Climatic Trends at the Bear Brook Watershed in Maine – Biogeochemistry of the Vernal Transition

Patel, K.[1] and Fernandez, I. J.[1,2]

[1]School of Forest Resources, University of Maine, ME, USA [2]Climate Change Institute, University of Maine, ME, USA

Introduction

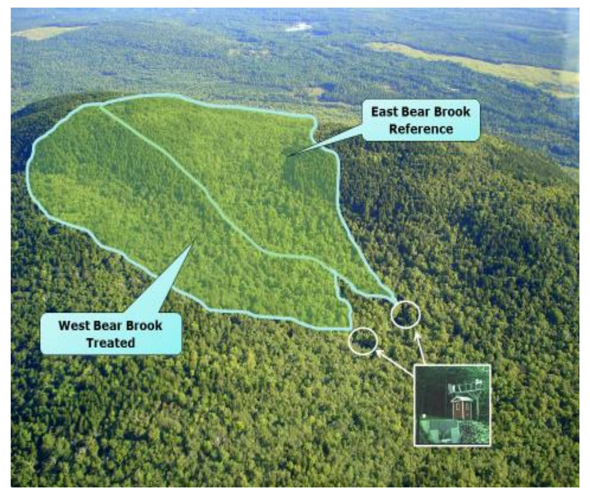
The northeastern region of the United States has been experiencing significant changes in climate; air temperatures have increased by about 0.8°C in the past century, with winter temperatures increasing more than summer temperatures (Hayhoe et al. 2007). Climate models predict a continuing warming trend, with projected increases of 2-5°C by 2100 (Groffman et al. 2012; IPCC, 2013). Long-term studies at the Bear Brook Watershed in Maine (BBWM) provide a framework to understand the relationships between changing climate and biotic and abiotic ecosystem processes. Snow acts as an insulator over the soil, reducing geothermal energy loss from the soil. It also forms a barrier to direct insolation and conduction from above. When the soil system transitions from winter conditions under the snowpack to exposed post-snowmelt conditions (i.e. the vernal transition), rapid changes take place in the physical soil environment (Groffman et al. 2001). With changing climate, snowmelt is demonstrating increased temporal variability, and biogeochemical processes could be influenced by these changes (Fitzhugh et al. 2003; Campbell et al. 2010). It is therefore of increasing importance to understand the biogeochemical characteristics of the vernal transition in order to determine the consequences of shifting temporal patterns of climate.

Key Questions

1. Is there evidence in the long-term record of data at the Bear Brook Watershed in Maine for linkages between snowmelt and biogeochemical processes, or changes in their timing?
2. Are nitrogen (N) and carbon (C) dynamics altered by the changing temporal characteristics of the vernal transition?
3. Does forest composition influence physical and biogeochemical processes associated with the vernal transition?

Site and Methods

This research is part of a long-term ecological research project at the BBWM in Beddington, Maine. Two paired watersheds, East Bear (reference) and West Bear (experimental) are just over 10 ha, and both are drained by first-order streams. The West Bear watershed has been chemically manipulated with bimonthly additions of ammonium sulfate ($(NH_4)_2SO_4$ (1,800 eq ha^{-1} year^{-1}) since the fall of 1989.



Both watersheds have similar vegetation, with the lower portions dominated by hardwoods (*Fagus grandifolia, Acer saccharum, Acer rubrum*), and the upper portions by softwoods (*Picea rubens, Abies balsamea, Tsuga canadensis*). Soils are Spodosols (Podzols) developed in thin till. Hardwoods are dominant on well-drained, thick (0.5-2 m) mineral soils in the lower elevations of the watershed, and softwoods dominate on thin (0-1m) mineral soils to Folists in the upper elevations (Norton et al. 1999).

Both streams have been continuously monitored for hydrology, with periodic sampling for stream chemistry since 1989. Data for stream samples reported here include dissolved organic carbon (DOC) and nitrate (NO_3^-), measured using OI Analytical Total Organic Carbon Analyzer and Dionex Ion Chromatograph, respectively. Discharge is reported as mean daily discharge in collaboration with the U.S. Geological Survey.

Snowpack records for Beddington were obtained from the Maine Geological Survey, which monitors snowpack weekly during the late winter.

