Water Research Institute
Annual Technical Report
FY 2003

Introduction

Research Program

Nitrate Mobility in Shallow Groundwater Near Biosolids Stockpiles

Basic Information

Title:	Nitrate Mobility in Shallow Groundwater Near Biosolids Stockpiles
Project Number:	2003ME18B
Start Date:	3/1/2003
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Funding Source:	104B
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Focus Category:	Agriculture, Nitrate Contamination, None
Descriptors:	
Principal Investigators:	Willem Brutsaert, John M. Peckenham

Publication

1. Peckenham, J.M., J. Nadeau, and A. Amirbahman (2003). Biosolids Leachate Experiment, New England Water Environment Association, Bedford, NH, November 13, 2003.
2. Peckenham, J.M. and J. Nadeau (2003). Biosolids Field Stacking Experiment, Maine Waste Waste Control Association, Casco, ME, September 18, 2003.
3. Peckenham, J.M., J. Nadeau, and A. Amirbahman (2004). Nitrogen Loss From The Controlled Field Stacking of Biosolids, Maine Water Conference, Augusta, ME, April 22, 2004.
4. Peckenham, J.M., J. Nadeau, A. Amirbahman, W. Brutsaert, and J. Wilson (2004). Leachate From Biosolid Stockpiles: Nutrients and Metal Mobility, Amer. Geophys. Union Mtg., Montreal, PQ, May 21, 2004.
5. Nadeau, James (2004, expected). MS Dissertation, Department of Civil and Environmental Engineering, University of Maine, Orono, Maine.

Title: Nitrate Mobility in Shallow Groundwater Near Biosolids Stockpiles.

Problem and Research Objectives

The loss of nitrate from biosolid (*i.e.* sludge) stockpiles is of great concern in Maine because groundwater is the common source of drinking water in rural areas. The use of farmland for landspreading organic wastes is a needed option for biosolids management. Biosolids are sludges that have been processed to be used as soil amendments. The quantification of leachate characteristics from biosolids stockpiles for typical soils is needed. For the past 3 years, over 90 per cent of the sewage sludge generated in Maine has been utilized as a soil amendment, after either being composted or lime-stabilized (biosolids). Sewage sludge is the by-product of making clean water, so it is generated year-round. However, since this product is only needed as a fertilizer during narrow windows in the crop cycle, it has to be stored. The most cost-effective and convenient method of storage is to stack the sludge in the field. Sludge may be stacked for up to 8 months before use.

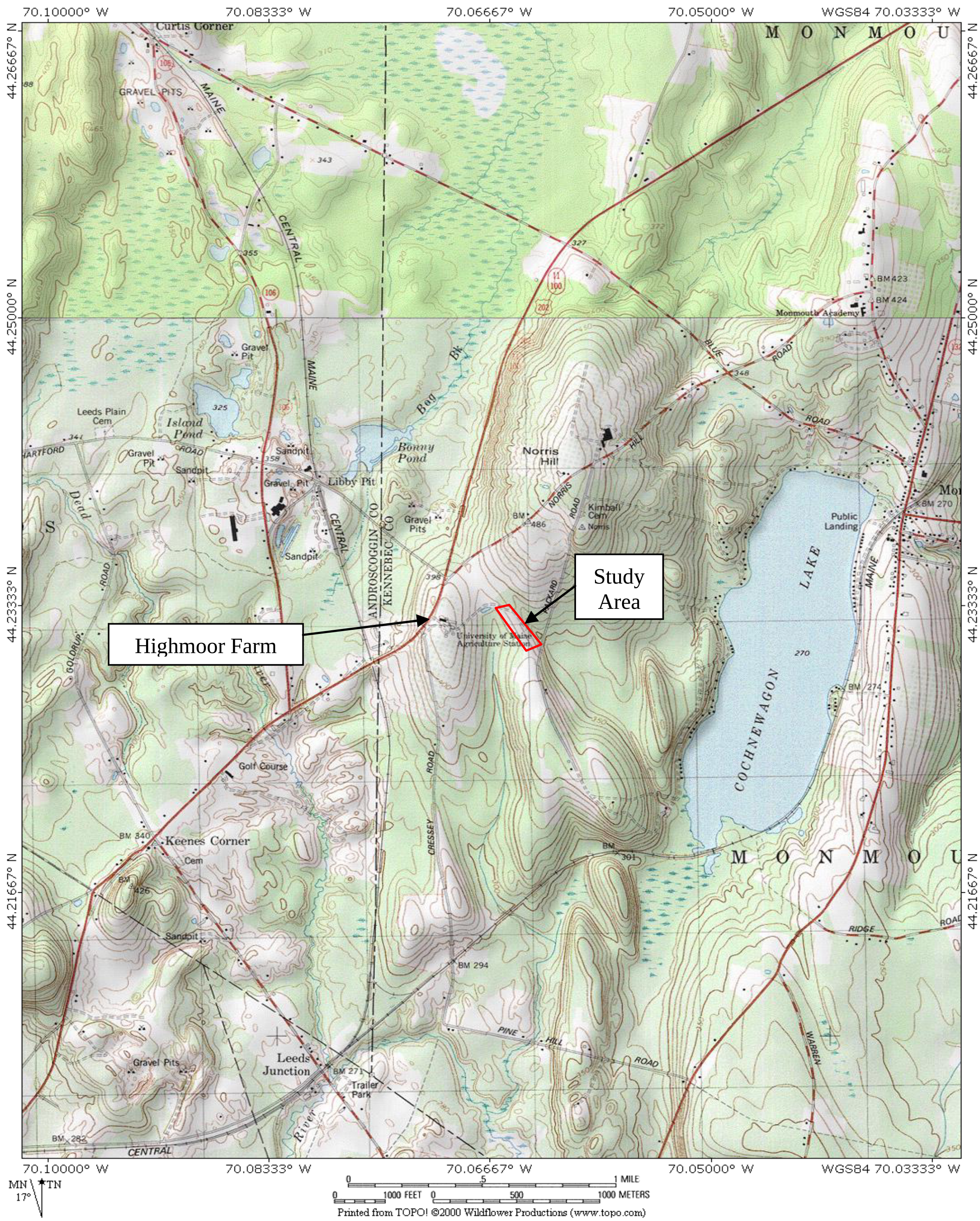
While field stacking is a standard agricultural practice, the Maine Department of Environmental Protection (MDEP) is concerned about the impacts to groundwater that the practice creates. In particular, the MDEP is concerned that nitrate-N leached from a pile may have significant adverse impacts on groundwater. The primary contaminant of concern for the study is nitrate-nitrogen (nitrate-N) and other forms of nitrogen that may change to nitrate in the environment. Nitrate-N and nitrite-N are a concern for groundwater contamination and are regulated under the federal Safe Drinking Water Act.

The objective of this study was to determine the potential for nitrogen species to move from stockpiled biosolids into the shallow groundwater. This study complements another co-located experiment using lined cells to measure the volume of leachate and runoff moving through and over stockpiles of class-B biosolids. This study is providing an independent measure of the concentration of nitrogen in these runoff pathways. Data from this study will be used as a basis for evaluating stockpiling rules under Maine Chapter 419 of the solid waste rules. Users of the resulting data are the Maine Department of Environmental Protection (MDEP) and biosolids-application stakeholders. The data will be used to evaluate current MDEP methods to model the attenuation of nitrate-N and other nitrogen forms in effluent from stockpiles in the vadose zone and ground water. The MDEP intends to model nitrate-N contamination of groundwater around stockpiles. The amount of nitrogen moving out of a representative stockpile is a critical parameter for the modeling. The data need to be representative of realistic leachate and runoff from biosolids stockpiles for actual regional soils.

Methodology

We measured nitrate-N and other forms of nitrogen moving out of biosolids stockpiles under field conditions at the Highmoor Farm in Monmouth, Maine (Figure 1). The design of the biosolids stockpile experiment is described here in summary detail to clarify how the groundwater study is integrated into an existing biosolids leachate characterization experiment funded by the Maine Department of Environmental Protection.

Figure 1. Location of Highmoor Farm in Monmouth and Leeds, Maine. Study area is outlined in red.



Existing Study. The existing biosolids stockpile study consists of three experimental plots: (1) a grass plot with pan lysimeters, (2) a rectangular lined cell (wide), and (3) a rectangular lined cell (narrow) (Figure 2). The stockpile above the pan lysimeter plot is laid directly on the ground with no barrier (4 meters x 10 meters). The lined cells are designed to capture runoff and leachate from two different pile geometries: linear (2.5 meters x 32 meters) and rectangular (5 meters x 25 meters). The surface runoff was collected via gutters along the bottom edge of the pile and above an impermeable membrane (flexible pvc liner). The pile was covered with a layer of sand over the liner and contained an under-drain to collect leachate.

Flow volumes for leachate and runoff from the lined cells were gauged along with rainfall amounts. Initial and final nutrient content and were analyzed for each iteration. Nitrogen species and total dissolved organic carbon (TOC) were determined in the underlying soil. Soil and leachate data were collected to calculate a mass balance profile of nutrients over the duration of the stockpiling. The piles were in place for 8-10 months depending on weather conditions. This time period corresponded to present allowable stockpiling duration limits.

Soil Water. An array of 17 pan lysimeters were located to capture water in the vadose zone directly below the stockpile. These were placed at three levels approximately 0.25m, 0.50m and 1.00m below the soil surface. Effluent samples were extracted from the lysimeters to determine the movement of nitrates through soil in an unrestricted condition (no liner) from stockpiles.

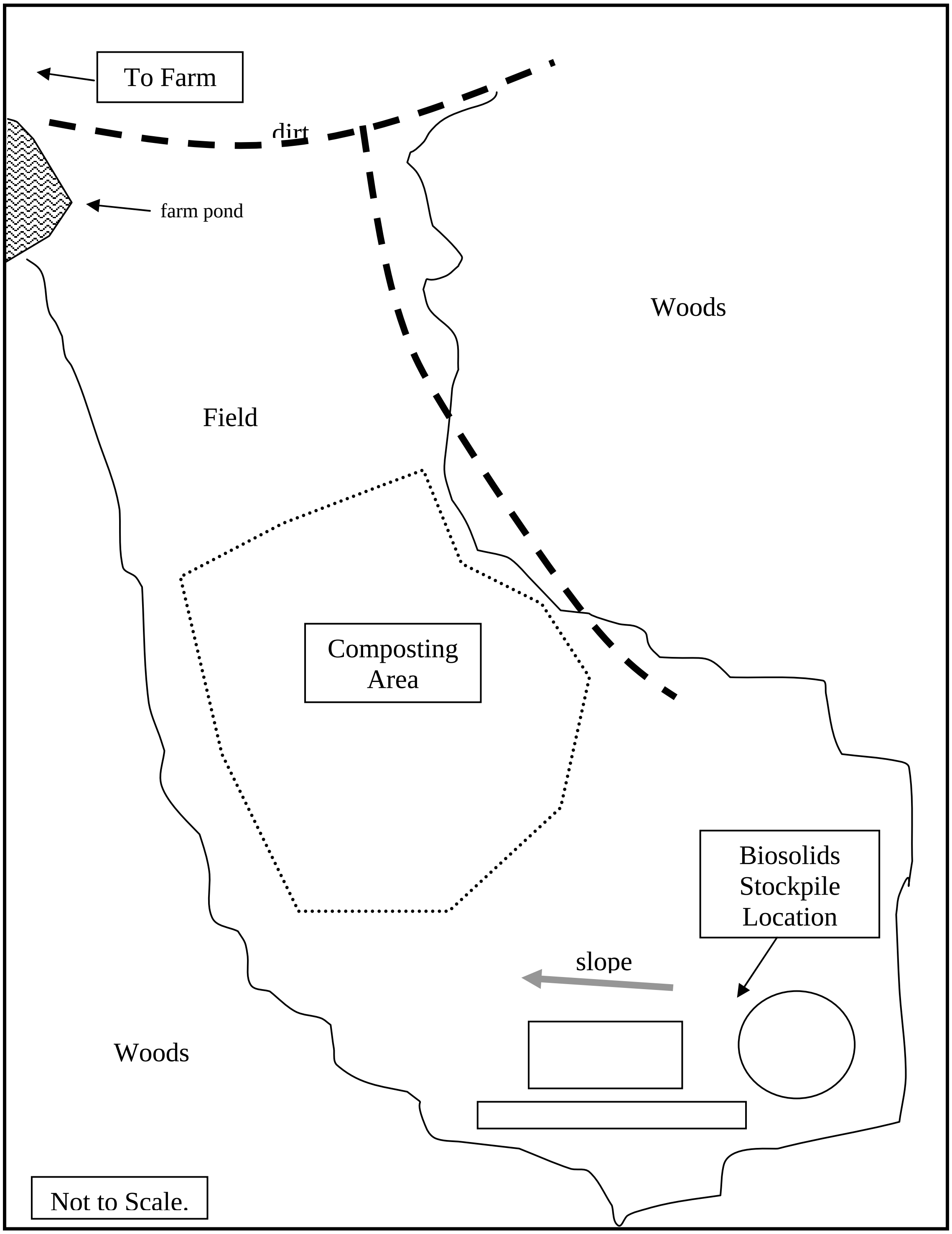
A composite water sample of soil solution (leachate) collected in the lysimeter plot was made for each vertical sampling level by event. The samples were composited to counteract the variability caused by installation and disruption of the soil column. The samples were analyzed for ammonia-N, nitrite-N, nitrate-N, total dissolved nitrogen, and total dissolved organic carbon.

Shallow Groundwater. Seven groundwater piezometers were installed vertically using truck-mounted push technology. Field conditions limited the vertical penetration to a range of 1.5 to 2.5 meters below grade. The piezometer array was completed near the lysimeter plot (three points), the lined piles (two points), 25 meters down-gradient of the lined piles (one point) and 200 meters cross-gradient as a background reference (one point).

Piezometers were constructed from 5-foot lengths (1.52 m) of 0.010-foot slotted 1-inch I.D. (0.305 cm slots, 2.54 cm diameter) pvc pipe. Solid pvc pipe was used above the screen to above grade. The screen was packed with filter sand, sealed with several inches of bentonite powder and then native fill to the surface. After completion, only one point had measureable water (the reference point, W6). Sufficient shallow groundwater was not collectable until after several significant rainfall events in the fall. The pan lysimeters were sampled monthly from July through October and the piezoemeters were sampled three times before the weather became too cold and the ground froze.

Water levels in the piezometers were measured during site visits with a water level indicator. Groundwater samples were collected by purging the wells of multiple well

Figure 2. Schematic layout of the experimental site (not to scale).



volumes of standing water, or to dryness. Purge water was collected as a precaution because of low water volumes. Upon recovery, groundwater samples were collected into glass and polyethylene jars as appropriate for the analytical method. Groundwater samples were analyzed for ammonia-N, nitrite-N, nitrate-N, total dissolved nitrogen, pH, and total dissolved organic carbon. Initial testing indicated that nitrate and nitrate were the anayltes of greatest concentration and later testing was limited to those two nitrogen species.

Sample Analysis were performed at the University of Maine according to Standard Methods and SW-846 Methods, as appropriate.

Principal Findings

Soils and Groundwater
The soil sampling probe was able to be pushed to a maximum depth of 2.74 meters. Advancement of the probe was stopped either by refusal on rock (bedrock or boulder) or excessive soil penetration resistance (dense soil). A total of 10 soil probes locations were sited and piezometers were installed in seven of these locations (Figure 3). Soils were logged in only the push-points where peizometers were installed.

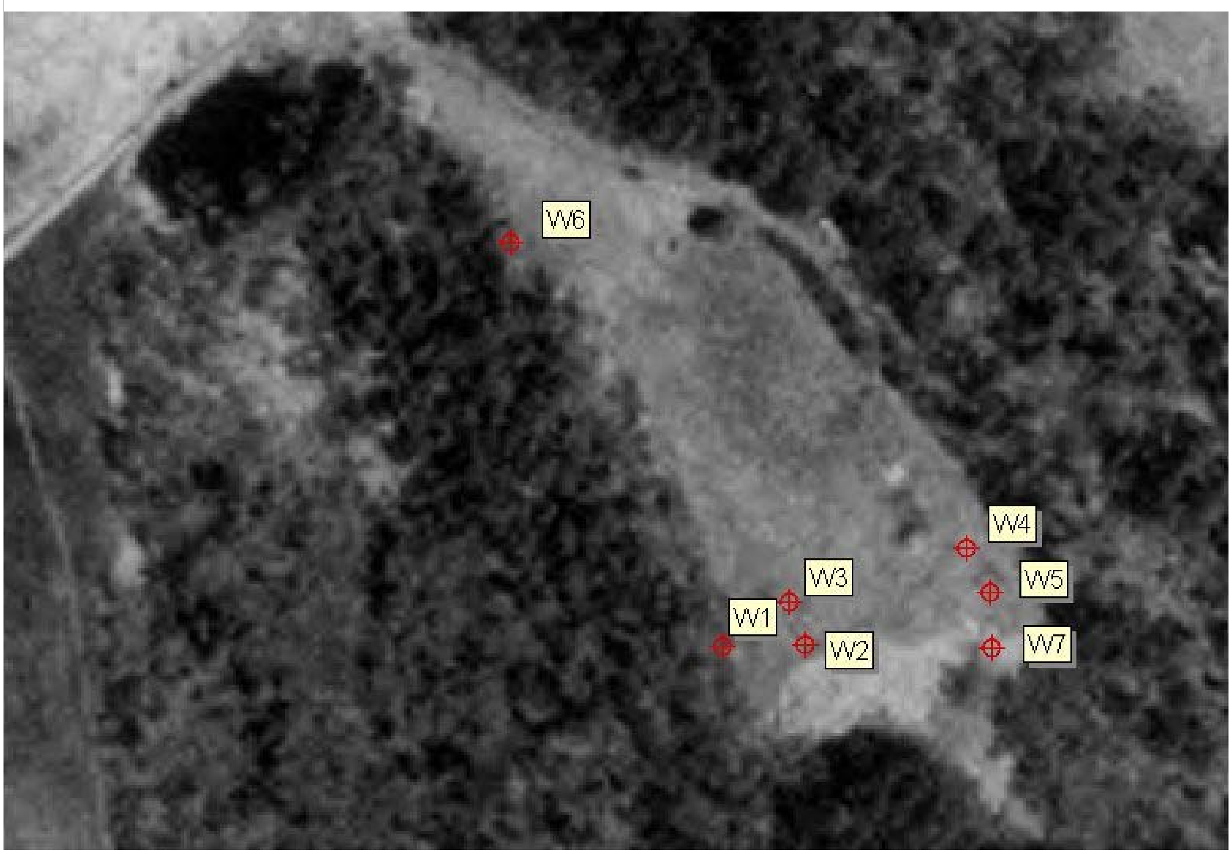
Table 1. Piezometer Construction Details.

Boring Number	Piezometer Number	Location	Total Depth (meters)	Screen Interval (meters)	Riser Length (meters)	Water Level at Completion (m bgs)
B-1	W1	46± m downslope of biosolids test cells	3.1	3.1-1.5	1.5	dry
B-3	W2	2± m east of lower end of long pile	2.7	2.7-1.2	1.5	dry
B-4	W3	Adjacent to wide pile level spreader	2.4	2.4-0.91	1.5	dry
B-5	W4	1.5± m north of lysimeter plot (uphill)	2.6	2.6-1.1	1.5	dry
B-7	W5	1.5± m north of lysimeter plot,15± feet east of W4	1.9	1.9-0.45	1.5	dry
B-8	W6	northwest corner of field in wet spot	3.6	3.6-2.1	3.1	0.3
B-10	W7	8± m east of lysimeters at top of rise	1.9	1.9-0.45	1.5	dry

The soils observed were consistent across the study area. The surface to approximately 10 centimeters was comprised of sod and dark brown organic soil. This organic layer graded into a layer 25± centimeters thick of dark-brown, friable sandy loam. This loam graded into a layer 90± centimeters thick of olive-brown, dense silty to sandy loam with up to 10 per cent pebbles to cobbles. Below this layer, the soil consisted of a layer 120± centimeters thick of moist olive-brown to gray, very-dense silty-sand with up to 10 per cent pebbles to cobbles. No evidence of mottling was observed in any soil samples. Boulders up to 80 centimeters in diameter were observed in excavations in the study area. This soil is interpreted to be glacial till derived (dense silt with pebbles to cobbles).

