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LTREB: Forest Ecosystem Response to Changes in Atmospheric Chemistry and Climate at the Bear Brook Watershed in Maine (BBWM)

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Principal Investigator: Fernandez, Ivan J. **Award ID:** 0210257

Organization: University of Maine

Submitted By:

Fernandez, Ivan - Principal Investigator

Title:

LTREB: Forest Ecosystem Response to Changes in Atmospheric Chemistry and Climate at the Bear Brook Watershed in Maine (BBWM)

Project Participants

Senior Personnel

Name: Fernandez, Ivan

Worked for more than 160 Hours: Yes

Contribution to Project:

As the lead PI, Ivan Fernandez oversees all management aspects of the project and directly supervises staff.

Name: Norton, Stephen

Worked for more than 160 Hours: Yes

Contribution to Project:

Stephen Norton contributes to management planning in concert with the other PIs and provides input to data analysis and interpretation.

Name: Rustad, Lindsey

Worked for more than 160 Hours: Yes

Contribution to Project:

Lindsey Rustad contributes to management planning in concert with the other PIs and provides input to data analysis and interpretation.

Post-doc

Graduate Student

Name: Sherman, Jessica

Worked for more than 160 Hours: Yes

Contribution to Project:

Jessica Sherman completed her M.S. degree during 2005 on soil chemical phenomena at BBWM. She was supported by the Maine Agricultural and Forest Experiment Station. Her study at BBWM was in part made possible by the BBWM program that is supported through LTREB and other NSF support. She has since graduated and is working in Wisconsin as a soil scientist.

Name: Laird, Mollie

Worked for more than 160 Hours: Yes

Contribution to Project:

Mollie Laird's MS research project is studying the longitudinal variations along Bear Brook streams during high discharge episodes. The goal is to understand the Al-Fe-P dynamics in the stream as a function of position in the watershed and time. Sampling at BBWM occurred in 2005.

Name: Bethers, Suzanne

Worked for more than 160 Hours: No

Contribution to Project:

Suzanne Bethers is carrying out an MS thesis research project at BBWM funded by other sources focusing on forest physiological processes. Her research benefits from the LTREB supported BBWM infrastructure and data.

Name: Kenlan, Peter

Worked for more than 160 Hours: No

Contribution to Project:
Peter Kenlan is carrying out an MS thesis research project at BBWM funded by other sources focusing on forest understory response to N and S treatments. His research benefits from the LTREB supported BBWM infrastructure and data.

Name: SanClements, Michael
Worked for more than 160 Hours: No
Contribution to Project:
Michael SanClements is a PhD student supported by other NSF funding studying soil metal and P dynamics at BBWM and other watersheds. Michael's research will heavily utilize BBWM and the LTREB supported data and infrastructure.

Name: Goss, Heather
Worked for more than 160 Hours: No
Contribution to Project:
MS student working on stream acidification experiments on multiple watersheds including BBWM.

Name: Holmes, Brett
Worked for more than 160 Hours: Yes
Contribution to Project:
MS student working on soil leaching of P and metals as influenced by the partial pressure of CO2 and DOC. He is using laboratory columns of intact soil cores from BBWM.

Name: Diehl, Melinda
Worked for more than 160 Hours: No
Contribution to Project:
MS student utilizing the BBWM precipitation and stream database as part of her thesis on acidification mechanisms at BBWM.

Name: Fatemi, Farrah
Worked for more than 160 Hours: Yes
Contribution to Project:
This is a new Ph.D. student beginning her work on soil solution dynamics at BBWM in the 2006-2007 academic year.

Name: Huntress, David
Worked for more than 160 Hours: Yes
Contribution to Project:
This is a graduate student working on stream dynamics for his MS degree at BBWM and other stream systems in Maine.

Name: Szillery, Johanna
Worked for more than 160 Hours: Yes
Contribution to Project:
This student finished her thesis program on soil solutions at the beginning of this NSF LTREB contract period.

Name: Jefts, Sultana
Worked for more than 160 Hours: Yes
Contribution to Project:
This student finished her thesis program on nitrogen dynamics at the beginning of this NSF LTREB contract period.

Undergraduate Student

Name: Obeng Nyarkoh, Ebenezer
Worked for more than 160 Hours: Yes
Contribution to Project:
An undergraduate student from Ghana, Ebenezer worked in our laboratories, on the root project and on data from the pilot HOBO temperature program from the previous year. Partial support by LTREB.

Name: Drouin, Anthony
Worked for more than 160 Hours: Yes

Contribution to Project:
Anthony Drouin is an undergraduate student who worked in our laboratories and assisted in various aspects of BBWM research, including the roots project. The majority of his support was not from LTREB although his work depended on LTREB supported infrastructure.

Name: Ladd, Emily

Worked for more than 160 Hours: Yes

Contribution to Project:
An undergraduate student who worked in our laboratories and assisted in various aspects of BBWM research. Not supported by LTREB.

Name: Graves, Rose

Worked for more than 160 Hours: Yes

Contribution to Project:
An undergraduate student who worked in our laboratories and assisted in various aspects of BBWM research. Not supported by LTREB.

Name: Burnham, Emily

Worked for more than 160 Hours: Yes

Contribution to Project:
Emily Burnham was involved with processing root core samples from the Bear Brook site. The project component she worked on was primarily supported by USDA funding.

Name: Hansen, Nicole

Worked for more than 160 Hours: Yes

Contribution to Project:
Nicole Hansen was involved with various aspects of the Bear Brook project dealing with root sample processing funded through USDA, nitrogen dynamics funded under NSF LTREB, and assistance in the NSF LTREB supported soil temperature and moisture program.

Name: Patten, Kyle

Worked for more than 160 Hours: Yes

Contribution to Project:
Kyle helped with various components of the program including USDA and NSF LTREB supported research.

Name: Jolosheva, Aida

Worked for more than 160 Hours: Yes

Contribution to Project:
Aida Jolosheva helped with various aspects of the Bear Brook program and has developed considerable expertise in digitizing minirhizotron imagery through support from USDA but based on the BBWM research site.

Name: Lovewell, Rustin

Worked for more than 160 Hours: Yes

Contribution to Project:
This is an undergraduate student worker who assisted in the field and laboratory work related to the HOBO dataloggers and N dynamics. He was supported by USDA and other NSF funding.

Name: Macdonald, Jason

Worked for more than 160 Hours: No

Contribution to Project:
This is an undergraduate student worker who assisted in the field and laboratory work related to the HOBO dataloggers and N dynamics. He was supported by USDA and EPA funding.

Name: Rackley, Sean

Worked for more than 160 Hours: Yes

Contribution to Project:
This is an undergraduate student worker who assisted in the field and laboratory work related to the HOBO dataloggers and N

dynamics. He was supported by University of Maine funding. He also assisted in related research on soil chemistry that was not directly supported by LTREB, but made possible by the BBWM program LTREB supports.

Name: Montgomery, Allison

Worked for more than 160 Hours: No

Contribution to Project:

This student has work in both laboratory sample preparation and in the field on this project and others.

Name: Parent, Mary Beth

Worked for more than 160 Hours: Yes

Contribution to Project:

This student has work in both laboratory sample preparation and in the field on this project and others.

Technician, Programmer

Name: Karem, Joseph

Worked for more than 160 Hours: Yes

Contribution to Project:

Joseph Karem was hired as the half-time technician supported by the LTREB funding. He was hired as a result of a competitive search process, and began work in February 2003. His initial work was on familiarizing himself with the BBWM project, and developing the existing HOBO temperature data from our pilot work in 2002 into final data sets. He has continued to maintain the full soil temperature monitoring program at BBWM, carried out periodic N mineralization measurements, oversees the project database, and in 2006 launched the first phase of the new BBWM web site as well as began worthing on a technical bulletin synthesis of the BBWM environmental measurement data to date.

Name: Walls, Tracey

Worked for more than 160 Hours: Yes

Contribution to Project:

Tracey Walls is a professional staff member supported by funds from other contracts who had a lead role in several projects including the multi-site roots project taking place at BBWM, Mt. Ascutney in Vermont, and the Harvard Forest in Massachusetts.

Other Participant

Research Experience for Undergraduates

Name: Lemin, Sarah

Worked for more than 160 Hours: Yes

Contribution to Project:

Sarah carried out a project on soil moisture at the Bear Brook site through supplemental funding as an REU on NSF LTREB in 2004.

