ISSN 1070–1524

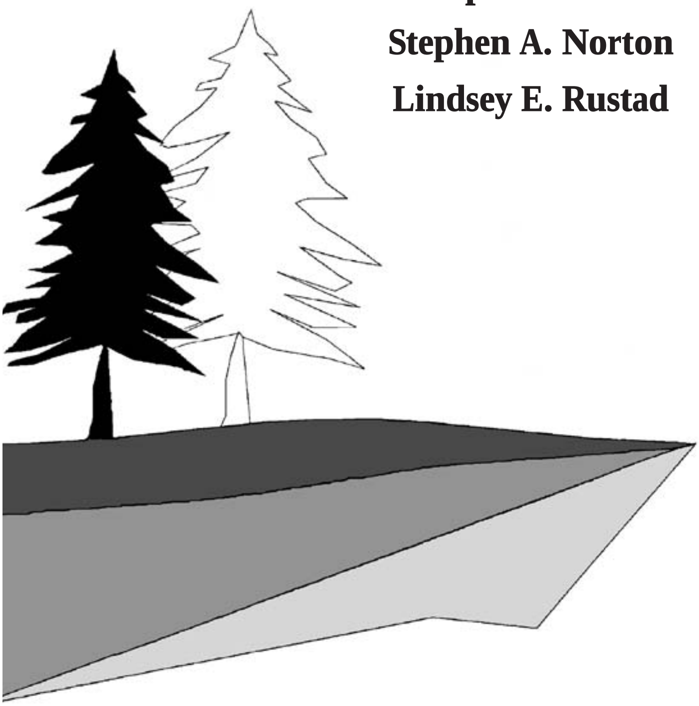
Temperature, Soil Moisture, and Streamflow at the Bear Brook Watershed in Maine (BBWM)

Ivan J. Fernandez

Joseph E. Karem

Stephen A. Norton

Lindsey E. Rustad



Technical Bulletin 196 December 2007

MAINE AGRICULTURAL AND FOREST EXPERIMENT STATION
THE UNIVERSITY OF MAINE

Temperature, Soil Moisture, and Streamflow at the Bear Brook Watershed in Maine (BBWM)

Ivan J. Fernandez
Professor, Department of Plant, Soil & Environmental Sciences

Joseph E. Karem
Scientific Technician, Department of Plant, Soil & Environmental Sciences

Stephen A. Norton
Professor, Department of Earth Sciences

Lindsey E. Rustad
Forest Ecologist, USDA Forest Service

Maine Agricultural & Forest Experiment Station
5782 Winslow Hall
University of Maine
Orono, ME 04469-5782

ACKNOWLDEGMENTS

The authors wish to acknowledge the support of the National Science Foundation Long-Term Research in Environmental Biology program (DEB-0210257) and the Maine Agricultural and Forest Experiment Station. We extend our appreciation to Sarah Nelson, Melinda Diehl, and J. S. Kahl for their contributions to the BBWM stream and precipitation data used in this analysis. Additional appreciation is extended to Cheryl Spencer, John Cangelosi, and the many student workers who assist in the BBWM program. We thank John Campbell and Shaleen Jain for their helpful comments on an earlier version of the manuscript.

CONTENTS

Figures

Tables

INTRODUCTION

The chemical and physical characteristics of our atmosphere have profound influences on natural ecosystems and the quality of life for all living organisms, including human beings. At the dawn of the 21st century we can begin to evaluate the progress we have made through environmental regulations in limiting chemical air pollutants such as sulfur (S) and nitrogen (N) that cause acid deposition (Stoddard et al. 2003). At the same time we are coming to grips with the gravity of greenhouse gas emission effects on climate (IPCC 2007) and associated consequences such as climatic warming, increased drought (Hayhoe et al. 2006), and an intensification of the hydrologic cycle (Huntington 2006). Evidence to date suggests we are seeing dramatic reductions in S deposition, little change in N deposition, and mixed results on how surface waters in the region have recovered in light of these trends. Nitrogen is often a limiting nutrient in terrestrial ecosystems and both atmospheric deposition and climate change alter N cycling in ecosystems. In fact, most of the effects of chemical air pollutants on terrestrial and aquatic ecosystems are strongly affected by the physical climate influencing them. Therefore, it is increasingly important to understand how the interactive effects of chemical and physical changes in climate influence the physical, chemical, and biological mechanisms that define ecosystems.