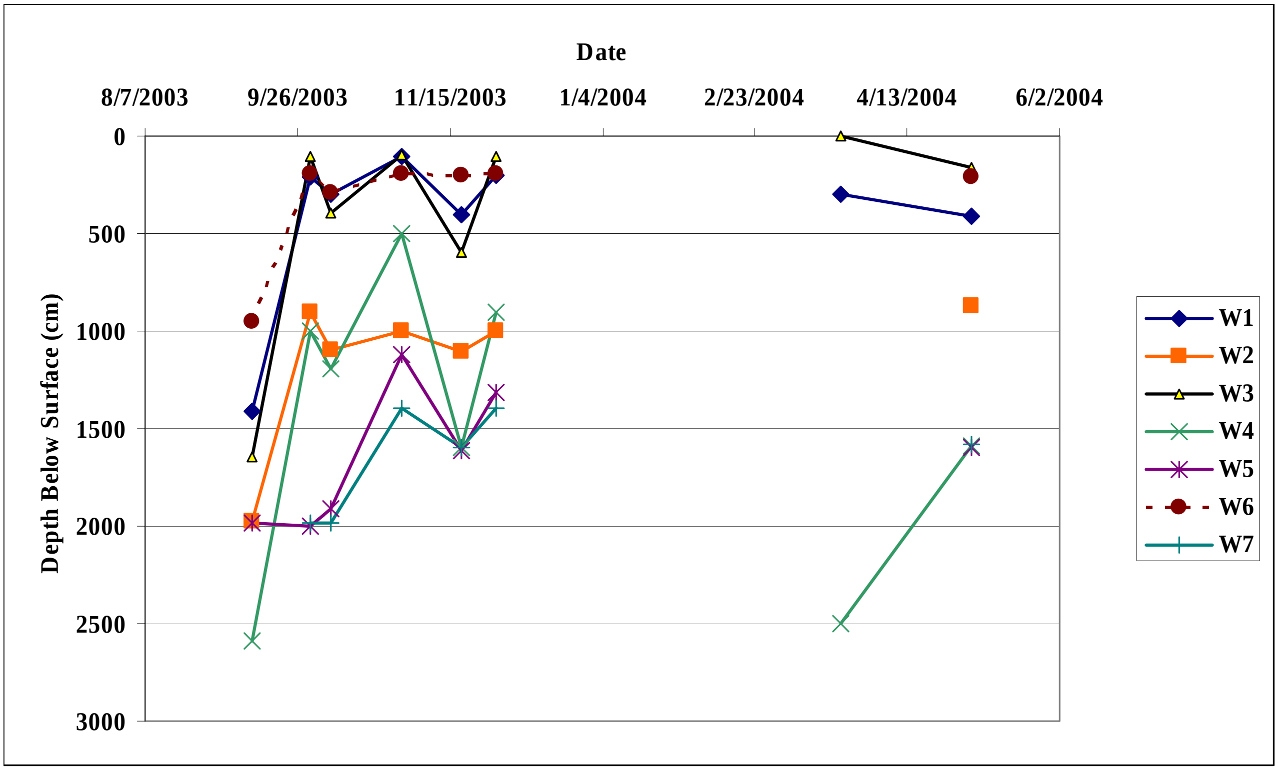
Groundwater was detected at completion in only one soil probe point (B-8) where piezometer W6 was installed. Piezometer completion details are summarized in Table 1. The piezometers were gauged for water levels in September, October, November, December, and April. The water in the piezeometers was frozen from December 2003 into April 2004. Relative water level trends are presented in Figure 4. It is clear from the data collected that these piezometers are saturated with groundwater seasonally.

Figure 3. Locations of piezometers at Highmoor Farm. The field is approximately 90 m. wide.



In general, the soils became saturated in the early fall as a consequence of increased rainfall. According to National Weather Service data for Auburn, Maine, rainfall was below normal for all of August 2003 until mid-September 2003 when precipitation events became more frequent. October 2003 was significantly above-normal for rainfall. During this period of time the piezometers exhibited evidence of soil saturation. The water in the piezometers froze by early December 2003 and the ice persisted through March 2004 and into April 2004 for some piezometers.

Figure 4. Temporal trends in relative water levels in the piezometers.



Shallow Groundwater Chemistry

Sufficient groundwater was present in a majority of the piezometers for sampling on September 30, October 8, and November 30, 2003. Samples collected in September and October were analyzed for ammonia-N, nitrite-N, nitrate-N, total dissolved nitrogen, pH, and total dissolved organic carbon. Some samples were of insufficient volume for all analytes, so nitrogen species was given a priority. The samples collected in November were analyzed for nitrite-N, nitrate-N, and total dissolved nitrogen only.

Nitrogen species were detected in all samples. Results are summarized in Table 2. Nitrate-N was the dominant species, accounting for over 90 per cent of the total nitrogen. Detected concentrations ranged from 0.2 to 91 mg/L, significantly above drinking water limits. Nitrite-N was also detected in concentrations ranging from <0.002 to 7 mg/L. Ammonia-N was detected in only three piezometers in concentrations ranging from 0.1 to 9 mg/L.

The occurrence of nitrogen species in the shallow groundwater exhibited a strong spatial relationship to the biosolids stockpiles (lysimeter plot on bare ground or the leachate discharge zone for the lined cells). The greatest concentrations were found in piezometer W2, followed by W3, W4, and W5. The more distant points, W1 and W6, had the lowest concentrations. The relative concentrations of the nitrogen species varied by sample location in an irregular manner (Figure 5). There are insufficient data to explain these differences.

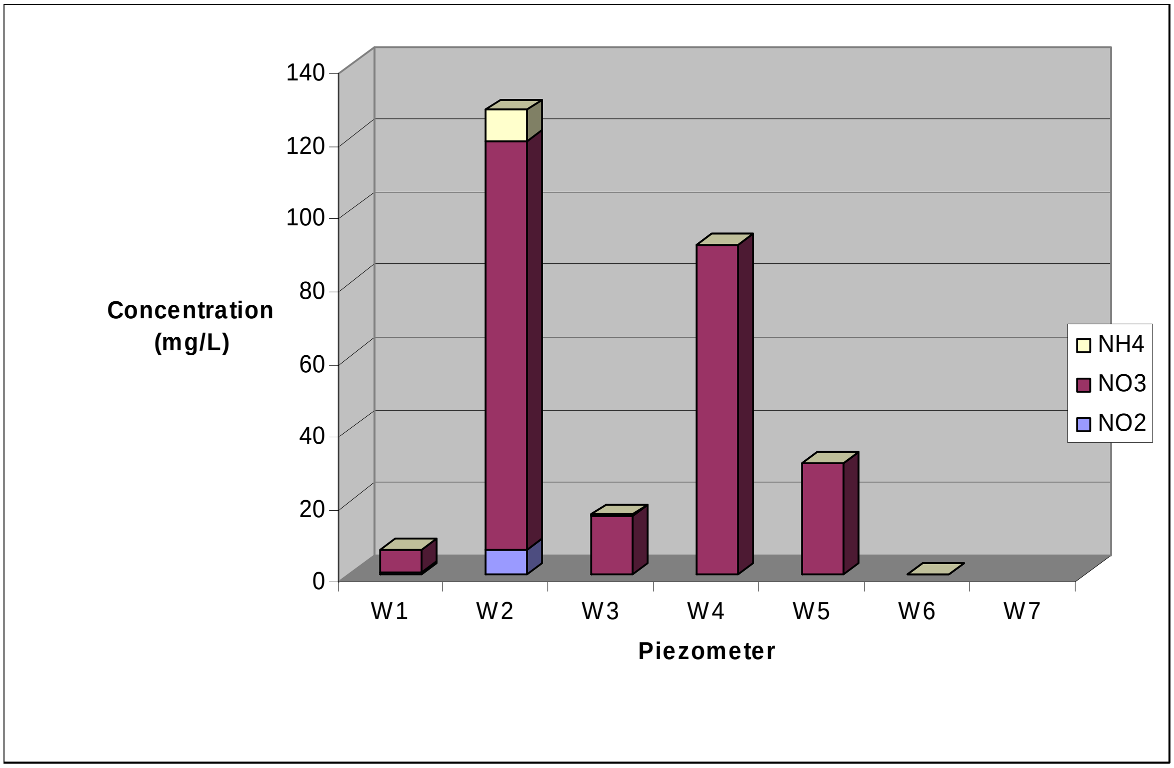
Table 2. Analytical results for the piezometers.

NO2-N	Station	9/30/2003	10/8/2003	11/30/2003	T-N	Station	9/30/2003	10/8/2003	11/30/2003
mg/L	1	0.795	0.135	0.010	mg/L	1	8.016	5.056	
	2	6.992	4.518	1.866		2	126.2	101	
	3	0.152	0.139	0.019		3	17.04	16.69	
	4	0.019		0.007		4	88.88		
	5	0.021		0.485		5			
	6	<0.009	<0.009	0.006		6	0.235	1.088	
	7			0.018		7			
NO3-N	Station	9/30/2003	10/8/2003	11/30/2003	TOC	Station	9/30/2003	10/8/2003	
mg/L	1	6.018	4.929	0.381	mg/L	1	4.58	3.98	
	2	112.1	85.98	46.14		2	9.94	7.53	
	3	16.02	16.75	24.36		3	5.12	4.00	
	4	90.74		20.61		4	4.61	2.83	
	5	30.66		18.82		5		3.76	
	6	0.224	1.082	0.336		6	1.32	1.33	
	7			7.83		7		10.77	
NH4-N	Station	9/30/2003	10/8/2003	11/30/2003					
mg/L	1	0.173	0.075						
	2	8.616	5.224						
	3	0.269	0.236						
	4	<0.05							
	5	<0.05							
	6	<0.05	<0.05						
	7								

Lysimeters. This summary includes results from the biosolids stockpile study (Peckenham, 2004). The results for the lysimeter plot must be interpreted carefully. This is because the soils had to be disturbed to install the pans. The natural soil structures were unavoidably changed. The results from the lysimeter samples exhibited two important characteristics: 1) leachate composition varied markedly within a given depth range, and 2) nitrogen species concentrations were significantly attenuated below two feet. The samples from the lysimeters were also very dark brown in the shallow samples and almost clear in the deep samples. However, some deep samples were colored, reflecting differential flow paths from the surface. Ammonium dominated the other nitrogen species. The concentrations detected exhibited marked variability at each sampling depth. This is interpreted to reflect preferred flow paths through the soil.

Overall the concentrations of TKN increased from one to two feet and then declined markedly from two to three feet (Figure 6). The differences in TKN by depth were statistically significant (ANOVA, $p<0.001$). These results imply that overall, nitrogen species are strongly attenuated through the soil column, and particularly between two and three feet. It is apparent that the leachate presents an elevated oxygen demand on the

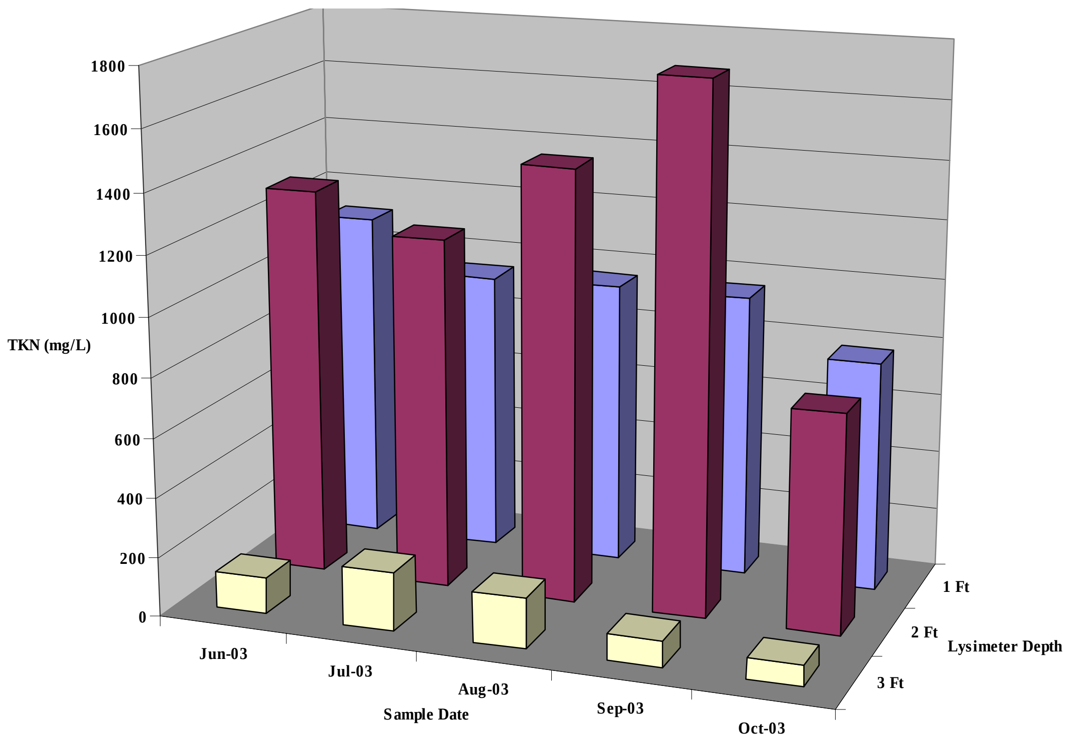
Figure 5. Nitrogen species concentrations in the piezometers. Point W2 is near the discharge from the long pile and point W4 is near the lysimeter stockpile.



At the one-foot depth ammonium-N accounts for 87% of the TKN, but this specie only is 78% of TKN at two-feet and 71% at three-feet. Although nitrate-N and nitrite-N increase with depth of sample, they are not sufficient volumetrically to compensate for the relative decrease of ammonium-N. This means that there is a relative increase in the proportion of organic nitrogen with depth.

Time-series trends for sampling depths exhibited different trends. The one-foot depth, although having high ammonium-N concentrations had slightly decreasing concentrations between June and October. At the two-foot depth, ammonium-N increased consistently from June to September, and then decreased by over 50% in October. At the three-foot depth, ammonium-N concentrations were only 10% of the values at two-feet. The concentrations increased from June to August then decreased from September to October. These results are intriguing because the input is nearly a constant concentration but the soil processes cause marked variations in nitrogen species concentrations.

Figure 6. Variations in total kjeldahl nitrogen in lysimeter samples.



Summary

The data collected to data suggest that nitrogen species are converted from ammonium-N to nitrate-N while moving through the soil under unsaturated to saturated conditions. The overall concentration of nitrogen species appear to be attenuated approximately by one order of magnitude for each vertical meter. Horizontal decreases must be occurring but can not be quantified with available data. Although leachate concentrations of nitrogen are high as a point load, attenuation through the soil column provides some protection to groundwater quality in shallow groundwater. Additional work is needed to assess deep groundwater.

Reference:

Peckenham, J. M. (2004). Maine Biosolids Stockpiling Study Project Report, Report to the Maine Depart. Env. Prot., 39 p.

Students Supported:

James Nadeau, M.S. Civil and Environmental Engineering, basis of Master's research project.

Jennifer Wilson, Ph.D., Ecology and Environmental Science, supporting thesis research for 2 semester (no longer a student at the University).

Elizabeth Dyzeck, B.S., Environmental Science (field assistant).

Defining ’natural’ reference conditions and indicators to assess cumulative impacts of shoreline development on lakes in Maine

Basic Information

Title:	Defining ’natural’ reference conditions and indicators to assess cumulative impacts of shoreline development on lakes in Maine
Project Number:	2003ME19B
Start Date:	4/1/2003
End Date:	3/31/2005
Funding Source:	104B
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Research Category:	Biological Sciences
Focus Category:	Ecology, Non Point Pollution, Recreation
Descriptors:	
Principal Investigators:	Kathy Webster, Roy James Bouchard

Publication

1. Ness, K., K.E. Webster, R. Bouchard. 2003. Defining reference conditions for measuring the effects of shoreline development on lakes in Maine. Poster presentation at North
2. Ness, K., K.E. Webster, R. Bouchard. 2004. Assessing the effects of shoreline development on lakes in Maine. Poster presentation at 6th Annual Association of Graduate Students Research Exposition, April 2004, University of Maine, Orono, ME.
3. Ness, K., K.E. Webster, R. Bouchard. 2004. Assessing the effects of shoreline development on lakes in Maine. Poster presentation at the Maine Water Conference, April 2004, Augusta, ME.

Defining 'natural' reference conditions and indicators to assess cumulative impacts of shoreline development on lakes in Maine

Problem and Research Objectives:

Increases in shoreline development due to the high demand for lake front property currently threaten lake ecosystems. Both new residential development and conversion of seasonal cottages to year round structures intensify the stress on both riparian and littoral habitats. The littoral habitat is a structurally complex and patchy environment that is an important interface between the land and open water. Structural complexity is a function of substrate type, coarse woody habitat, and macrophyte form (Nilsen and Larimore 1973; McLachlan 1970; Anderson et al. 1978; Beckett et al. 1992). Macrophytes in particular provide habitat and food resources for macroinvertebrate and fish species (Voights 1976; Crowder and Cooper 1982). Shoreline development can alter the littoral (near shore) habitats of lakes through reductions in macrophytes and decreases in the amount of coarse woody debris (Radomski and Goeman 2001; Christensen et al. 1996; Jennings et al. 2003). Residents often remove macrophytes and coarse woody debris because it interferes with recreational activities, resulting in reduced habitat quality for fish, macroinvertebrates, and zooplankton.

Although Maine is largely rural, many of the state's more than 5,000 lakes are at risk from shoreline development. In 1971, the State of Maine Department of Environmental Protection instituted protective shoreline regulations for lake riparian zones. The regulations under this act control development actions within 250 feet of the high-water mark for ponds greater than 10 acres in size and create 100 ft setbacks for structures (Kent 1998). The goals of the Shoreland Zoning Act include prevention and improvements in water pollution, conservation of aesthetically pleasing areas, protection of wetlands, conservation of shoreline habitats, protection of wildlife habitats, and control of recreational activities. The effectiveness of these state regulations has never been evaluated due to a lack of research regarding natural conditions of lake littoral habitats for comparison. Our research is designed to provide the State with tools and data to evaluate the efficacy of the Shoreline Regulations in protecting sensitive lake littoral zones.

The main research objective is to determine the effects of shoreline development on habitat complexity of littoral zones in small headwater lakes in Maine. The project has two phases. During the first phase we are defining the natural template of littoral habitats in a set of small headwater lakes having minimal development. These reference conditions provide base conditions for comparison with sites that have different intensities of development. The second phase of the project focuses on assessing the effects of shoreline structures constructed prior to and following passage of the shoreline zoning regulations on habitat complexity, defined by littoral macrophyte community types, coarse woody habitat and sediment composition.

Our specific goals are as follows:

- Describe natural condition of littoral habitats on lakes without shoreline development.
- Determine how shoreline development alters the natural condition of littoral habitats.
- Determine whether Maine Shoreland Zoning Regulations provide adequate protection to littoral habitats by contrasting habitat complexity at shoreline cottages constructed before and after implementation of the regulations.

- Identify a robust set of metrics for rapid assessment of littoral habitats.

Methodology:

Because lakes vary across a region, we established specific criteria for choosing the study lakes for the project. Lakes selected are between 50 and 200 acres in size, similar in hydrology (headwater), similar in geology, and have little or no development along the shoreline. These criteria were created to reduce inherent natural variability among the study lakes.

