Evidence of Transient Alteration of N Dynamics From an Ice Storm at the Bear Brook Watershed in Maine, USA

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INTRODUCTION

The Great Ice Storm of 1998

The North American Ice Storm of 1998 represented a unique meteorological event that resulted in damage to forests and transmission electrical infrastructure through specific areas of the eastern Canada and the northeastern U.S. This unique event occurred when cold air aloft resulted in frozen precipitation falling through a warmer air mass (with melting), then passing through a cold air mass at ground level. At ground level, the rain was super-cooled and it froze on contact. The severity of the 1998 event was largely attributable to the slow rate of movement of air masses causing these atmospheric conditions to persist for 3-5 days, allowing the accumulation of thick ice coatings that brought down power lines, branches, and entire trees. Figure 1 shows the distribution of the most heavily affected areas. The Bear Brook Watershed in Maine (BBWM) is a long-term ecosystem experiment located in the eastern portion of the damage range.

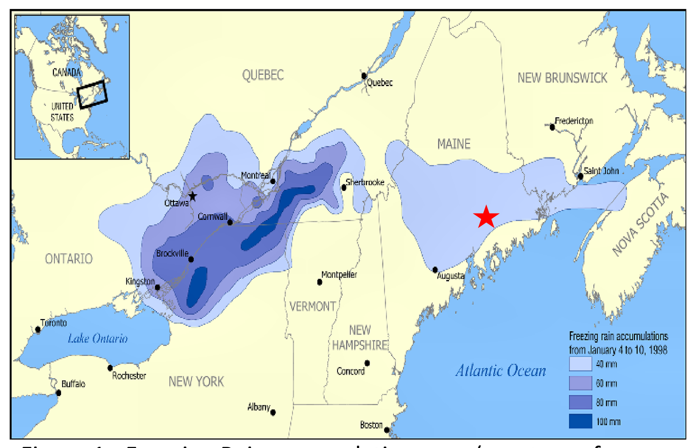


Figure 1 - Freezing Rain accumulation map (courtesy of Environment Canada) shows a large expansive area of ice accumulation greater than 40 millimeters (25.4mm equals 1 inch) across southeastern Canada, northern New York into the Champlain Valley of Vermont as well as central Maine. (http://www.erh.noaa.gov/btv/events/IceStorm1998/ice98.shtml)

Figure 2 - Example of Ice Storm damage in Maine during the Great Ice Storm of 1998.
http://fredlanga.blogspot.com/2008/12/ice-storm-1.html

Although no quantitative studies were conducted to define the damage to vegetation at the time, field observations indicated that light damage to the forest canopy was evident, primarily confined to the hardwood stands, creating small gaps in the canopy and the associated pulse of additional litterfall.

Objectives

The objectives of study were to evaluate patters of stream NO_3 concentrations and flux in the reference (East Bear) and treated (West Bear) watershed streams to determine the effects of ecosystem disturbance attributable to the 1998 ice storm.

Figure 3: Example of Ice Storm accumulations on tree foliage in Maine.
http://fredlanga.blogspot.com/2008/12/ice-storm-1.html

The Bear Brook Watershed in Maine

BBWM is in eastern Maine at 44°52' N. lat. and 68°06' W. long., 40 km inland from the Gulf of Maine. The watersheds occupy the upper 210 m of the southeast slope of Lead Mountain (elev. 475 m). Two nearly perennial, low dissolved organic carbon (DOC), low acid neutralizing capacity (ANC) streams drain the 10.3 and 11.0 ha contiguous watersheds. The forest is mixed northern hardwoods (*Fagus grandifolia* Ehrh., *Acer rubrum* L., *Acer saccharum* Marsh., *Betula alleghaniensis* Britton, *Betula papyrifera* Marsh., and *Acer pensylvaticum* Marsh.) with stands of softwoods (*Picea rubens* Sarg., *Abies balsamea* Mill., and *Tsuga canadensis* (L.) Carr.) dominating at higher elevations. Soils are predominantly coarse, loamy, mixed, frigid Typic Haplorthods, with Typic Haplohumods and Lithic Cryofolists, all derived from till averaging 0.9 m in thickness. The bedrock is dominantly quartzite and phyllite, intruded by dikes of granite. In WB, we have applied ammonium sulfate [$(NH_4)_2SO_4$] aerially to the entire watershed, bi-monthly since November of 1989, experimentally increasing N and S deposition by 25.2 kg S $ha^{-1}yr^{-1}$ and 28.8 kg N $ha^{-1}yr^{-1}$, respectively.