A continuous record of air and soil temperatures was obtained using HOBO® data loggers. Multiple data loggers were installed and used in the hardwood and softwood compartments in both watersheds, the number varying over time.

In a pilot study, soils were sampled in the East Bear hardwood compartment for a total of 4 collections from January to May of 2014 to evaluate potential changes in soil chemistry with respect to snowpack dynamics. Twelve samples were collected at 1 m intervals along 3 transects 120° from each other, centered on a continuous monitoring HOBO® data logger.

Soils were extracted and analyzed using methods outlined in Ohno and Bro (2006), Weishaar et al. (2003) and Jefts et al. (2004). Deionized water extracts of the soil were analyzed for DOC concentrations using Shimadzu TOC Analyzer and absorbance characteristics on a Shimadzu UV-VIS Spectrophotometer and a Hitachi Fluorescence Spectrophotometer. Soils were extracted with 2 M KCl to quantify *in-situ* exchangeable NH_4-N. Soils (field moist) were incubated at ambient conditions for 14 days and subsequently extracted with 2 M KCl to quantify potential net N-mineralization (PNNM).

Exploring the vernal transition at BBWM: 2001-14

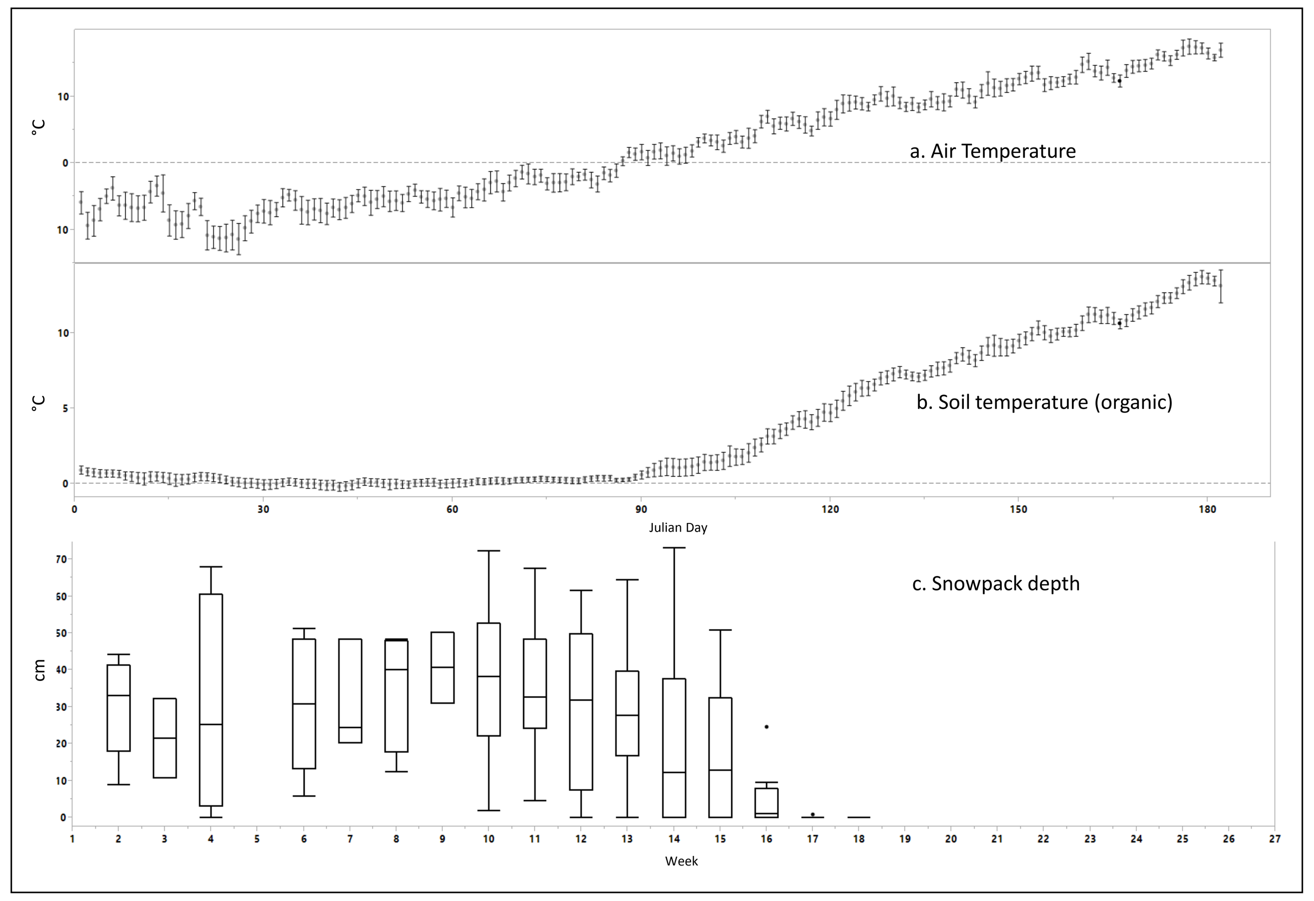


Figure 1
14-year daily averages (± standard error) for air temperature (1a) and soil temperature (1b) across the entire watershed, and 14-year weekly averages (± standard error) for snowpack depth (1c) for the months January through June.

Results: Air temperatures ranged from -25 to +25 °C; organic horizon temperatures ranged from -3 to +15 °C. Maximum snowpack depth ranged from 10 to 73 cm, with an average maximum depth of 49 cm across the 14 years; greatest snowpack depths were recorded in 2001 and 2011, while the lowest depth was recorded in 2006. Snowmelt typically begins around day 80-90, coincident with a rise in air and soil temperatures above 0 °C.