During the summer of 2003, graduate research assistant Kirsten Ness visited eight lakes representing undeveloped (5) and developed (3) conditions in downeastern Maine. Within each lake, sites were randomly selected within each of eight equidistant shoreline segments around the perimeter (Figure 1). Each site was divided into two 10 m subsites. Data were collected along a littoral transect lying parallel to shore (littoral transect), along a littoral transect lying perpendicular to shore (perpendicular transect), within a riparian plot, and with the shoreline zone (1m back from water) (Figure 2, Table 1).

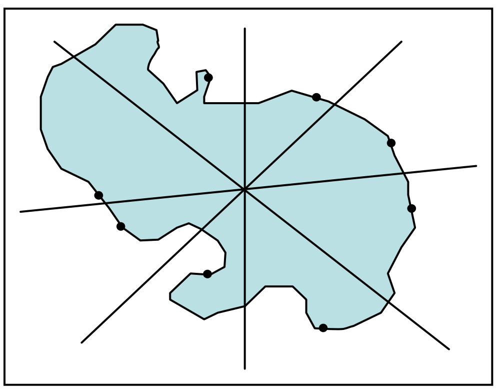

Figure 1: Sites are selected by splitting the shoreline into eight equal segments and randomly choosing one site in each segment.

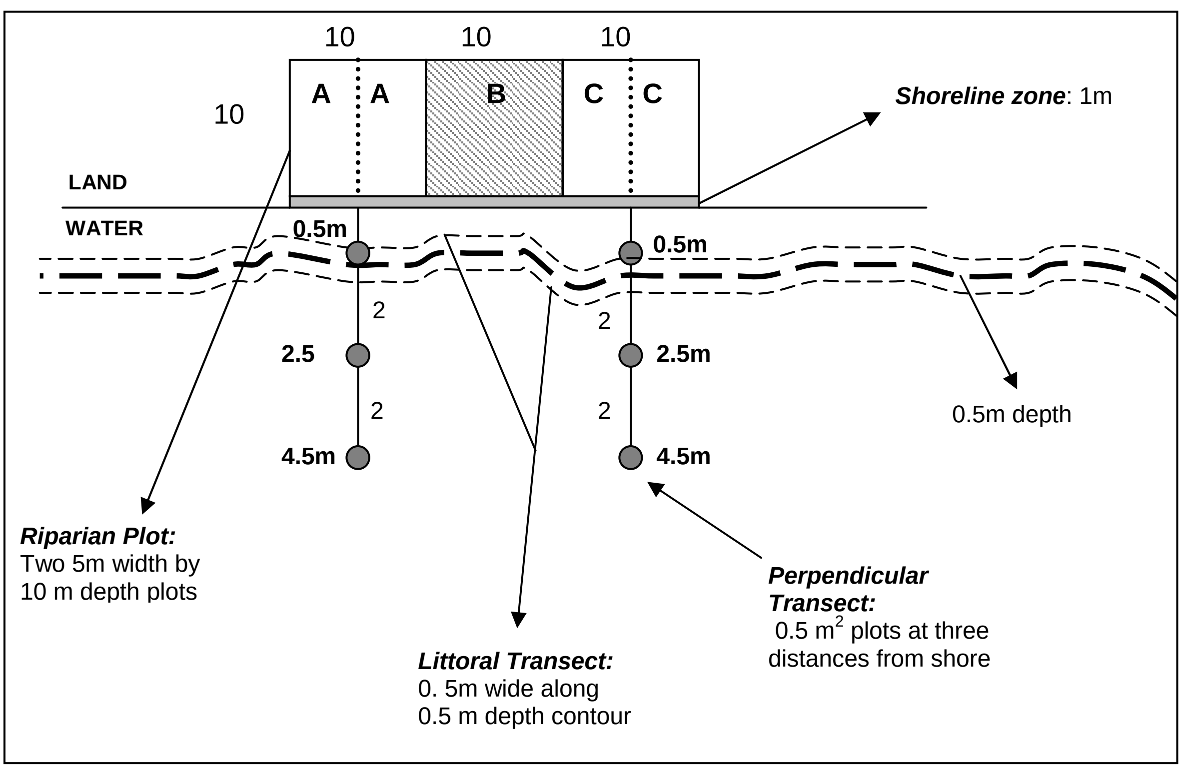

Figure 2: Sampling strategy used during summer 2003.

Data collection includes four types of variables defining (1) the riparian/littoral physical template, (2) littoral and riparian habitat complexity, (3) biophysical indicators, and (3) human activities near the shoreline (Table 1). The riparian/littoral template will be derived from slope, aspect, and littoral and shoreline sediment composition. Based on this template we will develop expectations for habitat complexity, which will be defined as a function of the amount of coarse woody debris and macrophyte community structure. Biophysical response variables include macroinvertebrate community structure, which is influenced by the complexity of the habitat, and sediment embeddedness, which is a measure of the amount of fine sediments overlying the original sediments. Embeddedness has been suggested to increase due to shoreline disturbance (Jennings et al. 2003). Finally, at developed sites we will assess the intensity of the human footprint by determining the composition and structure of riparian terrestrial vegetation, the type of structure and amount of impervious surface, and whether the structure was built prior to or after 1971 when shoreline regulations were instituted.

Table 1: Habitat and biological variables measured during summer 2003.

Variables	Littoral Transect (0.5m depth)	Perpendicular Transect	Riparian Plot	Shoreline Zone
Physical	*Substrate type[a] *Fetch *Aspect	*Substrate type[a] * Littoral slope	* Slope * Aspect	*Substrate type[a]
Habitat complexity	* Macrophyte structural type[b] * Coarse woody debris	* Macrophyte structural type[b] * Coarse woody debris	*Vegetation structure[c] and type[d]	* Vegetation structure[c] and type[d] *Overhanging vegetation
Biophysical Response Variables	*Macro invertebrate taxa *Substrate embeddedness[e]	*Macrophyte species *Substrate embeddedness[e]		
Measures of human activities	*Evidence of human use (boats, docks, etc)		*Impervious surfaces *Type and footprint of structure *Pre- or post-legislation	

[a]Substrate type = sand, cobble, boulder and bedrock
[b]Macrophyte structure = submerged, emergent, floating leaf,
[c]Vegetation structure = tree height category, shrub, etc.
[d]Vegetation type = deciduous, coniferous, or mixed
[e]Embeddedness = the relative degree to which the sediments are covered with fine silt

Principal Findings and Significance:

Data analysis to date has focused on using multivariate techniques, such as principal components analysis to quantify relationships among physical habitat variables and macrophyte structure. Preliminary results indicate that certain structural types of macrophytes are associated with different types of substrate. For example, emergent and submergent macrophytes prefer areas with fine sediments over cobble and gravel substrates. Such results will set the groundwork for interpreting findings from sites with development.

Additional analyses were conducted to determine whether the summer 2003 protocol should be revised for the 2004 sampling season. The analysis revealed that there was substantial variation among lakes, sites, and subsites within each lake. Based on this finding we will conduct more intensive sampling on four developed and four undeveloped lakes. We will increase the number of randomly selected sites on all lakes to 10-12 per lake. In addition, on developed lakes we will deliberately select sites with different types and intensities of shoreline development. This will enable a more direct comparison between shoreline structures built prior to and after the Shoreland Zoning Regulations took effect in 1970.

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Student Support

This project supports Kirsten Ness' research for her M.Sc. degree in Ecology and Environmental Science (EES), with a concentration in Water Resources. Matching funds from the University of Maine have provided her support via a Research Assistantship (2003-2004) and a Teaching Assistantship (2004-2005).

The functional role of forested seeps in maintaining hydrology, water quality and biological diversity in a New England watershed

Basic Information

Title:	The functional role of forested seeps in maintaining hydrology, water quality and biological diversity in a New England watershed
Project Number:	2003ME21B
Start Date:	6/1/2004
End Date:	2/31/2005
Funding Source:	104B
Congressional District:	2
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrogeochemistry, Wetlands, Groundwater
Descriptors:	
Principal Investigators:	Aram Calhoun, Bryan Dail, Andrew Reeve

Publication

The functional role of forested seeps in maintaining hydrology, water quality and biological diversity in a New England watershed.

Progress Report:

Problem and Research Objectives:

Integrated biogeochemical and hydrologic studies assessing the role of nutrient dynamics in forested catchments are needed to quantify seep landscape function (Cirmo and McDonnell 1997). Seeps are known to be hotspots for rare flora (and possibly fauna), thus reflecting unique edaphic and hydrologic habitat features. Recent research suggests that springs are an important source for nitrogen loading to streams within the Catskill Mountains of New York (Burns et al. 1998, West et al. 2001). However, the slow or lentic water flow in seeps, as compared to springs, may favor denitrification and N loss to the atmosphere. If denitrification is important in these systems, this would influence water quality and nutrient dynamics in streams that receive seep drainage or recharge. Because seeps and springs may integrate the water quality across large areas within a basin, they may provide a simple and inexpensive way to monitor the overall impacts of human activities and natural processes within a watershed (Manga 2001).

The central Maine landscape affords us an opportunity to evaluate baseline hydrologic, biochemical, and ecological functions of hillside seeps in an environment less influenced by anthropogenic influences. Given this, baseline indices of biological or hydrologic integrity may be developed. We propose to study the biogeochemical, hydrologic, and biological processes of forested hillside seeps and to directly address landscape scale functions.

The objectives of this research are:

1) To establish the extent to which seeps sustain low flow conditions in associated streams and the extent to which seeps buffer stream geochemistry.

2) To determine if saturated aerobic soils reflect nitrogen transformations similar to wetland systems and are in fact distinct from associated upland nitrogen cycling.

3) To augment existing forested seepage community data and to assess floral assemblages in seeps and surrounding uplands.

4) To document seasonal habitat preferences by amphibians in headwater catchments containing seeps.

Methodology:

Research will be conducted at two spatial scales. A primary research catchment has been chosen in northwest Hancock County for intensive sampling of three seeps. Additional seeps (thirty) will be chosen within the same physiographic region to assess regional variability.

Hydrological assessment of seeps will be conducted throughout the growing season by bi-monthly groundwater and surface water flow measurements and seasonal collection of groundwater and surface water samples. Groundwater flow and chemistry will be ascertained by installation of at least five groundwater well clusters (17 total) at each of three intensively monitored seepage wetlands. Individual well clusters will be spaced at depth increments of 0.5 to 1.5 m, to establish vertical hydraulic and chemical gradients. Seep surface flow will be measured using V-notch weirs installed at a point where seep surface flow is constrained and channelized.

Discharge through stream channels will be measured at several locations upstream and downstream of the seep to assess the impact of the seep on stream discharge and determine if the stream is gaining or loosing water to the groundwater system. Discharge measurements will be compared to stream stage and an empirical relationship will be developed between stage and discharge for the streams. The hydraulic conductivity of the geologic materials will be determined by measuring the recovery rates in a well after a volume of water is removed from the well. The porosity of sediment samples will be estimated by weight proportion of the split spoon sample when wet and dry, and assuming the volume of water lost is equal to the porosity. Discharge rates and groundwater velocities will be calculated with Darcy's Law using hydraulic head and hydraulic conductivity data.

Water samples will be collected from the surface-water and groundwater monitoring stations three times during the growing season. All water samples will be lab filtered (0.45 micron) and analyzed at the University of Maine's Environmental Chemistry Laboratory (ECL) for major anions (NO_3, SO_4 and Cl) and cations (Ca, Mg, Na, K, Fe, Mn). Nutrient samples will be analyzed at the ECL for inorganic N (NO_2 /NO_3 and NH_4^+), total nitrogen (TDN) and reactive phosphorus. Probes will be used to measure pH, dissolved oxygen, water temperature, and specific conductance bi-monthly in the field. Alkalinity will be measured in the laboratory using standard titration techniques. Collection of this data set will allow data quality to then be assessed through charge-balance calculations.

Evaluation of selective nitrogen uptake and cycling will be completed through concurrent, seasonal collection of: throughfall (19 funnel collectors), soils (18 soil sample locations), vegetation (3 dominant species at each site), and water (17 – groundwater well clusters, 6 – surface water points). The isotopic signature of N forms will be determined in each of the four pools by using solid state Isotope Ratio Mass Spectroscopy (IRMS). This data will also be used to assess the redox conditions within the seeps.

Soils will be classified and described at each of the seep study sites. Near each well cluster, soil profile descriptions, and an analysis of organic and mineral horizons (texture, percent organic matter, CEC, and pH) will be characterized and analyzed for nitrate and ammonium by The Maine Soil Testing Service and Analytical Lab.

Floristic inventories of all the study sites will be conducted in spring, mid-summer, and fall along three elevational transects corresponding to seep locations. Data will be collected following the protocol used by the Maine Natural Areas Program (nested plots for trees, saplings, shrubs, herbs/forbs, and bryophytes with cover classes recorded for each species) for inclusion in their database. In addition, data will be collected on tree basal area, vegetation in adjacent uplands (dominant species in each strata), and a volume measurement of standing and down deadwood (coarse woody debris and fine woody debris) using a method adapted from the US Forest service.

The relative abundance of amphibian assemblages will be assessed seasonally using funnel trap arrays, coverboard arrays, and time-constrained searches in all of the seeps and repeated in adjacent uplands along similar elevational gradients. Funnel trap arrays will consist of a series of 10m drift fences arranged in a "T" fashion, within or adjacent to each seep with eight aluminum 0.9x0.2m funnel traps placed near each end of the fence on each side. The traps will contain a sponge (re-wetted upon inspection) and cover objects to reduce amphibian desiccation or mortality. The funnel trap arrays will be opened over two-week intervals throughout the field season. A total of 50 coverboards will be used to identify additional species not apt to be captured by funnel traps. These will be numbered and placed at the wetland/upland boundary along the border of each seep and within vegetation gradients in each seep. The coverboards will be inspected in conjunction with visual encounter surveys conducted following seasonal wet and dry periods concurrent with the sampling periods for soil and water analysis.

Principal Findings:

This grant currently provides support for the 2004 field season. As such, data collection is continuing throughout this year.

Significance for the project:

This funding has allowed the research to continue for a second field season and allow for additional surface water analysis from additional seep sites.

Provide publication citations associated with the research project:

To date no publications are associated with this project.

Additional Project information:

Student Support:

This research currently provides partial support for one full time doctoral candidate. This funding has also allowed employment of four undergraduate student workers. Two work-study students were employed during the spring 2004 academic period to assist data processing, while one work-study and one student worker will assist fieldwork and laboratory activities during the summer of 2004.

Notable Awards and Achievements:

To date, this project has not generated any notable achievements or awards.

Publications from Prior Projects:

To date, there have been n o publications as a result of funding form this source regarding the research.

References Cited:

Burns, D. A., P. S. Murdoch, G.B. Lawrence (1998). "Effect of groundwater springs in nitrate concentrations during summer in Catskill mountain streams." Water Resources Research 34: 1987-1996.

Cirmo, C. and McDonnell, J. (1997). Linking the hydrologic and biogeochemical controls of nitrogen transport in near-stream zones of temperate-forested catchments: a review. Journal of Hydrology, 199:88–120.

Manga, M. (2001). Using springs to study groundwater flow and active geologic processes. Annual Reviews in Earth and Planetary Science, 29:201–228.

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Effects of local and landscape heterogeneity on mercury loadings in palustrine amphibians from Acadia National Park, Maine

Basic Information

Title:	Effects of local and landscape heterogeneity on mercury loadings in palustrine amphibians from Acadia National Park, Maine
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Descriptors:	
Principal Investigators:	Aria Amirbahman, Michael Bank, Cynthia Loftin

Publication

1. Bank. M.S. 2004 (In Prep). Mercury bioaccumulation and habitat dynamics of lotic and lentic amphibians. Doctoral Dissertation University of Maine, Orono, Maine.
2. Bank, M. S., C.S. Loftin, A. Amirbahman, J. Peckenham and R.E. Jung. 2003 (Invited Oral Presentation). Mercury bioaccumulation in lotic and lentic amphibians. In Assessing the depositional, geological, and biological factors that control mercury deposition in aquatic ecosystems of northeastern North America - USDA Northern Research Station, Northern States Research Cooperative Mercury Research Workshop, December 3-4, 2003, Portland, Maine (Special Mercury in the Northeast Issue Ecotoxicology Published Abstract).
3. A. Bank, M. S., C. S. Loftin, A. Amirbahman, J. Peckenham, T. A. Haines, and R. E. Jung. 2004 (Invited Oral Presentation). Mercury bioaccumulation in lotic and lentic amphibians: regional conservation implications for surface water ecosystems in the Northeastern United States. Gulf of Maine Research Institute Seminar Series, Portland, Maine, January 12, 2004.
4. Bank, M. S., C.S. Loftin, A. Amirbahman, J. Peckenham. T.A. Haines, and R.E. Jung. 2004 Mercury bioaccumulation in lotic and lentic amphibians from Acadia National Park, Maine. Maine Water Conference, April 21, 2004. Augusta, Maine.
5. Bank, M. S., C.S. Loftin, A. Amirbahman, T.A. Haines, and R.E. Jung. 2004 (Invited Oral Presentation). Mercury bioaccumulation in lotic and lentic amphibians: regional conservation

implications for aquatic ecosystems in the Northeastern United States. 2004 Joint Meeting of Ichthyologists and Herpetologists (USGS-ARMI Invitational Symposium), May 31, 2004, Norman, Oklahoma.

Mercury Bioaccumulation in Green Frog (*Rana clamitans*) and Bullfrog *(Rana catesbeiana)* Tadpoles from Acadia National Park, Maine, USA

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Running header: Mercury Bioaccumulation in Tadpoles

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Abstract

Mercury (Hg) contamination in the northeastern United States, including Acadia National Park (ANP), is well documented and continues to be a public health issue of great concern. Hg contamination of wild amphibians has received little attention despite mounting evidence and reports of worldwide population declines. Here we report total Hg and methyl Hg concentrations for water, sediment, and green frog and bullfrog tadpoles (~ 1 year of age) from ANP, Maine, USA. Average total Hg concentrations in green frog and bullfrog tadpoles were 25.1 ± 1.5 and 19.1 ± 0.8 Hg ng/g wet wt, respectively. Average total Hg was highest for green frog tadpoles sampled from the Schooner Head site, a small semi-permanent pond where Ranavirus was detected during the summer 2003 sampling period. Methyl Hg comprised 7.6-40% of the total Hg in tadpole tissue (wet wt. basis), and average total Hg levels in tadpoles were significantly different ($P < 0.05$) among pond sites ($n = 9$). Total Hg in pond water was a significant predictor of tadpole total Hg levels ($P < 0.05$). Dissolved organic carbon was a significant predictor of both total Hg ($P < 0.05$) and Methyl Hg ($P < 0.05$) in water, and total Hg in water was also strongly correlated with Methyl Hg in water ($P < 0.05$). The methylation efficiency (ME) rates defined as total Hg:Methyl Hg ratio in pond waters sampled at ANP were higher than the reported ME for national parks located in the western region of the United States. Of the 9 ponds we sampled at ANP, 44% had ME greater than 10% suggesting that wetland food webs in the park are likely susceptible to high levels of total Hg bioaccumulation. These findings may be important to National Park Service resource managers especially considering the Class I airshed status of ANP and the strong potential for negative effects to aquatic ecosystem structure and function from Hg pollution.

Problem and Research Objectives

Mercury (Hg) contamination in the northeastern United States, including Acadia National Park (ANP), is well documented (Bank et al. In Press, Burgess 1997) and continues to be a public-health issue of great concern (Schober et al. 2003, Mahaffey et al. 2004). Fish consumption advisories due to elevated levels of mercury have been issued in 44 states because mercury contamination has been identified as a serious health risk for pregnant women, the developing fetus, and children. Effects of this pollutant are not isolated to humans. Fish and amphibians from remote aquatic sites can often bioaccumulate significant amounts of methyl Hg (Wiener et al 2003 and references therein). Hg has no beneficial role in metabolic function, and no level of Hg accumulation is considered safe for any organism (Eisler 1987, 2000).