Years of schooling completed: Junior

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2004 2004

REU Funding: REU supplement

Organizational Partners

USDA Forest Service - Northeastern Forest Experiment Station

Dr. Lindey Rustad, one of the lead PIs on the BBWM project, is attached to this station of the USDA Forest Service and as such, this organization contributes in-kind her time to many of the BBWM initiatives. In addition, there are several funded projects taking place at BBWM solely or in combination with other sites that receive support through the USDA FS Northeastern Forest Experiment Station. New NSF funding from other contracts is also allowing us to collaborate directly with the USDA Forest Service Fernow research watershed in West Virginia through Dr. Mary Beth Adams and her colleagues.

US Geological Survey

The USGS staff in Augusta, Maine cost-shares the expense of hydrological monitoring for both weirs at the BBWM and develops hydrologic data from this program. One of the critical contributions of LTREB funding is to provide the other half of the costs of hydrological monitoring that we share with this agency.

International Paper

The BBWM project was on International Paper land who oversaw the lease for the site for a nominal annual fee but essentially contributed the land to this long-term research initiative and helps with logistical aspects of site management. During 2004 the land was purchased by GMO Renewable Resources of Boston who has taken over the contracts and support previously offered by International Paper. Sustainable Forestry Initiatives continues to manage the site for GMO, which is a subsidiary of International Paper.

Institute for Ecosystems Studies

During the initial two years of this NSF LTREB we completed a collaborative project with scientists from the Institute for Ecosystem Studies in Millbrook, NY. The focus of that project has been to study nitrogen trace gas fluxes and nitrogen cycling in the reference and treatment watersheds. This project is now complete, and final reports and papers are being developed or are completed and listed as appropriate in the deliverables for this LTREB. One thesis from the University of Maine was completed, and two published papers resulted from the work of that student (Sultana Jefts). The work was conducted by scientists and students from both institutions.

University Louis Pasteur

The University of Maine continues to develop a collaborative program with the University Louis Pasteur, Strasbourg, France. The centerpiece of the initial exchange has become the common research interests and strengths in watershed studies. During May of 2003 a contingent of three scientists from ULP (Bertrand Fritz, Marie-Claire Pierret-Neboit, Gaetana Quaranta-Millet) visited the University of Maine with a focus on interacting with scientists from the Bear Brook watershed. This also included a day in the field at BBWM discussing common interests. The BBWM study serves as the US counterpart to their own research at the Strengbach watershed (http://ohge.u-strasbg.fr/indexuk.html), Vosges Mountains, Northeastern France. As a result of other NSF contracts awarded in 2004 that build on the LTREB supported BBWM program, in 2005 we began a formal program of collaborative research with the Strengbach watershed scientists from University Louis Pasteur, as well as colleagues in the Czech Republic working at one of their research watersheds. The BBWM site is source of a collaboration through LTREB and other NSF funding with the Strengbach watershed in France, and with the Lesni potok watershed in the Czech Republic under the auspices of the Czech Geological Survey. Ivan Fernandez and Stephen Norton both visited the European sites in 2005 and project staff sampled the French watershed in 2006.

Duke University

The BBWM site was included in the research of doctoral student Matthew Wallenstein working under William Schlesinger from Duke University in 2003 and 2004. Matthew was doing research at BBWM dealing with microbial biomass and functional group responses to treatments. Matthew used the BBWM site as well as the Harvard Forest, MA and Mt. Ascutney, VT nitrogen experiment sites in his study. The PIs from this NSF LTREB are also involved in research at all three sites dealing with soil and root responses to N treatments. Matthew's work at BBWM is providing unique and important insights on belowground responses not evident from either tree or geochemical responses we have documented to date. In 2004 Matthew completed his PhD and is now collaborating with us as a post-doctoral associate of Joshua Schimel at the University of California-Santa Barbara.

Syracuse University

Mark Bremer is doing research for his doctoral thesis studying microbial community structure at BBWM and other sites, focusing on nitrifiers and methanotrohps, biomolecular markers for acid stress, and as well as modeling. He is working with Andria Costello and other faculty at Syracuse University, and has used BBWM as one of the key sampling sites for his study. As with many visiting scientists at BBWM, we provide some level of logistical support as well as scientific collaboration.

University of New Hampshire

We were recently approved for a project funded through USDA as part of the NSRC to do a small-scale study of the implications for acidification on soil phosphorus. This research is being conducted at BBWM as well as the nitrogen study sites at the Harvard Forest, MA and Mt Ascutney, VT. The lead PI for the project is Ivan Fernandez, lead PI on this NSF LTREB, with coPIs from the University of New Hampshire and the USDA Forest Service.

Department of Interior National Park Service

The PIs of this NSF LTREB are also directly involved in research at the nearby (~60 km) Acadia National Park. Part of the research effort at Acadia includes a pair of forested watersheds and we are often using the BBWM watersheds and the Acadia watersheds in an integrated manner to compare a range of ecosystem conditions relative to processes controlling ecosystem response to perturbation. The BBWM PI group interacts with science and management personel from Acadia in this context, most regularly David Manski who oversees their research program.

University of California-Santa Barbara

Matthew Wallenstein, in a post-doctoral position with Joshua Schimel at the University of California-Santa Barbara, is a co-PI with us on a USDA funded project at BBWM that builds on the program made possible through LTREB. His focus is on microbial and biochemical characteristics of BBWM soils important for phosphorus dynamics.

Plymouth State University

J. Stephen Kahl from Plymouth State University has been a long-time collaborator on the BBWM project. He also is the lead PI on a Regional Long Term Monitoring (RLTM) project funded by US EPA that provides additional support for stream chemistry measurements in the reference East Bear stream.

Czech Geological Survey

Scientists from the Czech Geological Survey have collaborated with University of Maine scientists on this project, exchanged samples, and hosted visits by each team for the purpose of collaboration and field sample collections.

Other Collaborators or Contacts

There are frequently contacts from scientists at other institutions in the US and abroad to obtain articles from the BBWM site or to plan to potentially involve the site in their future work. BBWM is listed as part of the Global Terrestrial Observing System Terrestrial Ecosystem Monitoring Sites (GTOS-TEMS), and has been a vital data and results contributor to a number of synthesis efforts, some of which are noted in the publications section of the report. Several of these are NSRC funded regional, national or international synthesis efforts dealing with climate change, nitrogen saturation, and base cation depletion to name a few. Similarly, the BBWM project has been the subject of frequent seminars on the University of Maine campus, and is used routinely in several classes on soils, geochemistry and ecology as a model system for instruction.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

The following annual report summarizes progress to date for the last year of this NSF LTREB. The activities and findings information is organized around the original project objectives.

Objective 1. 'Study the response of the calibrated East Bear Watershed to long-term patterns of ambient S, N, and base cation deposition. This will be accomplished by maintaining high quality deposition and stream export data from the reference watershed in support of studies of soils, litterfall and forest response that are not supported through this proposal but will be possible from other extramural funding as long as this base program continues.'

During the period of this contract we have continued to maintain a measurement program for precipitation and stream chemistry in the reference (East Bear) and treated (West Bear) watersheds, and have collaborated with the US Geological Survey in carrying out hydrological monitoring. This remains an essential framework for ongoing research supported by other contracts for internal watershed processes, including several initiatives funded by NSF. As a result of cost-sharing between this LTREB and the US Geological Survey, real time and historical stream data are continuously available via the USGS web presence for East Bear brook (http://waterdata.usgs.gov/me/nwis/uv/?site_no=01022294&PARAmeter_cd=00065,00060) and West Bear brook (http://waterdata.usgs.gov/me/nwis/uv/?site_no=01022295&PARAmeter_cd=00065,00060).

Objective 2. 'Study the temporal progression of N saturation at the West Bear Watershed. This will be accomplished by continuing the decadal-scale whole ecosystem N & S addition experiment ongoing at the West Bear Watershed. Funds from LTREB will be used specifically to continue hydrological measurements and data management of deposition and export, as well as data on ecosystem processes generated from

a range of studies supported through other funding but not synthesized to date.'