The Bear Brook Watershed in Maine (BBWM) is a whole-ecosystem chemical manipulation initiated in 1987 to study the effects of acid deposition on forests and surface waters (Norton and Fernandez 1999). The focus of this research was to understand the biogeochemical response of watersheds with emphasis on chemistry and hydrology. In 2001 a program was initiated to provide more detailed measurements of temperature and moisture to examine critical linkages amongst chemical, biological, and physical processes that ultimately work together to define ecosystem function. The purpose of this publication is to provide data from the initial phase of soil temperature, air temperature, and soil moisture measurements at the site. In addition, we have incorporated aspects of relevant precipitation and streamflow characteristics available for the full project period.

MATERIALS AND METHODS

Site Description

The Bear Brook Watershed in Maine is the site of a long-term, gauged, forested, first-order paired-stream watershed study located in eastern Maine (44°52' N lat., 68°6' W long.) approximately 40 km from the Atlantic Ocean. The site lies on the southeastern slope of Lead Mountain, with a total relief of 210 m and maximum elevation of 475 m. Two nearly perennial, low dissolved organic carbon (DOC), and low acid neutralizing capacity (ANC) streams (East Bear and West Bear) drain 10.3- and 11.0-ha contiguous watersheds. Vegetation in each stream watershed is dominated by northern hardwoods (*Fagus grandifolia* Ehrb., *Acer rubrum* L., *Acer saccharum* Marsh., *Betula alleghaniensis* Britt., *Betula papyrifera* Marsh., and *Acer pensylvanicum* Marsh.), with stands of softwoods at higher elevations dominated by red spruce (*Picea rubens* Sarg.) with minor balsam fir and hemlock (*Abies balsamea* Mill. and *Tsuga canadensis* (L.) Carr.). There is a mixed wood zone that is transitional between the upper softwood and lower hardwood zones in these watersheds. For the purposes of this research, we focused on the end members of the forest composition spectrum: softwoods and hardwoods. This species focus resulted in an experimental design consisting of four compartments represented by two forest types (hardwood and softwood) in each of two watersheds (East Bear and West Bear). Soils are primarily coarse, loamy, isotic, frigid Typic Haplorthods developed on till averaging 1 m in thickness, with coarse-loamy, isotic, frigid Typic Haplohumods in some areas of the upper elevations supporting softwood forest types. There are minor occurrences of Folists in the uppermost portions of the watershed. Bedrock is predominantly quartzites and meta-pelites, intruded locally by granite.

Temperature

Air and soil temperatures were measured using HOBO™ H8 Outdoor/Industrial four-channel data loggers manufactured by Onset Computer Corporation, Bourne, MA. In July 2001, two data loggers were installed in each of the four compartments at BBWM (eight total) representing both forest types and watersheds. In June 2003, two additional data loggers were installed in each compartment bringing the total to four per compartment (16 total). Each data logger was equipped with four external temperature sensors at the terminal end of a 183 cm (i.e., -ft) input cable. This allowed temperature data to be collected by each data logger from four sources. Sensor positions included (1) air temperature at 100 cm above the surface to minimize interference from the snowpack, (2) organic horizon (O horizon) temperature where sensors were threaded into the center of the organic soil horizon, (3) at a depth of 10 cm from the top of the mineral soil that typically corresponded to the upper B horizon, and (4) at 25-cm depth from the top of the mineral soil that typically corresponded to the lower B or BC horizon. Temperature was recorded by all data loggers continuously at 3-hour time intervals starting at 00:00 (midnight).

Precipitation

Precipitation depth was determined using a Belfort™ Universal Precipitation Gauge (Belfort Instrument, Baltimore, MD) located on a stage in a clearing next to the East Bear weir above the gauge house. The precipitation gauge collected precipitation (e.g., rain, snow, hail) in a weighing chamber and was designed to convert the weight of accumulating precipitation into depth equivalents (i.e., cm). These data were continually recorded on a mechanical rotating chart. For the results reported here, data were summed at 3-hour time intervals starting at 00:00.