Atmospheric deposition is believed to be the important source of Hg in the northern U.S., with deposition rates in the range of 5 to 10 $\mu g/m^2$-yr (Fitzgerald et al. 1991). Wet deposition of Hg at ANP has averaged 7.9$\mu g/m^2$-yr since 1995 (Hg Deposition Network (MDN), National Atmospheric Deposition Program {NADP}). Accumulation rates of Hg to the sediment at two locations in Acadia were 100-200 $\mu g/m^2$-yr in the 1980s, suggesting that a large amount of dry Hg input is not measured by the wet-only MDN collector. These rates are comparable to those reported from urban lakes (Engstrom and Swain 1997) and presumably reflect deposition of Hg from upwind sources (e.g., the metropolitan regions and solid waste incinerators in the northeastern US). These high deposition rates at Acadia are a major concern for the Park Service, considering the Class I air quality status of the Park, and the ecological implications of Hg advisories. This high deposition of Hg makes Acadia especially well-suited as a natural field laboratory for investigations on Hg bioaccumulation in palustrine wetland biota.

Hg contamination of wild amphibians has received little attention (although see Burger and Snodgrass 1998, Gerstenberger and Pearson 2002) despite mounting evidence and reports of worldwide population declines (Houlahan et al. 2000). Amphibians are widely distributed across watersheds, are a vector of Hg transport into the surrounding riparian zone and uplands, and comprise an energy base on which biota from higher trophic levels depend. Methyl Hg can be toxic to aquatic biota, impairing productivity, growth and development, eliciting aberrant behavior, and potentially causing death (Wiener and Spry 1996). Methyl Hg chronic exposure, may also potentially increase individual susceptibility to disease (Taylor et al. 1999, Bennett et al. 2001).

The specific objectives of this investigation were to: 1) determine and evaluate total and methyl Hg concentrations for water, sediment, and tadpoles [bullfrog (*Rana catesbeiana*) and green frog (*Rana clamitans*)]; 2) compare Hg concentrations among the two sample species and among pond sites including 3 sites where amphibian die-offs and disease have been reported; 3) evaluate trends between tadpole length and weight measurements with total mercury concentrations; 4) evaluate trends between pond water chemistry and tadpole mercury concentrations; and, 5) determine total and methyl Hg bioconcentration factors from each pond site. We also present data on tadpole capture efficiency and discuss the use of these species as indicators of Hg bioaccumulation in wetland ecosystems.

Methodology

Study site

We report concentrations of total Hg in bullfrog and green frog tadpoles from ANP (44º21'N, 68º13'W). The park includes 12,260 ha on Mount Desert Island and 2,973 ha in surrounding parcels. ANP has 26 mountains, and ~20% of the park is classified as wetland habitat including marshes, lakes, ponds, streams (elevation range 50-250m), vernal pools, swamps, and bogs (Calhoun et al. 1994). The park also contains salt marshes, marine aquatic beds, and intertidal shellfish flats. Terrestrial habitats include peatlands, coniferous forest, and upland and riparian deciduous forests. The area is dominated by white spruce (*Picea glauca*), red spruce (*Picea rubens*), and balsam fir (*Abies balsamea*). Dominant deciduous tree species include birch (*Betula* spp.), aspen (*Populus* spp.), maple (*Acer* spp.), and red oak (*Quercus rubra*). In 1947 a human-caused fire burned 6,880 ha of northeast Mount Desert Island.

Field sampling design.

We collected tadpoles [~ 1 year of age, Gosner stage 27-37 (Gosner 1960)] from 9 pond sites in Acadia National Park using standard minnow traps baited with cat food (Kibble & Bits). Traps were baited in the afternoon hours (later than 1400 hours) and checked by 0800. We recorded the capture efficiency (number of tadpoles categorized by species/number of trap-nights) at each site. From our catch we randomly selected 10-11 tadpoles to be analyzed individually for total Hg and 4-10 individuals for composite analysis of total and Methyl Hg. After capture tadpoles were measured (total length, snout-vent length, tail length), rinsed with pond water and killed using MS-222 (>500mg/L) (Tricaine Methane Sulfonate - Argent Chemical Laboratories, Inc., Redmond, WA) buffered with equal amounts of sodium bicarbonate. Once killed animals were rinsed with pond water, placed in an individual sterile plastic bag (Whirl-Pak, M-Tech Diagnostics Ltd., Cheshire UK), labeled and frozen prior to analysis. All capture and euthanasia methods were approved by the University of Maine Animal Use and Care Committee (IACUC).

Water chemistry sampling and analyses

General water chemistry at each site was characterized by measuring temperature, % dissolved oxygen, and specific conductance (Table 1) weekly during June 2003 at all pond sites (except New Mill and Duck Brook ponds, *n*=1 as a result of restricted access) using glass electrodes in the field (YSI handheld Model 85 & Model 63, YSI International, Yellow Springs Ohio). Water samples for chemical analyses (closed cell pH, dissolved organic carbon, chlorophyll *a*, and acid neutralizing capacity) were also collected (*n* = 2; one sample from each pond was collected on the same day and then replicated one week later). For field sampling and storage of water Hg and water Methyl Hg samples, we used low-level trace metal clean techniques (Patterson and Settle 1976; Olson *et al*., 1997; Olson and DeWild, 1999). Each field staff member wore plastic gloves and collected water samples in cleaned Teflon bottles. Samples were preserved with low-Hg 6 M HCl (1% by volume) and double bagged in the field. Bottles were uncapped and capped under water to minimize contamination. Total Hg and Methyl Hg water chemistry samples were collected from a pond shore location in close vicinity to tadpole capture sites (~0.3-0.6 meters depths). We collected sediment using a standard clean plastic scoop. All water, biota, and sediment chemistry laboratory analyses were completed at the University of Maine Environmental Water Chemistry Laboratory in Orono, Maine, except for the Methyl Hg samples that were analyzed at Brooks Rand Laboratories, WA.

Mercury analyses

Total Hg in water was determined by cold vapor atomic fluorescence spectroscopy (CVAAS; Gill and Fitzgerald 1987, Bloom and Fitzgerald 1988, Olson and DeWild 1999). Methyl Hg in water was analyzed using the distillation and aqueous ethylation followed by measurement with CVAAS, according to EPA method #1630. We processed all biotic samples for total Hg using acid digestion and CVAAS measurement, based on EPA Method 245.6.

Following capture, wet weights of samples were recorded, and composite samples of 4-10 tadpoles from each of the 9 pond sites were used for analysis of total Hg and MeHg. For Methyl Hg analysis, composites were freeze-dried, freeze-fractured, homogenized and then analyzed for both total Hg and Methyl Hg content with a modified version of Draft EPA Method 1630, combined with alkaline digestion. Methyl Hg tadpole data were calculated on a dry weight basis. We converted the dry weight Methyl Hg data to wet weight using the average % moisture with methods described by Stickel et al. (1973) following the formula: wet weight = dry weight Hg x (1 - % moisture/100).

Accuracy of analytical techniques was evaluated by analyzing certified reference Materials (International Atomic Energy Agency-356 and TORT-2 {National Research Council Canada} for Methyl Hg; DOLT-2 {National Research Council Canada} for total Hg) with each sample batch, and by determining the Hg recovery from spiked homogenates. Precision of Hg analytical techniques was evaluated using one duplicate sample for each composite analysis run. For each sample run we used reagent blanks to document any laboratory contamination.

Data analyses.

We examined data normality using Lillefor's test (Zar 1999) and used log transformations as necessary for mercury concentration data. We used correlation matrices to examine relationships between water chemistry variables and frog tissue mercury concentration data. We discarded independent variables with *R*-values ($\leq$ 0.6) that were not statistically significant (P >0.05). When independent variables were correlated, we used the one with the higher *R*-value in linear regression modeling (Zar 1999). We also used correlation matrices to test for significant trends between individual tadpole body measurements (total length, snout-vent-length, and tail length) and total Hg concentrations. Bioconcentration factors (BCF) were calculated for individual ponds using the formula: BCF = log ($biota_{concentration}$ / $water_{concentration}$). We used the tadpole total Hg composite and Methyl Hg composite samples to determine the BCFs for each pond site. We also calculated the average BCF based on total Hg data from individual tadpoles and made comparisons among sites with one-way analysis of variance (ANOVA). Average tadpole tissue total Hg concentrations among sites were compared with ANOVA. We used nested ANOVA to test for differences in total Hg between species for individual tadpoles, and Mann-Whitney *U*-tests were used for evaluating differences among total Hg and Methyl Hg for sediment and tadpole composite samples. We accepted statistical significance at $P<0.05$. All statistical tests were performed with SYSTAT 10.2 (SYSTAT Inc., 2002).

Principal Findings

Total Hg and Methyl Hg bioaccumulation and bioconcentration factors

Average total Hg concentrations were not significantly different ($ANOVA_{nested}$ $F = 1.06$, df = 1,7, $P = 0.34$) between green frog (mean = 25.1$\pm$1.5 Hg ng/g wet wt) and bullfrog tadpoles (mean = 19.1 Hg ng/g wet wt. $\pm$0.8 Hg ng/g wet wt, Figure 1). Methyl Hg comprised 7.6-40% of the total Hg in tadpole tissue (wet wt. basis), and average total Hg levels in tadpoles were significantly different among pond sites ($F = 10.84$, $df = 8, 83$, $P < 0.001$, Figure 1). Since these species were considered to be phylogenetically and functionally similar, and we did not detect significant differences in Hg levels between species, we pooled species data to increase our replicates for subsequent statistical analyses.

Methyl Hg levels in green frog composite samples ranged from 0.003 to 0.023 mg/kg wet wt., whereas bullfrog composites ranged from 0.011 to 0.022 mg/kg wet wt., and we did not detect a different between species ($U = 9.0$, df= 1, $P = 1.0$, Table 2). Total Hg in green frog composite samples ranged from 0.027 to 0.110 mg/kg wet wt., whereas bullfrog composites ranged from 0.042 to 0.075 mg/kg wet wt., and a difference between species was not detected (U = 8.0, df= 1, P = 0.8, Table 2). Additionally, we detected no statistical differences between species for total and methyl Hg concentrations in water or sediment (Table 2).

Bioconcentration factors for both total Hg and Methyl Hg were calculated for each pond site. Total Hg BCFs for individual tadpoles were significantly different among sampling sites (F = 45.05, df=8,83, P< 0.001). Our data show that methyl Hg was generally more readily bioconcentrated in tadpoles in comparison to total Hg (Figure 2).

Capture efficiency and body morphometry of tadpoles

Capture efficiency of each species varied among sites. Both species were captured simultaneously only at Lower and Upper Hadlock Ponds, which are connected by the lower reach of Hadlock Stream (Figure 3). We detected a significant relationship between cholorophyll *a* concentrations and tadpole capture efficiency (R^2 = 0.73, P < 0.05). We did not detect any significant relationships between individual bullfrog or green frog tadpole body measurements and total Hg concentrations (P > 0.05 for each species separately and P > 0.05 for all data combined).

Mercury dynamics and pond chemistry

We detected a significant relationship between average total Hg in tadpole tissue and average total Hg in water (R^2 = 0.48, P < 0.038). Water DOC levels and mean Methyl Hg concentrations in water were also correlated (R^2 = 0.58, P < 0.02, Figure 5), as were average pond ME (Figure 4) and total Hg in sediment (R^2 = 0.70, P < 0.005). Additionally, pond sediment Methyl Hg was best predicted by average chlorophyll *a* concentrations (R^2 = 0.57, P < 0.02). Average DOC concentrations were a good predictor of both average water total Hg (R^2 =

0.91, $P < 0.001$, Figure 5) and average water Methyl Hg ($R^2 = 0.58$, $P < 0.02$, Figure 5). We also detected a significant relationship between average Methyl Hg in water and average total Hg in water ($R^2 = 0.52$, P < 0.03, Figure 5). Sediment total Hg concentration was negatively correlated with pH ($R^2 = 0.61$, $P < 0.01$). We detected significant differences in average water total Hg ($F = 41.11$, df = 8, $P < 0.001$) among sampling ponds, however average water Methyl Hg concentrations were not statistically different among sites ($F = 3.13$, df = 8, $P = 0.054$ - Table 2).

Significance for the Project

Total Hg and Methyl Hg bioaccumulation and bioconcentration factors

Our results indicate that mercury bioaccumulation in tadpoles varies across sampled pond sites in ANP and that total Hg concentrations in pond water were significantly correlated with average tadpole total Hg concentrations. The percent Methyl Hg present in tadpoles (7.6-40%) was relatively similar to the range reported for benthic invertebrate detritivores (20-25% MeHg) and grazers (30-40 % MeHg) sampled from two hydroelectric reservoirs in Quebec (Tremblay et al. 1996). Average total Hg was highest for green frog tadpoles sampled from the Schooner Head site, a small semi-permanent pond where Ranavirus was detected in tadpoles during the 2003 summer sampling period (D. Green USGS NWHL pers. comm., Figure 1).

Very little data exist on the potential link between Hg and disease in animal biota. However, Bennett et al. (2001) reported that mean liver concentrations of Hg, Selenium (Se), Hg:Se molar ratio and Zinc were significantly higher in harbor porpoises (*Phocoena phocoena*) that died from infectious disease compared to healthy porpoises. Although mercury has no known benefit to biota and no level is considered safe (Eisler 1987, 2000), currently the link between Hg and amphibian disease is unknown and further research is required to determine the effect of Hg chronic exposure on susceptibility to disease in amphibians.

Bank *et al*. (In Review, In Press) measured an average total Hg concentration of 66.1 ± 3.4 ng/g wet wt (*n*=116) for 1-3 year old larval northern two-lined salamanders (*Eurycea bislineata bislineata*) from 14 streams in ANP. Larval two-lined salamanders likely had higher mercury concentrations due to their invertebrate diet (Petranka, 1984) in comparison to both green frog and bullfrog tadpoles which are grazers. Differences in age may also contribute to observed differences in total Hg levels among salamanders and tadpoles.

Gerstenberger and Pearson (2002) reported mercury concentrations in brain, muscle kidney and liver for adult bullfrogs from a wetland in Meadow Valley Wash, Nevada. Mercury concentrations from the Gerstenberger and Pearson (2002) investigation (*n* = 28 adult bullfrogs) ranged 0.004-0.142 mg/kg for brain, 0.012-0.117 mg/kg for muscle, 0.036-0.252 mg/kg for kidney and 0.046-0.458 mg/kg for liver tissue. Burger and Snodgrass (1998) reported no effect of depuration on Hg concentrations prior to lab analysis, and whole body concentrations of total Hg for bullfrog tadpoles (*n* = 40) sampled from the Carolina Bay wetland at Savannah River Site, North Carolina, were slightly higher than ANP bullfrog tadpoles, averaging 36.0±1.7 *u*g/kg on a wet weight basis and 181.0±9.9 *u*g/kg on a dry weight basis.

Bioconcentration factors for both amphibian species from this study (Figure 2) were comparable to biota found at similar trophic levels collected from Seal Cove Pond and Hodgdon Ponds in ANP by Burgess (1997) who reported BCF values of 4.0 to 4.5 (total Hg) and 5.0 to 5.5 (Methyl Hg) in amphipods. BCFs for Methyl Hg were higher than BCFs for total Hg on all except one pond (Figure 2). Boudou and Ribeyre (1981), Burgess (1997), and Watras and Bloom (1992) also showed that MeHg was transferred up the food chain more efficiently than inorganic Hg primarily as a result of uptake at low trophic positions and differential Hg species compartmentalization (Mason et al 1995). Moreover, Pritchardt et al. (2002) reported that as algal biomass increases, the concentration of Methyl Hg per cell decreases. This in turn resulted in lower rates of dietary intake and reduced bioaccumulation for grazers (*Daphnia*) in oligotrophic aquatic ecosystems. These findings have important implications for the transfer and biomagnification of Methyl Hg in lake and pond ecosystems and may assist in the building of spatially explicit predictive models for identifying surface waters containing highly contaminated aquatic biota based on algae community and population dynamics.

Capture efficiency and body morphometry of tadpoles

Only 2 of the 9 sites had simultaneous captures of both tadpole species suggesting that green frog and bullfrog tadpoles do not often co-occur at ANP (Figure 3). These species may potentially partition habitat resources at both macro- and micro-habitat scales and may be a result of complex interactions of inter-specific competition, larval development, abiotic factors (e.g., temperature, hydroperiod), and predator avoidance mechanisms (Duellman and Trueb 1994). Werner and McPeek (1994) reported that bullfrog tadpoles were often located in permanent water bodies, whereas green frog tadpoles used both temporary and permanent ponds, and green frog tadpoles were often more successful where bullfrogs and fish were absent.

Chlorophyll *a* concentrations indicate primary productivity in aquatic ecosystems. Only chlorophyll *a* was significantly related to tadpole capture efficiency (Table 3). These data suggest that tadpole capture efficiency was highest at pond sites with higher primary production. We did not detect any statistical relationships between tadpole body measurements and total Hg concentrations possibly because our sample was derived from only one age class and had a narrow size range of body lengths. Gerstenberger and Pearson (2002) similarly reported that length and weight measurements were poor predictors of total mercury concentrations in adult bullfrog tissue.

Mercury dynamics and pond chemistry

Acidified freshwater ecosystems with high temperatures, DOC, sulfate reducing bacteria, sulfate, or inorganic Hg (II) levels facilitate MeHg bioaccumulation and biomagnification (Gilmour et al. 1991, Krabbenhoft et al 1998b, Benoit et al. 1999, Wiener et al. 2003 and references therein). Concentrations of total Hg (range 1.2 - 9.4 ng/L) and Methyl Hg (range = 0.04 – 1.22 ng/L) in ANP pond water were comparable to lakes in 8 western national parks (Lassen Volcanic, Yellowstone, Glacier, Grand Teton, Rocky Mountain, Sequoia & Kings Canyon, Yosemite) investigated by Krabbenhoft et al. (2002). DOC levels at ANP (range = 2.79 – 18.6 mg/L) were substantially higher than those reported for western national parks (range = 0.2 – 11.7 mg/L) by Krabbenhoft et al. (2002). DOC was a significant predictor of both total Hg and Methyl Hg in water, and total Hg in water was strongly correlated with Methyl Hg in water (Table 3, Figure 5). Johnson et al. (in press) similarly showed a strong association (R^2 = 0.60, $P < 0.05$) between DOC and total Hg for two streams in ANP. These findings were expected since Hg has a strong binding affinity for dissolved organic matter (Wallschlager et al. 1996). The relationship between DOC and mercury bioaccumulation is inherently complex, and regression data from this present investigation show that DOC was more strongly correlated with total Hg (R^2 = 0.91) than Methyl Hg (R^2 = 0.58) in ANP pond water (Figure 5). Wallschlager et al. (1996) reported that in ecosystems where Hg is primarily transported by organic matter and derived from soils and wetlands, Hg and DOC would be expected to be positively correlated. Moreover, Ravichandran (2003) suggested that correlations between DOC and Hg may or may not exist for aquatic ecosystems being directly affected by atmospheric deposition. DOC reactivity with Hg is also likely dependent on its structural and chemical composition and by the presence and activity of other ions in the water column (Babiarz 2001, Ravichandran 2003).