As stated above, we have continued the high quality mass balance for chemistry and hydrology in both the treated and reference watersheds during the five years of the contract, in part supported by NSF LTREB. We are also in the 19th year of whole-ecosystem chemical manipulations with N and S, and our 21st year of research in East and West Bear watersheds overall. Figures 1 and 2 [attached] show the temporal patterns of potential net N mineralization and soil temperature over two years of measurements. The temperature monitoring program was installed during year 1. These data provide a temporal perspective on N dynamics in soils at BBWM in response to treatments. We are also developing data on the relationship between temperature and potential net N mineralization now possible through the LTREB supported program of HOBO dataloggers throughout both watersheds. The results in Figures 1 and 2 show a coincidence between soil temperature and N dynamics that could reflect seasonal patterns in both parameters or causal relationships, and likely both. Summer high temperatures are associated with maximum potential net N mineralization rates, and do not appear to be limited by moisture at these sites. Figure 3 [attached] looks at these same data on an XY graph. O horizon N mineralization rates are significantly higher than B horizons, and there appears to be a significant increase in N mineralization above ~12 C in these ecosystems. Clearly the treated West Bear watershed soils, both O and B horizons, have higher rates of potential net N mineralization at all soil temperatures, but respond in parallel to the reference East Bear soils to temperature differences. Stream chemistry continues to track the evolution of both East and West Bear to ambient and treatment responses to N dynamics in these watersheds.

Objective 3. 'Determine if a definable relationship exists between short and longer-term climate and the biogeochemical and hydrologic processes currently under study at both watersheds. This will be accomplished by establishing an ongoing air and multiple soil depth temperature measurement program in major contrasting stand and soil types in both reference and treated watersheds at the BBWM. We will specifically evaluate linkages between temperature, N dynamics (mineralization, nitrification), and surface water N export in both the reference and treated watersheds.'

During the first year (2003) we began to assemble data on soil and air temperature from both historical measurements at BBWM as well as new data from a pilot project in 2001-2002 using HOBO dataloggers. In 2003 we installed 16 HOBO dataloggers across both watersheds evenly distributed among the four compartments of forest types and watersheds at the BBWM. We continued the soil temperature measurement program during 2005 and 2006 with excellent performance in datalogger reliability and data reporting, much improved over the pilot study prior to the beginning of this LTREB. Figure 4 [attached] shows data from both the pilot study, as well as the two full years of the expanded LTREB network. This figure shows the grand means across all 16 dataloggers, demonstrating the patterns of temperature variation over time in air, the O horizon, and at 10 and 25 cm depths in the mineral soils. Air temperature for the pilot study prior to LTREB in winter are not included because the probes were buried by the snowpack during the initial years until the systems were reconfigured during the implementation of the more recent LTREB program. Current monitoring reflects repositioned air sensors to provide quality continuous data through the winter.
In 2004 we installed two Onset mini-weather station soil moisture stations to explore the efficacy of this equipment and develop our technique as a pilot project. This was expanded to four stations in 2005, one in each major BBWM compartment, to further these studies. Figure 5 [attached] includes some of the soil moisture data in a plot that integrates data on air and one depth of soil temperature, streamflow, and soil moisture. These data are an example of how we are now able to look at various interactions among both the chemical and physical processes taking place in our watersheds. Figure 5 shows that at BBWM we experience rapid streamflow responses to precipitation events, and soil moisture increases more slowly as capillary water reaches a new equilibrium throughout the soil. There are often small soil temperature decreases with precipitation events, but the response is inconsistent and depends on antecedent moisture and other factors. These data are from the hardwood forest compartment in East Bear. The influence of senescence and leaf fall on reducing ET and increasing sensitivity in streamflow to precipitation events is evident after September. These types of data will be used by this LTREB and associated research at BBWM to better understand the interactions among chemical, biological, and hydrological processes. In 2006 we wrote a technical bulletin that was published that examines the details of air and soil temperature along with some initial soil moisture measurements and the long-term stream record.

Objective 4. 'Provide support to strengthen the data management efforts at the BBWM, thereby making this long-term record more accessible to the scientific community with an interpretive interface to be used by educators and policy makers through an expansive web presence.'

This project objective is being addressed through the development of a database for critical long-term measurements, and the development of a web presence for the BBWM program. During the first year of this LTREB the focus was on organizing historical and new temperature data from BBWM, organizing historical and new N cycling data from BBWM, and beginning the development of a new BBWM web presence. More time was required during the first three years in developing the database to logically and efficiently handle the high volume of data generated by our temperature measurement program. A new BBWM web presence was launched in 2005 and the old site was taken off line. The new web presence was developed to conform with Section 508 of the Federal Rehabilitation Act Amendments. The initial phase of this web presence provides for a user-friendly portal that would be of interest to the public, students, teachers, policy-makers and scientists, but

further development for technical information, data access, and presentations remains to be done and is a part of the work of the new NSF LTREB contract that builds on this initial NSF LTREB's framework.

Objective 5. 'Provide support for graduate student training and undergraduate student experiences in research. The ongoing program at BBWM has provided the framework for numerous graduate student projects as well as opportunities for undergraduate students to gain direct work experience in science.'

Two students completed theses and graduate degrees (Sultana (Shah) Jefts and Johanna Szillery) during the first year of this NSF LTREB contract, and one student conducted a special project applying an N cycling model (PnET-CN) to the BBWM (Cullen Wilson). During 2005 Jessica Sherman (MS project focusing on soil metal fractions) and Alex Elvir (PhD project focusing on tree physiological response to treatments) completed their degrees and published their findings. In 2006 Melinda Diehl (MS project focusing on stream chemistry trends over time), Heather Goss (MS focusing on stream acidification effects on metal mobilization), Mollie Laird (MS focusing on episodic stream processes) and Peter Kenlan (MS project focusing on understory vegetation response to treatments) completed their programs. Brett Holmes (MS project focusing on DIC-metal-P interactions on soil surfaces) completed his MS degree in Engineering in 2007. Suzanne Bethers (MS project focusing on tree physiology), David Huntress (MS project on stream dynamics), Michael SanClements (PhD project focusing on soil metal and P interactions), and Farrah Fatemi (PhD project focusing on C-N-P linkages) are current students.

This past year approximately 7 undergraduate students have been employed in work experience positions related to the BBWM project supported by LTREB and other NSF funding. In addition, we were fortunate to be awarded an REU for this LTREB contract for the 2003 field season that supported Sarah Lemin who did a project on gravimetric moisture content that was instrumental in our implementation of the soil moisture measurement program described above.

Findings: (See PDF version submitted by PI at the end of the report)

The BBWM project is in its 19th year of N and S treatments to the West Bear watershed. As such, we are able to describe ecosystem processes not evident in short-term experimental research. The treated West Bear watershed has shown evidence in soils, soil solutions, vegetation and stream chemistry to validate our concepts of the evolution of base cation depletion due to chronic acidification stressors. The West Bear watershed continues to evolve along the path of N saturation, and is only now showing patterns of response in N dynamics that differ by forest type and soil horizon, and that have not previously been defined earlier in the study. The chronic acidification of the West Bear watershed has shown a biogeochemical evolution in acid neutralization mechanisms and recent data shows a progression from base cation to an aluminum acid neutralization phase, and most recently there is evidence of a contribution from iron buffering mechanisms. There is some evidence of forest growth changes due to treatments but the signal in both foliar chemistry and growth is inconsistent in both time and among species. Sugar maple is the species showing the greatest response to the treatments in West Bear. New findings suggest a possible control on stream sulfate attributable to alunite phases in soils not previously identified as an important mechanism in long-term acidification responses nor captured in widely used models. Extensive studies of soil fractions of Al, Fe and P are demonstrating a progressive mobilization and depletion of metals and P as a result of long-term acidification.

Research on belowground processes that include root studies show that fine root biomass is negatively affected by treatments. Thus, it appears that there is a sequence of response to N and S induced acidification that develops over time starting with rapid solution geochemical changes, followed by biogeochemical changes in soils, microbial populations, fine roots, and ultimately as detectable changes in net primary productivity. Because of the base program of temperature and moisture measurements made possible through LTREB funding, we are now able to begin to directly relate ecosystem processes to temperature and moisture parameters, and thus to short and long-term climate. The figures (attached) show initial assessments of patterns of soil temperature by forest type and depth, showing varying patterns of temperature with depth between the hardwood and softwood forest types. These insights can be significant for soil biota, root, and geochemical mechanisms.

We have seen the evolution of acidification for nearly two decades of study at BBWM, and the changing role of ecosystem components in whole ecosystem response. Many of these long-term ecosystem mechanisms of response are the subject of various studies currently underway.

Training and Development:

As noted above, the BBWM site continues to be possible due in part to this NSF LTREB. As such, we can report a continuation of graduate student thesis projects and undergraduate student research experiences as a result of this research. To date, this NSF LTREB involved 14 undergraduate student workers in the BBWM program, along with 12 graduate thesis projects.

Outreach Activities:

The project offers insights on forest ecosystem behavior that have been presented or prepared for presentation at various public and scientific

forums as noted below.

