

SUMMARY OF MAJOR RESEARCH PROJECTS AT THE EXPERIMENTAL LAKES AREA DURING 2006

12 December 2006

Research activity on site at the ELA during 2006 was constrained by delays in construction of two new residential facilities. Construction personnel occupied portions of one of the remaining residences until late July when the second new structure was finally made available for researchers to use. As a result, some on-site research was postponed or cancelled, particularly during May and June. However, September and October saw research activity significantly above the historical levels for these months. Total on-site research activity for the April through November period was just over 4,000 person-days and involved approximately 105 different researchers representing more than fifteen different universities, government agencies and private companies.

Two significant agreements affecting the future of ELA operations were negotiated during 2006. The first has resulted in DFO Real Property Management relieving DFO Science of responsibility for operation of the ELA physical infrastructure. This includes field station buildings and utilities infrastructure, as well as Pine Road maintenance. The second agreement, which is currently awaiting signatures, would see Environment Canada participate as a partner with DFO in supporting the ELA facility and conducting research on site.

During 2006, the experimental phase of the Cage Aquaculture study was in its fourth year, with research activity levels similar to those of 2005. The METAALICUS study was in its sixth year of ecosystem-scale, experimental manipulation, also with a level of on-site sampling activity similar to that of 2005. A "final" season of sampling was conducted on the ELA Reservoir Project (ELARP) reservoir, which has undergone experimental, seasonal flooding each year since 1993. The long-term, ecological research (LTER) program continued, with limited support from core funding. On-site meteorological monitoring, with support from Environment Canada, moved into its 38th consecutive year. ELA Lake 227 was experimentally fertilized with phosphorus for the 38th consecutive year. One university-based study utilized this eutrophic system. A second university-based study investigated climatic and environmental changes over varying time scales. Several other graduate student studies were ongoing or wrapping up.

The following is an attempt to summarize the status of most major research projects by providing some information about their purposes, and designs. Any preliminary results have been omitted from this summary. For information about results, the reader should refer to published sources, or contact the appropriate researcher(s) directly. These projects are grouped under several broad category headings.

Note:

Using information provided by research project leaders and other ELA staff, John Shearer compiled this summary. The summary is intended as an overview of research activities at the ELA during 2006. For more detailed information, the reader should contact those researchers responsible for each study, or refer to published literature. Where appropriate, names of principal investigators, graduate students, and their affiliations are noted. Other DFO Experimental Lakes Area staff members and seasonal employees also provide support for most of these projects.

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LONG-TERM MONITORING AND CLIMATIC FACTORS

In order to assess objectively the effects of anthropogenic perturbations on aquatic ecosystems, it is essential to systematically monitor non-perturbed systems over long time periods. Only thus can we hope to evaluate the effects of naturally-occurring events (weather, cyclic climatic oscillations) on these ecosystems and factor these effects into our interpretations of impacts resulting from human activities. Of course, natural perturbations also can have significant effects on processes within these small lake ecosystems.

Over almost four decades, researchers at the E.L.A. have been collecting data on natural lake ecosystems in support of, and as references for, the experimental studies. Increasingly, these data sets have become invaluable in their own right because of the unusual scope and length of the records, and we have established a formal long-term monitoring program at the ELA. In recent years, various external groups have also conducted various monitoring research, particularly in relation to climatic change.

LONG-TERM ECOLOGICAL RESEARCH (LTER) AND DATA MANAGEMENT

Principal Investigators:

- S. Kasian, LTER Coordinator and ELA Data Manager
- K. Beaty, P. Blanchfield, D. Findlay, D. Guss, L. Hendzel, R. Hesslein, M. Lyng, K. Mills, S. Page, M. Paterson, J. Shearer, M. Stainton, M. Turner.

All principal investigators are Fisheries and Oceans Canada, Experimental Lakes Area staff.

Project Description and Goals:

In 1998 the Long-Term Ecological Research (LTER) project was established to co-ordinate the hydrological, chemical, and biological monitoring of long-term, reference lakes at the ELA. Responsibilities for collection of meteorological data and management of the ELA multidisciplinary database were added to the project in 1999.

There are three objectives for the project:

1. To provide an envelope of expected natural variability against which experimental results can be assessed.
2. To provide a long-term record for the detection of change due to the effects of region-wide perturbances resulting from global stressors (e.g. climate change, atmospheric contaminant loading and stratospheric ozone depletion), for the assessment of variance and for the interpretation of ecological relationships.
3. To provide a secure and accessible database of ecological data collected at the ELA, which serves the information needs of ELA researchers.

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Activities in 2005:

Long-term records of meteorology and hydrology of the Lake 239 basin were maintained. Meteorological variables (air temperature, precipitation, wind speed and direction, bright sunshine and evaporation) were monitored daily. The 3 inflowing streams and outflow of Lake 239 were monitored for volume of flow (continuous record) and chemical composition (weekly). The five core lakes (114, 224, 239, 373, and 442) were again monitored, where possible, for all major disciplines which include: hydrology, water temperature, secchi depth and light extinction profiles, water chemistry, primary production, epilithon, phytoplankton populations and nutrient status, zooplankton, and fish. Primary production and epilithon monitoring programs were reduced to fewer lakes. Some discipline specific monitoring continued in other lakes to maintain long-term records.

Measurements of limnological variables and samples for chemistry, phytoplankton and zooplankton analyses were taken every 2 weeks through the open water season and twice over winter (shortly after ice-on and before ice-off). Surface water temperature was measured continually in all LTER lakes. Primary production measurements were done on a regular schedule but only for lakes 114, 239 and 373. L373 and L239 epilithon were sampled three and two times respectively for metabolic activity, particulate chemical composition and algal taxonomy. Phytoplankton and zooplankton analyses included identification to species and biomass estimates. *Chaoborus* and *Mysis* in lakes 373 and 240 were sampled for comparisons to specific experimental lakes. Mark-recapture work to estimate fish populations occurred in spring and/or fall, depending on the species. Movements of lake trout and white suckers in Lake 373 were studied with acoustic telemetry for the purpose of comparison to those in the Aquaculture experimental lake.

Progress continued with archiving data in the ELA Database, improving the functionality of the Retrieval application and developing day-to-day data management applications for researchers. Most core data sets were brought up to date with 2005 data. Two new data sets, from departing scientists, were archived in the ELA Database. They were the mercury in fish from the Lake 979 flooding experiment, and the algal nutrient status indicators. The epilithon database, while not incorporated into the structure of ELA Database, was affiliated with it while modifications are being made. Further enhancements were made to the Retriever application to incorporate more data sets into the long-term reporting and data analyses options

Presentations:

The following presentation was made at Environment Canada's Ecological Monitoring and Assessment Network (EMAN) National Science Meeting in November 2006:

A perspective on trends in aquatic ecosystems from 35 years of multi-disciplinary monitoring at the Experimental Lakes Area, northwestern Ontario. S. Kasian, K. Beaty, M. Lyng, S. Page, D. Findlay, M. Paterson, J. Shearer, and K. Mills.