Percent methyl Hg as total Hg is a good predictor of ME in aquatic ecosystems. Surface waters with ME that exceed 10% often contain biota with high concentrations of total Hg (Gilmour et al. 1998, Krabbenhoft et al. 1999, Krabbenhoft et al. 2002). ME rates in ANP exceeded those reported from selected western national parks (Krabbenhoft et al. 2002) that ranged from 0.0 to 0.13. From our sample, 4 of the 9 ponds (44%) had ME rates greater than 10% (Figure 4) suggesting that ANP wetland food webs are likely susceptible to bioaccumulating high levels of total Hg. Correlations between ANP pond ME and Methyl Hg in sediment and between chlorophyll *a* and Methyl Hg in sediment were significant (Table 3). We hypothesize that ME in ponds may be related to methyl Hg concentrations in sediment, which are often controlled by the activity and production of sulfate reducing bacteria (Compeau and Bartha 1985, Winfrey and Rudd 1990, Gilmour et al. 1992). Sulfate reducing bacteria may have been more active and abundant at ponds with greater chlorophyll *a* concentrations (i.e., sites with higher primary productivity). However, future research on the complex interactions between pond ME, sediment dynamics and pond productivity is required to further evaluate this hypothesis.

Conservation implications

Hg pollution in aquatic ecosystems located in national parks remains a daunting challenge for natural resource managers especially considering the class I airshed status of ANP and the potential long-term ecological ramifications of surface water contamination. In cases where community level studies are impractical, green frog and bullfrog tadpoles may be effective indicators of Hg bioaccumulation in pond ecosystems, given that these species are relatively abundant, easily field identified, have a wide distribution, and can be reared for companion laboratory experiments or for *in situ* toxicology studies (Lower and Kendall 1990). Moreover, future studies should also evaluate the statistical relationship between DOC and total Hg in water and biota in an effort to establish and test spatially explicit predictive models.

Although this investigation is the first to characterize mercury bioaccumulation in tadpole tissue where amphibian disease has been confirmed (D. Green, USGS NWHL, pers. comm.), the link between occurrence of amphibian disease and Hg exposure is unclear. Future investigations should evaluate if Hg, other contaminants, or other abiotic conditions (i.e., drought) potentially increase susceptibility of amphibian populations to disease. We also recommend that toxicology studies use Methyl Hg exposure regimes that reflect natural pond conditions, and examine the long-term and sub-lethal effects of this contaminant with the synergistic or cumulative effects of stress from the presence of predators and/or predator cues (Relyea and Mills 2001). Expanding amphibian monitoring programs to include heavy metal biomonitoring of amphibians, water, seston, minnows, and other aquatic organisms from higher trophic positions should be considered for the effective management of surface water ecosystems in national parks.

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Table 1. Average (± SE) temperature and water chemistry values for the 9 sample ponds in Acadia National Park, Maine, USA, June, 2003.

Pond Site	Species Sampled	Temp (ºC)	Specific Conductance (*u*S/cm)	Dissolved Oxygen (%)	pH	Acid Neutralizing Capacity (*u*eq/L)	Dissolved Organic Carbon (mg/L)	Chlorophyll a (*u*g/L)[a]
Duck Brook [b]	Green Frog	22.6	43.9	76.5	5.5 ± 0.1	37.1 ± 2.6	8.6 ± 0.6	9.7
Leech*	Bullfrog	23.5 ± 1.3	53.13 ± 14.6	72.8 ± 27.2	6.3 ± 0.29	144.5 ± 9.5	3.7 ± 0.29	23.0
New Mill [b]	Bullfrog	22.9	45.5	75.9	6.5 ± 0.0	85.2 ± 3.1	3.1 ± 0.02	2.2
Duck	Green Frog	21.6 ± 0.7	28.5 ± 0.42	36.9 ± 6.7	4.9 ± 0.0	2.6 ± 0.25	7.9 ± 0.7	1.2
Lower Hadlock**	Bullfrog	23.5 ± 0.8	48.9 ± 8.1	56.1 ± 15.5	6.5 ± 0.03	40.9 ± 0.6	2.9 ± 0.09	1.1
Hodgdon	Green Frog	22.1 ± 0.9	60.5 ± 11.8	31.9 ± 5.1	6.2 ± 0.13	120.0 ± 8.0	8.5 ± 0.3	3.7
Upper Hadlock	Green Frog	22.2 ± 0.9	54.6 ± 6.4	55.1 ± 15.6	6.5 ± 0.1	46.6 ± 1.8	3.5 ± 0.17	1.4
Heath	Green Frog	19.9 ± 1.2	46.1 ± 3.2	17.5 ± 5.8	5.5 ± 0.01	50.5 ± 4.6	16.8 ± 1.6	7.1
Schooner Head Beaver***	Green Frog	24.9 ± 0.9	95.2 ± 3.2	58.1 ± 13.4	6.5 ± 0.13	231.5 ± 15.5	17.2 ± 1.5	13.0

* Confirmed Disease Site (Icthyophonus, 2001 – D. Green USGS-NWHL pers. comm.).
** Confirmed Disease Site (Ribeiroia, 2001, Ranavirus, 2002 – D. Green USGS-NWHL pers. comm.).
*** Confirmed Disease Site (Ranavirus, 2001, 2003 – D. Green USGS-NWHL pers. comm.).
[a, b] No standard error available.

Table 2. Total Hg and Methyl Hg concentrations in water, sediment and green frog and bullfrog tadpoles (~ 1 year old) from 9 ponds sampled in Acadia National Park, Maine, USA, June 2003. Standard errors are reported only for total Hg and Methyl Hg in water (*n* = 2).

Pond Site	Species Sampled	Mean ± SE Water Total Hg (ng/L)	Mean ± SE Water Methyl Hg (ng/L)	Sediment Total Hg (mg/kg dry wt.)	Sediment Methyl Hg (*u*g/kg dry wt.)	Tadpole Composite Methyl Hg (mg/kg wet wt.)	Tadpole Composite Total Hg (mg/kg wet wt.)	Tadpole % MeHg
Duck Brook	Green Frog	3.5 ± 0.6	0.57 ± 0.04	0.107	1.04	0.003	0.027	11.1
Leech*	Bullfrog	2.8 ± 0.4	0.51 ± 0.04	0.157	2.22	0.022	0.075	29.3
New Mill	Bullfrog	2.5 ± 0.2	0.23 ± 0.03	0.020	0.16	0.016	0.042	38.1
Duck	Green Frog	2.5 ± 0.2	0.34 ± 0.08	0.186	0.63	0.012	0.030	40.0
Lower Hadlock**	Bullfrog	1.3 ± 0.05	0.08 ± 0.003	0.038	0.14	0.011	0.075	14.7
Hodgdon	Green Frog	4.4 ± 0.1	0.19 ± 0.11	0.038	1.63	0.03	0.110	27.3
Upper Hadlock	Green Frog	1.4 ± 0.05	0.07 ± 0.03	0.016	0.09	0.005	0.066	7.6
Heath	Green Frog	7.0 ± 0.9	1.05 ± 0.17	0.172	0.88	0.023	0.103	22.3
Schooner Head Beaver***	Green Frog	8.4 ± 1.1	0.56 ± 0.49	0.069	0.70	0.016	0.075	21.3

* Confirmed Disease Site (Icthyophonus, 2001 – D. Green USGS-NWHL pers. comm.).

** Confirmed Disease Site (Ribeiroia, 2001, Ranavirus, 2002 – D. Green USGS-NWHL pers. comm.).

*** Confirmed Disease Site (Ranavirus, 2001, 2003 – D. Green USGS-NWHL pers. comm.).

Table 3. Correlation matrix of pond chemistry variables and total Hg and Methyl Hg in water, sediment, and tadpoles sampled from 9 ponds in Acadia National Park, Maine, USA, June 2003.

	Tadpole Capture Efficiency	Mean Tadpole Hg	Chlorophyll *a*	Mean DOC	Mean ANC	Mean Water Total Hg	Mean Water MeHg	Sediment MeHg	Sediment Total Hg	Pond Methylation Capacity	Tadpole MeHg
Tadpole Capture Efficiency	1.000										
Mean Tadpole Hg	0.059	1.000									
Chlorophyll *a*	**0.854**	-0.036	1.000								
Mean DOC	0.176	**0.656**	0.204	1.000							
Mean ANC	**0.614**	0.575	**0.610**	0.373	1.000						
Mean Water Hg	0.305	**0.694**	0.350	**0.953**	**0.611**	1.000					
Mean Water MeHg	0.326	0.159	0.482	**0.763**	0.132	**0.718**	1.000				
Sediment MeHg	0.458	-0.178	**0.755**	0.125	0.381	0.225	0.349	1.000			
Sediment Total Hg	0.363	-0.207	0.418	0.381	-0.191	0.247	**0.703**	0.461	1.000		
Pond Methylation Efficiency	0.423	-0.559	0.579	0.092	-0.212	0.034	**0.654**	0.505	**0.838**	1.000	
Tadpole MeHg	0.123	0.303	0.265	0.298	0.453	0.435	0.273	0.583	0.175	-0.002	1.000

Figure Legends

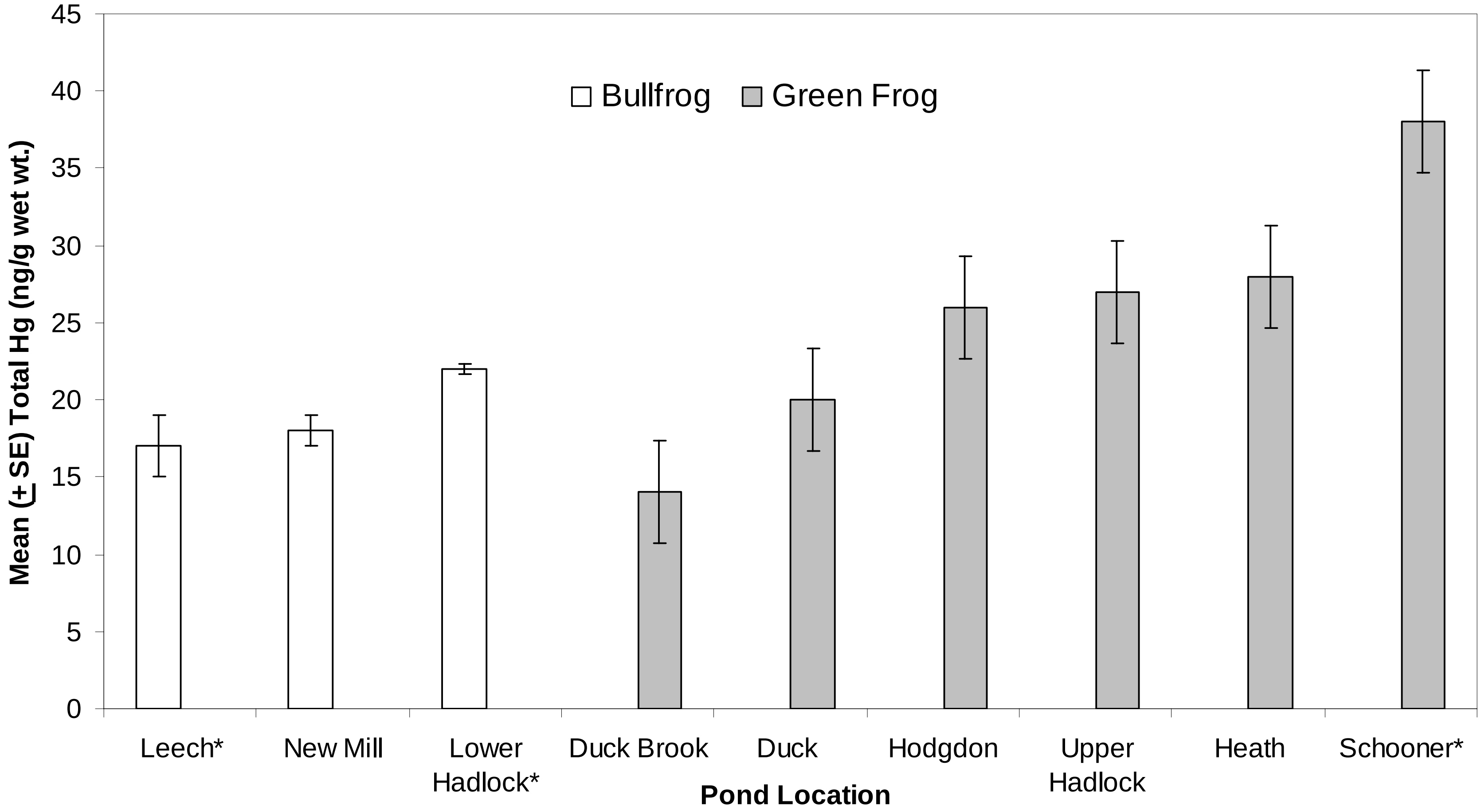
Figure 1. Average (± SE) Total Hg in green frog and bull frog tadpoles sampled from 9 ponds in Acadia National Park, Maine, USA, June 2003. Asterisk denotes disease/die-off site (D. Green, USGS-NWHL pers. comm.).

Figure 2. Bioconcentration factors (log {biota concentration/water concentration}) for total Hg (composite and individual samples) and Methyl Hg from 9 ponds in Acadia National Park, Maine, USA, June 2003. Asterisk denotes disease/die-off site (D. Green, USGS-NWHL pers. comm.).

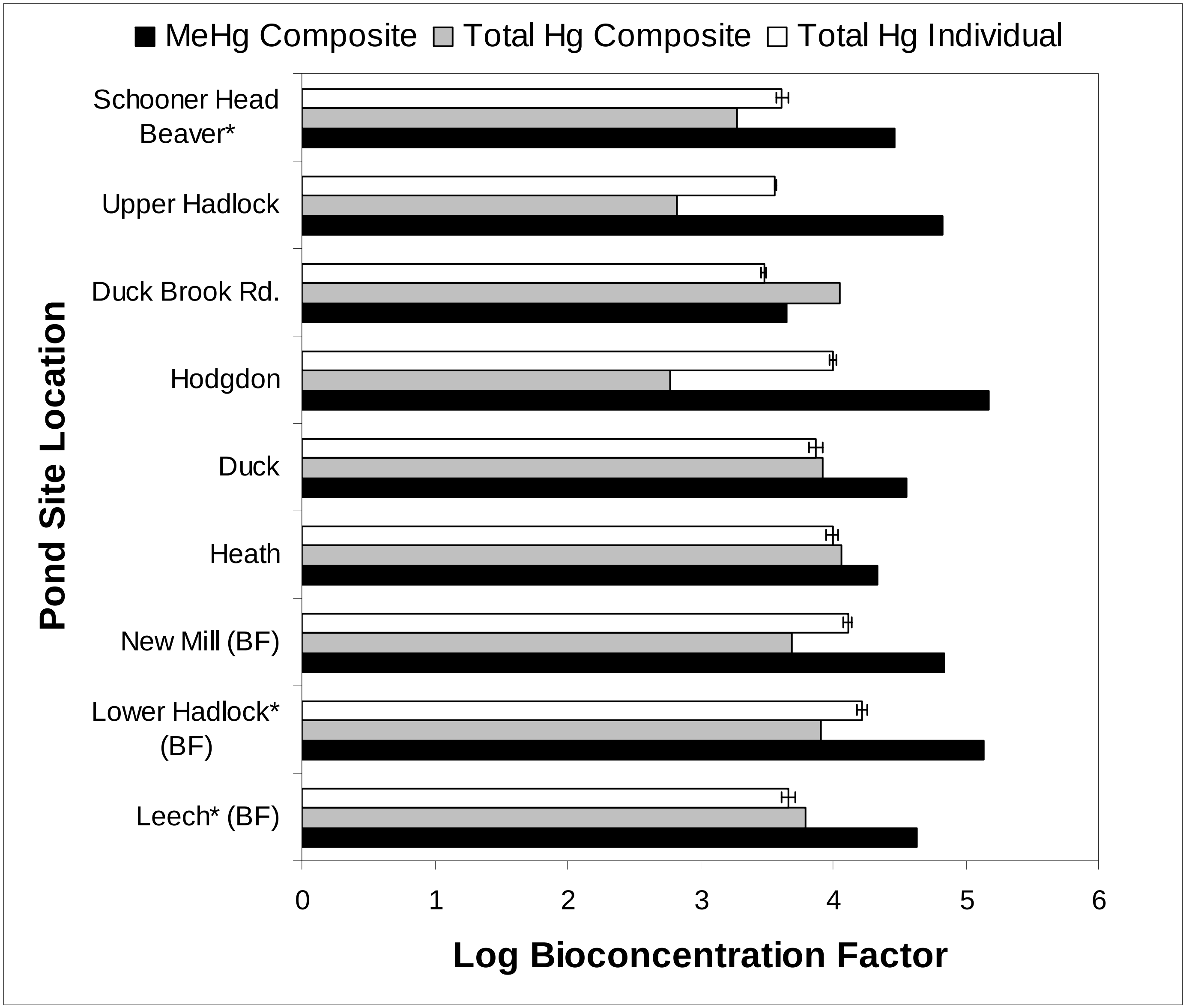
Figure 3. Capture efficiencies (number of tadpoles/trapnight) of green frog and bullfrog tadpoles sampled from 9 ponds in Acadia National Park, ME, June, 2003. Asterisk denotes disease/die-off site (D. Green, USGS-NWHL pers. comm.).

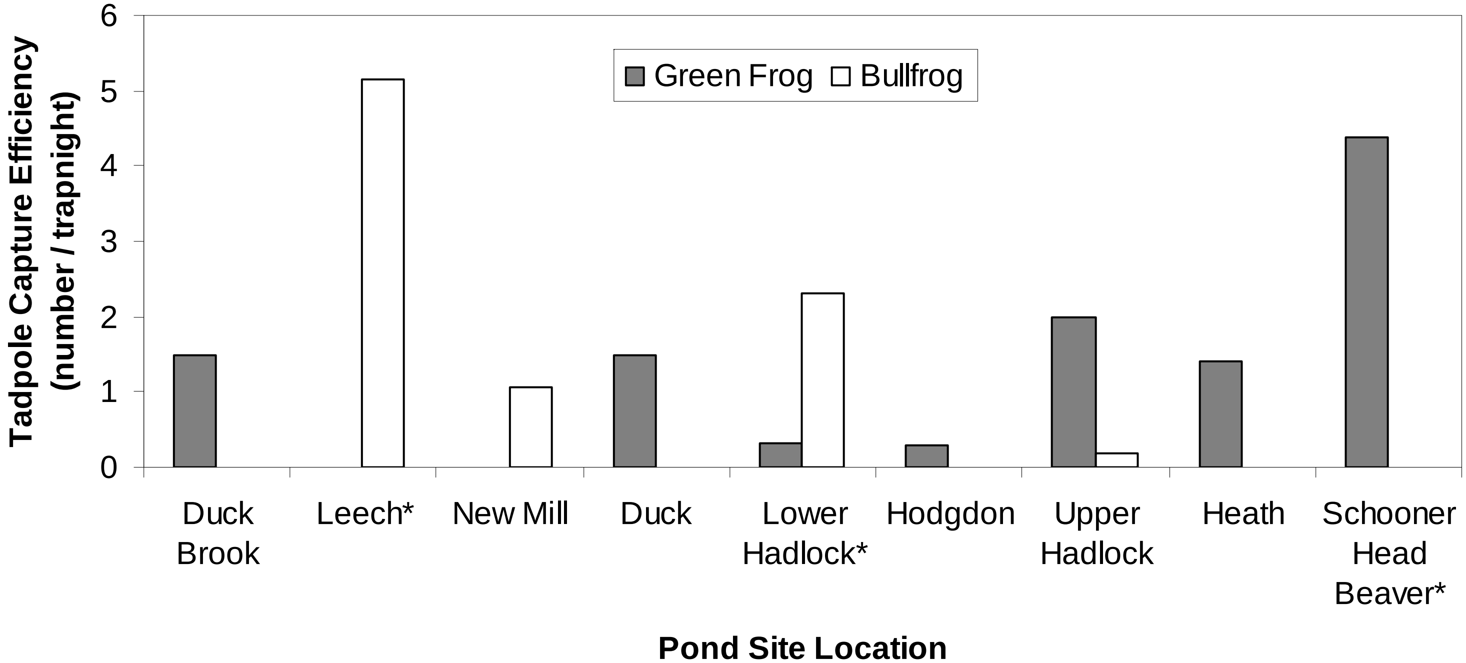
Figure 4. Distribution of methylation efficiency (Total Hg: Methyl Hg in water) rates for 9 ponds in Acadia National Park, Maine, USA, June 2003. Asterisk denotes disease/die-off site (D. Green, USGS-NWHL pers. comm.). Sites with (BF) on the x-axis denote bull frog sample ponds. All other sites represent green frog tadpole sample ponds.

