northern hardwoods of New Hampshire*. Long Term Ecological Research All Scientists Meeting. Estes Park, CO.

Status = OTHER; Acknowledgement of Federal Support = Yes

Yanai, R.D., J. Campbell, S. L. LaDeau, K.C. Weathers, C.R. See, and M.B. Green. (8/8/12). *Quantifying Uncertainty in Precipitation Estimates*. Ecological Society of America Annual Meeting. Portland, OR.

Status = OTHER; Acknowledgement of Federal Support = Yes

Bae, K., Yanai, R.D., S.P. Hamburg, J.D. Blum, M.A. Arthur, M.A. Vadeboncoeur, C.R. See, and C.R. Levine (8/6/12). *Sustainable harvest requires calcium supply from soil pools: Ecosystem budgets for second-growth northern hardwoods in New Hampshire*. Ecological Society of America Annual Meeting. Portland, OR.

Status = OTHER; Acknowledgement of Federal Support = Yes

See, C., B.A. Quintero, and Yanai, R.D. (8/6/12). *Nitrogen and phosphorus resorption efficiency ratios vary with stand age in northern hardwoods*. Ecological Society of America Annual Meeting. Portland, OR.

Status = OTHER; Acknowledgement of Federal Support = Yes

Yanai, R.D., C.R. Levine, C.R. See, J.L. Campbell, M.B. Green, S.L. LaDeau. (7/11/12). *Certain Progress in Uncertainty Analysis*. Hubbard Brook Ecosystem Study Annual Cooperators. West Thornton, NH.

Status = OTHER; Acknowledgement of Federal Support = Yes

Levine, C.R., R.D. Yanai, J.L. Campbell, M.B. Green. (3/13/12). *Quantifying Uncertainty in Ecosystem Studies*. Northeast Soil Monitoring Cooperative Annual Meeting. Troy, NY.

Status = OTHER; Acknowledgement of Federal Support = Yes

Bae, K., R.D. Yanai, T.J. Fahey, and M.C. Fisk. (1/26/12). *Fine root biomass and soil respiration reflect belowground carbon allocation in response to nutrient limitation in New Hampshire northern hardwoods*. New York Society of American Foresters Winter Meeting. East Syracuse, NY.

Status = OTHER; Acknowledgement of Federal Support = Yes

See, C.R., R.D. Yanai, and B.A. Quintero. (1/26/12). *Nitrogen and phosphorus resorption efficiency ratios vary with stand age in northern hardwood forests*. New York Society of American Foresters Winter Meeting. East Syracuse, NY.

Status = OTHER; Acknowledgement of Federal Support = Yes

Diggs, F., R. Yanai, and T. Horton (1/26/12). *Mycorrhizae distributions by depth in northern hardwood ecosystems*. New York Society of American Foresters Winter Meeting. East Syracuse, NY.

Status = OTHER; Acknowledgement of Federal Support = Yes

Levine, C.R., R.D. Yanai, J.L. Campbell, M.B. Green. (1/11/12). *Quantifying Uncertainty in Ecosystem Studies*. Hubbard Brook Cooperators Meeting. Millbrook, NY.

Status = OTHER; Acknowledgement of Federal Support = Yes

Frey, S. J. K., N. Rodenhouse, S. Sillett, R. Holmes, M. Betts. (8/14/12). *Ups and downs: long-term songbird population trends across an elevational gradient in the Hubbard Brook Experimental Forest, NH*. North American Ornithological Societies. Vancouver, BC.

Status = OTHER; Acknowledgement of Federal Support = Yes

Hallworth, M., S. Sillett, P. Marra. (8/14/12). *Quantifying migratory connectivity for a neotropical migratory bird using direct and indirect techniques*. North American Ornithological Societies. Vancouver, BC.

Status = OTHER; Acknowledgement of Federal Support = Yes

Kaiser, S.A., T.S. Sillett, N.L. Rodenhouse, R.T. Holmes, M.S. Webster, Michael S. (8/14/12). *Sex-specific parental responses to weather-induced variability in food resources across a climate gradient*. North American Ornithological Societies. Vancouver, BC.