Long-term Data Sets Requested by Researchers:

The distribution of stand-alone versions of the ELA Database to collaborating researchers continued. This has reduced the number of individual requests for data that must be answered.

ELA staff and graduate students have logged 350 requests for data from the ELA Database.

Plans for 2007:

The intention is to continue the LTER monitoring so that long-term records of natural variation in boreal shield lakes can be maintained. Funding is currently not secure.

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A partnership with Environment Canada, for support of the field station and research at the ELA is anticipated. Details are not yet known but the possibility for expanded monitoring of airshed, terrestrial, and hydrological variables, as well as chemical contaminants, will be explored.

Specific Ancillary Studies:

Meteorological Monitoring

The ELA is the site of long-term monitoring of meteorological variables via a meteorological station (met site) that uses equipment provided by the Meteorological Service of Canada (MSC) of Environment Canada and is operated by ELA staff. Ken Beaty, with assistance from Mark Lyng, Ray Pambrun, and others, has primary responsibility for this facility and data are contributed to the MSC national climate database. Established in June of 1969, this site is now in its 38th year of continuous monitoring. Meteorological variables (air temperature, precipitation, wind speed and direction, bright sunshine and evaporation) were monitored daily again in 2006.

These climatic data are essential for our understanding of interactions between climatic variables and the lake ecosystems we study. Increasingly, they provide a basis for understanding many of the long-term patterns observed in our ELA data sets.

Canadian Air and Precipitation Monitoring Network (CAPMoN)

ELA personnel, under the direction of Ken Beaty, continued to operate a CAPMoN station at the ELA met site in 2006. The CAPMoN program (http://www.msc.ec.gc.ca/capmon/index_e.cfm), which monitors both atmospheric and precipitation chemistry at a network of sites across Canada, is funded and coordinated by Environment Canada. The ELA site, which has been operating since the 1980's, monitors ground-level ozone, SO₂ and HNO₃ in the atmosphere, Cl, SO₄, NO₃, Na, NH₄, Ca, K, Mg, pH, and mercury in precipitation. It has frequently been used as a baseline reference for sites in eastern Canada.

Canadian Network Isotopes in Precipitation (CNIP)

The ELA is a node in a Canadian network monitoring isotopes (¹⁸O, Deuterium) in precipitation. This network (<http://sciborg.uwaterloo.ca/~twdedwar/cnip/cniphome.html>), coordinated from the University of Waterloo, comprises sites distributed broadly across Canada, including the high Arctic. Its current goal is "to discern fundamental linkages between the isotopic composition of precipitation and synoptic climate and to aid in designing and optimizing a more permanent future network". Ken Beaty is the ELA researcher responsible for the ELA site.

CLIMATIC AND ENVIRONMENTAL CHANGE AT DIFFERENT TEMPORAL AND SPATIAL SCALES

A research group, headed by Dr. Brian Cumming, from the Paleoecological Environmental Assessment and Research Lab (PEARL) at Queen's University, is conducting a suite of paleological and historical monitoring studies at the ELA. The purpose is to delineate patterns of climatic and environmental change over periods ranging from the 4 decades of historical record to the last 12 millennia. The specific studies currently underway are as follows:

Decadal Scale Changes in Lake Levels over the Last 2000 Years

Principal Investigator: Dr. Kathleen Laird, Research Associate, PEARL, Queen's University

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Funding Sources: Premier's Excellence Research Award to Brian Cumming
Manitoba Hydro

The focus of this study is to reconstruct past variations in lake level from the main ELA reference lake, Lake 239. By studying a transect of cores taken at depths of approximately 8, 10, and 12 m depth in the NW basin of lake 239, the researchers are using changes in physical sediment characteristics and biological communities to track decadal-scale changes in lake levels over the last 2000 years.

Changes in Vegetation and Limnology over the Last 12,000 Years

Investigators: Melissa Moos, Ph.D. Candidate, and Dr. Brian Cumming, Queen's University

Funding Sources: NSERC Doctoral Grant to Melissa Moos
NSERC Discovery Grant to Brian Cumming

The second major project being undertaken on Lake 239 focuses on changes in vegetation and limnology over the last 12,000 years from core taken in a depth of ~30 m. This project will focus on changes in vegetation by analyses of pollen species composition, diatoms and changes in charcoal (total concentrations and accumulations, as well as specific charcoal morphotypes that the researchers suspect are related to primary deposition of charcoal). Ms Moos also hopes to analyse the archived ELA phytoplankton samples that have been collected over the last 40 years to gain a better understanding of algal seasonality and how these samples are related to the paleolimnological record over this time frame.

Changes in Diatom and Chrysophyte Communities over the Last 150 Years

Investigators: Dr. Mihaela Enache, Post Doctoral Fellow, Queen's University
Dr. Andrew Paterson, Ontario Ministry of Environment
Carole Cheung, M.Sc. Candidate, Queen's University

Funding Source: Best in Science Program
Ontario Ministry of Environment

The researchers sampled ~40 lakes within the ELA that have not been subjected to large-scale experimental manipulations. They are asking the question: Have the diatom and chrysophyte communities changed over the last 150 years, and, if so, what is the most likely cause of these changes?

Dr. Enache is undertaking this project in collaboration with Dr. Paterson. All of the diatom communities from present-day assemblages and from samples representing pre-industrial times have been analysed. M.Sc. student Carole Cheung is analysing the chrysophyte communities from these lakes, as well as from lakes from other parts of the province that have been subject to different anthropogenic disturbances.

Different Charcoal Morphotypes and their Relation to Climate

Investigators: Dr. Brian Cumming, Erin MacMillan (Honours Student), Shelly Wilkinson (Honours Student), Queen's University.

Two honours theses are investigating the potential of different charcoal morphotypes and their relation to climate on differing spatial and temporal scales (Erin MacMillan and Shelly Wilkinson). This research is utilizing known fire histories in the ELA.

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Changes in Chrysophyte Species Composition and Accumulation

Investigators: Dr. Brian Cumming, Christina Clarke (Honours Student), Queen's University

A third fourth-year honours thesis is being undertaken on the sediment cores from the north and south basins of ELA Lake 226. Ms. Clarke is studying the changes in chrysophyte species composition and accumulation in the sediment cores before, during, and after nutrient additions, and comparing these to recorded changes over the period in which they were monitored.

CLIMATE-MEDIATED CHANGES IN HABITAT USE BY LAKE TROUT (*SALVELINUS NAMAYCUSH*)

Purpose

To define lake trout habitat and determine potential loss through climate changes.

Principal Investigators

- John M. Plumb (M.Sc. Candidate)
- Dr. Paul J. Blanchfield

Department of Zoology, University of Manitoba, Winnipeg, MB, and Fisheries & Oceans Canada, Freshwater Institute, Winnipeg, MB

Funding Sources

Project funding to PJB provided by Climate Change Impacts and Adaptation Directorate (NRCan).