Fatemi, Farrah R., Ivan J. Fernandez, Kevin S. Simon, D. Bryan Dail, and Lindsey E. Rustad. 2008. Response of forest soil CNP dynamics to N enrichment at the Bear Brook Watershed in Maine: Clues from extracellular enzyme activities. (Paper 596-4). Presented at the ASA-CSSA-SSSA International Meetings. Houston, Texas. October 5-9. [CD-ROM]. ASA, CSSA, SSSA, Madison, WI.

SanClements, Michael D., Ivan J. Fernandez, Stephen A. Norton, Aria Amirbahman and Lindsey E. Rustad. 2008. Metal controls on forest floor and B horizon extractable phosphorus in forested watersheds. (Paper 596-2). Presented at the ASA-CSSA-SSSA International Meetings. Houston, Texas. October 5-9. [CD-ROM]. ASA, CSSA, SSSA, Madison, WI.

Fernandez, Ivan J., Stephen A. Norton, Lindsey E. Rustad, G. Bruce Wiersma, and Kevin S. Simon. 2008. New challenges for the third decade of whole-ecosystem experimental manipulations at the Bear Brook Watershed in Maine (BBWM). (Paper 699-20). Presented at the ASA-CSSA-SSSA International Meetings. Houston, Texas. October 5-9. [CD-ROM]. ASA, CSSA, SSSA, Madison, WI.

Fernandez, I.J. 2008. Carbon and nutrients in Maine forest soils. Abstract and presentation at the 11th North American Forest Soil Conference. Blacksburg, VA. p. 106.

Fatemi, F.R., I.J. Fernandez, L.E. Rustad, K.S. Simon and S.A. Norton. 2008. The effects of N enrichment on forest CNP stoichiometry at the Bear Brook Watershed in Maine. Abstract and presentaiton at the 11th North American Forest Soil Conference. Blacksburg, VA. p. 66.

SanClements, M.D., I.J. Fernandez, and S.A. Norton. 2008. Evolution of phosphorus fractions from an upland watershed to lake sediments. Abstract and presentation at the 11th North American Forest Soil Conference. Blacksburg, VA. p. 100.

Bethers, Suzanne. June 2007. Unraveling the Physiological Effects of Elevated Acid Deposition on Sugar Maple Regeneration. Poster and abstract. North American Forest Ecosystem Workshop, Vancouver, British Columbia, Canada.

'Calcium Cycling: Insights from Bear Brook Watershed in Maine.' February 21, 2007. Workshop sponsored by the Center for Research on Sustainable Forests. University of Maine, Orono, Maine.

Norton et al., 2006, The Bear Brook Watershed in Maine (BBWM): Twenty years and counting. University of Uppsala, Sweden.

Norton, S.A., 2006, Bogs Matter: A comparison of upland and wetland aquatic chemistry. Atlantic Salmon Commission et al., Whitneyville, Maine.

Norton, S. A., 2006, Downeast Rivers: Some unanswered questions. Atlantic Salmon Commission, Bangor, Maine.

Wiersma, G.B. Bear Brook Watershed in Maine. September 27, 2006. Presentation. Department of Forestry, College of Agriculture, University of Kentucky, Lexington, KY.

'Long-term Monitoring and Data Systems: New Paradigms for Basic Research.' December 5, 2006. Workshop sponsored by the Center for Research on Sustainable Forests. University of Maine, Orono, Maine.

SanClements, Michael, Ivan Fernandez, Stephen Norton, Aria Amirbahman, and Lindsey Rustad. 2006. Distribution of Soil Phosphorus Fractions in Acid Soils of Forested Watersheds. (Paper 234-5) Presented at the ASA-CSSA-SSSA International Meetings. Indianapolis, Indiana. November 12-16, 2006. [CD-ROM]. ASA, CSSA, SSSA, Madison, WI.

Rustad, Lindsey, Ivan Fernandez, Steve McNulty, and Allison McGill. 2006. Linkages between fine root dynamics and soil chemistry at three long-term nitrogen manipulation experiments in the northeastern United States. (Paper 203-8) Presented at the ASA-CSSA-SSSA International Meetings. Indianapolis, Indiana. November 12-16, 2006. [CD-ROM]. ASA, CSSA, SSSA, Madison, WI.

Diehl, M., Kahl, J. S., Fernandez, I. J., Norton, S. A., and Webster, L., 15 year response of stream chemistry to acidification and recovery at the Bear Brook Watershed, Maine: BIOGEOMON2006, 6th International conference, Santa Cruz, June 2006.

Fernandez, I. J., Norton, S. A., and Rustad, L. E., The difficulty in defining long-term ecosystem response mechanisms with short-term experimental manipulations: BIOGEOMON2006, 6th International conference, Santa Cruz, June 2006.

Goss, H. V., Navrßtil, T., Norton, S. A., and Rohovec, J., Contrasting chemical response to artificial acidification of five acid-sensitive streams:

BIOGEOMON2006, 6th International conference, Santa Cruz, June 2006.

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Web/Internet Site

URL(s):

http://www.umaine.edu/DrSoils/bbwm/bbwm.html

Description:

This is the existing BBWM web presence that will be replaced by a new NSF LTREB supported effort to improve site information and data access. The new web site is being developed off line.

Other Specific Products

Contributions

Contributions within Discipline:

The Bear Brook Watershed in Maine (BBWM) is a long-term, whole-watershed experiment involving a number of scientific disciplines that includes, but is not limited to, geochemistry, soil science, ecology, forestry, hydrology, microbiology, atmospheric science and a more broadly defined environmental science. The project has been a multi-disciplinary, multi-investigator project since its inception. As such, these disciplines also support a critical modeling component of the project that provides an important framework for planning this science, as well as achieving outreach goals to regulators and managers. Because the BBWM experiment is in its 17th year, we are able to discover mechanisms of whole-ecosystem response rarely possible in typical short-term research. At BBWM we are particularly excited by the recent evidence of calcium and other base cation depletions in the treated watershed, changing characteristics of processes in N dynamics evident after 19 years not seen earlier in the study and important for understanding the nitrogen saturation phenomenon, a progression of mechanisms of acid neutralization in soils in both the treated watershed (in response to treatments) and even the reference watershed in response to chronic ambient acid deposition and changing patterns of particularly sulfur deposition, and evidence of new mechanisms controlling stream sulfate export related to secondary soil minerals.

The BBWM study offers opportunities to study the linkages among different processes in the watershed, and thus the intersection of different disciplines. The study illustrates how single discipline research can be limited in its ability to define whole ecosystem function, and shows how the synergy among disciplines changes in its character over time while remaining critical to this scale of research throughout the study period to date. NSF LTREB funding for BBWM provides critical resources to support the framework for mechanistic research, and contributes to that research specifically through its support of work on hydrology, temperature, and nitrogen dynamics.

The work at BBWM is significant because it advances both individual disciplines as well as the integration among disciplines. It is significant because it provides a unique experimental field laboratory to test hypotheses, build models, and provide key data to managers and regulators. The study is of interest to those developing national assessments of surface water quality and forest health as influenced by a changing chemical and physical climate, as well as state and regional concerns for water quality, salmon habitat, carbon sequestration and forest management.

Contributions to Other Disciplines:

Because of the systems-level nature of the overall project, there could be possible applications within this project beyond the disciplines listed above that could include engineering (hydrological or physical science aspects, electrical), physics, biology (zoology, wildlife biology, entomology, pathology, plant and animal physiology), and even computer science related to applications for field research. The BBWM project has been the centerpiece of interdisciplinary research in the past involving biogeochemistry, sociology, and economics. The BBWM continues to be catalyst for this type of research on both a regional and international scale.

Contributions to Human Resource Development:

o providing opportunities for research and teaching in science and engineering areas;

As stated, the BBWM project has provided a rich opportunity for the lead scientists to develop research programs on spatial and temporal scales not feasible on typical short-term research projects. The project continues to provide a basis for numerous graduate student theses in geology, soil science, forestry and related disciplines. The project regularly employs undergraduate students majoring in programs such as Ecology and Environmental Sciences, Geology, Forestry, Wildlife Biology and Biology and this reporting period has seen a continuation of this history.

o improving the performance, skills, or attitudes of members of underrepresented groups that will improve their access to or retention in research and teaching careers;

The BBWM project over the past five years has been the site of research that involved seven graduate and twelve undergraduate women, a graduate student from South America, an undergraduate student from Africa, an undergraduate student from Kyrgyzstan and five women and

four men in technical support positions.

o developing and disseminating new educational materials or providing scholarships; or

The BBWM project has been the basis for examples of concepts in forest ecosystem and watershed function in a range of classes that include soil science, geochemistry, soil chemistry and forest ecology.

o providing exposure to science and technology for pre-college teachers, young people, and other non-scientist members of the public.