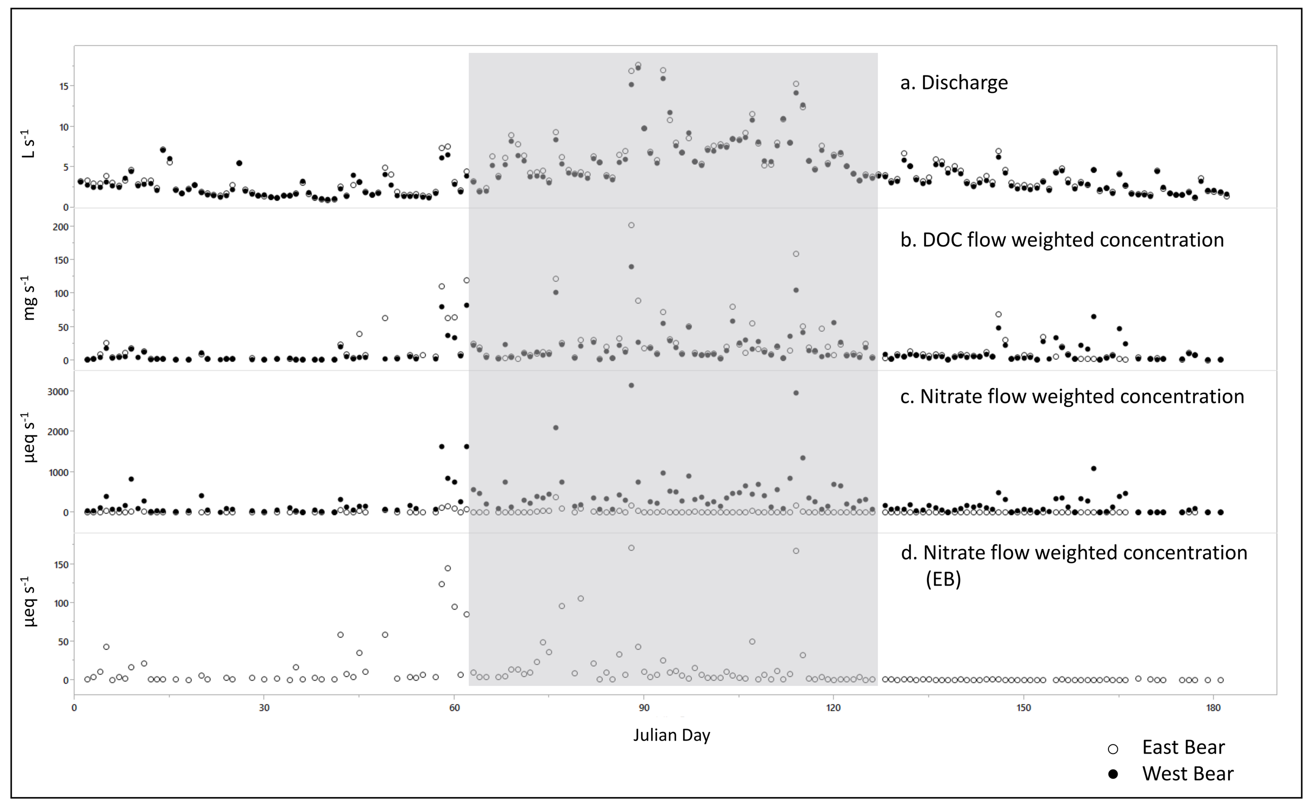


Figure 2
Long term 14-year averages for stream discharge (2a), as well as DOC (2b) and NO_3^-, expressed as flow weighted concentration. Stream NO_3^- is presented for both the reference East Bear and the experimental West Bear for comparison of watersheds (2c), as well as the reference East Bear alone (2d) in order to expand the scale.
The highlighted area represents the period of snowmelt activity over the 14 year period.

Results: Stream discharge increased during periods of snowmelt by 1-2 orders of magnitude.