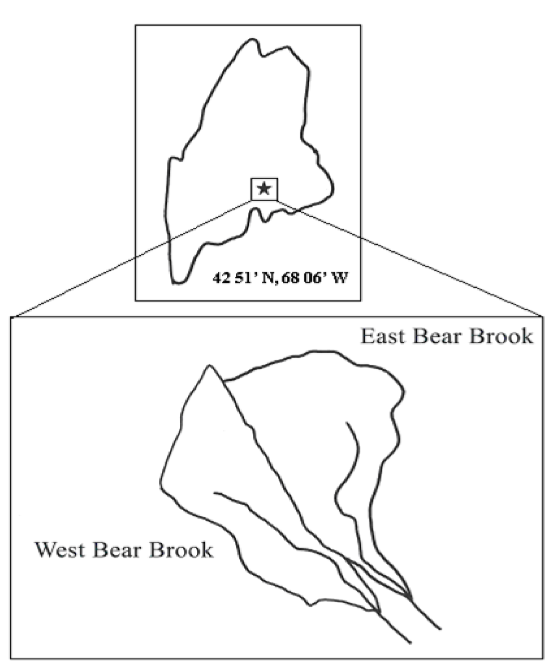
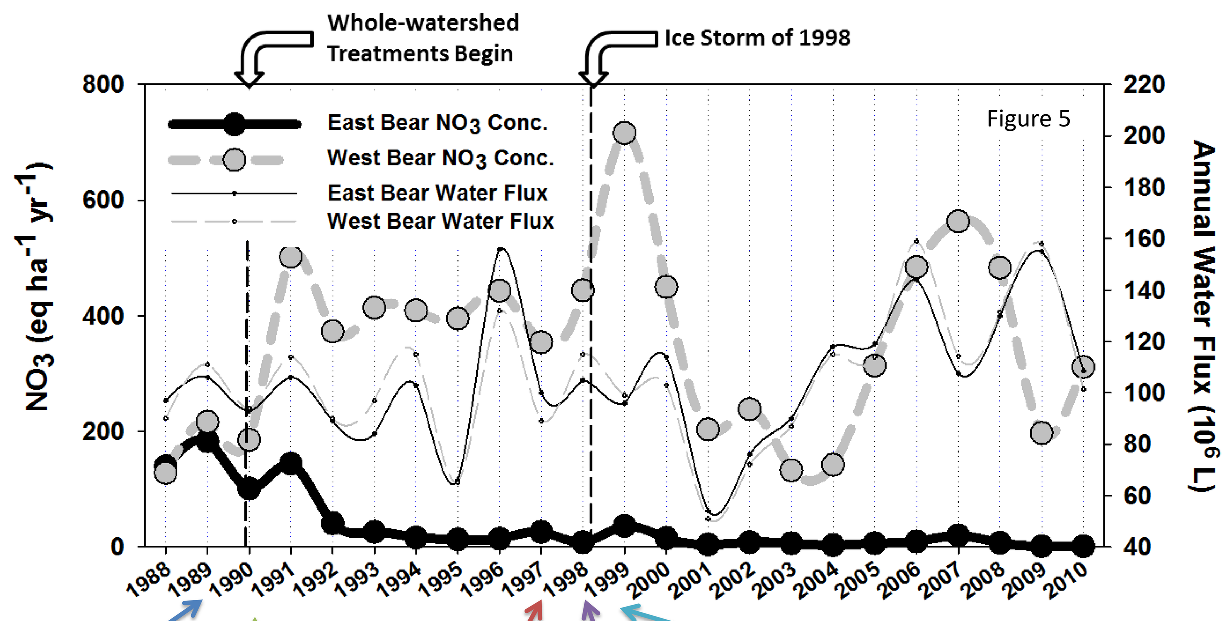


Figure 4 -Relative location and set up of Bear Brook Watershed In Maine

RESULTS AND DISCUSSION

Figure 5. Annual flow-weighted mean concentrations of NO_3 and hydrologic flux in streams from 1988-2010. Total dissolved inorganic N (DIN) export was only slightly greater, as NH_4 is typically <10% of DIN and nearly always <1 µeq L^{-1}. Because NH_4 stream data are incomplete, we present only the NO_3 concentrations.