Status = OTHER; Acknowledgement of Federal Support = Yes

Lany, N.K, M.P. Ayres, E.E. Stange, T.S. Sillett, N.L. Rodenhouse, and R.T. Holmes. (8/14/12). *Spring leaf phenology, insect availability, and the timing of breeding by a migratory songbird in a North American temperate forest.* North American Ornithological Societies. Vancouver, BC.

Status = OTHER; Acknowledgement of Federal Support = Yes

Matthews, S., L. Iverson, A. Prasad, M. Peters, N. Rodenhouse (8/15/12). *Integrating pattern and process across spatial scales to assess the potential effects of climate change on forest birds.* North American Ornithological Societies. Vancouver, BC.

Status = OTHER; Acknowledgement of Federal Support = Yes

McDonald, M.J., Jr. (7/11/12). *Moose and Black-throated Blue Warblers: Commensalism?* 48th Annual Meeting of the Hubbard Brook Cooperators. North Woodstock, NH.

Status = OTHER; Acknowledgement of Federal Support = Yes

Townsend, A., S. Sillett, M. Webster, E. Cooch, N. Lany, S. Kaiser, N. Rodenhouse, R. Holmes. (8/15/12). *Warm spring linked to higher fecundity, lower survival, and stable populations of black-throated blue warblers.* North American Ornithological Societies. Vancouver, BC.

Status = OTHER; Acknowledgement of Federal Support = Yes

#### Other Publications

Rustad, L. E. and K. F. Lambert, J. Campbell, J. Dukes, T.G. Huntington, J. Mohan and N.L. Rodenhouse. (7/10/12). *Changing Climate, Changing Forests: the impact of climate change on forests of the northeastern United States and eastern Canada.* USDA forest Service Northern Research Station, General Technical Report NRS-99. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 48 p..

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: Hubbard Brook Ecosystem Study

URL: <http://www.hubbardbrook.org>

Description: Posting of related educational-support materials can be found at this link.

Title: Hubbard Brook Research Foundation

URL: <http://www.hubbardbrookfoundation.org>

Description: Postings of related educational support material can be found at this link.



- Title: Bird population and community studies at HBEF  
 URL: <http://www.hubbardbrook.org/research/animals/bird/holmes-intro03.htm>  
 Description: An introduction to ongoing research projects re bird population and community studies.
- Title: Smithsonian Migratory Bird Center  
 URL: <http://nationalzoo.si.edu/scbi/migratorybirds/blog/default.cfm?id=5>  
 Description: A description of our research on the effects of climate change on Black-throated Blue Warblers is presented at this site.
- Title: 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: Reproductive Success of Migratory Birds  
 URL: <http://hubbardbrookfoundation.org/what-limits-the-reproductive-success-of-migratory-birds/>  
 Description: Educational activity for high school students: an online population ecology model for reproductive success of the migratory songbird.
- Title: HBRF Science Links Program  
 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.

### Other Products

Product Type: Other

Description: The LTER grant partially supports the eddy covariance measurements made at the Bartlett Experimental Forest AmeriFlux site. Data through the end of 2011 have been contributed to the AmeriFlux database for processing and public distribution.

<http://ameriflux.ornl.gov/fullsiteinfo.php?sid=75>

Other: AmeriFlux site

## Participants

### Research Experience for Undergraduates (REU) funding

How many REU applications were received during this reporting period? 14

How many REU applicants were selected and agreed to participate during this reporting period? 4