The BBWM project has historically been the subject of presentations to public school classes and civic organizations. The site is used in public talks dealing with examples of the linkage between science and policy, several of which are noted in the deliverables of this report.

Contributions to Resources for Research and Education:

The NSF LTREB funding directly supports the maintenance of hydrological monitoring at BBWM and the development of a new web presence for general information about the research of interest to a broad audience, as well as eventually hosting data for other researchers. This funding also supported the purchase of additional datalogger equipment to improve the temperature and soil moisture measurement program at BBWM that will be used for ongoing research and ultimately be available to both the lay and scientific community via the BBWM web presence. The site, and the data and findings it produces, become increasingly valuable as a resource for other scientists, educators and the public and we hope to further promote those opportunities in the coming years. For the numerous faculty involved in research at BBWM, examples of science from this project have become an integral part of their various curricula.

Contributions Beyond Science and Engineering:

This project is studying the effects of a simulated air pollution stress in the form of increased nitrogen and sulfur deposition on forests, soils, and surface waters in a changing climate. It is providing information that has a direct influence on how state and federal regulators view current controls, environmental risks, and management alternatives. To the extent that these policy decisions are influenced by the availability of high quality scientific information on these issues, it is reasonable to suggest that this project has tangible consequences for environmental policy and the social and economic consequences that result. This project has contributed directly to Clean Air Act (CAA) reauthorization in 1990, recent assessments of CAA effects, and regional concerns for forest productivity, carbon sequestration in forests, salmon habitat, water quality, and climate change.

Categories for which nothing is reported:

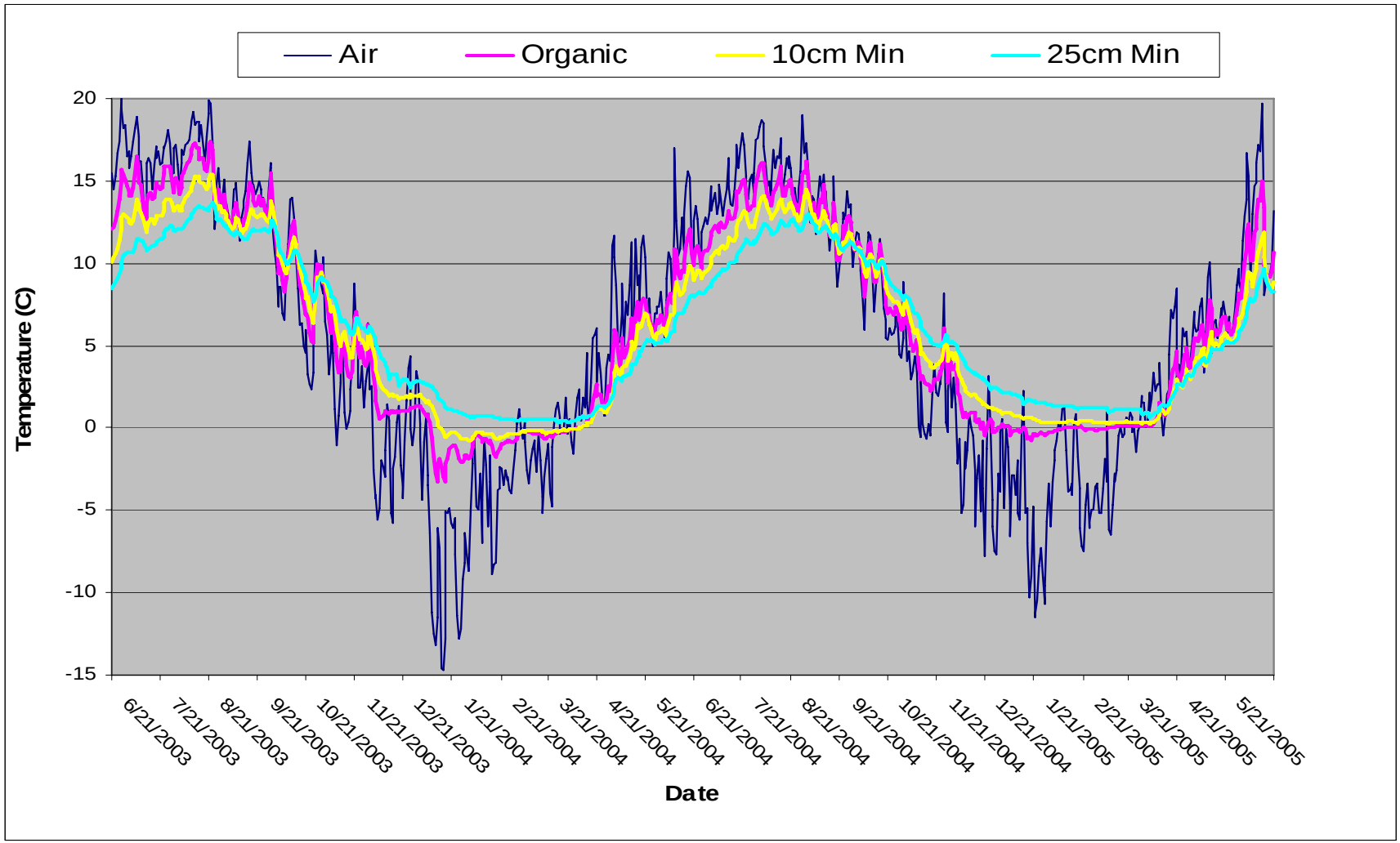
Any Product

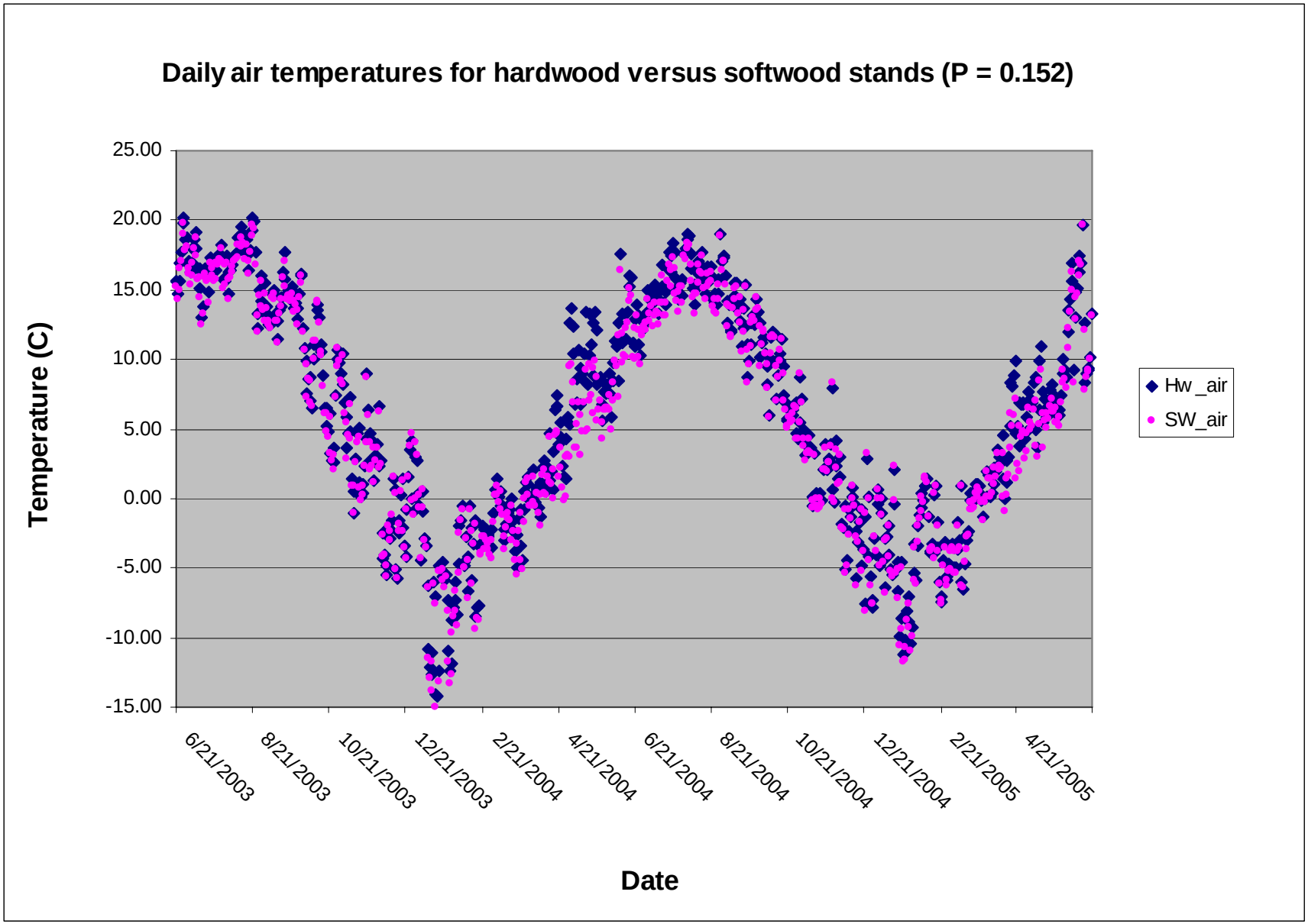
From the Preliminary Assessment of BBWM Soil Temperature from the NSF LTREB Program