Prior to 1990, calibration monitoring showed good agreement between East and West Bear Brook [NO_3]. Both were elevated as was typical in the early 1990s; this was attributed to climatic factors that influenced surface waters in the region (Mitchell et al. 1996).

After whole-watershed treatments began, East Bear stream [NO_3] decreased to near detection limits while West Bear [NO_3] increased.

The Great Ice Storm of 1998 altered the pattern of N dynamics in West Bear (an initial increase, followed by decrease in [NO_3]). East Bear stream [NO_3] was largely unaltered.

In the **1998 growing season following** the winter ice storm, [NO_3] during high flow events captured with ISCO samplers increased by ~23% over weekly stream samples, compared with 12% higher in the year prior to the ice storm.

In 1999, West Bear had overall increased [NO_3], which we attribute to increased litter input from storm damage, especially in hardwoods, and even greater impacts on mineralization in the forest floor from increased insolation. This was similar to findings at Hubbard Brook (Bernhardt et al. 2003), where it was suggested that [NO_3] export would have been even higher if it were not for in-stream N uptake. The N enrichment in West Bear has reduced in-stream N uptake (Mineau et al. 2012) and facilitated the strong [NO_3] stream signal evident in West compared to East Bear.

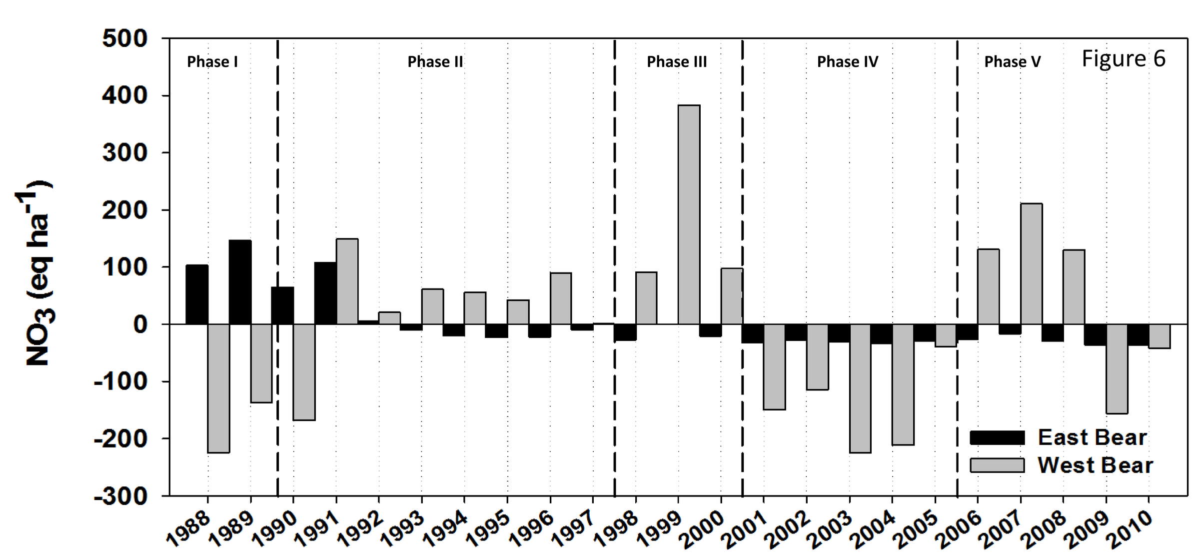


Figure 6. Differences in annual stream NO_3 flux compared to the 22 year mean flux for each watershed. These data suggest patterns of NO_3 through time that help define the influence of the ice storm on watershed N dynamics.

Phase I → Flux differences prior to whole-watershed treatments to West Bear.