Peak concentrations of DOC and NO_3^- occurred during snow thaw, attributable to release of NO_3^- stored in the snowpack, as well as flushing of DOC and NO_3^- from the soil. Both streams showed similar flow and chemistry patterns, although the NO_3^- concentration in WB was an order of magnitude greater due to the multi-decadal bimonthly N additions.

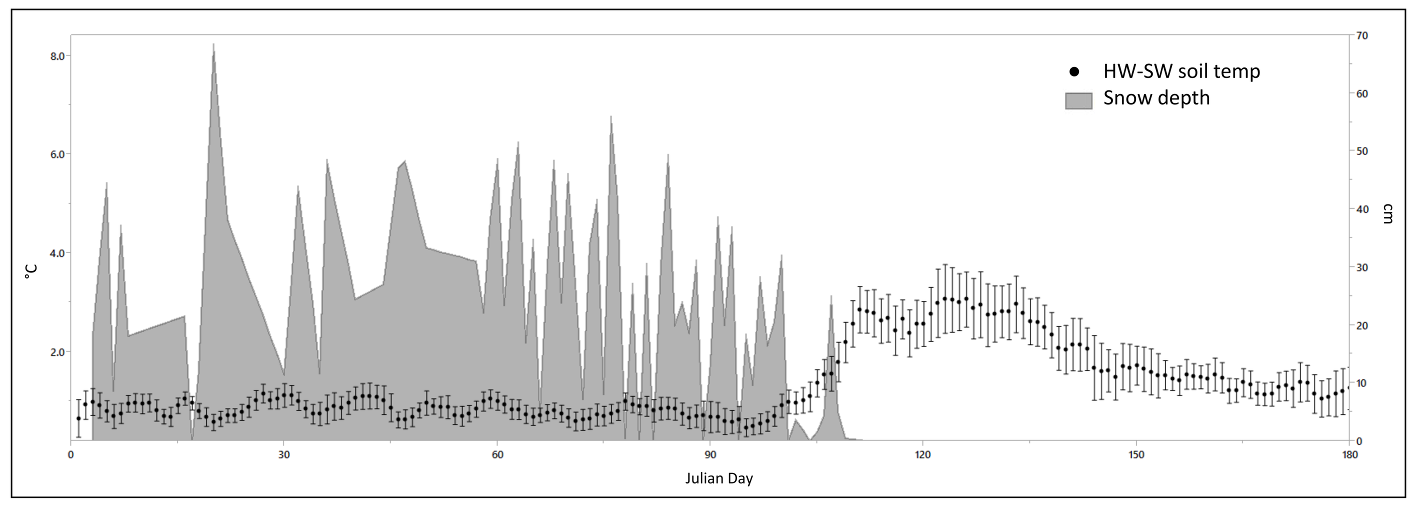


Figure 3
Changes in O horizon temperature in response to snowmelt. This is presented as the difference in soil temperature between hardwood and softwood forest types, averaged across the 14-year period (± standard error).