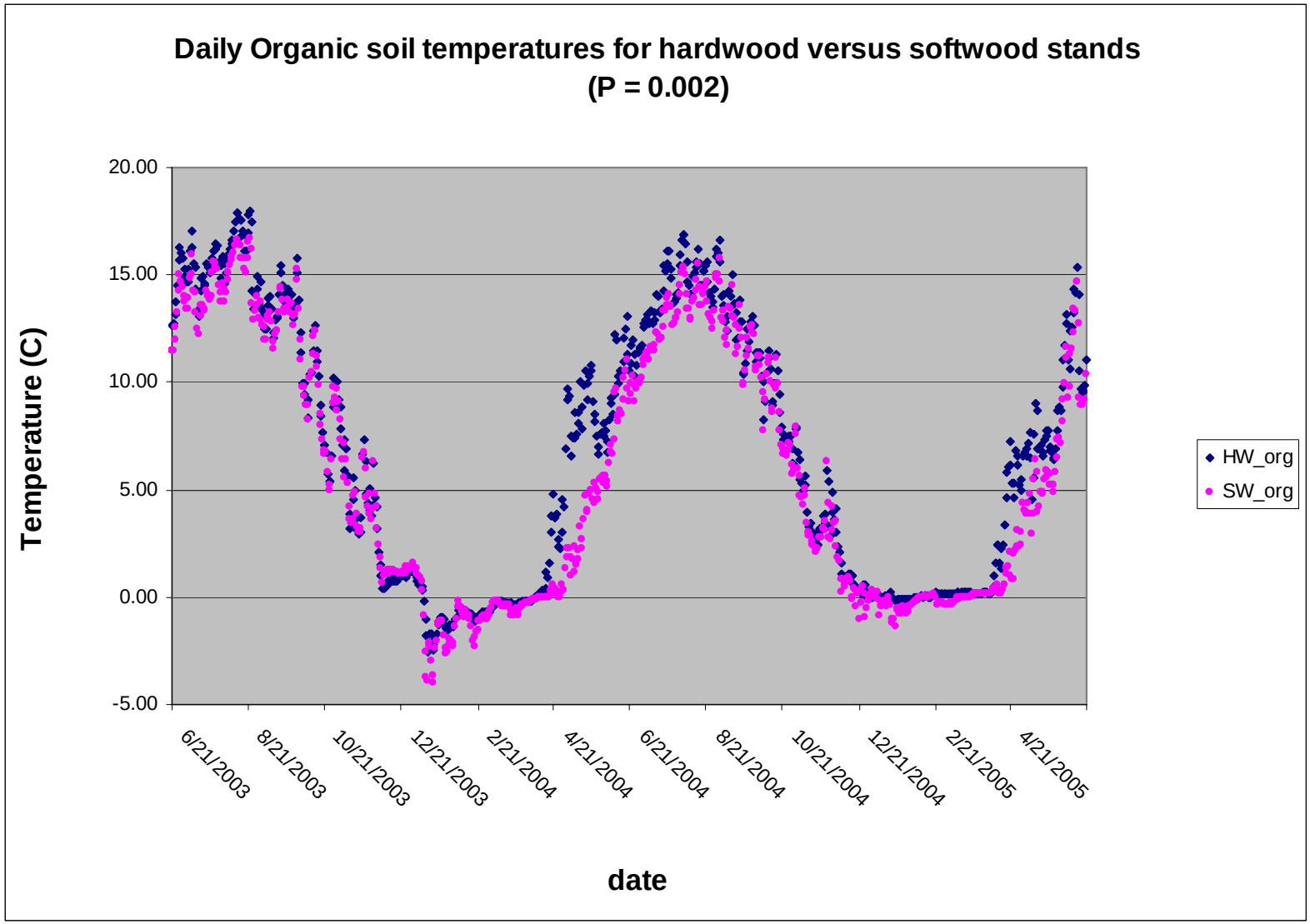
Air and Soil Horizon Temperature Statistics for the Bear Brook Watershed of Maine

	Mean	SE	Median	Min	Max	Range	n
				°C			
				Bear Brook Watershed			
Air	5.06	0.07	5.54	-30.45	31.02	61.47	23392
Organic	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	5.70	-0.61	14.60	15.21	23392
				Hardwood Forest			
Air	5.18	0.10	5.76	-30.17	30.72	60.89	11696
Organic	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	14.60	14.46	11696
				Softwood Forest			
Air	4.95	0.10	5.40	-30.45	31.02	61.47	11696
Organic	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

Average temperatures at BBWM from June 2003 to June 2005




Daily air temperatures for hardwood versus softwood stands (P = 0.152)
Temperature (C)
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
6/21/2003
8/21/2003
10/21/2003
12/21/2003
2/21/2004
4/21/2004
6/21/2004
8/21/2004
10/21/2004
12/21/2004
2/21/2005
4/21/2005
Date
Hw _air
SW_air