Project Description

The researchers monitored the depth and habitat choices of acoustically tagged lake trout in an ELA lake during two years of contrasting climatic conditions (i.e., 2003, a hot and dry year, and 2004, a cool and wet year). They used pre-existing meteorological and limnological data to define the thermal habitat of lake trout and examine the potential effects of climate-mediated changes in lake thermal structure on lake trout habitat and behaviour. They developed an individually-based population model that was validated with observed behavior from acoustically-tagged lake trout. The model was subjected to various climate change scenarios to assess the potential impacts of climate change on lake trout behaviour, growth, and survival.

Current Status

Mr. Plumb's thesis defence is scheduled for December 18, 2006. The publication of chapters of this thesis will take place in 2007.

SEISMIC MONITORING STATION

Natural Resources Canada, Seismology & Electromagnetism Section, installed an automated seismic monitoring station at the ELA in June of 2004. The station is located atop a bedrock ridge between Lake 239 and Roddy Lake (468), in the clearing created in 2003 by the removal of the FLUDEX site 1 reservoir. Fully automated with a satellite data uplink, this is part of a small network of stations installed in northwestern Ontario and is expected to remain in place for up to 5 years.

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HABITAT ALTERATION AND ECOSYSTEM PRODUCTIVITY

As humans have perturbed and manipulated aquatic ecosystems for various purposes, unexpected impacts have frequently occurred. Often these impacts have been manifested in major population shifts and alterations of energy flow within the food web. If we can better understand the factors which control system productivity and structure, and the food chain linkages affected by these perturbations, we will be better able to develop effective management and regulatory strategies for minimizing the adverse effects on aquatic ecosystems of many human perturbations. The following projects are intended to improve our knowledge of these linkages.

FERTILIZATION OF LAKE 227

Rationale

Eutrophication remains one of the most common water quality problems in much of the world. As most ELA lakes are naturally oligotrophic, it has proved advantageous to maintain at least one study lake in which the primary productivity is elevated. This enables researchers to compare physical, chemical and food web characteristics in other ELA lakes with those in a more productive system, more typical of those in many areas of Canada, and elsewhere.

Research Activities

Lake 227 was fertilized with phosphorus for the 38th consecutive year in 2006. This original ELA ecosystem-scale experiment was initiated in 1969 to demonstrate that atmospheric carbon dioxide could provide the carbon necessary for algal blooms in eutrophic lakes. Prior to 1990, all additions included various combinations of nitrogen and phosphorus. The ratio of phosphorus to nitrogen was changed during these previous stages of the experiment to test whether this would influence the dominant algal groups. Since 1990, only phosphorus has been added. During 2006, phosphorus, as phosphoric acid, was again added to Lake 227 surface waters for twenty consecutive weeks (2.5 litres per week) during the ice-free season. The acid was diluted with lake water in a plastic barrel and dribbled via *Tygon* tubing into the near-shore water. The required acid was carried to the lake weekly. Sodium bicarbonate, to be used as a neutralizing agent in case of an acid spill, is stored on site.

We continued to monitor water chemistry, phytoplankton, and zooplankton in Lake 227 during 2006. Also, Dr. Lewis Molot, of York University, and colleagues conducted enclosure studies of noxious cyanobacteria in this lake, utilizing the enhanced productivity of this system and the 38 years of historic data record during which the lake has been experimentally fertilized.

CONTROL OF NOXIOUS CYANOBACTERIA BY BIOLOGICALLY AVAILABLE IRON

Purpose

High nutrient loadings are important risk factors for the formation of cyanobacterial blooms in eutrophic systems. Cyanobacteria have higher Fe requirements than eukaryotic algae; hence, cyanobacteria may be Fe-limited in oligotrophic systems while eukaryotic algae are P-limited. It was hypothesized that reducing the biological availability of Fe in eutrophic Lake 227 would reduce the abundance of cyanobacteria.

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Despite considerable research, the mechanism that accounts for the displacement of eukaryotic algae by large cyanobacteria at high nutrient loading is unclear. We tested two hypotheses this year:

- reduction of biologically available iron in the euphotic zone will reduce cyanobacterial biomass and also cause a shift in species composition from cyanobacteria to eukaryotic algae
- Cyanobacterial allelopathy promotes cyanobacterial dominance when cell density reaches a critical level

The ability of nitrate to control ferrous iron mobilization from reduced sediments was also tested.

Research Team

- Dr. Lewis Molot, Department of Geography, York University, Toronto, Ontario
- David Findlay, Freshwater Institute, Fisheries and oceans Canada, Winnipeg, Manitoba
- Dr. Sue Watson, National Water Research Institute, Environmental Canada, Burlington, Ontario
- Guiyou Li (M.Sc. Candidate, Department of Geography, York University, Toronto, Ontario)
- Olga Bykova (Ph.D Candidate) Department of Geography, York University, Toronto, Ontario)

Funding

- NSERC Strategic grant
- DFO in-kind

Description

Twelve 2 m x 3 m enclosures were installed in Lake 227 in May 2006 prior to the appearance of cyanobacteria (*Aphanizomenon*). The experimental design called for 3 replicates each of the following:

- control
- nitrate addition to oxidize sediments and reduce Fe flux from sediments,
- ammonium addition as control for nitrate addition
- oxine addition to chelate iron and reduce biological availability

The enclosures were sampled twice weekly from mid-May until the end of June (seven weeks) for chlorophyll-*a*, ferrous iron, dissolved and particulate iron, phytoplankton, nitrate, TP, pH, ammonia, TKN, and cyanobacterial toxins. All enclosures also received phosphorus additions at the same rate as open water Lake 227. The main deep-water stations in Lakes 227 and reference Lake 239 were also sampled every 1-2 weeks.

Findings from this experiment will be presented at Canadian Society of Limnology in January 2007 (See reference) and will be incorporated into primary publications and masters degree (G. Li).

The field work portion of this study is complete and no experimental work currently is planned for 2007. Data analysis and publishing will be the focus for 2007.

Publications and Presentations

Molot, L.A., S.A. Miller, D.L. Findlay, N. Kelton, P.J. Dillon, S.B. Watson, and G. Li. Environmental controls of small and large cyanobacterial relative abundance in oligotrophic and eutrophic waters. In preparation for Spring 2007 submission.

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Li, G., L. Molot, D. Findlay, and S. Watson. (2007) Iron regulation of bloom forming cyanobacteria abundance. Presentation to the Canadian Society of Limnology in January 2007.

Guiyou Li is expected to submit his Masters thesis this spring. A paper will be submitted this spring for peer-reviewed publication.

RESERVOIR IMPACTS AND POSSIBLE MITIGATION

In Canada, reservoirs are generally created primarily for generation of hydroelectricity. Many cause flooding over large areas of northern wetland and forest land. The water levels in these reservoirs tend to be drawn down during the winter periods when electrical demand is high and water flows are low.