### What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Gary M Lovett	Co-Investigator	2

Name	Most Senior Project Role	Nearest Person Month Worked
Gene E Likens	Co-Investigator	12
Donald C Buso	Other Professional	12
Mark B Green	Co-Investigator	1
Michael J Rice	Technician	12
Samuel Fashu-Kanu	Graduate Student (research assistant)	12
Afshin Pourmokhtarian	Graduate Student (research assistant)	12
Mario Montesdeoca	Technician	12
Colin Fuss	Graduate Student (research assistant)	12
Isaac Allen	Undergraduate Student	2
Jim Wood	Undergraduate Student	1
Austin McDonald	Undergraduate Student	0
Tim Hauber	Undergraduate Student	1
Shinjini Goswami	Graduate Student (research assistant)	7
Russell Auwae	Graduate Student (research assistant)	3
Tera Ratliff	Graduate Student (research assistant)	7
Owen Patterson	Technician	3
Joel Blum	Co-Investigator	1
Geoff Wilson	Other Professional	12
Jacquelyn Wilson	Other Professional	6
Peter M Groffman	Co-Investigator	2
Timothy J Fahey	PD/PI	1
Ruth Yanai	Co-Investigator	2

Name	Most Senior Project Role	Nearest Person Month Worked
Heather Engelman	Technician	4
William O'Neill	Technician	1
Andrew Richardson	Co-Investigator	1
Bridget O'Neill	Research Experience for Undergraduates (REU) Participant	3
Logan Bryant	Research Experience for Undergraduates (REU) Participant	3
Megan Mondelli	Research Experience for Undergraduates (REU) Participant	3
Leighton King	Research Experience for Undergraduates (REU) Participant	3
Joe Yahna	K-12 Teacher	1
Sarah Thorne	K-12 Teacher	0
Rick Biche	K-12 Teacher	1
Rebecca Steeves	K-12 Teacher	1
Peter Dumont	K-12 Teacher	1
Jonathan J Stein	Undergraduate Student	2
Anna L. Meyer	Undergraduate Student	2
John F. Butler	Undergraduate Student	2
Brett C Manning	Undergraduate Student	3
Dana M. Williams	Undergraduate Student	1
Julie Vining	Undergraduate Student	1
Julia N Adams	Undergraduate Student	1
Stephen R Kolbe	Technician	2
Clarice Bayer	Technician	3

Name	Most Senior Project Role	Nearest Person Month Worked
David P Grunzel	Technician	3
Michael J McDonald	Graduate Student (research assistant)	3
Nina K Lany	Graduate Student (research assistant)	3
Sarah J.K. Hadley	Graduate Student (research assistant)	2
Michael Hallworth	Graduate Student (research assistant)	3
Kikang Bae	Graduate Student (research assistant)	4
John J. Battles	Staff Scientist (doctoral level)	2
Nicholas Rodenhouse	Co-Investigator	3
Chris Johnson	Staff Scientist (doctoral level)	2
Melany Fisk	Co-Investigator	2
Myron Mitchell	Co-Investigator	2
Scott Bailey	Co-Investigator	2
Kevin McGuire	Co-Investigator	2
Michelle Pruyn	Co-Investigator	2
Tianjun Hou	Undergraduate Student	2
Alexis Heinz	Technician	1
Natalie Cleavitt	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Charles T Driscoll	Co PD/PI	12
Michelle Pruyn	Co-Investigator	1
Trevor Keenan	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Min Lee	Undergraduate Student	3
Lisa Martel	Technician	2

Name	Most Senior Project Role	Nearest Person Month Worked
Katherine Shepard	Technician	2
Lourdes Morillas	Graduate Student (research assistant)	2
Javier Roales	Graduate Student (research assistant)	2
Suzanne Pierre	Technician	1
Jorge Duran	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Jennifer Morse	Postdoctoral (scholar, fellow or other postdoctoral position)	9
Mary Margaret Koppers	Technician	6
Tamir Puntsag	Graduate Student (research assistant)	1
Cynthia Wood	Technician	6
Mary E Martin	Other	3
Edward J Donovan	Undergraduate Student	1
Ryan K Kolmeister	Undergraduate Student	1
Samuel Werner	Graduate Student (research assistant)	0

#### What other organizations have been involved as partners?

Name	Location
Hubbard Brook Research Foundation	Woodstock, NH
Plymouth State University	Plymouth, NH

#### 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.

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## **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.