Daily Organic soil temperatures for hardwood versus softwood stands
(P = 0.002)
Temperature (C)
20.00
15.00
10.00
5.00
0.00
-5.00
6/21/2003
8/21/2003
10/21/2003
12/21/2003
2/21/2004
4/21/2004
6/21/2004
8/21/2004
10/21/2004
12/21/2004
2/21/2005
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HW_org
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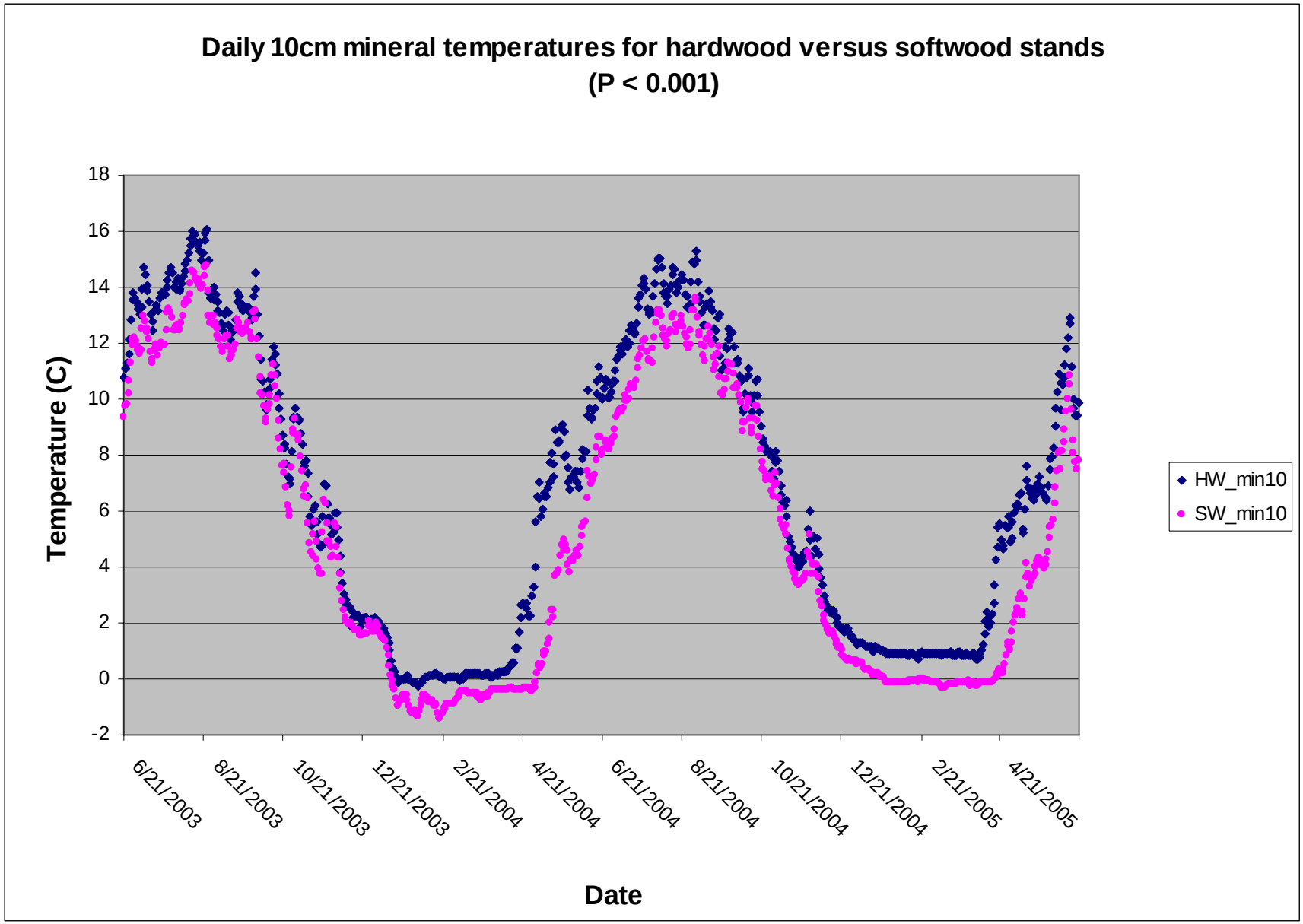
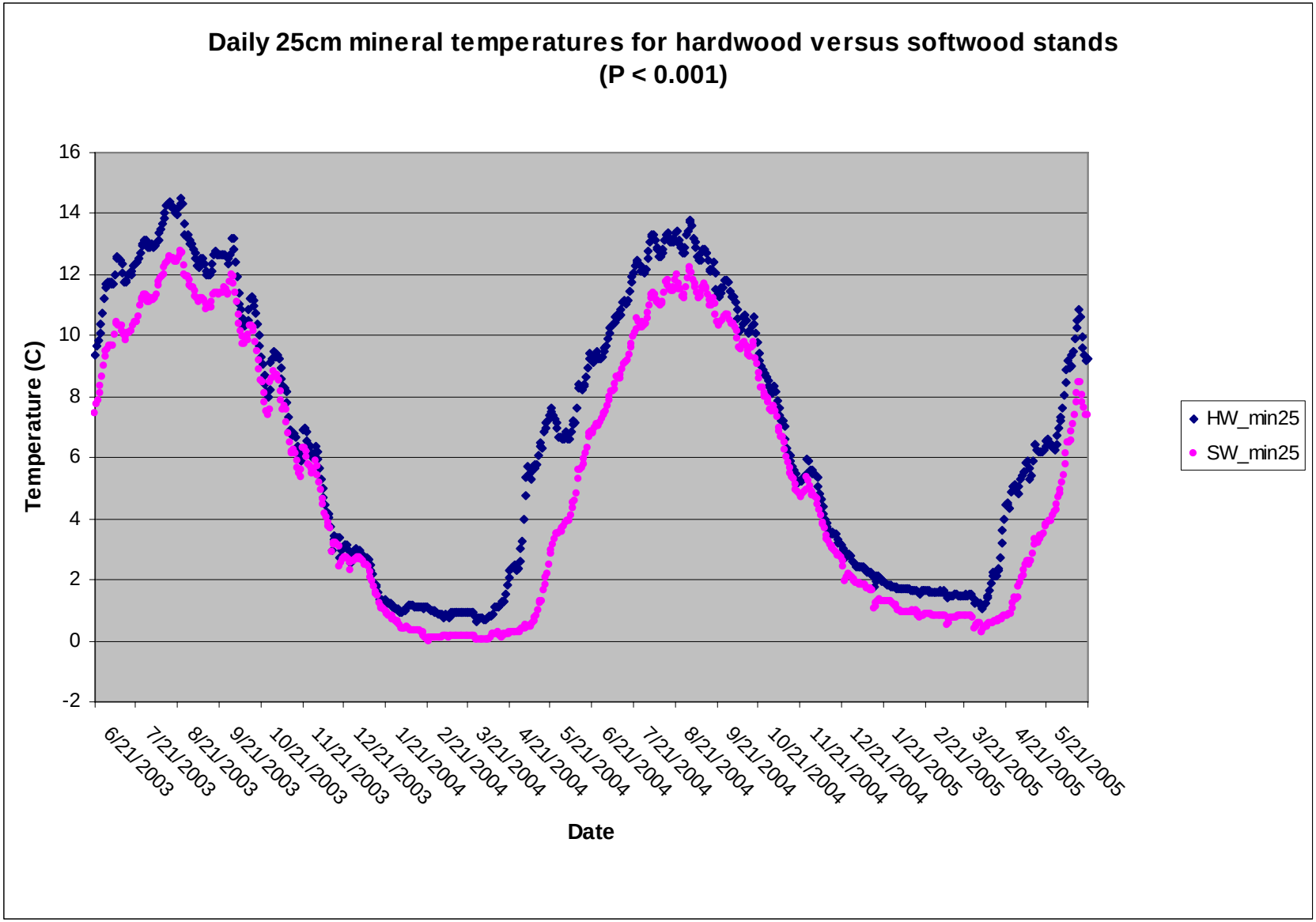

Daily 10cm mineral temperatures for hardwood versus softwood stands
(P < 0.001)
Temperature (C)
18
16
14
12
10
8
6
4
2
0
-2
6/21/2003
8/21/2003
10/21/2003
12/21/2003
2/21/2004
4/21/2004
6/21/2004
8/21/2004
10/21/2004
12/21/2004
2/21/2005
4/21/2005
Date
HW_min10
SW_min10


Daily 25cm mineral temperatures for hardwood versus softwood stands
(P < 0.001)
Temperature (C)
16
14
12
10
8
6
4
2
0
-2
6/21/2003
7/21/2003
8/21/2003
9/21/2003
10/21/2003
11/21/2003
12/21/2003
1/21/2004
2/21/2004
3/21/2004
4/21/2004
5/21/2004
6/21/2004
7/21/2004
8/21/2004
9/21/2004
10/21/2004
11/21/2004
12/21/2004
1/21/2005
2/21/2005
3/21/2005
4/21/2005
5/21/2005
Date
HW_min25
SW_min25

Supplemental Information for NSF LTREB **Award**—0210257 (Fernandez et al.)

Figure 1 – Potential net N mineralization results for the O horizon soils for 2003 and 2004. Temperatures presented are the means for the period of incubation in the potential net N mineralization measurements.

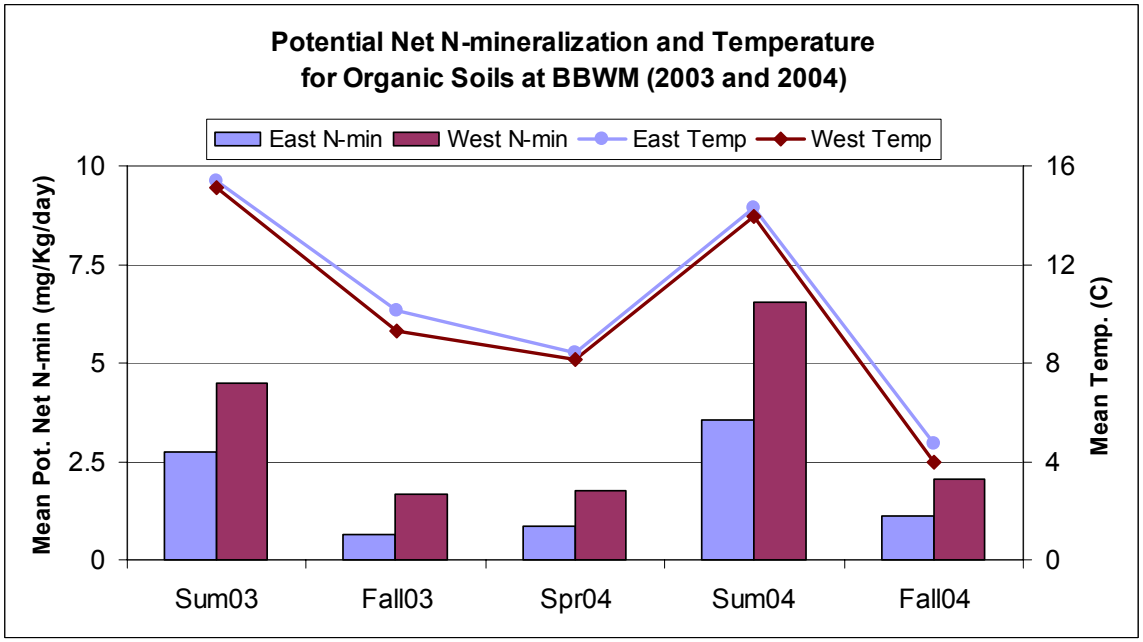


Figure 2 – Potential net N mineralization results for the B horizon soils for 2003 and 2004. Temperatures presented are the means for the period of incubation in the potential net N mineralization measurements.