Soil Moisture

A single HOBO™ Micro Station data logger (Onset Computer Corporation, Bourne, MA) was installed in each of the hardwood and softwood stands in the East Bear watershed during June of 2003 and 2004, respectively (two total). These were intended as a pilot program of soil moisture measurements to evaluate the equipment and data. The data logger in the hardwood stand was equipped with a single ECH2O™ soil moisture sensor with a 64-cm^2 (3.2 × 20 cm) sensing surface at the terminal end of a 3.5-m input cable. The sensor was inserted vertically into the mineral soil after cutting a thin slice through the O horizon and upper mineral soil with a tile spade. The sensor was then inserted into the mineral soil so the top of the sensor area was at the top of the mineral soil and an integrated measure of volumetric soil moisture content (i.e., m^3 water per m^3 soil) in the upper 20 cm of mineral soil was obtained. Soil moisture readings were collected continuously at 3-hour intervals starting at 00:00. The HOBO™ Micro Station in the softwood stand was installed as described above, but had two ECH2O™ soil moisture sensors. Both moisture sensors were installed in the same manner and were located 2 m apart at the data logger station. Replicate soil moisture sensors were installed to evaluate precision in the measurements of soil moisture in the top 20 cm of mineral soil. According to Onset Computer Corporation, accuracy of these sensors is ± 3%. Data presented in this study for soil moisture in the East Bear softwood stand represent the mean of the two readings. Based on these data, the average difference in soil moisture between probes was 0.9%.

Streamflow

Surface hydrologic flux from each watershed was gauged with 120° V-notch weirs anchored on bedrock. Hydrologic monitoring was carried out in collaboration with the U.S. Geological Survey and real time streamflow data were available for East and West Bear at the time of this writing under the Narraguagus River Basin on the Web (http://waterdata.usgs.gov/me/nwis/current/?type=flow). Streamflow data recorded at 3-hour intervals starting at 00:00 were used for this study.

Statistical Analyses

The experimental design for this research was a split-plot design, with watersheds as the main experimental units. Each watershed was split into hardwood and softwood subunits yielding four compartments. Because no significant temperature differences were detected between East and West Bear, and soil moisture data were only collected in East Bear, the two forest zones were used as the main experimental units for these analyses.

Differences ($P < 0.05$) in temperature and soil moisture between forest types were examined using a one-way ANOVA (PROC GLM, SAS for Windows 8.1). No transformation of temperature or soil moisture data was necessary to meet the assumptions of normality. Normality was assessed by examining skewness, kurtosis, and the Shapiro-Wilk W statistic (PROC Univariate, SAS for Windows 8.1). To detect temperature differences in air and all three soil depths, a separate one-way ANOVA was calculated for data collected at each of the four sensor positions described above. A Tukey's means separation test was used to evaluate differences among soil temperature probe positions.

Correlations between soil moisture and streamflow in East Bear were evaluated using Pearson correlation analysis (PROC CORR, SAS for Windows 8.1). No transformation of data was necessary for this method. Streamflow data collected at the same 3-hour time intervals as soil moisture data were used for this analysis.

RESULTS AND DISCUSSION

Air and Soil Temperature

Figure 1 illustrates the continuous time series for air and soil temperatures at BBWM. The overall annual pattern of temperature fuctuation is sinusoidal. Temperatures reach their minima in January and maxima in August for each year reported here. The January minima for the data in Figure 1 were -14.7, -3.6, -0.8, and 0.33°C for air, the organic horizon (O), 10-cm and 25-cm depth in the mineral soil, respectively. The August maxima were 20.0, 17.4, 15.4, and 13.7°C for air, the O horizon, 10-cm and 25-cm depth in the mineral soil, respectively. At BBWM, the temperatures from above the soil surface and below the forest canopy (air), through the surface O horizon, to the shallow underlying mineral soil (10 cm depth), to the deeper mineral soil (25 cm depth) show a typical vertical profle of characteristics that include

1. a gradient of temporal variability from the most variable (air temperatures) to the least variable (25 cm mineral soil temperatures), and
2. a biannual temperature inversion with air temperatures colder than soils in the winter and warmer than soils in the summer.