Figure 5. (A) Relationship between DOC and total Hg in water from 9 ponds in Acadia National Park, Maine, USA, June 2003, (B) relationship between DOC and Methyl Hg in water from 9 ponds in Acadia National Park, Maine, USA, June 2003, (C) relationship between total Hg and Methyl Hg in water from 9 ponds in Acadia National Park, Maine, USA, June 2003. Asterisk denotes disease/die-off site (D. Green, USGS-NWHL pers. comm.).

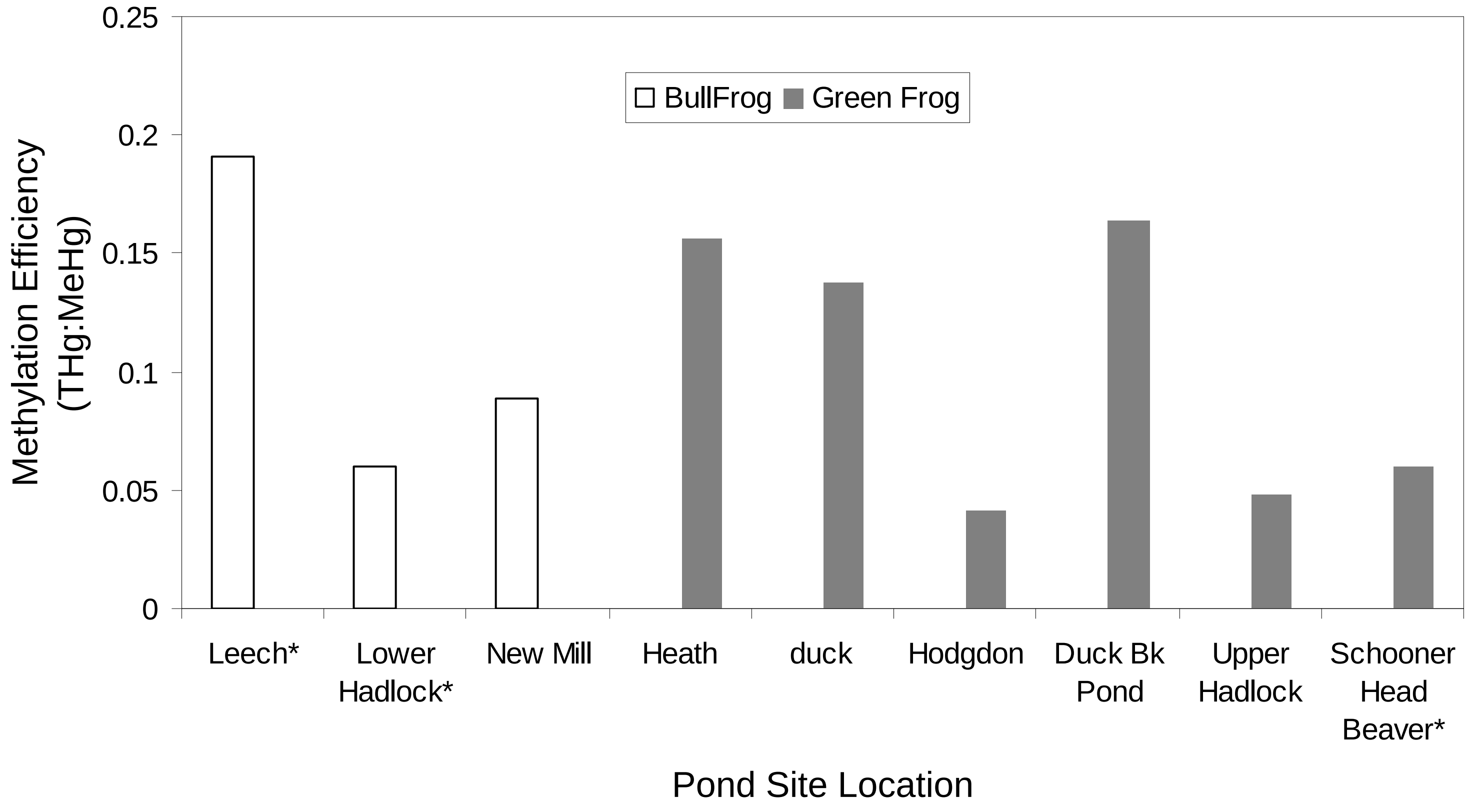


Bullfrog
Green Frog
Mean (+ SE) Total Hg (ng/g wet wt.)
45
40
35
30
25
20
15
10
5
0
Leech*
New Mill
Lower Hadlock*
Duck Brook
Duck
Hodgdon
Upper Hadlock
Heath
Schooner*
Pond Location

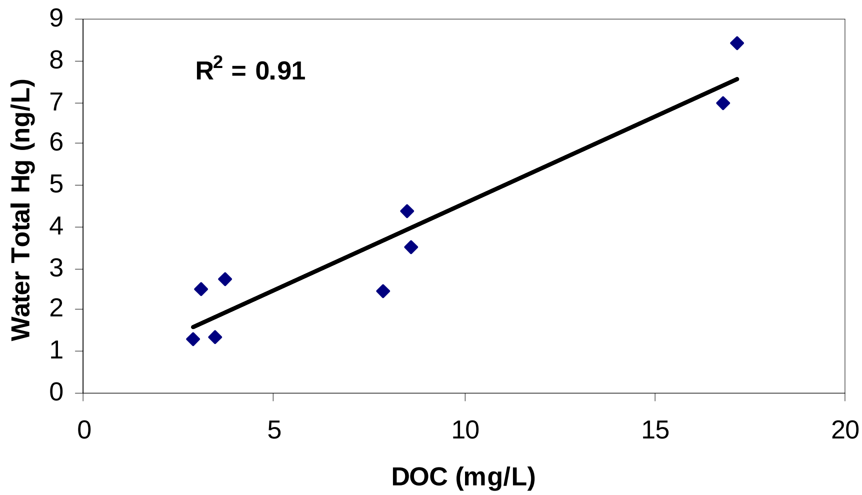

MeHg Composite
Total Hg Composite
Total Hg Individual
Schooner Head Beaver*
Upper Hadlock
Duck Brook Rd.
Hodgdon
Duck
Heath
New Mill (BF)
Lower Hadlock* (BF)
Leech* (BF)
Pond Site Location
0
1
2
3
4
5
6
Log Bioconcentration Factor



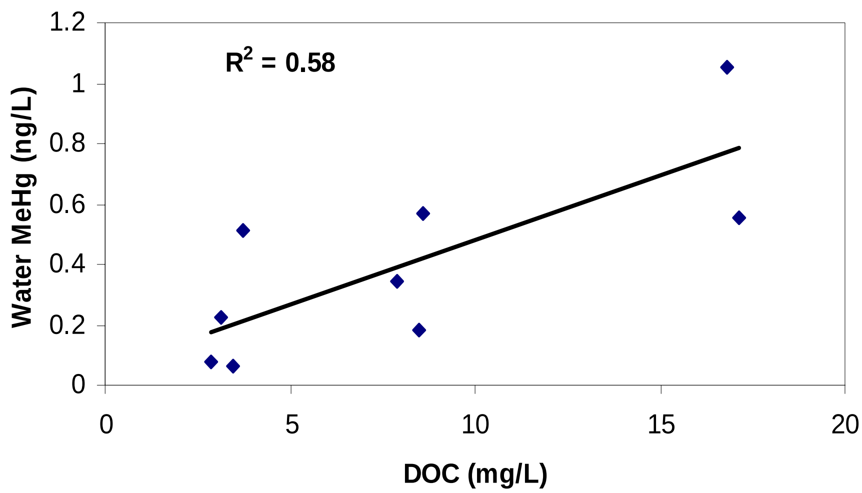
Tadpole Capture Efficiency (number / trapnight)
6
5
4
3
2
1
0
Green Frog
Bullfrog
Duck Brook
Leech*
New Mill
Duck
Lower Hadlock*
Hodgdon
Upper Hadlock
Heath
Schooner Head Beaver*
Pond Site Location



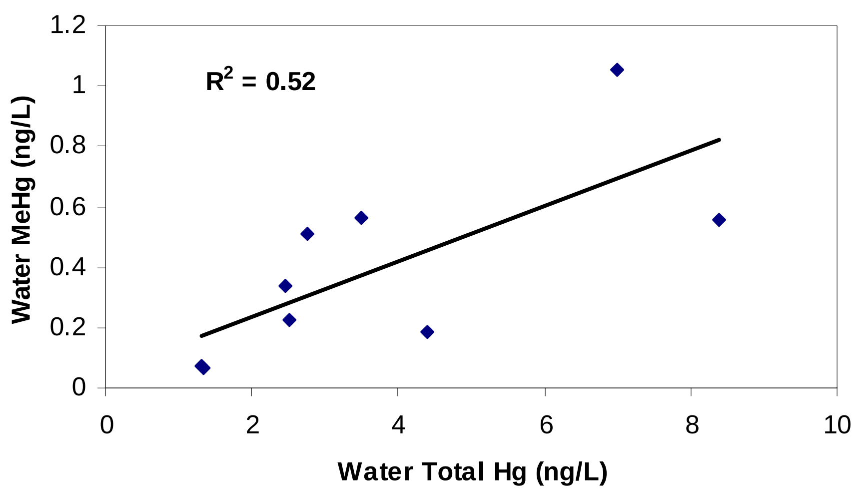
0.25
0.2
0.15
0.1
0.05
0
Methylation Efficiency (THg:MeHg)
BullFrog
Green Frog
Leech*
Lower Hadlock*
New Mill
Heath
duck
Hodgdon
Duck Bk Pond
Upper Hadlock
Schooner Head Beaver*
Pond Site Location



R² = 0.91
Water Total Hg (ng/L)
DOC (mg/L)
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20



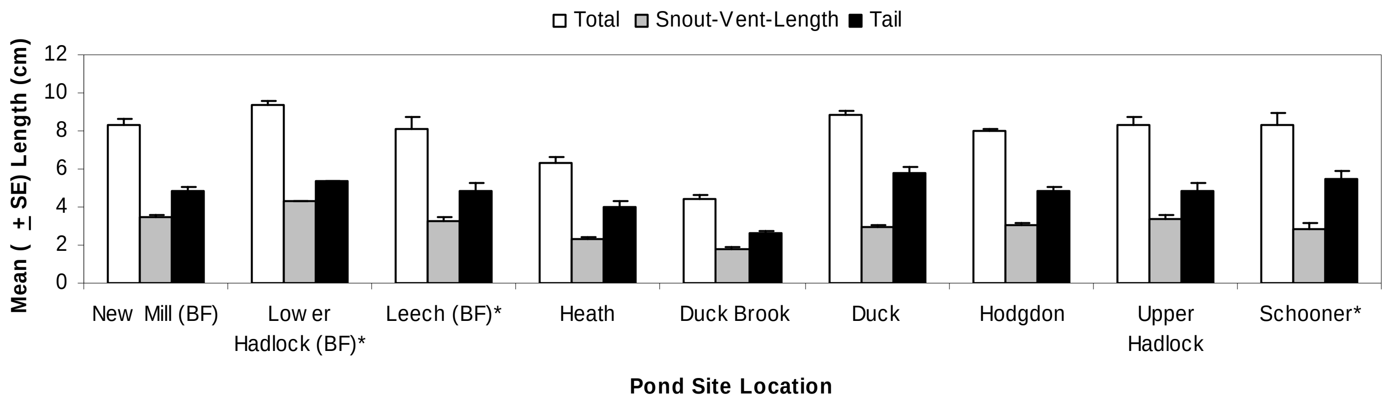
R² = 0.58
Water MeHg (ng/L)
DOC (mg/L)
0
0.2
0.4
0.6
0.8
1
1.2
0
5
10
15
20



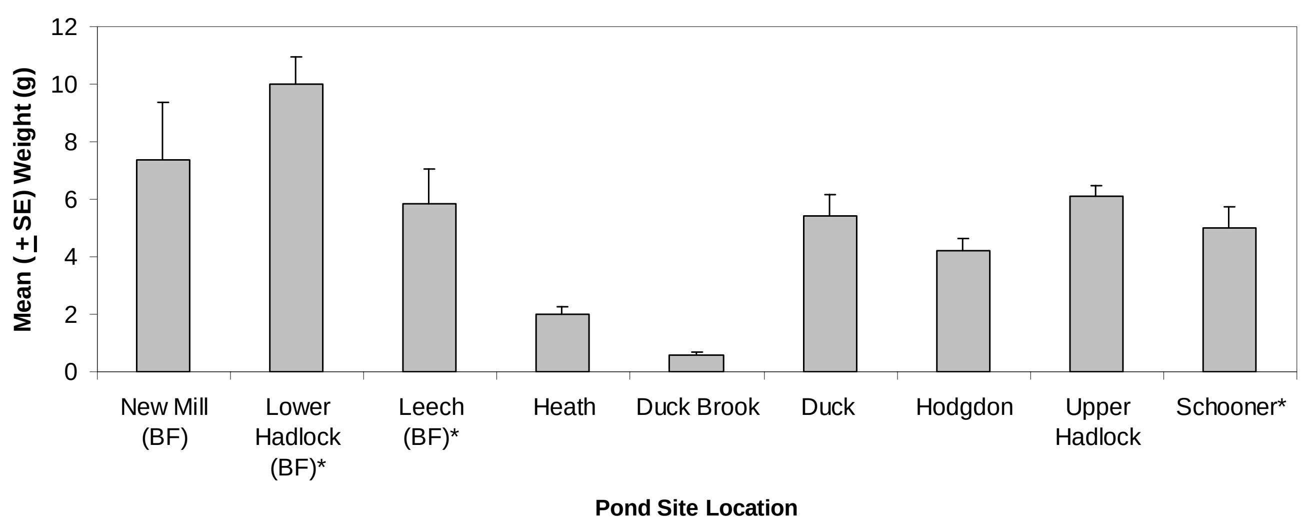
R² = 0.52
Water MeHg (ng/L)
Water Total Hg (ng/L)
0
0.2
0.4
0.6
0.8
1
1.2
0
2
4
6
8
10

Appendix 1. (A) Average (± SE) weight (g) of green frog and bullfrog tadpoles from Acadia National Park, Maine, June 2003. Asterisk denotes disease/die-off site (D. Green, USGS-NWHL pers. comm.). (B) Average (± SE) total, snout-vent, and tail lengths (cm) of green frog and bullfrog tadpoles from Acadia National Park, Maine, June 2003. Asterisk denotes disease/die-off site (D. Green, USGS-NWHL pers. comm.).

A



B



Does aluminum geochemistry control the trophic status of oligotrophic lakes?

Basic Information

Title:	Does aluminum geochemistry control the trophic status of oligotrophic lakes?
Project Number:	2001ME1481G
Start Date:	1/1/1997
End Date:	1/1/1997
Funding Source:	104B
Congressional District:	second
Research Category:	Water Quality
Focus Category:	Surface Water, Water Quality, Non Point Pollution
Descriptors:	Oligotrophic Lakes, Metal Cycling
Principal Investigators:	Stephen A. Norton, Aria Amirbahman, Roy James Bouchard, Jeffrey S Kahl

Publication

1. Norton,S. A., Fernandez, I. J., Kahl, J. S., and Reinhardt, R., 2002, Acidification trends and the evolution of neutralization mechanisms through time at the Bear Brook Watershed in Maine (BBWM), USA: 4th International Symposium on Ecosystem Behavior (BIOGEOMON), Reading, England.
2. Reinhardt,R. L., Norton, S. A., Handley, M., and Amirbahman, A. 2002, Mobilization and linkages among P, Al, and Fe during high discharge events at the Bear Brook Watershed in Maine, USA: 4th International Symposium on Ecosystem Behavior (BIOGEOMON), Reading, England.
3. Vesely, J., Majer, V., Kopacek, J., and Norton, S. A., 2002, Climate warming accelerates decreased aluminum concentrations in lakes recovering from acidification: 4th International Symposium on Ecosystem Behavior (BIOGEOMON), Reading, England.
4. Norton, S. A., Fernandez, I. J., and Kahl, J. S., 2002, Intersections of monitoring, manipulation, and modeling: 4th International Symposium on Ecosystem Behavior (BIOGEOMON), Reading, England.
5. Veselý, J., Majer, V., Kopacek, J., and Norton. S. A., 2003, Increasing temperature decreases aluminum concentrations in Central European lakes recovering from acidification: Limnol. Oceanogr. 48, 2346-2354.
6. Amirbahman, A., Pearce, A. R., Bouchard, R. J., Norton, S. A., and Kahl, J. S., 2003, Relationship between hypolimnetic phosphorous and iron release from eleven lakes in Maine, U.S.A.: Biogeochem., 65, 369-386.
7. Navrátil, T., Vach, M., Norton, S. A., Skøivan, P., Hruka, J., and Maggini, L., 2003, Chemistry and modeling of the response of a small stream in a forested catchment (central Czech Republic) to a

short-term in-stream acidification: Hydrol. Earth Syst. Sci., 7, 411-422
8. Norton, S. A., Fernandez, I. J., Kahl, J. S., and Reinhardt, R. L., 2004 Acidification trends and the evolution of neutralization mechanisms through time at the Bear Brook Watershed in Maine (BBWM), USA: Water, Air, Soil Pollut.,
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11. Coolidge, Kyle, 2004, Current and historic speciation and accumulation rates of Al, Fe, and P in sediments of three Maine lakes. M. Sc. Thesis, Unpublished, University of Maine. (to be finalized in June, 2004)
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14. Reinhardt, R. L., Norton, S. A., Handley, M., and Amirbahman, A., 2002, Mobilization and linkages among P, Al, and Fe during high discharge events at the Bear Brook Watershed in Maine, USA: 4th International Symposium on Ecosystem Behavior (BIOGEOMON), Reading, England.
15. Norton, S. A., Fernandez, I. J., and Kahl, J. S., 2002, Acidification trends and the evolution of neutralization mechanisms through time at the Bear Brook Watershed in Maine (BBWM), USA: 4th International Symposium on Ecosystem Behavior (BIOGEOMON), Reading, England.
16. Norton, S. A., Fernandez, I. J., and Kahl, J. S., 2002, Acidification trends and the evolution of neutralization mechanisms through time at the Bear Brook Watershed in Maine (BBWM), USA: 4th International Symposium on Ecosystem Behavior (BIOGEOMON), Reading, England.
17. Vesely, J., Majer, V., Kopacek, J., and Norton, S. A., 2002, Climate warming accelerates decreased aluminum concentrations in lakes recovering from acidification: 4th International Symposium on Ecosystem Behavior (BIOGEOMON), Reading, England.
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Final Report

Does aluminum geochemistry control the trophic status of oligotrophic lakes?

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Problem and Research Objectives

The broad objective of the proposed project was to determine which lakes are especially susceptible to eutrophication from P loading and why. Specifically we examined the relationships between watershed type, Al mobility, and the influence of Al mobility on P mobility.

The major goals in the aqueous geochemical component of this research were to:

1. Determine the relationships between the concentration of solid and aqueous forms of P and Al, in the headwater streams and their receiving lakes.
2. Characterize the flux of reduced Fe and released P from the lake sediment during summer anoxia, and establish any possible correlation between the concentrations of dissolved and particulate Al and P in the water column.

The major goals in the paleolimnological component of this research were to:

1. Characterize the changes in the flux of labile (acid soluble) $Al(OH)_3$ and associated P, to determine if the timing can be linked with air pollution or land development.
2. Compare the changes in the P-adsorption capacity of sediment versus the variations in the Al flux.