Results: Hardwood O horizon responded more rapidly to the loss of the snowpack with increasing temperatures in the late spring/early summer. Lack of foliar cover during the winter for hardwood species results in the earlier loss of the snowpack in the spring compared to the softwood forest type. The temperature difference decreases with leaf out, as canopy closure in the hardwoods progressively decreases insolation, making stand conditions more similar to softwoods.

Vernal transition 2014: A pilot study

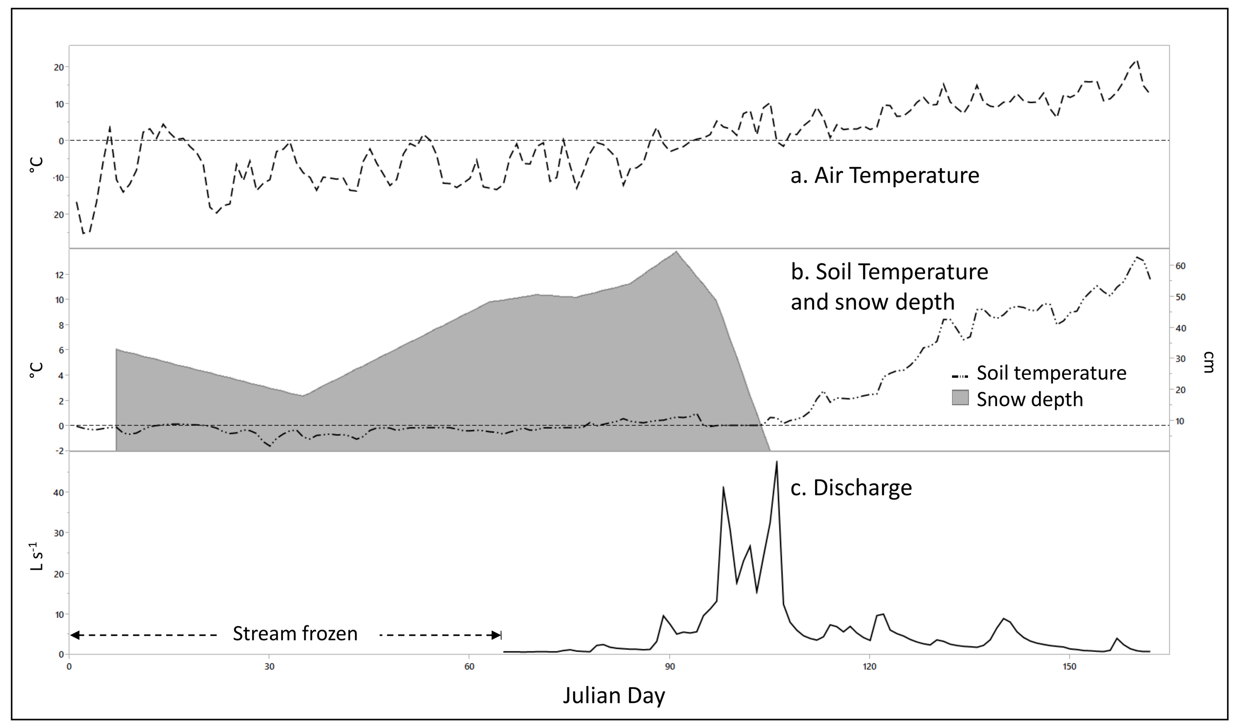


Figure 4
Daily averages for the year 2014 to date – air temperature (4a), soil temperature and snowpack depth (4b), and East Bear stream discharge (4c).

Results: The temporal trends observed for air temperature, soil temperature and snowpack depth during the 2014 pilot study followed the same pattern as observed over the long-term 14-year period at this site (see Figure 1).