Phase II → Post-treatment phase with consistent low East Bear NO_3 export and elevated West Bear NO_3 export in response to treatments.

Phase III → The immediate, acute ice storm response showing accelerated stream NO_3 export in West Bear, with 1999 being the most dramatic. There was little evidence of accelerated export in East Bear with continued high N retention in the ecosystem.

Phase IV → This phase represents a period of intensified N retention in West Bear and no notable change in East Bear stream NO_3 export. This response may reflect a depletion of labile N and C pools in the soil during Phase III, likely in the hardwood component of the watersheds. It is noteworthy that there was a consistent pattern of accelerated NO_3 retention in West Bear for 5 years following Phase III.

Phase V → This period may or may not represent a new steady-state variability in N dynamics, and additional years of data will be required to address this unknown.

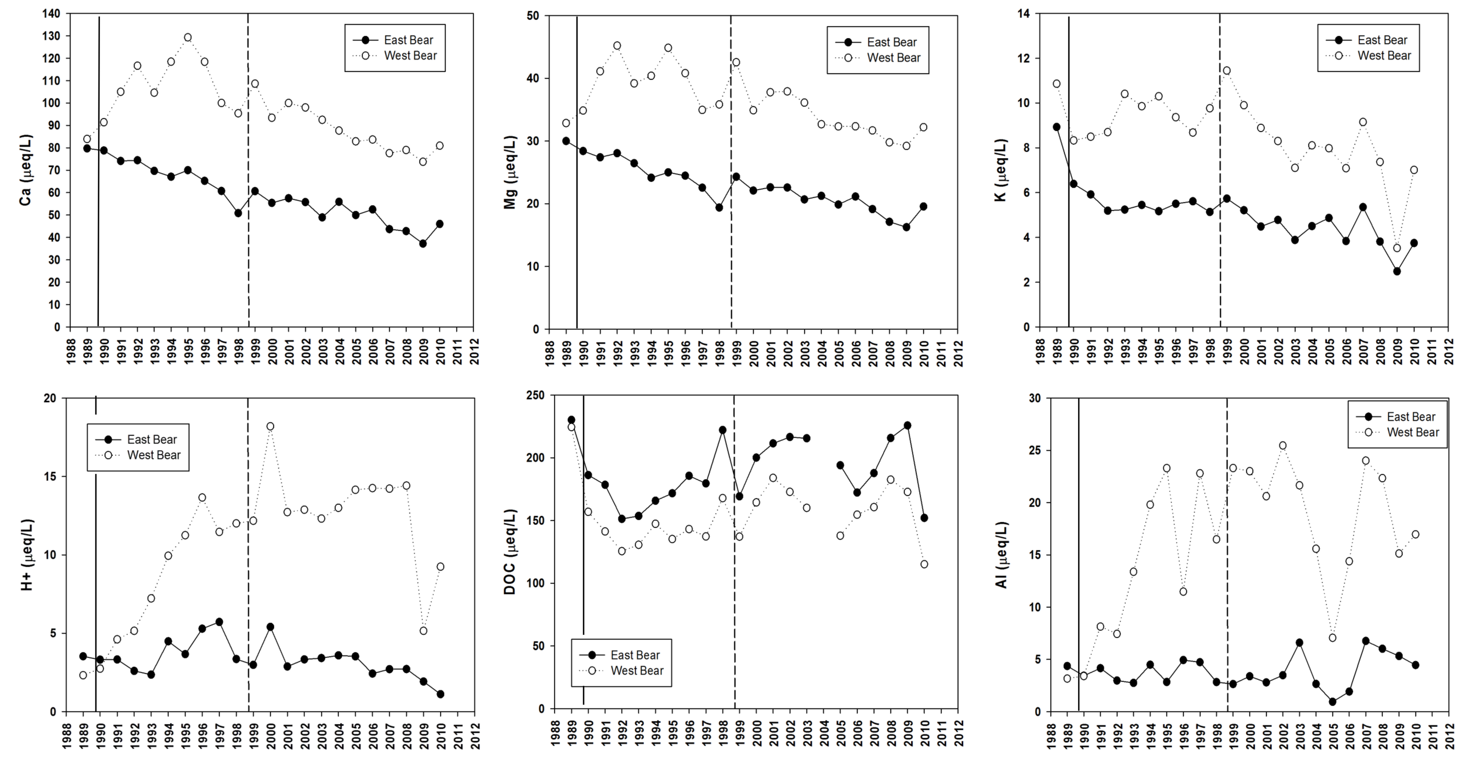


Figure 7. Time series for flow-weighted concentrations of complementary solutes in East and West Bear streams. Solid vertical line represents the start of whole-watershed treatments to West Bear. Dashed vertical line represents the 1998 ice storm.