More Al going to the lake sediment per unit time is critical to increasing the ability of the sediment to sequester P from the water column and to prevent release of P from the sediment into the hypolimnion during summer anoxia. The extant studies report only the changes in the concentration of labile P or Al in the sediment (White and Gubala, 1990; Kopacek et al., 2000), but not fluxes. We proposed to estimate the flux of Al and P to the sediment.

Methodology

This project assessed watershed stream and lake water and sediment geochemistry in a paired lake comparison. The initial phase of the study involve site characterization and selection, parameter selection and detailed experimental design. We evaluated three stream-lake systems in Maine; Highland, Penneseewassee and Salmon Lakes. These lakes have historical chemical data. The first two are oligotrophic, the latter is mesotrophic. These lakes all develop hypolimnetic summer anoxia and have similar morphometry and oxygen regimes. The geochemical analysis performed in this research will contribute to the existing database collected previously (Pearce, 2000).

Fieldwork in the original proposal included:

- Sampling of water in major tributaries to characterize Al and P loading to each lake.
- Sampling of the water column at several localities on the lakes. The sampling protocol was similar to that used previously (Pearce, 2000).
- Core sediment sampling for paleolimnological analysis for deposition of Al, P, and selected trace elements.

Two field components were added to the research as a consequence of (a) an unusual hydrologic year and (b) some interesting questions about mechanisms that control release of P from sediments.

- Collection of stream samples at Bear Brook Watershed in Maine during high discharge episodes
- Collection of short sediment cores from the three lakes to study the short-term changes in sediment chemistry caused by the development of anoxia.

Lake Inlet Stream Chemistry: Water samples were collected sporadically from up to six inlet streams of each of three lakes during periods of low to moderate flow. Water samples were collected in acid-washed bottles automatically using ISCO samplers at Bear Brook and by hand at other localities. The following constituents were analyzed in both filtered and unfiltered water samples: base cations (Ca, K, Mg, and Na), acid anions (SO_4, NO_3, Cl, and F), P, Fe, Mn, Al (speciated), ANC, pH, DIC (closed cell in unfiltered only), and DOC. The DIC concentration in filtered samples was calculated from the ANC and pH measurements.

Lake water column chemistry: Lake water was collected sporadically for one year from at least four different depths at two or more localities on each lake using the methods of Pearce (2000). One site was over the "deep hole" in each lake. We measured the same constituents as at the inlet stream. The data will be compared to those obtained in summer 1999 for the same lakes by Pearce (2000).

Sediment chemistry:

Stream sediments were not collected from each stream as originally planned.

One lake sediment core was retrieved from the deep part of each of three lakes with a stationary piston corer, 10 cm in diameter. Sediment was generally sectioned in intervals 0.5 cm thick from 0 to 10 cm depth, and in 1 cm intervals below 10 cm to the bottom of the core. Water concentration (H_2O) and loss on ignition (LOI) were determined by standard methods. Sediment chronology was determined by measuring ^{210}Pb, ^{137}Cs, and ^{241}Am on selected interval, permitting the establishment of absolute age back into the 19th century and thus enabling the calculation of accumulation rates for sediment and elements. We determined the concentrations of sequentially extractable metals. With knowledge of the age of the sediment, LOI, H_2O, and concentrations of elements (and their speciation), we calculated the rate of accumulation of each of the measured elements, and their species.

1. Principal Findings: The reader is referred to the publications for more detail on methods and results. Briefly:
   a. The field year (2002) proved to be a record drought year and as a consequence, surface runoff was very low, highly erratic (driven by isolated convective storm input), and difficult to characterize. Delivery of Al to the lakes by surface water was low making testing of certain aspects of the research impossible.
   b. Lake water column data (still under analysis by the graduate student) indicate conditions similar to those found by Pearce (2000), with the added information that Al and P do exist in particulate form. However, because of the low input from the watershed, these elements were not present in sufficiently high concentrations to clearly indicate any linkage through space and time for that ice-free season.
   c. The studies added at the Bear Brook Watershed site in Maine yielded very valuable insights about the linkage of Al transport and the transport and bioavailability of P in streams (see publications). Indeed, Al geochemistry exerts the dominant control of P at this oligotrophic site.
   d. The sediment "long" core studies indicated that most P in sediment of the two oligotrophic lakes is associated with solid $Al(OH)_3$ in the sediment, whereas the P in the sediment of the mesotrophic lake is largely associated with Fe hydroxide phases. The flux of P to the sediments in the oligotrophic systems was comparable to that in the mesotrophic system. This has been true for the several hundred years represented by the sediment. No substantial changes over the last 200 years are indicated. This is likely because none of the three lakes appear to be sensitive to acidification and thus the flux of Al would be relatively low and constant through the last 100 years. Development of hypolimnetic anoxia caused release of P to the hypolimnion in the mesotrophic lake, but not in the oligotrophic lake, consistent with the hypothesis that sequestration of P by Al phases is not reversible during anoxia.
      We also were able to reconstruct the sediment accumulation history of several air contaminants (e.g., Cd and Pb) and their speciation in the sediment record. The records are normal for the region. They reinforce that atmospheric contamination and thereby the flux of these contaminants, at least for select elements, has peaked or is decreasing. This material is being incorporated into a short manuscript, probably to be submitted to the Journal of Paleolimnology.
   e. The sediment "short" core time series studies suggest that the chemistry and metal speciation in the upper few cm of sediment are quite dynamic. These data are still being analyzed.
2. Significance of the project:
   This project has provided a substantial amount of evidence consistent with the hypothesis that ***the trophic status of oligotrophic surface waters may be controlled by Al geochemistry***.

5. Provide publication citations associated with the research project (see below):

Additional Project Information

Student Support

Two graduate students were substantially supported; one received limited support:

Raquel Reinhardt was supported for two years in the M.Sc. program. Although the first year was very productive for her (see publications), she has not completed the write-up of the lake water column data.

Kyle Coolidge was supported for 1.5 years and recently defended his M.Sc. and was completely successful. His thesis is in revision.

Ken Johnson was supported for most of the Fall 2002 semester but then left the program.

Several undergraduates participated in field work for both sediment and water-related research.

Notable awards and achievements

No awards.

Based partly on the stream water and lake sediment results from this project, we developed and submitted a research proposal to the National Science Foundation, Ecosystem Program. The Grant Proposal is titled "Abiotic controls on the trophic status of oligotrophic waters". We believe this will be funded. We will link our research on Al-P relationships from the soil to lake sediments at four study sites, including Bear Brook in Maine (Reinhardt et al., 2004).

Information Transfer Program

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2003ME24B
Start Date:	3/1/2003
End Date:	2/28/2004
Funding Source:	104B
Congressional District:	2
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Steve Kahl, John M. Peckenham

Publication

1. Campbell, J. L., J.W. Hornbeck, M.J. Mitchell, M.B. Adams, M.S. Castro, C.T. Driscoll, J.S. Kahl, J.N. Kochenderfer, G.E. Likens, J.A. Lynch, P.S. Murdoch, S.J. Nelson, and J.B. Shanley, 2004. A Synthesis of Nitrogen Budgets from Forested Watersheds in the Northeastern United States. Water, Air, and Soil Pollution 151: 373-396.
2. Johnson, K.B., Nelson, S.J., Kahl, J.S., Haines, T.A. and Fernandez, I.J.: 2004b, Mass balances of mercury and nitrogen in burned and unburned forested watersheds at Acadia National Park, Maine, USA, Environ. Monit. Assess.
3. Kahl, J.S. and S. Nelson, 2004. guest editors, special issue of Environmental Monitoring and Assessment on watershed research at Acadia National Park.
4. Kahl, J.S., J. Stoddard, R. Haeuber, S. Paulsen, and others, 2004. Response of surface water chemistry to changes in acidic deposition: implications for the upcoming debate on the federal Clean Air Act. Environmental Science and Technology, Feature Article in review.
5. Peckenham, J., J. Kahl, S. Nelson, K. Johnson, and T. Haines, 2004. Landscape controls on mercury in streamwater at Acadia National Park, USA, Env. Monit. Asses., in press.
6. Schauffler, M., Nelson, S.J., Kahl, J.S., Jacobson, G.L., Jr, Haines, T.A., Patterson, W.A., III, and Johnson, K.B.: 2004, Paleoecological assessment of watershed history in PRIMENet watersheds at Acadia National Park, USA, Environ. Monit. Assess.
7. Amirbahman, A. P. Ruck, I Fernandez, T. Haines, and J.S. Kahl, 2003. The effects of fire on mercury distribution in soils of Acadia National Park. Water Air, Soil Pollut., in press.
8. Campbell, J, J. Hornbeck, M. Mitchell, M. Adams, M. Castro, C. Driscoll, J.S. Kahl, and others, 2003. Input-output budgets for inorganic nitrogen for 24 watersheds in the northeastern United States. Water Air Soil Pollut., in press.

9. Kahl, J.S., S.J. Nelson, J.L. Stoddard, S.A. Norton, T.A. Haines, 2003. Lakewater chemistry at Acadia National Park, Maine, in response to declining acidic deposition. In press, Joint Conference Proceedings: The 2003 George Wright Society Biennial Conference and CR2003: A Conference for the National Park Service and Its Partners.
10. Peckenham, J.M., J. S. Kahl, and B. Mower, 2003. Background mercury concentrations in river water in Maine, USA. Env. Monit. Assess., 89, pp. 129-152.
11. Hallsworth, R., 2003. Waterlines Vol. 9 No. 1. Newsletter, Senator George J. Mitchell Center, March 2003.
12. Hallsworth, R., 2003. Maine Water Conference Program. Senator George J. Mitchell Center, April 2003
13. Hallsworth, R., 2003. PEARL Links with Laptop Initiative. Fogler Library newsletter article, The Olive Tree, v 11 number 1, summer 2003
14. Hallsworth, R., 2003. PEARL: One-Stop Shopping for your Lake Data! Cooperative Extension Water Quality newsletter article, summer 2003
15. Hallsworth, R. and Schmitt, C., 2003. Waterlines Vol. 9 No. 2. Newsletter, Senator George J. Mitchell Center, October 2003.
16. Kahl, J.S., 2003. Re-use planning for the former Schoodic Point Navy base: the Schoodic Education and Research Center at Acadia National Park. Consultant report to the National Park Service. 37 p.
17. Kahl, J.S., S. Nelson, J. Stoddard, S. Norton, T. Haines, B. Breen, and B. Gawley, 2003. Twenty years of surface water chemistry: how does Acadia NP fit into the regional response to acid rain? Chapter 8 in: Final report for EPA/NPS PRIMENet, Mitchell Center, University of Maine, Orono, ME.
18. Kahl, J.S., S. Nelson, T. Haines, and K. Johnson, 2003. Mercury and nitrogen dynamics in response to fire in paired watersheds at Acadia National Park. Chapter 7 in: Final report for EPA/NPS PRIMENet, Mitchell Center, University of Maine, Orono, ME.
19. Kahl, J.S., S. Nelson, A. Amirbahman, J. Eckhoff, I. Fernandez, H. Good, T. Haines, G. Jacobson, K. Johnson, R. Lent, D. Manski, M. Nielsen, S. Norton, J. Parker, J. Peckenham, P. Ruck, L. Rustad, M. Schauffler, K. Tonnessen, B. Wiersma, 2003. Inferring regional patterns and responses in N and Hg biogeochemistry using two sets of gauged paired-watersheds. Final report to EPA and National Park Service, Mitchell Center, University of Maine, Orono, ME. 171 p., plus attachments.
20. Nelson, S. and J.S. Kahl (editors), 2003. Inferring regional patterns and responses in N and Hg biogeochemistry using two sets of gauged paired-watersheds. Final report to EPA and National Park Service (9 chapters), Mitchell Center, University of Maine, Orono, ME. 172 p.
21. Nelson, S., R. Hallsworth, J. Boothroyd, J. Ledenican, M. McGarry, J.S. Kahl, V. Venkataraman, 2003. PEARL: Promoting Conservation, Responsible Recreation, and Public Education Through Innovative Information Technology. Final Project Report to Maine Outdoor Heritage Fund. December 22, 2003
22. Nelson, S.J., J.S. Kahl, (editors) 2003. Final Integrated Report: Establishing paired gauged watersheds at Acadia National Park for long-term research on acidic deposition, nitrogen saturation, forest health, and mercury biogeochemistry (1998-2002). Submitted to US EPA and National Park Service.
23. Morse, C., J.S. Kahl, and D. Witherill, 2003. Measuring the impact of development on Maine surface waters. Information Digest, Senator George Mitchell Center, 12 p.
24. Peckenham, J.M., 2003. Moving from Source Assessment to Source Protection Workshop, Maine Water Utilities Association Annual Winter Meeting.
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27. Schmitt, C., Hallsworth, R., 2004. Safe Drinking Water. Information Digest, Senator George J. Mitchell Center, Drinking Water Program/ Department of Human Services, 8p.
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29. Seger, E., 2003. Seepage Lakes as Indicators of Climate Change: Is Maine Really Cooling? M.S. Thesis, December 2003.
30. Stoddard, J., J.S. Kahl, F. Deviney, D. DeWalle, C. Driscoll, A. Herlihy, J. Kellogg, P. Murdoch, J. Webb, and K. Webster, 2003. Response of surface water chemistry to the Clean Air Act Amendments of 1990. EPA/620/R-03/001, U.S. Environmental Protection Agency, Washington, DC. 78 p.

INFORMATION TRANSFER, FY03

The Senator George J. Mitchell Center for Environmental and Watershed Research
Dr. Jeffrey S. Kahl, Director
John Peckenham, Assistant Director
Ruth Hallsworth, Outreach and Development Coordinator
Sarah Nelson, Research Associate
Ken Johnson, Field Coordinator
Tanya Hyssong, Laboratory Manager
Jennifer Boothroyd, Scientific Technician
Dr. Mary Ann McGarry, College of Education
Dr. Peter Vaux, PEARL Project Director
Sherman Hasbrouck, Publications Advisor

Introduction

One goal of the Mitchell Center is to foster increased cooperation and communication between the academic community, state agencies, environmental organizations, and private companies. The Mitchell Center is a vehicle for the State of Maine to access the substantial technical abilities of the University of Maine on issues of water resources. Information transfer is an important role in this mission. Using part-time staff and non-federal funding, the Center will continue to disseminate research results, organize meetings, participate in statewide forums, serve on committees dealing with water resource issues, work with teachers and conduct special projects.

Summary for 3/03-2/04

Publications

Peer-reviewed articles.

Campbell, J. L., J.W. Hornbeck, M.J. Mitchell, M.B. Adams, M.S. Castro, C.T. Driscoll, **J.S. Kahl,** J.N. Kochenderfer, G.E. Likens, J.A. Lynch, P.S. Murdoch, **S.J. Nelson**, and J.B. Shanley, 2004. A Synthesis of Nitrogen Budgets from Forested Watersheds in the Northeastern United States. Water, Air, and Soil Pollution 151: 373-396.

Johnson, K.B., Nelson, S.J., **Kahl, J.S.,** Haines, T.A. and Fernandez, I.J.: 2004b, 'Mass balances of mercury and nitrogen in burned and unburned forested watersheds at Acadia National Park, Maine, USA', Environ. Monit. Assess.

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Evans, G.C., S. Norton, I. Fernandez, **J.S. Kahl**, and D. Hanson, 2004. Changes in concentrations of major and trace metals in northeastern U.S and Canadian sub-alpine forest floor. Water, Air, and Soil Pollution, in press.

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Reports and Miscellaneous Publications

Hallsworth, R., 2003. Waterlines Vol. 9 No. 1. Newsletter, Senator George J. Mitchell Center, March 2003.

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Hallsworth, R., 2003. PEARL Links with Laptop Initiative. Fogler Library newsletter article, The Olive Tree, v 11 number 1, summer 2003

Hallsworth, R., 2003. PEARL: One-Stop Shopping for your Lake Data! Cooperative Extension Water Quality newsletter article, summer 2003

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Kahl, J.S., **S. Nelson**, T. Haines, and **K. Johnson**, 2003. Mercury and nitrogen dynamics in response to fire in paired watersheds at Acadia National Park. Chapter 7 in: Final report for EPA/NPS PRIMENet, Mitchell Center, University of Maine, Orono, ME.

Kahl, J.S., **S. Nelson**, A. Amirbahman, J. Eckhoff, I. Fernandez, H. Good, T. Haines, G. Jacobson, **K. Johnson**, R. Lent, D. Manski, M. Nielsen, S. Norton, J. Parker, J. Peckenham, P. Ruck, L. Rustad, M. Schauffler, K. Tonnessen, B. Wiersma, 2003. Inferring regional patterns and responses in N and Hg biogeochemistry using two sets of gauged paired-watersheds. Final report to EPA and National Park Service, Mitchell Center, University of Maine, Orono, ME. 171 p., plus attachments.

Nelson, S. and **J.S. Kahl** (editors), 2003. Inferring regional patterns and responses in N and Hg biogeochemistry using two sets of gauged paired-watersheds. Final report to EPA and National Park Service (9 chapters), Mitchell Center, University of Maine, Orono, ME. 172 p.

Nelson, S., R. Hallsworth, J. Boothroyd, J. Ledenican, M. McGarry, J.S. Kahl, V. Venkataraman, 2003. PEARL: Promoting Conservation, Responsible Recreation, and Public Education Through Innovative Information Technology. Final Project Report to Maine Outdoor Heritage Fund. December 22, 2003

Nelson, S., 2003. Progress Report to the Margaret E. Burnham Charitable Trust: Water resources mapping software. July, 2003.

Nelson, S.J., **J.S. Kahl**, (editors) 2003. Final Integrated Report: Establishing paired gauged watersheds at Acadia National Park for long-term research on acidic deposition, nitrogen saturation, forest health, and mercury biogeochemistry (1998-2002). Submitted to US EPA and National Park Service.

Morse, C., **J.S. Kahl**, and D. Witherill, 2003. Measuring the impact of development on Maine surface waters. Information Digest, Senator George Mitchell Center, 12 p.

Peckenham, J.M., 2003. Moving from Source Assessment to Source Protection Workshop, Maine Water Utilities Association Annual Winter Meeting.

Peckenham, J.M. and **C. Schmitt,** 2003. Moving from Source Assessment to Source Protection in Maine, Amer. Water Works Assoc. Symposium on Source Water Protection.

Schmitt, C., 2003. The Effects of the 2001-2002 Drought on Maine Surface Water Supplies, M.S. Thesis, December 2003.

Schmitt, C., Hallsworth, R., 2004. Safe Drinking Water. Information Digest, Senator George J. Mitchell Center, Drinking Water Program/ Department of Human Services, 8p.

Schmitt, C., Hallsworth, R., 2004. Protecting Groundwater Supplies: Maine's Source Water Protection Program. Information Digest, Senator George J. Mitchell Center, Drinking Water Program/ Department of Human Services, 8p.

Seger, E., 2003. Seepage Lakes as Indicators of Climate Change: Is Maine Really Cooling? M.S. Thesis, December 2003.

Stoddard, J., **J.S. Kahl**, F. Deviney, D. DeWalle, C. Driscoll, A. Herlihy, J. Kellogg, P. Murdoch, J. Webb, and K. Webster, 2003. Response of surface water chemistry to the Clean Air Act Amendments of 1990. EPA/620/R-03/001, U.S. Environmental Protection Agency, Washington, DC. 78 p.

Professional Presentations

Kahl, J.S., S. Paulsen, and J. Stoddard, 2003. Evaluating of the effectiveness of the Clean Air Act for changes in surface water acidification. *Invited plenary*, National Atmospheric Deposition Program annual meeting, October, 2003. Washington DC

Kahl, J.S., 2003. Is water chemistry the smoking gun for endangered Atlantic Salmon? *Invited lecture*, College of the Atlantic, July, 2003.