Since the early 1990s, ELA researchers have been investigating the ecological effects of flooding caused by reservoir creation and operation. In most cases, this has involved experimental alteration of water levels, as a simulation of what typically occurs during the creation and operation of reservoirs. The focus of these studies has been the production and fate of methylmercury and various greenhouse gases.

This work is now winding down, but data analyses are ongoing and a mesocosm study of possible mercury mitigation using low concentrations of selenium was conducted in 2005.

EXPERIMENTAL LAKES AREA RESERVOIR PROJECT (ELARP)

Objectives

The Experimental Lakes Area Reservoir Project (ELARP) is a whole-ecosystem flooding experiment designed to examine the production and mobilization of methylmercury (MeHg) in response to flooding, and to determine if reservoirs are significant sources of the greenhouse gases (GHG) carbon dioxide (CO₂) and methane (CH₄) to the atmosphere.

Research Participants in 2006

Fisheries and Oceans Canada

- Michael Paterson,
- Ray Hesslein,
- Andy Majewski,
- Diane Orihel,
- Leslie Roos,
- Alexis Burt

University of Waterloo

- Richard Elgood,
- Sherry Schiff,
- Jason Venkiteswaran

Historical Summary

In June, 1993, following two years of background studies, the outflow of a ELA Lake 979 and its surrounding wetland was dammed, and the water level raised 1.4 meters to flood 14 hectares of peatland. Direct by-products of the decomposition of the flooded vegetation in the peatland are

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CO₂ and CH₄. Mobilization of MeHg within the flooded ecosystem and release to the atmosphere of CO₂ and CH₄ in response to the flooding were monitored intensively. A non-flooded wetland system (ELA Lake 632), was monitored as a reference. Following winter drawdown, flooding of Lake 979 was repeated in summer and fall of 1994 and 1995, as detailed studies continued in both wetland systems. In all three years, dramatic increases in MeHg and in release of the GHG were observed in response to flooding.

During the open-water periods of 1996 through 1998, the 979 wetland was experimentally flooded, but the system was studied less intensively. GHG emissions and MeHg mass-balance budgets were monitored. In 1999, and again in 2000, the system was flooded, but no ecosystem monitoring was conducted. During the open water period of 2001, the system was flooded once again and a regular monitoring program was carried out. Flooding was repeated in 2002, 2003, 2004, and 2005, but only minimal general monitoring was conducted.

Monitoring in 2006

In 2006, the reservoir was flooded and regular monitoring, similar to that done in 2001, was conducted.

Sampling Conducted

Water samples were collected every 2 weeks from the inflows, outflow, and pond of Lake 979 for analysis of total mercury, methylmercury, and standard water chemistry parameters. In conjunction with water sampling, vertical profiles of temperature, light, and dissolved oxygen were obtained from the center buoy. Zooplankton samples were also collected every 2 weeks for analysis of methylmercury and biomass. Finescale dace were stocked in three enclosures in Lake 979 in June, and approximately 10 fish per enclosure were captured in July, August, and September. The enclosures were removed in late September. Between July and September, data loggers were installed on the peat islands to measure changes in the buoyancy of the peat. Water and peat samples were collected by the Waterloo group (see below) for analysis of stable isotopes of carbon and oxygen in carbon dioxide and methane. Concentrations of carbon dioxide, methane and oxygen were assessed in two ways. Manual sampling for gas chromatography was carried out in a number of locations in the pond and peat every two weeks. Also, a continuous monitoring device for the gases was moored at the center of the pond. It analyzed the surface waters every three hours.

Future of the Study

The wooden components of the dam are showing their age and will require repair or replacement if the study is to continue beyond 2006. At this time, no funding is available to carry out these repairs. In the absence of such funding, we anticipate that 2006 will be the final year of sampling.

As required by the ELA operating agreement, the existing dam will be removed and the natural flow regime restored at the end of this study.

Fluxes and Isotopic Composition of Greenhouse Gases Twelve Years Post-flood

Project Goals

- To determine if the flooding and drawdown of a boreal wetland over ten years has changed the production and flux of greenhouse gases using concentration, stable carbon isotopes (¹²C and ¹³C) and vegetation coverage data.

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- To determine the storage of CO₂ and CH₄ (as dissolved gas and bubbles) in the flooded peat.
- To estimate the mass of stored material in the floating peat.

Principal Investigators

- Dr. Sherry Schiff
- Dr. Barry Warner
- Jason Venkiteswaran (PhD Candidate)

Department of Earth Science, University of Waterloo, Waterloo, ON, N2L 3G1

Summary of Work during 2006

In summer 2004, L979 centre buoy, L979 east inflow, and L240 outflow samples were collected for DIC, CH₄, and O₂ concentration, as well as stable carbon and oxygen isotopes. To determine the diffusive flux rate and isotopic ratio of the CO₂ and CH₄ from the wetland surface to the atmosphere, static flux chambers were deployed at ten sites on the wetland. To determine the ebullitive (bubble) flux and isotopic ratio of the CO₂ and CH₄ from the wetland surface to the atmosphere, vertical profiles of bubbles entrapped within the flooded peat were sampled.

In September 2006, the following were collected: (1) peat cores, (2) measurements of peat thickness, (3) measurements of depth-to-water-table, (4) pore-water profiles, and (5) pore gas profiles. Approximately 30 short and long peat cores were collected across the wetland. Hundreds of measurements of peat thickness and depth-to-water-table were taken. More than a dozen pore-water and pore gas profiles were collected for CO₂, CH₄ and their carbon isotopic ratio.

Continuation of Study/ Spin-off Research

As 2006 was the last scheduled year of flooding in ELARP, the data collected represent the culmination of 12 years of seasonal flooding and may represent the beginning of a study on ecosystem recovery after disruption.

MERCURY AND SELENIUM INTERACTIONS IN LAKES AND RESERVOIRS

Purpose or Goal

The purpose of this study was to investigate the effects of selenium (Se) on Hg cycling at levels unlikely to cause Se toxicity. We asked: What is the lowest range of Se concentrations that can effectively lower MeHg in fish without introducing a risk of Se toxicity? Our null hypothesis was that there is no effect on Hg methylation or bioaccumulation after adding Se to water. We studied the relationship between Se and MeHg concentrations in a freshwater food web to determine whether Se additions to lake water will affect MeHg production or bioaccumulation. We also evaluated the mode of action of Se on MeHg bioaccumulation to determine if Se affects Hg methylation or MeHg bioaccumulation.