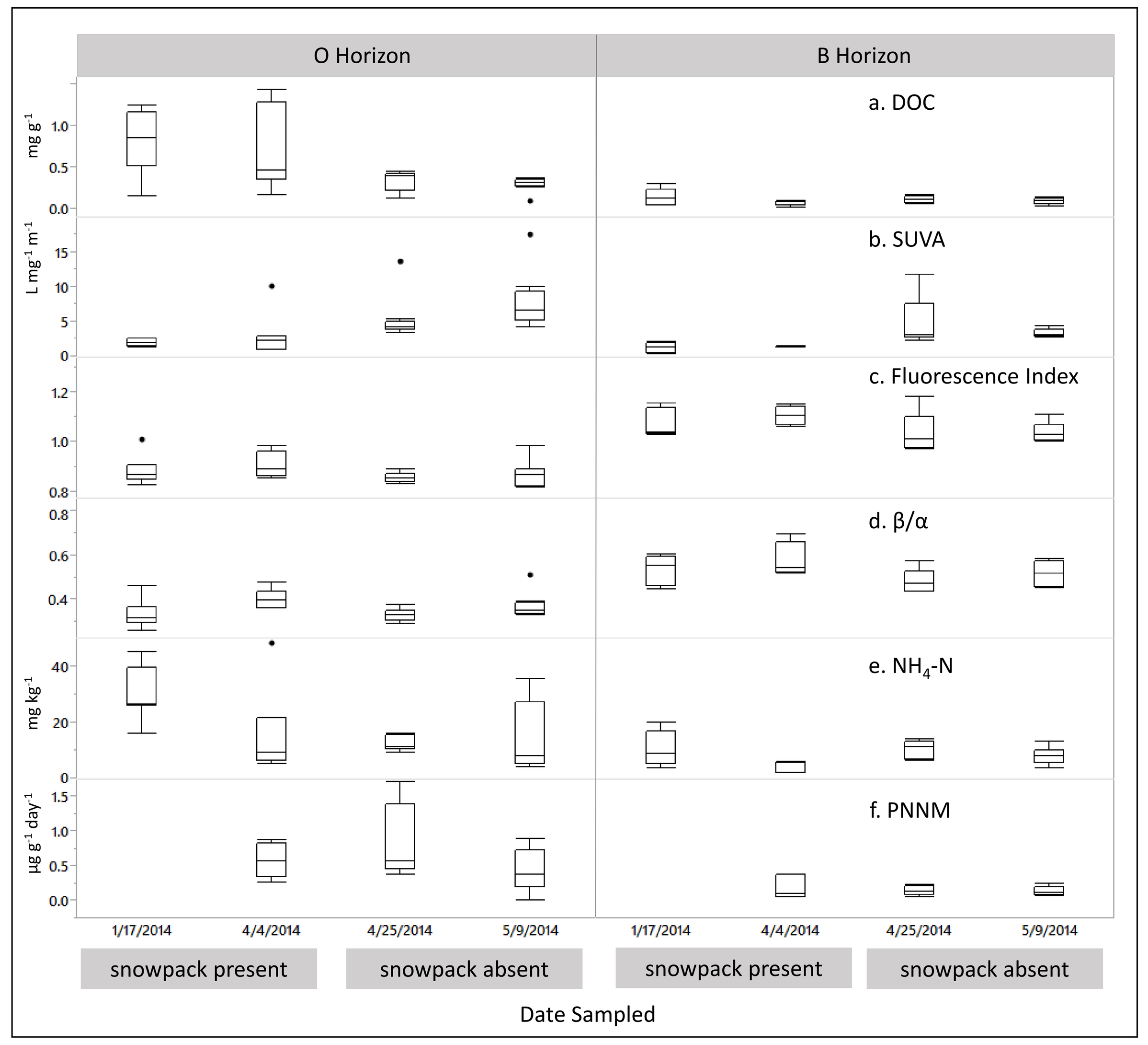


Figure 5
Soil C and N characteristics from the 2014 pilot study collections: extracted DOC concentration (5a), specific ultra-violet absorbance, SUVA (5b), fluorescence parameters (5c, 5d), extractable NH_4-N concentrations (5e), and potential net N-mineralization, PNNM (5f).

Results: DOC concentrations and fluorescence characteristics (fluorescence index and β/α ratio) of soil water extracts had no significant temporal trend during the transition from snowpack to post-snowpack conditions.
SUVA of organic horizon water extracts showed a significant increase after snowmelt, indicating that the organic matter was more aromatic after the snowpack disappeared.
Except for the January 2014 collection, no significant changes occurred in extractable NH_4-N concentrations and potential net N-mineralization (PNNM) of soils.