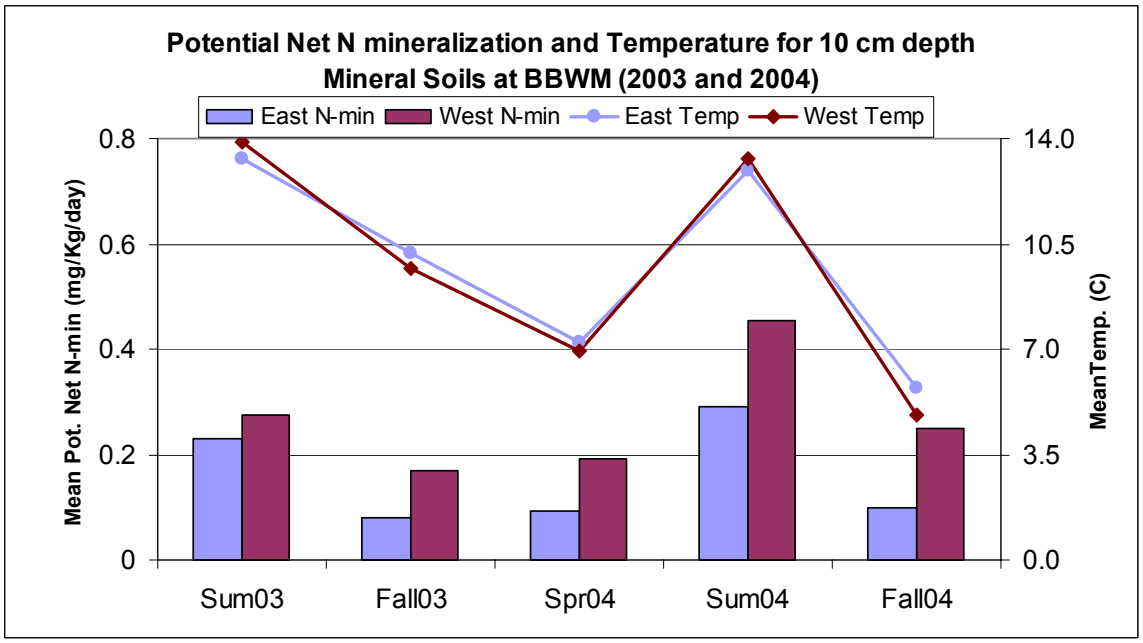


Figure 3 – The relationship between soil temperature and potential net N mineralization in the 2004 data at BBWM.

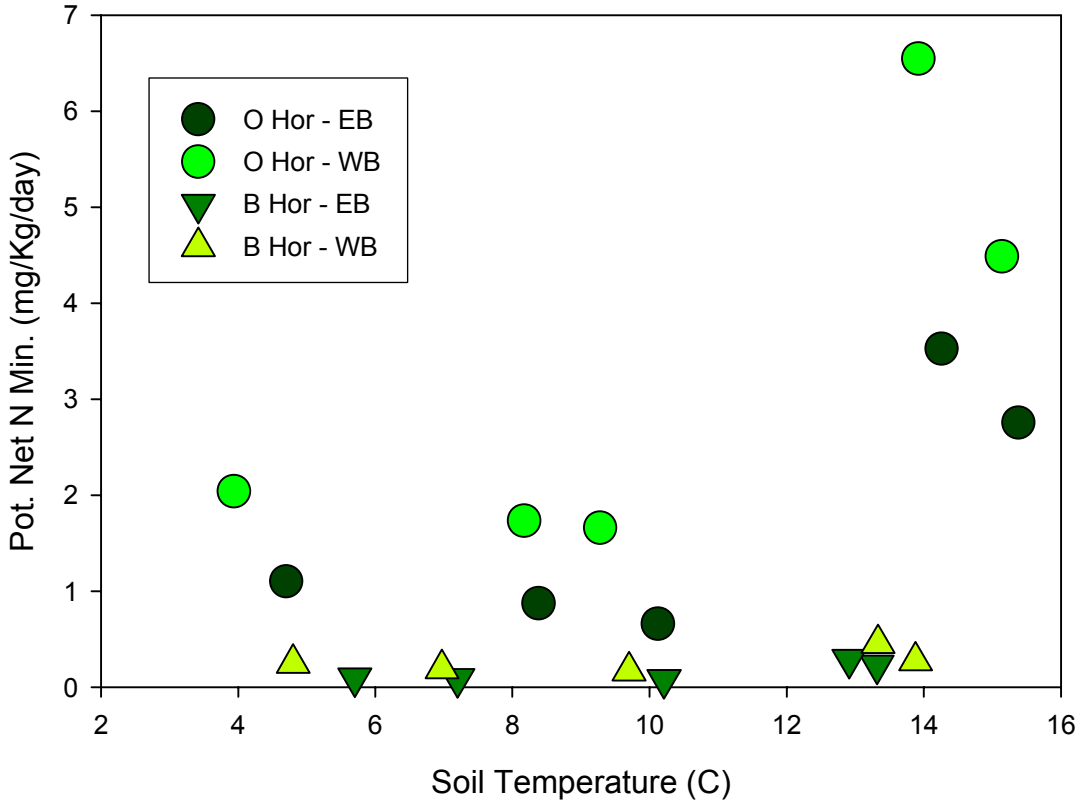


Figure 4 – The 2004 soil and air temperature record from the Bear Brook Watershed in Maine. Data are whole ecosystem averages for BBWM across watersheds and forest types. The year 2004 represents the most complete data set with all HOBO dataloggers functional in all compartments.

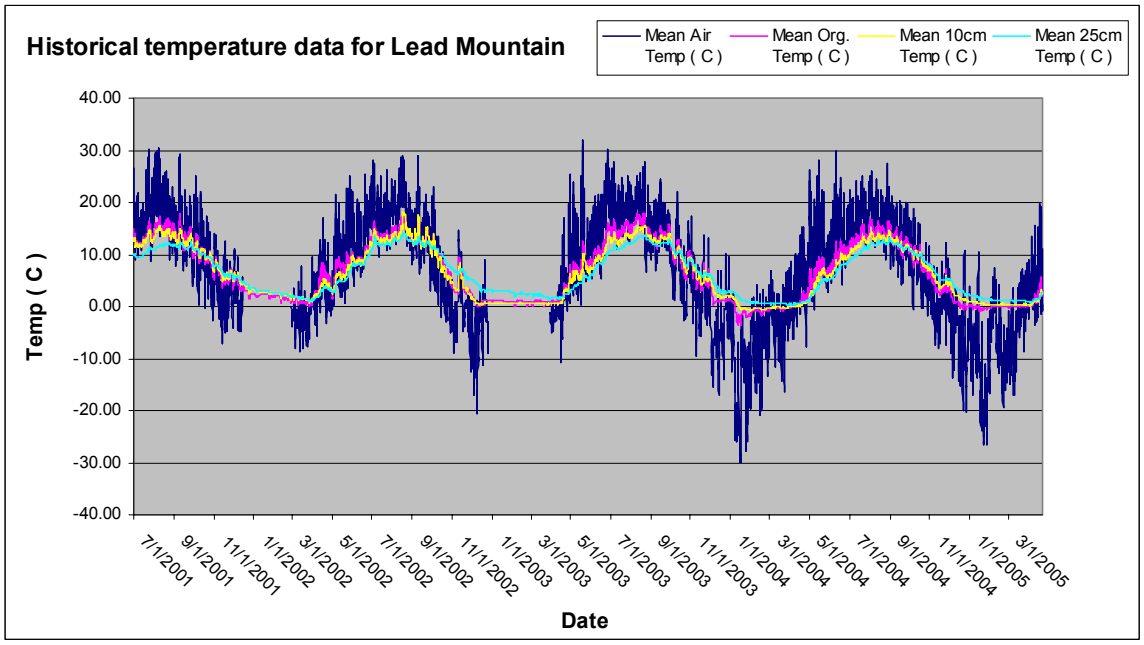


Figure 5 – A time series plot for precipitation, soil moisture, soil temperature, and streamflow data for October, 2003.