New Challenges for the Third Decade of Whole-Ecosystem Experimental Manipulations at the Bear Brook Watershed in Maine (BBWM)

Ivan J. Fernandez[1], Stephen A. Norton[1], G. Bruce Wiersma[1], Lindsey E. Rustad[2] and Kevin S. Simon[1]

[1]University of Maine and [2]USDA Forest Service

Introduction

The Bear Brook Watershed in Maine (BBWM) is a long-term paired forested watershed research site that uses whole ecosystem experimental manipulations to study the effects of chronic elevated nitrogen (N) and sulfur (S) deposition. Investigations include studies of numerous biogeochemical pools and fluxes, as well as soil ecology and tree biology. Many responses to treatment early in the project were correctly predicted; some decadal responses were not. As we begin the third decade of research, we have revealed the evolution of acidification, base cation depletion, ambient recovery to declining S deposition, accelerated N cycling, metal (Al and Fe) mobilization and associated consequences for phosphorus (P) dynamics, declines in fine root biomass, and tissue enrichment and depletion in tree roots-foliage-litter that parallels soil changes. There is no evidence of tree growth responses except for sugar maple, which is in decline. Ecosystem responses regarding N dynamics, sulfate adsorption, tree physiology and growth, metals and phosphorus now under investigation are different than predicted in 1989 and demonstrate the essentiality of long-term research. Current studies also include climate change, acidification responses, and the ecological stoichiometry of C, N, and P in terrestrial and stream ecosystems. To the right is a timeline of selected activities, stochastic events, and ecological surprises. The stochastic events become valuable research opportunities because they occur within the framework of the long-term research and can be studied. The ecological surprises are, in fact, examples of how short-term research can be poorly adapted to studying long-term environmental issues. This research has been supported by numerous sources of funding, including the National Science Foundation Long-Term Research in Environmental Biology program (NSF LTREB).

The BBWM Site

BBWM site location in eastern Maine.

- Bear Brook Watershed in Maine (BBWM) is located in eastern Maine, USA, 60 km from the Atlantic Ocean.
- East and West Bear Brook form the paired-watershed experiment at BBWM, and drain an11.0 and 10.3 ha watershed each, respectively.
- The lower reaches of the watersheds are dominated by northern hardwoods, with the upper reaches dominated by softwoods, primarily red spruce.

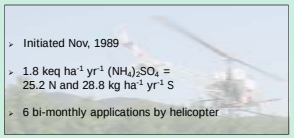
BBWM v-notch weir (East Bear), gage House, and precipitation monitoring station.

Methods

- The experimental design at BBWM consists of two 1st order forested stream watersheds with two major forest types represented in each watershed for a total of four compartments (1- East Bear Hardwoods, 2- East Bear Softwoods, 3- West Bear Hardwoods, 4- West Bear Softwoods)

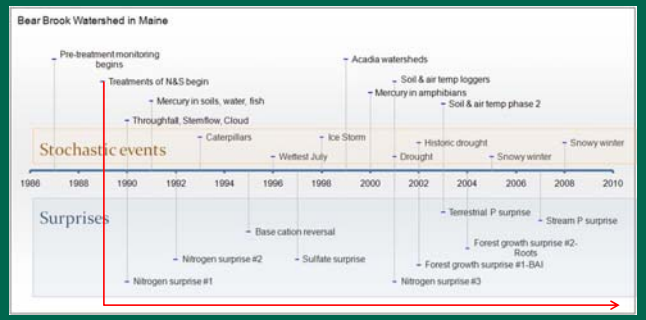
- Chemical and hydrological mass balance in each watershed is estimated from precipitation measurements (Aerochem metrics and Belfort collectors) and v-notch weirs with continuous measurements of hydrology (in collaboration with the U.S. Geological Survey) posted on the internet in real time.
- Numerous studies over the past two decades have reported on form and function of soils, soil solutions, throughfall, stemflow, litterfall, litter decomposition, tree growth, foliar chemistry, root processes, precipitation, and streams.
- Some measurement systems are anchored in long-term plots, sample trees, and experimental locations that provide for long-term continuity in this research.

Treatments

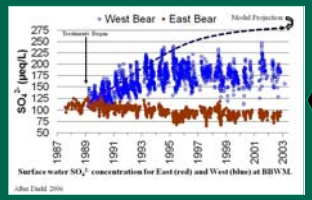


USGS Gaging

A BBWM Timeline of Events

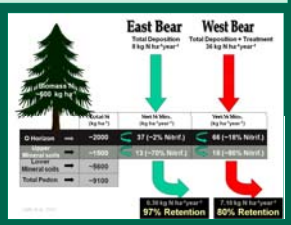


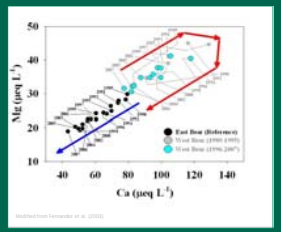
Examples of BBWM Science



Stream SO_4 - The time series of stream SO_4 concentrations shows (a) increasing stream SO_4 concentrations in the treated West Bear, (b) a trend for decreasing concentrations in East Bear due to declining ambient SO_4 deposition, and (c) a plateau in the West Bear SO_4 concentrations after 1995 despite continued treatments. This was not predicted by the models that supported Clean Air Act policy, and current research is trying to define the underlying mechanisms for this unexpected long-term response to treatments.