Table 1 provides descriptive statistics for the 24-month period of data reported here. The overall mean temperatures for air and soil at BBWM were similar, ranging between 5.06 and 6.18°C during the measurement period. Mean soil temperatures were slightly higher than air temperatures, which is typical. Soil materials and the plants growing on them absorb the greatest part of the radiant energy from the sun, while air absorbs a much smaller amount. The atmosphere receives most of its radiant energy from the soil below (Kohnke 1968). There are limited high-quality long-term data for rural landscapes in Maine to compare these means for air temperature and even fewer for air temperature below a closed forest canopy. The Northeast Regional Climate Center reports a 30-year annual average (1961–1990) air temperature for the open air sites at Caribou and Portland, Maine, to be 3.8 and 7.4°C, respectively (http://met-www.cit.cornell.edu/ccd/nrmavg.html). BBWM is geographically between these sites so the means reported here seem reasonable and refect the air temperature below a largely closed forest canopy, which is typically cooler. Air temperature exhibited the greatest annual variance ranging from -30.45 to 31.02°C; sensors deepest in the mineral horizon exhibited the least variance, rang-

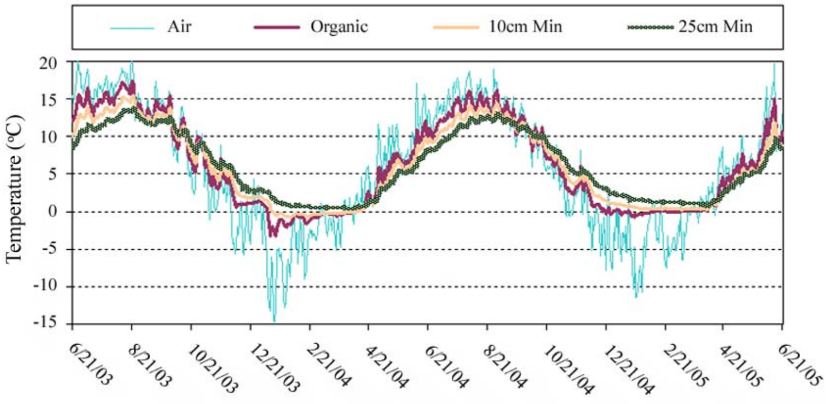


Figure 1. Time series for air and soil temperatures at BBWM from June 2003 to June 2005 by sensor position.

Table 1. Descriptive statistics for air and soil horizon temperatures (°C) at the Bear Brook Watershed in Maine.

	Mean	SE	Median	Min	Max	Range	n
Overall							
Air	5.06	0.07	5.54	-30.45	31.02	61.47	23392
O horizon	6.18	0.04	5.39	-5.64	18.95	24.59	23392
10cm Mineral	5.98	0.03	5.39	-1.75	16.47	18.23	23392
25cm Mineral	6.01	0.03	5.7	-0.61	14.6	15.21	23392
Hardwood Forest Type							
Air	5.18	0.1	5.76	-30.17	30.72	60.89	11696
O horizon	6.66†	0.06	6.52	-4.17	18.95	23.11	11696
10cm Mineral	6.71†	0.05	6.52	-0.77	16.47	17.24	11696
25cm Mineral	6.69†	0.04	6.42	0.14	14.6	14.46	11696
Softwood Forest Type							
Air	4.95	0.1	5.4	-30.45	31.02	61.47	11696
O horizon	5.69	0.05	4.45	-5.64	17.24	22.88	11696
10cm Mineral	5.25	0.05	4.15	-1.75	14.98	16.73	11696
25cm Mineral	5.33	0.04	4.57	-0.61	13.22	13.83	11696

†Indicates significant difference between forest types.

ing from -0.61 to 14.60°C. This amounts to four times the range in temperature for the air below the forest canopy as compared to the mineral subsoil. It is noteworthy that trees, as individual organisms, experience both highly variable air temperature regimes in their aboveground components and relatively modest temperature variations in their rooting environment simultaneously.