Principal Investigators

- Mariah Mailman,
Natural Resources Institute, University of Manitoba
and

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Freshwater Institute, Fisheries and Oceans Canada,

- R.A. (Drew) Bodaly,
Project Leader, Penobscot River Mercury Study, Orono, Maine
and
Freshwater Institute, Fisheries and Oceans Canada

Funding Sources

- Tennessee Valley Authority (TVA) \$48,000
- Electric Power Research Institute (EPRI) \$39,600
- Hydro-Québec \$77,500
- Manitoba Hydro \$100,000

Work Carried Out

We added Se as sodium selenite (Na_2SeO_3) to mesocosms at the Experimental Lakes Area, at concentrations of 0, 0.1, 0.2, 0.4, 0.8, and 1.6 $\mu\text{g}\cdot\text{L}^{-1}$. We also added a stable isotope of Hg (^{198}Hg or spike Hg) as mercuric chloride at a concentration of 0.3 $\mu\text{g}\cdot\text{L}^{-1}$. We followed spike Hg in water, surface sediment, particulates, periphyton, zooplankton, Chironomid larvae, and small yellow perch to determine whether Se additions affected Hg methylation and trophic transfer.

Current Status of the Study

M. Mailman is analyzing the data and writing results in thesis format. The proposed thesis defence is scheduled for the end of March, 2007.

Publications in Preparation

Mailman, M., Bodaly, R.A. (Drew), and Flett, R. *Can selenium additions lower methyl mercury concentrations in freshwater fish without imposing toxicity? A mesocosm study.* We will submit this manuscript to Environmental Toxicology and Chemistry.

Mailman, M. and Bodaly, R.A. (Drew). *Mercury and selenium mass balance budgets in experimental mesocosms.* We will submit this manuscript to Environmental Science and Technology.

Mailman, M., Van Walleghem, J., and Bodaly, R.A. (Drew). *A review of selenium and mercury interactions in freshwater fish.* We will submit this manuscript to Water, Air, and Soil Pollution.

Mailman, M. and Thompson, S. *History of Impacts to First Nations from Damming in Northern Québec and Manitoba: Towards Politically, Economically, Environmentally, and Socially Sustainable Energy.* We will submit this manuscript to the Aboriginal Press at the University of Manitoba.

MERCURY LOADING AND BIOACCUMULATION

Certain substances, when released into natural ecosystems, may persist for years in a toxic form, and may bioaccumulate within the food chain to create health problems for higher organisms, including humans, particularly when exposures are chronic.

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While such persistent toxicants are often experimentally studied under laboratory conditions, only studies conducted in real ecosystems can effectively examine the complexity of ecosystemic pathways and compartments in which these substances move and accumulate. Some controlled experimentation in real ecosystems is required to validate existing and proposed regulatory standards for these substances.

Current studies at the ELA, both on a whole watershed scale, and in various mesocosms, are helping to answer the questions about mercury contamination in aquatic biota, particularly fish, and delineate the linkages between mercury in fish and the mercury that is deposited from the atmosphere.

MERCURY EXPERIMENT TO ASSESS ATMOSPHERIC LOADING IN CANADA AND THE UNITED STATES (METAALICUS)

Background and Rationale

The relationship between atmospheric mercury deposition and fish mercury concentrations has not been established, but is central to assessing the benefits of emissions controls being considered or implemented in North America and internationally. Efforts to examine this relationship with field datasets are confounded by many factors that can affect mercury cycling and bioaccumulation in the environment. Changes in sulphur deposition, lake acidity, land use, fish growth rates, hydrology and climate, for example, all have the potential to complicate attempts to isolate the effects of mercury loading on fish mercury concentrations.

As a result of the above complications interpreting field data, researchers designed an experiment that uses stable mercury isotopes to examine the effect of mercury loading on methylmercury (MeHg) production and concentrations in biota. METAALICUS involves the addition of stable, non-radioactive, mercury isotopes to a whole ecosystem to see if there is a response in fish mercury concentrations. Pilot scale studies began in 1999 and the full scale experiment began at Lake 658 in 2001. Mercury has been added to the Lake 658 ecosystem each year since 2001, including 2006. Multiple years of mercury additions are needed because the ecosystem has not yet fully responded.

Experimental Objectives

METAALICUS is designed with the following overall objectives:

- To determine the relationship between the atmospheric deposition of mercury to a lake ecosystem and the MeHg concentration of fish.
- To determine the response time of MeHg in a whole ecosystem, including fish, to changes in rate of atmospheric deposition of mercury (Hg(II)).
- To establish the relative importance of mercury deposited on uplands, wetlands, or on to the lake surface as sources of MeHg to fish.

Participants

Principle Investigators:

- Michael Paterson, DFO Winnipeg
- R. Harris, Tetra Tech Inc., Toronto

Other DFO Winnipeg Investigators:

- P. Blanchfield, C. Podemski, K. Sandilands

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Other Investigators:

- M. Amyot, Université de Montréal, Montréal, QC
- C. Babiarz, U. of Wisconsin, Madison, WI
- B. Branfireun, U. of Toronto, Toronto, ON
- R.A. (Drew) Bodaly
- C. Gilmour, Smithsonian Institute, MD
- H. Hintelmann, Trent University, Peterborough, ON
- J. Hurley, U. of Wisconsin, Madison WI
- C. Kelly, R & K Research Inc., Saltspring Is., BC
- D. Krabbenhoft, USGS, Madison WI
- S. Lindberg, Oakridge National Laboratory, Oakridge, TN
- J. Rudd, R & K Research Inc., Saltspring Is., BC
- V. St.Louis, U. of Alberta, Edmonton, AB
- M. Tate, USGS, Madison WI

International Advisory Panel:

- J. Munthe, Swedish Environmental Research Institute (IVL).
- E. Swain, Minnesota Pollution Control Agency
- R. Hesslein, Department of Fisheries and Oceans, Winnipeg.
- J. Wiener, University of Wisconsin, Lacrosse

Study Description

As described above, METAALICUS is a whole-ecosystem experiment in which mercury loading to a headwater lake and its watershed is being altered experimentally. Lake 658 at ELA was selected for the study. It is a small (8.4 ha), low productivity, headwater lake on the Canadian Shield and is one of the lakes reserved for research at the ELA. Background studies documenting site conditions prior to the experiment were carried out in 1999-2000 and are discussed in the 2001 *Summary of Major Research Projects at the ELA*.

Mercury additions with different isotopic signatures are being applied to the lake, upland and wetland at a rate of $22 \mu\text{g m}^{-2}\cdot\text{yr}^{-1}$ (^{202}Hg , ^{200}Hg and ^{198}Hg respectively). The power of using isotopes lies in the ability to follow the newly deposited mercury separately from background mercury. Applying mercury with different isotopic signatures to the upland, wetland and lake also allows us to determine the relative contributions of these sources to fish mercury levels.

ELA is a low deposition area for mercury, with approximately $2\text{-}7 \mu\text{g m}^{-2}\cdot\text{yr}^{-1}$ of wet mercury deposition (2000-2006). The low mercury deposition rate at ELA means that adding the equivalent of about 1/6th of a teaspoon (approximately 12.5 g) of mercury per year increases wet Hg deposition to the 52-ha Lake 658 ecosystem (lake and watershed) by approximately 5 fold. This addition results in a mercury wet deposition rate to the experimental system that is comparable to rates currently observed in some parts of the US Northeast and Florida.