- The base cations calcium (Ca), magnesium (Mg), and potassium (K) all showed a limited response to the ice storm with increased concentrations for 1-2 years in the context of an overall long-term decline. This increase would be driven by both increased mineralization and increased export of strong anions.
- There was a multi-year increase in dissolved organic carbon (DOC) of greater duration in West Bear compared to East Bear stream. This, along with a decrease in pH, are consistent with increased mineralization and nitrification.
- No clear response signal was evident for aluminum (Al).

Table 1 - O horizon fine earth (<6 mm) total N (kg ha^{-1}) and C/N ratio for Bear Brook 1998 and 2006 quantitative soil studies. Data are presented by study compartment as East Bear hardwoods (EBHW), East Bear softwoods (EBSW), West Bear hardwoods (WBHW), and West Bear softwoods (WBSW). Significantly different means between years within compartments are noted by an asterisk (after SanClements et al., 2010).

Parameter	Year	Study Compartment			
		EBHW	EBSW	WBHW	WBSW
Total N	1998	1511 *	2718	1350	2537
	2006	584	2339	797	1888
C/N	1998	24	30	25 *	27
	2006	23	32	22	27

Little evidence exists in tree foliar chemistry (e.g., Elvir et al. 2005) to suggest an increased N uptake specifically associated with the ice storm of 1998. SanClements et al. (2010) found overall declines in O horizon N pools between 1998 and 2006, but only the differences in the East Bear hardwood compartment of the study were significant. This could support the hypothesis that accelerated mineralization immediately following the ice storm in 1998 reduced forest floor mass, consistent with the N dynamics model proposed here. At the same time, warming trends over recent decades could also be a factor in lower O horizon mass and N content.

CONCLUSION

It is challenging to determine many of the ecological consequences of stochastic events like The Great Ice Storm of 1998 in the absence of long-term ecological data. The Bear Brook Watershed in Maine represents a type of ecological observatory that provides a multi-decadal time series of stream responses in the context of a paired watershed experiment. It is within that longer-term framework that we can better define complex responses in ecosystem function. The data suggest a multi-phase response in West Bear to this acute disturbance that lasted for 5-7 years. These results suggest an immediate acceleration of N export from the West Bear watershed because N retention in both the soils and streams was significantly lower due to long-term N enrichment. In East Bear, the reference watershed, any acceleration of NO_3 production in the soils was retained in soil, vegetation, and the stream before export at the weirs.

References

Elvir, J.A., L. Rustad, I. Fernandez, G.B. Wiersma. 2005. Can. J. For. Res. 35:1402-1410.

Mitchell, M.J., C.T. Driscoll, J.S. Kahl, G.E. Likens, P.S. Murdoch, L.H. Pardo. 1996. Environ. Sci. Technol. 30:2609–2612.

Mineau, M.M., K.S. Simon, I.J. Fernandez, S.A. Norton, H.M. Valett. 2012. In: Fernandez, I.J. et al. (eds.) BIOGEOMON 2012 – 7th International Symposium on Ecosystem Behavior. Conference Program and Abstracts. ISBN 978-0-87723-108-0. Villanova University.

Sanclements, M.D., I.J. Fernandez, S.A. Norton. 2010. Env. Monit. Assess. 171:111-128.

Bernhardt, E.S., G.E. Likens, D.C. Buso, C.T. Driscoll. 2003. Proc. Nat. Acad. Sci. 100:10304–10308.

This research is supported, in part, by the National Science Foundation Long-Term Research in Environmental Biology Program (DEB 0639902, 1119709). Other long term funding is through US EPA ORD and CAMD through the Universities of New Hampshire and Maine.