There was no statistically significant difference in mean annual air temperature between softwood and hardwood stands at BBWM (P = 0.152) (Table 1; Figure 2a). However, soil temperature means were consistently lower in softwood vs hardwood stands ($P < 0.05$) in all soil horizons (Table 1; Figure 2b–d). The lower light infltration in softwoods is believed to be responsible for the lower soil temperatures. This does not translate into different air temperatures by forest type because of the relatively steeply sloping environment of these watersheds allowing for ease of cold air drainage downslope even without turbulent mixing factors. These differences in soil temperature between forest types appear to increase with depth in the soil. Consistently, the greatest differences in soil temperature between forest types occur during the spring and summer seasons. This likely refects the increasing infuence of a denser canopy in these softwood stands dominated by relatively mature, closed canopy red spruce trees compared to the more heterogeneous and less dense mixed and hardwood stand conditions. The importance of these differences can be illustrated by examining the relative delay for softwood soils to reach a particular temperature in the spring compared to hardwood soils. For example, if we examine more closely the time series of temperature data in the spring and choose a benchmark temperature of 6°C, we see a notable delay in the rate of soil warming for softwood compared to hardwood soil temperatures (Figure 3a–f). In organic soils, it took softwood stands 35 days longer in the spring of 2004 to reach 6°C than hardwood stands, and 22 days longer in the spring of 2005 (Figure 3a,b). This can also be seen in mineral soils where it took softwood stands 38 (2004) and 30 (2005) days longer for sensors at 10-cm depth in minerals soils, and 35 (2004) and 24 (2005) days longer for sensors at 25-cm depth in mineral soils, to reach 6°C in softwoods compared to hardwoods, respectively.

Differences in the thermal input to soil-plant systems can be described by heat units. Heat units, calculated by adding the daily temperatures above some base, are another way of looking at the total heat energy budget for a period of time (Baskerville and Emin 1969; Wang 1960). This cumulative representation of temperature is thought to be better correlated with plant growth functions in

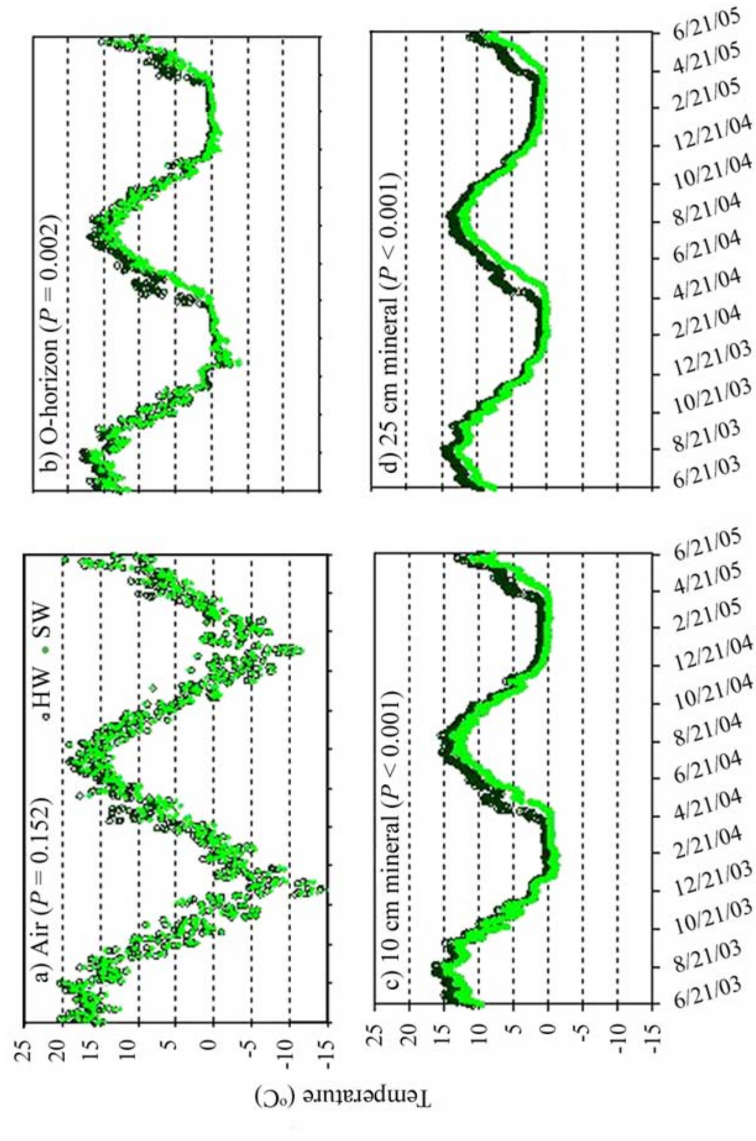


Figure 2. Daily temperatures for hardwood vs softwood stands.

1865 THE UNIVERSITY OF MAINE

M A F E S
W H
O ME 04469 5782

5 5 38900