Mercury concentrations are being monitored in all major compartments in the lake, watershed, and atmosphere. Detailed process studies are also being carried out to follow the movement and transformations of mercury through the watershed and lake, as well as air/surface exchange of mercury. This process-based approach will allow us not only to document what happens, but also to understand why. This is essential if we are to use the results of the study to make predictions for other locations. The approach is also providing critical information for an existing model that predicts fish mercury concentrations in lakes and the effects of remedial actions such as reductions in mercury loading.

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The experiment is being carried out in two phases. Phase I involved pilot and baseline studies in 1999-2000, to prepare for Phase II. The ELA Management Board approved Phase I studies at the February 1999 and February 2000 meetings. Final approval of the full-scale experiment for 2001 through 2003 was obtained in March 2001. Permission to continue adding mercury to the ecosystem for the 2004-2006 periods was granted in February 2004.

Milestones

- (1999-2000) Two years of pilot scale experiments; pre-addition background monitoring of candidate lakes. The Lake 658 ecosystem was selected for study.
- (2001-2006) Six years of whole-ecosystem isotope additions to the lake surface. Terrestrial Hg additions were completed in 2006
- (2007) The research team is recommending continued Hg additions to the lake only.
- (After the loading phase) Monitoring of food web methylmercury concentrations until conditions return to pre-addition levels.

Public Consultation

During 2000, public information meetings were conducted in Dryden and Kenora to discuss the project with the public. In addition a presentation was made to three NGO's at a meeting in Toronto. Feedback from these presentations was positive. It should be noted that there has been no public opposition or negative media coverage in connection with METAALICUS since permission was originally granted and the project began. Scientific, public, and governmental feedback has been very positive.

Pilot Scales Studies

Pilot-scale studies from 1999-2004 were described in the *Summaries of Major Research Projects at the ELA* for 2000-2005, based on results available at the time. These included:

- Isotopic Hg(II) additions to small upland plots;
- Isotopic Hg(II) additions to a wetland plot; and
- Additions of isotopic mercury to lake enclosures

In 2006, some of the pilot-scale studies done from 1999-2005 were continued or expanded to gain additional knowledge. Updates to the pilot-scale studies follow:

Pilot Isotopic Hg(II) Additions to Upland and Wetland Catchments

Results from studies in a small upland plot (600 m²) initiated in 1999 and continued to the present show a steady migration into the soil profile of four years of successive spike additions (different isotope each year). Continued monitoring at this site, and experiments specifically designed to examine small-scale, soil-zone migration of the spike, should help to estimate transfer rates and aid predictions of whole-ecosystem response for the Lake 658 study.

Another plot-scale study at the Lake 115 wetland involved the addition of ²⁰²Hg to the surface of the wetland to test whether we could detect the spike above background concentrations and variability, and as a tool to examine fate and transport processes. The added Hg migrated both vertically and/or horizontally in peat and pore waters, and rapid methylation of the spike was observed within one day of application. Results of this study were published by Branfireun et al. (2005)

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Additions of Isotopic Mercury to Lake Enclosures

During 2000-2001, a study of isotopic additions of $^{200}\text{Hg}(\text{II})$ to four enclosures was carried out at Lake 239 at the ELA. The enclosure experiments in 2000-2001 confirmed for the first time that the new isotopic analytical methods being used could indeed follow added mercury isotopes through the water, sediments and food web, including fish. Results are discussed in the 2001 *Summary of Major Research Projects at the ELA*, and published by Paterson et al. (2006).

In 2002, eleven mesocosms were installed in Lake 240 at the ELA. Over two years, mesocosms received different amounts of inorganic mercury [$\text{Hg}(\text{II})$] to simulate atmospheric deposition rates between 1x and 15x the annual rate of wet deposition at the ELA. Mercury added to the mesocosms in 2002 and 2003 was enriched in ^{202}Hg and ^{200}Hg , respectively. Results of this MESOSIM experiment are discussed in *Summary of Major Research Projects at the ELA* for 2002 and for 2003, and a MESOSIM mass balance paper was published by Orihel et al. (2006).

Whole-Ecosystem Mercury Additions at Lake 658

Lake 658 Research Activities

After two years of pilot and baseline studies in 1999-2000, METAALICUS went “full scale” in June 2001. Stable non-radioactive $\text{Hg}(\text{II})$ isotopes are being applied to the upland, wetland, and directly to the lake surface in the Lake 658 watershed at ELA. The upland, wetland and lake are receiving mercury additions enriched with ^{200}Hg , ^{198}Hg , and ^{202}Hg respectively. In each case the annual application rate is approximately $22 \mu\text{g}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ in terms of the total amount of mercury being added. Isotopes are being applied directly to the lake at a depth of 0.7 m by mixing from a boat, over a series of 9 applications during the ice-free season. Upland and wetland areas are being sprayed once per year by an airplane flying low over the canopy. Isotopes have been applied during the 2001-2006 field seasons.

Impact on Downstream Lakes

Based on pilot-scale studies and our knowledge of the behaviour of mercury in ELA lakes, most of the added mercury will be bound to particles (soils, peat, sediments) in the Lake 658 ecosystem or returned to the atmosphere in the long term. Mercury in the Lake 658 outflow enters a very large downstream lake (Winnange Lake, approximately 1000x larger than Lake 658). Monitoring is being carried out in Winnange Lake to verify that the Winnange Lake food web is not impacted by the experiment. The concentrations of the three different mercury isotopes added to the Lake 658 watershed were examined in young-of-the-year yellow perch and northern pike prior to the addition of isotopes (June 2001) and two and four years after mercury additions (2003, 2005). Small amounts of lake isotope (less than 5% of total mercury) were identified in a few fish. It is likely that these fish were feeding right at the Lake 658 outflow and we have conducted further surveys of fish in different locations in Winnange Lake in 2006. Results of these studies are not yet available. No added isotope has been detected in the sediments of Winnange Lake, just offshore of the outflow from Lake 658.

2007 Field Season

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Detailed monitoring of site conditions, mercury concentrations, and the fate and transport of mercury will be continued in 2007. Pilot-scale studies will also continue. The project team is recommending continued additions of mercury to the surface of the lake only (subject to receiving necessary approvals), while the mercury additions to the terrestrial system were completed in 2006.

Lake Restoration

Prior to the beginning of METAALICUS, it was anticipated that MeHg concentrations in the food web following the mercury additions would be within the range presently observed in remote Canadian lakes that do not receive local anthropogenic mercury sources. This has been the case to date. If fish mercury concentrations do increase significantly in Lake 658, as a result of METAALICUS, it is expected that concentrations will return to background levels after mercury additions are stopped.