Nitrogen Mass Balance - Unlike SO_4, controls on N dynamics in forestecosystems are complex, and strongly influenced by biotic factors. The figure to the right shows elements of a N mass balance demonstrating (a) a nearly total retention of N in East Bear, (b) a high N retention in West Bear despite the years of N additions, and (c) accelerated N cycling within the West Bear watershed as a result of N additions.

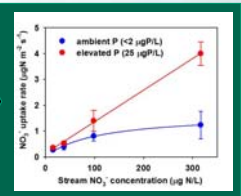




Base Cation Depletion - This figure shows the progression over time of the volume-weighted Ca and Mg concentrations in East and West Bear streams. West Bear shows a treatment induced increased export phase followed by depletion after ~1995. East Bear shows a progressive decline in the reference stream in response to declines in ambient SO_4 deposition over the nearly two decades of this study. No new equilibrium has yet been achieved. Total Ca export is approximately equal to soil Ca and Mg depletion as determined from quantitative soil pit studies.

Sugar Maple Decline – Treatments have increased concentrations of nutrients in most trees. To date, almost no aboveground changes in tree growth have been detected. Sugar maple is the exception, and appears to have rapidly increased increment growth rates in response to treatments, yet both watersheds now show an ongoing growth decline. Current research is determining the mechanisms for these growth trends and the degree to which this is characteristic of sugar maple in the region.

Ecological Stoichiometry – This figure illustrates microbial uptake of NO_3 in the streambed of the reference watershed with and without the addition of P. The lower curve flattens out because demand for N becomes saturated with increasing N concentration in the water. Adding P dramatically increases in-stream N uptake. BBWM research is beginning to uncover both terrestrial and aquatic mechanisms defining the interaction of N and P limitations that are enhanced by both watershed treatments and a changing climate.



Accomplishments

The BBWM program has tested hypothesis and provided empirical evidence of biogeochemical and ecological processes not recognized as critical prior to this research. Only through long-term, intensive research can this be accomplished. Broad highlights of the work ongoing at BBWM include:

- Over 75 graduate and undergraduate students have gained experience in research through undergraduate student researcher positions and graduate thesis research. Numerous others have utilized BBWM for classroom projects and examples of science.
- BBWM has resulted in >100 papers in the scientific literature, and has resulted in even more presentations at various scientific conferences.
- Research results from BBWM have directly and indirectly contributed to environmental decision-making on state and national policy.
- BBWM has been utilized by high school science teachers and students to gain hands-on experience in research.
- BBWM is one of the few forested watershed research sites in the world capable of defining whole ecosystem responses on decadal time-scales.
- BBWM remains a key site contributing data and findings to regional, national, and international syntheses.

The Future

The Bear Brook Watershed in Maine continues to test hypotheses on watershed acidification, recovery from S deposition, N saturation, base cation depletion, carbon sequestration and fractionation, the effects of these changes on the ecological stoichiometry of C, N, and P, and the biogeochemical response of these ecosystems to a changing climate.

Notable scientific objectives as BBWM begins the third decade of research and whole-ecosystem experimental manipulations include:

- What are the controlling mechanisms for S retention and release? We have discovered that our understanding of short-term response mechanisms do not persist on a decadal time scale.
- What is the fate of chronically elevated N deposition to these forests? Has West Bear achieved a new equilibrium or will retention continue to decline? Is "N Saturation" evident and progressive?
- How does extant climate warming and late season soil moisture stress alter biogeochemical function? Can we model past responses and develop better projections for the future based on more mechanistic insights?
- What biological processes govern whole-ecosystem mass balance, particularly with respect to tree growth and microbial processes in soils and sediments?
- How does decadal scale N enrichment from below alter C cycling in these forests? What shifts in the ecological stoichiometry of C, N, and P are emerging and what is their importance in ecosystem function?

Acknowledgements

Support for the Bear Brook Watershed in Maine over the past twenty years has been the result of funding from the U.S. Environmental Protection Agency, the USDA Forest Service, the Maine Agricultural and Forest Experiment Station, the forest products industry, and the National Science Foundation. This project would not have persisted without the support of the National Science Foundation Long-Term Research in Environmental Biology Program (NSF LTREB). BBWM is currently partially supported through NSF LTREB contract DEB-0639902 as we begin hypothesis testing in the third decade.