The January collection occurred during a period of unseasonably high temperatures and snow thaw, possibly explaining the deviation in NH_4-N concentration.
A comparison of the data presented here (5e) with past data for this site from during the growing season (not shown) indicated that there was no significant difference in winter/spring soil extractable NH_4-N concentration as compared to that during the growing season.

Conclusions

An evaluation of historical BBWM data indicated that the period of time representing a transition from late winter to spring is characterized by the anticipated rising temperatures, the loss of the snowpack, and some evidence for rapidly increasing discharge and biotic processes. There are indications in stream chemistry that this results in increased variability, particularly for C and N dynamics. The 2014 pilot study was consistent with the characteristics of a vernal transition suggested by the 14 year record. However, the 2014 pilot study showed no evidence of temporal trends in soil C and N characteristics that would result in changes in stream chemistry. Future research at BBWM on this issue will include multiple forest types, and additional biotic and abiotic processes to define the vernal transition and its relevance to plant phenology, forest nutrition, soil C-N dynamics, and stream water quality.

References

Campbell, John L., Scott V. Ollinger, Gerald N. Flerchinger, Haley Wicklein, Katharine Hayhoe, and Amey S. Bailey. 2010. "Past and Projected Future Changes in Snowpack and Soil Frost at the Hubbard Brook Experimental Forest, New Hampshire, USA." *Hydrological Processes* 24 (17): 2465-2480.

Fitzhugh, Ross D., Gene E. Likens, Charles T. Driscoll, Myron J. Mitchell, Peter M. Groffman, Timothy J. Fahey, and Janet P. Hardy. 2003. "Role of Soil Freezing Events in Interannual Patterns of Stream Chemistry at the Hubbard Brook Experimental Forest, New Hampshire." *Environmental Science & Technology* 37 (8): 1575-1580.

Groffman, Peter M., Lindsey E. Rustad, Pamela H. Templer, John L. Campbell, Lynn M. Christenson, Nina K. Lany, Anne M. Socci, et al. 2012. "Long-Term Integrated Studies show Complex and Surprising Effects of Climate Change in the Northern Hardwood Forest." *Bioscience* 62 (12): 1056-1066.

Groffman, Peter M, Charles T Driscoll, Timothy J Fahey, Janet P Hardy, Ross D Fitzhugh, and Geraldine L Tierney. 2001. "Colder Soils in a Warmer World: A Snow Manipulation Study in a Northern Hardwood Forest Ecosystem." *Biogeochemistry* 56 (2): 135-150.

Hayhoe, Katharine, Cameron P Wake, Thomas G Huntington, Lifeng Luo, MarkD Schwartz, Justin Sheffield, Eric Wood, et al. 2007. "Past and Future Changes in Climate and Hydrological Indicators in the US Northeast." *Climate Dynamics* 28 (4): 381-407.

IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Stocker, T. F., D. Qin, G.-K. Plattner, M. TIgnor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.)Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Jefts, Sultana, Ivan J. Fernandez, Lindsey E. Rustad, and D. Bryan Dail. 2004. "Decadal Responses in Soil N Dynamics at the Bear Brook Watershed in Maine, USA." *Forest Ecology and Management* 189 (1–3): 189-205.

Norton, S., J. Kahl, I. Fernandez, T. Haines, L. Rustad, S. Nodvin, J. Scofield, et al. 1999. "The Bear Brook Watershed, Maine (BBWM), USA." *Environmental Monitoring and Assessment* 55 (1): 7-51.

Ohno, Tsutomu and Rasmus Bro. 2006. "Dissolved Organic Matter Characterization using Multiway Spectral Decomposition of Fluorescence Landscapes." *Soil Science Society of America Journal* 70 (6): 2028-2037.

Weishaar, James L., George R. Aiken, Brian A. Bergamaschi, Miranda S. Fram, Roger Fujii, and Kenneth Mopper. 2003. "Evaluation of Specific Ultraviolet Absorbance as an Indicator of the Chemical Composition and Reactivity of Dissolved Organic Carbon." *Environmental Science & Technology* 37 (20): 4702-4708.