After the experiment has been completed, the study lake will be monitored until fish mercury concentrations return to pre-addition levels and the lake returns to conditions specified in Section VII. 3. of the *ELA Memorandum of Agreement*. During this recovery period, concentrations of mercury in fish and sediments in Winnange lake will also be monitored every second year.

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IN-STREAM CYCLING AND TRANSPORT OF MERCURY FROM THE LAKE 222 OUTFLOW

Participants:

Principle Investigators:

D. Krabbenhoft, USGS, Middleton, WI
M. Tate, USGS, Middleton, WI

Other Participants:

G. Aiken, USGS, Boulder, CO
C. Babiarz, University of Wisconsin, Madison, WI
S. Chadwick, University of Wisconsin, Madison, WI
J. Hurley, University of Wisconsin, Madison, WI
M. Olson, USGS, Middleton, WI

Project Purpose:

The purpose of this experiment was to gain a better understanding of mercury cycling and transport in small streams. The results from the stream experiment are complimentary to the METAALICUS project, and will aid in the overall interpretation and transferability of that project.

Experimental Objectives:

- To determine how natural humic acid complexes control mercury transport downstream
- To better understand mercury partitioning when complexed with different ligands in the stream environment (e.g., natural dissolved organic carbon (DOC), chloride)

Study Description:

The stream injection experiment was carried out at the outflow of Lake 222 during the week of August 28th, 2005. No further field studies were conducted in 2006, but analyses of the experimental results continued.

The average discharge of the study stream reach during the week was very low ($0.001 \text{ m}^3 \cdot \text{s}^{-1}$), and the tracer injection rate was $40 \text{ ml} \cdot \text{s}^{-1}$, which had no significant impact on stream discharge.

Over the course of the experiment, four different injections were executed. The first, a potassium bromide injection, was done on the day before the three mercury injections to establish the transport characteristics for a conservative tracer (bromide). The information from this injection is critical for establishing the precise sampling locations and times during the mercury tracer injections. For each mercury tracer injection, a different single mercury isotope was used for each test, with the exception of the first injection, which contained two mercury isotope tracers: inorganic mercury (^{201}Hg) and methylated mercury (Me^{199}Hg) that were diluted into a concentrated solution of DOC from a Lake 302 upland stream. On the following two days,

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successive injections of ^{202}Hg in a concentrate of Everglades DOC, and ^{200}Hg diluted into a HCl matrix were made.

Each mercury tracer injection lasted approximately 8 minutes. Samples were collected simultaneously at four stations downstream from the injection point (10 m, 17 m, 37 m, 51 m). Samples were collected up to 120 minutes after the injection started. Temperature, conductivity, dissolved oxygen, and pH were continuously monitored at the closest sampling site to the injection point. At the end of the experiment, a limited number of small fish (about 12) were collected from the stream.

Results of this study have now been determined and are being used to support other studies, including METAALICUS.

Future Plans

Currently, there are no plans to continue or repeat this study. The results of the 2005 experiment were presented at the Eighth International Conference on Mercury as a Global Pollutant in Madison, Wisconsin, in August 2006.

MERCURY ELIMINATION BY FISH IN THE WILD

Purpose of Study

To estimate the rate at which fish lose mercury in the wild.

Principal Investigators

- Jillian L.A. Van Walleggem (M.Sc. Candidate)
- Dr. Paul J. Blanchfield.

Department of Zoology, University of Manitoba, Winnipeg, MB, and Fisheries & Oceans Canada, Freshwater Institute, Winnipeg, MB

Funding Sources

Project funding to PJB provided by Manitoba Hydro. Further support for JLA VW from the ELA Graduate Scholarship, Manitoba Graduate Scholarship, Duff Roblin Fellowship, University of Manitoba Graduate Fellowship, University of Manitoba Student's Union Scholarship and Department of Zoology (Welch award).

Brief description

Yellow perch and northern pike that had naturally accumulated labeled Hg were collected from Lake 658 (the site of the METAALICUS study, see above) and transferred to a non-manipulated lake (Lake 240). In 2004-2006, losses of labeled mercury were monitored in three separate studies:

- 1) by yellow perch in Lake 240 over 440 days;
- 2) by yellow perch in an experimental reservoir (Lake 979) over 90 days;
- 3) by northern pike in Lake 240 over 2 years.

In 2005, field work for studies 1 and 2 had been completed, while sampling of northern pike for study 3 continued in spring 2006.

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Current status

Thesis requirements are completed. The research findings from studies 1 and 2 are currently being prepared for publication. In spring 2007, we plan to sample the northern pike again before publishing study 3.

Publication

Van Wallegem, J.L.A. 2006. The elimination of mercury by fish in the wild. Masters thesis. Department of Zoology, University of Manitoba. Winnipeg, Manitoba.

ENVIRONMENTAL IMPACTS OF AQUACULTURE

As wild fish populations come under increased pressures from human exploitation, commercial aquaculture or “fish farming” has become increasingly important as a source of fish protein for humans. While most Canadian aquaculture has focused on marine systems, there is increasing interest in freshwater aquaculture, in the Great Lakes and potentially in smaller inland systems. Until now, little research has focused on the environmental impacts of such activities in freshwater lakes.

IMPACTS OF CAGE AQUACULTURE ON LAKE ECOSYSTEMS

Goals or Purpose

This whole ecosystem study has been developed to assess the environmental and ecological impacts of cage aquaculture under current industry practices. The study will determine the impacts of aquaculture on water quality, primary production, sediments and native invertebrate and fish communities. A mass balance approach and the measurement of stable sulfur, carbon and nitrogen isotopes is being used to trace the movement of aquaculture-related waste materials in the ecosystem. Originally planned for three years, in 2004 the project received approval for an additional four years of funding from the Aquaculture Co-operative Research and Development Program (ACRDP). The project has just completed its fourth year of fish production. We are in the process of applying to ACRDP for funding to support a single, additional year of fish production and then will go on to study ecosystem recovery for two years.

Major Participants and Contributors

Participants:

- Cheryl L. Podemski, Freshwater Institute, Fisheries & Oceans
- Ken H. Mills, Freshwater Institute, Fisheries & Oceans
- Michael Paterson, Freshwater Institute, Fisheries & Oceans
- Michael Turner, Freshwater Institute, Fisheries & Oceans
- Paul J. Blanchfield, Freshwater Institute, Fisheries & Oceans
- Ray Hesslein, Freshwater Institute, Fisheries & Oceans
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- Dave Findlay, Freshwater Institute, Fisheries & Oceans
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- Rebekah Rooney, MSc candidate, University of Manitoba
- Michelle Wetton, MSc candidate, University of Manitoba
- Kelly Hille, MSc candidate, University of Manitoba
- Dominique Bureau, University of Guelph

Contributors:

- Aquaculture Co-operative Research and Development Program
- Northern Ontario Aquaculture Association
- MTM Aquaculture
- Aquacage Fisheries
- Martin Mills
- NSERC

2006 Study Activities

This study is comprised of three related components; namely, operation of a cage aquaculture farm in ELA Lake 375, monitoring of physical, chemical and biological factors in Lake 375, and comparisons of the Lake 375 study with larger, commercial operations elsewhere.