Kahl, J.S., 2003. Chemistry trends and spatial distribution of Maine lakes. Maine Volunteer Lake Monitoring Program annual meeting. Lewiston ME. June, 2003 *(invited)*.

Kahl, J.S., 2003. The environmental chemistry of salmon rivers: is there an acid rain link? *Invited lecture*, College of the Atlantic, May, 2003.

Kahl, J.S., 2003. Biologically-relevant aquatic chemistry: the intersection of the Clean Air Act and the Endangered Species Act. US EPA Corvallis OR Research Laboratory, April 18, 2003 *(invited)*.

Kahl, J.S., J. Stoddard, and D. Manski, 2003. Evaluating the effectiveness of the Clean Air Act in recovery of surface waters: The 2002 EPA Assessment of the Clean Air Act. George Wright Society biannual meeting. San Diego, CA, April 15, 2003.

Kahl, J.S., and K. Tonnessen, 2003. Developing a cooperative national research network of calibrated watersheds in the National Parks. George Wright Society biannual meeting. San Diego, CA, April 14, 2003.

Kahl, J.S., and K. Johnson, 2003. Status and trends in water chemistry in downeast Maine relative to Atlantic salmon. Proceedings, Water quality and recovery of Atlantic Salmon; is there a link? March, 2003.

Kahl, J.S., 2003. pH: the persistently problematic parameter for public policy planning. Proceedings, Water quality and recovery of Atlantic salmon; is there a link? March, 2003.

Kahl, J.S., 2003. Invited speaker, National Academy of Sciences panel on the future of water research

Nelson, S., 2003. Gordon Research Conference – Catchment Science, July 20-25, 2003, New London, NH. *Can forest fires affect nitrogen retention for centuries? Patterns of nitrogen flux in a chronosequence of burned watersheds (Poster)*

Nelson, S., 2003. American Geophysical Union Chapman Conference on Ecosystem Interaction with Land Use Change, June 14-18, 2003, Santa Fe, NM. *The Effects of Increasingly Variable Climate and Disturbance History on Episodic Acidification at a Coastal Maine Site, USA (Poster)*

Nelson, S., 2003. Forest Explorations, Acadia National Park, May 31, 2003, Bar Harbor, ME. *Hydrologic pathways and mercury research in forested watersheds at Acadia (invited)*

Nelson, S., 2003. College of the Atlantic, Bar Harbor, ME, May 30, 2003. *Patterns in N and Hg processing in lakes and streams across Maine (Invited)*

Nelson, S., 2003. Maine Water Conference, April 16, 2003, Augusta, ME. *Maine's Lakes and Research Watersheds: Indicators of Response to the Clean Air Act (Oral)*

Peckenham, J. M., 2003. Source Water Protection and Lakes, presented at the Congress of Lake Associations Annual Meeting, June 21, 2003.

Peckenham, J.M., 2003. Source Water Protection and Security. University Council for Water Research meeting, Washington DC.

Peckenham, J.M., 2003. Biosolids Experiment and White Paper. Maine Water Pollution Control Association meeting, Casco Maine.

Peckenham, J.M., J. Nadeau, and A. Amirbahman (2003) Biosolids Leachate Experiment, New England Water Environment Association, Bedford, NH, November 13, 2003.

Peckenham, J.M. and J. Nadeau, 2003. Biosolids Field Stacking Experiment, Maine Waste Waste Control Association, Casco, ME, September 18, 2003.

Peckenham, J.M., 2003. Biosolids Leachate Experiment. New England Waste Water Association meeting, Manchester, NH.

Peckenham, J.M., 2003. Maine's Source Water Protection Program, Protecting our Drinking Water at the Source Conference, Worcester, MA, October 17-18, 2003.

Peckenham, J.M., 2003. Boothbay Regional Water District, Protecting our Drinking Water at the Source Conference, Worcester, MA, October 17-18, 2003.

Peckenham, J.M., 2003. Arsenic Removal for Small Water Supplies (series of 4 workshops for small community water systems in Maine) September/October, 2003.

Peckenham, J.M., 2003. Moving from Source Assessment to Source Protection Workshop, Maine Water Utilities Association Annual Winter Meeting, February 11, 2003.

Schmitt, C., 2003. Drinking Water Supplies Pushed to the Edge, Poster Presentation, Maine Water Conference, April 2003.

Conferences, Workshops, Annual Meetings

Maine Water Conference 2003 Augusta Civic Center, Augusta, ME. April 16, 2003. The Maine Water Conference was founded in 1994 by the University of Maine Water Research Institute as an annual forum for water resource professionals, researchers, consultants, citizens, students, regulators, and planners to exchange information and present new findings on water resources issues in Maine. Guest speakers at this year's plenary session included: Dr. Robert Sanford, University of Southern Maine; John McPhedran, Maine Department of Environmental Protection; Dawn Gallagher, Commissioner, Maine DEP; and Bill Townsend, Maine Rivers. Afternoon sessions included: Sprawl and Ecosystem Health; State of Maine's Environment; Stormwater and Wastewater Issues; How Beaches Work; Lake Education Roundtable. A juried student poster competition and exhibit area were available for viewing throughout the day.

Congress of Lake Associations Annual Meeting 2003 University of Maine campus, Orono, ME. June 21, 2003. Mitchell Center staff worked closely with COLA volunteers to organize the annual meeting on the UMaine campus. It is the first time the conference has taken place in northern Maine. Organization involved working with other campus services to schedule meeting locations, food arrangements and AV equipment rental.

Linkages between Acid Rain and Atlantic Salmon meeting Black Bear Inn, Orono, ME. Mitchell Center Director Steve Kahl joined participants from NOAA Fisheries and the Atlantic Salmon Commission on the conference organizing committee. Kahl and Mitchell Center staff member Ken Johnson provided oral and poster presentations entitled: "Is there a link between water chemistry and salmon populations?"

Public Service

Media/Press

6/19/03, CBS Evening News, **John Peckenham** interviewed by Betty Chin, Poland Spring Class Action Lawsuit

7/10/03, Lewiston Sun, **John Peckenham** interviewed by Trevor Maxwell, Poland Spring Class Action Lawsuit

7/10/03, AP Wire Service, **John Peckenham** interview, Poland Spring Class Action Lawsuit

8/27/03, News Conference, attended by **John Peckenham** and **Catherine Schmitt** concerning issues regarding contamination of Birch Stream by airplane deicing chemicals

9/26/03, Boothbay Register, **John Peckenham** interview on Boothbay Regional Water District and Knickerbocker Lake

12/11/03, Bangor Daily News, **John Peckenham** (with J. Rubin and C. Clavet) interview with Misty Edgecomb on MtBE

1/12/04, Portland Press Herald, **John Peckenham** interview with Chen Yap on MtBE

Birch Stream Op Ed by Pechenham and Kahl

12/24/03, Bangor Daily News, article on Steve Kahl's election as NIWR President.

12/25/03, Portland Press Herald, article on Steve Kahl's election as NIWR President.

12/24/03, Maine Public Radio, feature on Steve Kahl's election as NIWR President.

12/24/03, Lewiston Sun, article on Steve Kahl's election as NIWR President.

12/24/03, Penobscot Times, article on Steve Kahl's election as NIWR President.

October 2003, National Park Service News Release: *2003 Canon National Parks Science Scholars Announced Scholarships Announced at the Vth World Parks Congress in South Africa.* Mitchell Center Ph.D. student **Sarah Nelson** is one of the recipients.

12/11/03, Bangor Daily News: *UM Grad student tracking Acadia winter trends*. Article on Canon award winner and Mitchell Center Ph.D. student **Sarah Nelson**.

Workshops and Other Activities

PEARL – Public Educational Access to Environmental Information **–** Under the direction of Steve Kahl and Peter Vaux of the Nature Conservancy, major new funding was secured in 2003 which will move PEARL into the next phase of development in 2004. Funding from Maine Inland Fisheries and Wildlife and USGS will allow the integration of stream and river data into the database. This will provide the support needed for the addition of databases from the Maine Aquatic Biodiversity Project and from IF&W. Funds from the Atlantic Salmon Commission will allow salmon fisheries data to be added. Some of these funds will also be used to create interfaces for specific user groups which will provide educational features along with data specific to that particular group – for example, anglers. Maine Department of Environmental Protection continues to provide long-term support for the project.

Arsenic Removal for Small Water Supplies - Assistant Director John **Peckenham**, in conjunction with colleagues from the Maine Drinking Water Program and the Environmental Protection Agency, provided a series of four workshops for small community water system operators in Maine. These workshops took place during September/October 2003.

Protecting Our Drinking Water at the Source Conference **-** Assistant Director **John Peckenham** lead two workshops at this conference held in Worchester, MA: Maine's Source Water Protection Program, and Boothbay Regional Water District, October 17-18, 2003.

Maine Project WET - Project WET Director **Mary Ann McGarry** has worked closely with Maine Lakes Conservancy Institute to integrate aspects of Project WET, PEARL, and Maine's Laptop Initiative into a unique educational program. Working with middle school students and teachers, the project provides hands-on study of Maine's most important freshwater natural resource utilizing MLCI's floating classroom. Ongoing professional development workshops draw on Project WET's interdisciplinary hands-on activities and demonstrate the ease with which these activities can be implemented. Participating teachers are also introduced to the PEARL database system to which students and teachers will have the opportunity to funnel scientific findings and data that they have researched themselves. Teachers have the opportunity to become a dynamic part of the creation of PEARL's "Students Portal," an exciting concept which allows students a view into, and a means to contribute interactively to, comprehensive lake-science findings represented by PEARL.

Cove Brook Watershed Council Management Plan **-** Mitchell Center graduate student **Heather Caron** was contracted by the Cove Brook Watershed Council to create a watershed management plan that would serve as a guide for restoration, protection and future planning efforts within the watershed. Cove Brook is one of eight rivers in the state of Maine with habitat for federally protected Atlantic salmon. Historically this river was home to many spawning salmon and other fish species. Funding efforts for this project came from the State Planning Office and the Salmon Commission.

Penobscot River and Bay Institute **-** May-June 2003: Penobscot River Keepers Expeditions. These were day-long canoe expeditions on the Penobscot River with students in grades 7 to 12. In 2003 we provided about 450 students with an opportunity to learn about rivers, watersheds, history, and ecology.

Dexter Middle School Career Day **–** October 2003: Graduate student Jennifer Boothroyd made presentations on careers in environmental science to groups of students at Dexter Middle School.

NIWR Annual Meeting **–** Feb. 28-Mar. 2004: Director **Steve Kahl**, along with Mitchell Center staff and students organized the 2004 NIWR annual meeting in Washington DC. Planning included scheduling speakers, registering participants, preparing evaluations, and traveling to DC to ensure the event ran smoothly.

Kenduskeag Watershed Tour 2003 **–** Assistant Director John Peckenham collaborated with teacher Ed Lindsey to conduct a watershed tour of Kenduskeag stream for students at Bangor Central High School.

Committees and Service:

Steve Kahl

- *Hancock County Aquatic Invasive Plant Working Group (2003 -)*
- *Eco-reserves classification advisory committee*, Nature Conservancy (2002-03)
- *March Island Wildlife Management Committee* (local towns; 2002-03)
- *Environmental Policy Advisory Committee*, gubernatorial candidate John Baldacci (2002)
- *Global Program of Action Coalition, Gulf of Maine Forum committee (*regional coalition 2002-*)*
- *Chair, Boat launch and invasive species committee*, Hopkins Pond Association (2002-03).
- *Union River Watershed Coalition* (local agencies, 2001 -)
- *Atlantic Salmon Research and Information Management Committee* (multi-agency, 2001 -)
- *Headwater Streams Research Advisory Committee* (Forest Products Industry; 2000 - 03)
- *Drinking Water Education Strategy Task Force* (State Planning Office, 2000-01)
- *Maine Watershed Management Advisory Committee* (2000 -)
- *Mercury Products Advisory Commission* (Gubernatorial appt, 2000 – 03)
- *River Flow Management Commission* (Gubernatorial appt, 1998 -)
- Co-chair, *Council on Environmental Monitoring & Assessment* (Gubernatorial appt, 1997 -)
- *Maine Forest Advisory Team* (interagency/industry/environmental advisory group (1997- 00)
- *Scientific Advisory Panel*, Maine Forest Biodiversity Project (1996-98).
- Organizing committee and co-sponsor, *Maine Water Resources Conference* (1993-2000).
- *Maine Great Ponds Task Force*, 1995-97 (Gubernatorial appointment).
- *Maine Environmental Priorities Project* ('Ecology' & 'Monitoring' working groups; 1994-97).
- *Technical Support, Pushaw Lake Association*, 1995-96. Public service grant, Univ. Maine.
- Hopkins P. Lake Association (2003 -)
- Friends of Acadia National Park (2001 -)
- Maine Lakes Conservancy Institute (1999-)
- Univ. of Maine Graduate Board (1999-01)
- ME Lake Volunteer Monitor. Prog.(1996-)
- Nat'l Institutes Water Resources (1998-01)
- Penobscot Institute (1994-96)
- Environmental Policy Roundtable (2004 -)
- Freshwater Ecology Research Group (2003 -)
- University Research Council (VP-Research; 2002 -)

- University Environmental Sustainability Coalition (2000 - 03)

John Peckenham

- *River Flow Advisory Commission – Drought Task Force*
- Board of Directors, *Penobscot River and Bay Institute*
- New England Governors & Eastern Canadian Premiers ‘acid rain’ working group
- *Maine DEP-Consulting Engineers of Maine Task Force*
- *Water Resources Committee,* Maine Water Utilities Association
- *Watershed Committee*, Maine DEP and USEPA Region I
- *Union River Watershed Coalition* (local agencies)
- *Project S.H.A.R.E.* (multi-agency)
- *Northern Maine Children’s Water Festival Committee*
- *Maine Water Conference Organizing Committee and Meeting Co-Chair 2000, 2001, 2002,2003*
- *Ad Hoc Committee on Antimony in Drinking Water*
- *Planning Consortium- Environmental Health Tracking System, Maine DHS*

Environmental Justice

- Assisted woman in Glenburn with a water supply contaminated by tri-chloroethylene. Analyzed water samples and worked to get problem resolved by the Department of Human Services.
- Assisted apartment tenants in getting the Maine Air National Guard, City of Bangor, and Maine Department of Environmental Protection to respond to contamination of stream by aircraft de-icing chemicals (on-going).

Sarah Nelson

- Co-Chair, Maine Water Conference 2004
- Maine Water Conference Organizing Committee
- Ecological Society of America, Member
- American Geophysical Union, Member Biogeosciences Section
- University of Maine Professional Employees Advisory Council
- *Subcommittees of PEAC: Nominations Committee, Professional Development Survey Committee*
- Association of Graduate Students Grant Review Committee
- Chair, Town of Clifton Planning Board (2002-2003). Received $3500 software grant for GIS projects.

Andrea Grygo

- Union River Watershed Coalition

Student Support

Notable Awards and Achievements

Mitchell Center Graduates: Students Catherine Schmitt and Emily Seger graduated with Master's degrees from the Water Resources option in the Ecology and Environmental Science Program. Schmitt's thesis is titled, The Effects of the 2001-2002 Drought on Maine Surface Water Supplies. Seger's thesis is titled, Seepage Lakes as Indicators of Climate Change: Is Maine Really Cooling?

Mitchell Center Student receives NALMS conference "Best Student Poster" award: In early November, Graduate student Kirsten attended the North American Lake Management (NALMS) Conference in Mashantucket, CT. While at the conference, Kirsten presented a poster based on her thesis study design and conceptual model, as well as preliminary results from the project's summer 2003 sampling. Entitled "Defining reference conditions for measuring the effects of shoreline development on lakes in Maine", the poster received the "Best Student Poster" award at the conference. Kirsten's advisor is Dr. Katherine Webster who is the principal investigator on the study along with Roy Bouchard of the Maine Department of Environmental Protection.

Mitchell Center's collaborative partner receives international award for "Effective and Creative Education" The Maine Lakes Conservancy Institute (MLCI) received the Technical Excellence Award in Public Education and Outreach from the North American Lake Management Society (NALMS). The award was presented at the 2003 NALMS International Conference held in Connecticut, and was given in recognition of the Maine Lakes Conservancy Institute's " Effective and Creative" educational programs. These programs are a collaboration of MLCI, Project WET and PEARL.

Mitchell Center Director on 2003 UMaine Research Honor Role: Director Steve Kahl was listed in the top 25 ranking for research funding at the University Maine out of 600 faculty. This is the third concurrent year that Kahl has made the list.

Mitchell Center Graduate Students Receive Travel Awards: Students Melinda Diehl and Cecilia Clavet received awards from the Nancy Morse Dysart '60 Academic Travel Awards. The fund provides financial support to students who wish to participate in professional conferences, organized meetings, club competitions, research and other events of an academic nature. The selection committee of alumni representatives reviews applications for professional appearance and award funds based on the persuasiveness of the applicants essays in illustrating the potential benefits to the University of Maine and the state.

Kahl appointed to Land Use Regulation Commission: The Maine State Senate has confirmed Steve Kahl's appointment to the state's Land Use Regulation Commission (LURC). LURC acts as the local planning and zoning board for a region that encompasses 421 townships, eight towns, 32 plantations and 424 islands

Project WET Director and Mitchell Center student appear in Fox video: Mary Ann McGarry and graduate student Sara Colburn appeared in a “Yes! to Youth” video during a “floating classroom” presentation. Yes! To Youth is an organization which involves 7-12 grade students in the broadcast media. The video aired on Fox television stations in the Portland, ME area throughout February.

***Student Sarah Nelson receives prestigious Canon Award*:** Mitchell Center Ph.D. student Sarah Nelson has received one of eight 2003 Canon National Park Science Scholarships awarded in September to students studying at national parks in North and South America. Nelson will use the $78,000 three-year scholarship to analyze winter trends in watershed chemistry at Acadia National Park. Her project is titled, *Closing the loop on hydrologic and mass balances for a temperate forested park.*

Mitchell Center receives funds from Maine Community Foundation: The Maine Community Foundation provided funding for a community project to develop a pilot regional lakes assessment program in Hancock County. This will provide long-term water quality monitoring of area lakes. The objective is to bring together organizations already active in lake monitoring in the region, and grow the program by adding more lakes and recruiting more lake associations through time. This project will serve an important environmental education role for Hancock County communities – better informed communities will yield better stewardship.

Graduate Student has article published: Catherine Schmitt, a graduate student at the Mitchell Center has had a number of articles published in local Maine publications related to the environment and water resources. 2003 articles included *Tracking Acid Rain Across New England*, published in Northern Sky News, November 2003.

The USGS base grant provided a basis for the Senator George J. Mitchell center to secure other research funding. In addition to support from the US EPA to continue acid-rain related research, the following projects were funded in 2003:

Title: PEARL.
Investigator: Kahl/Vaux
Agency: Maine Department of Environmental Protection.

Title: Fisheries Data Integration Project
Investigator: Kahl/Vaux
Agency: Maine Department of Inland Fisheries and Wildlife

Title: Developing PEARL as the Environmental Database for Atlantic Salmon Restoration
Investigator: Kahl/Vaux
Agency: Atlantic Salmon Commission

Title: Water Chemistry Trends in Downeast Salmon Tributaries
Investigator: Kahl/Johnson
Agency: Atlantic Salmon Commission

Title: Investigating the Effects of Water Chemistry on Juvenile Atlantic Salmon in Downeast Maine
Investigator: Kahl/Johnson
Agency: NOAA Fisheries

Title: Calcium Enhancement of Downeast Area Rivers
Investigator: Kahl/Johnson
Agency: Project SHARE

Title: Biosolids White Paper
Investigator: Peckenham
Agency: State Planning Office

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	3	2	0	0	5
Masters	10	2	0	0	12
Ph.D.	4	0	0	0	4
Post-Doc.	0	0	0	0	0
Total	17	4	0	0	21

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Publications from Prior Projects