Lake 375 Farm Operation

On May 29, 2006, a team of over 30 ELA staff and students moved approximately 10,000 female rainbow trout into the net pen in Lake 375. The fingerlings were obtained from Cedar Crest Farms. Total mortality over the summer was 247 fish. Fish were harvested on October 30, 2006. Fish remained healthy throughout and no antibiotic use was required. Total feed usage over the production cycle was approximately 9,740 Kg. Estimated total production of trout was 7,783.1 kg.

Temperature and dissolved oxygen were measured and recorded within the cage daily. Fish were fed two times per day and total feed usage was carefully monitored and recorded. Mortalities were removed daily by netting and weekly by SCUBA diving; all morts were enumerated and individually weighed. Inventories to determine average weight of the fish were conducted monthly. Dr. Paula Azevedo and Dr. Bureau are modeling the farm's waste production using feed inputs, fish size, water temperature, and digestibility coefficients measured from the same batch of feed. This year, on a weekly basis, waste feed was estimated by suspending eight sediment traps (diameter approximately 10 cm) at the bottom of the cage during feeding and then retrieving the traps and counting pellets captured by each trap.

Lake 375 Ecosystem Monitoring

Limnology

On a monthly basis, samples for water quality analysis were collected along depth profiles in both the north and south basin of the lake. Also on a monthly basis, but on alternate weeks (resulting in biweekly sampling), depth-integrated samples were collected from the epi-, meta-, and hypolimnion at the same stations. During spring and fall turn-over, additional depth-integrated samples were collected over the depth of the cage (1-10 m) and analyzed for all forms of phosphorus and nitrogen. Sediment traps were collected weekly in both basins to

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determine sedimentation rates of carbon, nitrogen, and phosphorus. Many of the water chemistry samples remain to be analyzed. On a biweekly basis, a YSI multi-parameter probe was used to construct meter by meter depth profiles for temperature, oxygen, pH, conductivity, turbidity, and fluorescence at 12 stations placed along the north-south axis of the lake. Secchi depths were also determined at each station.

Phytoplankton and Bacteria

Phytoplankton and bacteria were sampled bi-weekly from the deep stations in the north and south basins throughout the ice-free season in 2006 using an integrated sampler. Samples have been analyzed and data are in the process of being worked up.

Algal physiology and phytoplankton nutrient status measurements, which include the use of composition ratios and physiological measurements (alkaline phosphatase, nitrogen debt, and nitrogen fixation activity), explore the roles of essential nutrients (C, N, P) and physical factors in controlling algal species composition, succession and blooms, and chemical composition (lipids/carbohydrates, proteins, composition ratios, cell quotas). The species composition and biochemical composition of algae, together with other phytoplankton and zooplankton data can determine the efficiency of food chains, the effects of perturbation, the production and consequences of harmful phycotoxins, and also the bio-availability of environmental toxic substances and their rates of removal from surface waters. Unfortunately, these measures had to be discontinued in L375 and L373 in 2005 due to the impending retirement of the individual responsible for this work.

Bacterial biomass and turn-over rates in Lake 375 for 2006 have been analysed.

Littoral Periphyton

Our benthic algal sampling program was designed to evaluate the hypothesis that if phosphorus (and nitrogen) is mobilized from the aquaculture operation, we can expect the productive capacity of the littoral zone to increase. From a metabolic perspective we would expect to observe increased photosynthetic potential because of the high dissolved inorganic carbon in L375, which alleviates carbon limitation typical of epilithic biofilms in ELA lakes. From a food-quality perspective, we also expect that if the availability of phosphorus (and nitrogen) are increased, stoichiometry of littoral biofilms (especially C: P) will be enhanced. Note though that timelines associated with nutrient dynamics will likely vary with the nutrient, and in terms of sensitivity to detection by a mid-summer synoptic sampling program. Although N might become available during the open-water season if ammonia from fish wastes exceeds pelagic demand, P release from the fish waste will likely depend upon cycling through the anoxic hypolimnion and require entrainment into the epilimnion during spring and fall overturns.

In 2006, a new graduate student, Kelley Hille, joined the research team to study the effects of the cage farm on periphyton communities. L375 and L373 were sampled synoptically for metabolic information and for taxonomy + chemical composition. Samples are still being processed.

In order to simulate littoral shorelines in closer proximity to cage operations, six Plexiglas trays holding 8 ceramic tiles (2x2 cm²) were placed in Lake 375 and 1 tray placed in reference Lake 373 in May 2004. In addition, 1 tray was placed directly inside the cage. The trays were positioned in a transect 50, 100 and 150 m north and south of the fish cage at a depth of 1 m. In 2004, 2005 and 2006, an additional tray was placed directly inside the cage. The trays were sampled monthly with 2 tiles per tray being removed. The September sample represented accumulated seasonal growth of periphyton. Samples from 2006 are still being analyzed.

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Zooplankton

In 2006, we continued to collect samples to estimate the abundance, biomass, and species composition of zooplankton and invertebrate predators (primarily *Mysis relicta*) in Lake 375 and reference Lake 373. These organisms are important food for fish and also act as indicators of changes in water quality. Zooplankton samples were collected at the deep station in both the north and south basins of L375 on a biweekly basis. Samples were collected in L375 from the epilimnion and the hypolimnion at each station using a double-barreled net. A tube sampler was used to collect samples from six locations located around L373. Mysis were collected monthly in L373 and L375 at least one hour after sunset using a 0.75 m diameter net. Samples were collected along transects traversing the long axis of each lake; there was a total of 11 stations in L375 and 8 stations in L373.

Samples from 2006 have not yet been processed.

Sediments and Associated Biota

To examine the impacts of the farm on productivity of lake benthos, on a biweekly basis sediment cores were collected by a KB gravity corer along depth transects (11, 13, 15, 17, 19, 21 m) in both basins of L375 and in the reference lake (L373). Samples were collected at 11 m and deeper because experience has shown that hard (rock) substrates in shallower waters of these two lakes prevent operation of the corer. Samples were sieved through a 250 µm sieve and were preserved in 10% formalin. These samples are being processed, but progress is constrained by the limited funding and staff available for this work. We have made significant progress in the past year, and samples from 2002, 2003, and some of 2004, have now been enumerated but not fully identified.

In order to examine the near-field impacts of the farm on sediments and benthic invertebrates, we have been sampling sediments along a distance transect from the farm. In 2003 and 2004 this transect was sampled monthly during the production cycle. In 2005, the frequency of sampling along this transect was reduced to two times a year: once in May prior to the introduction of fish to the cage, and once after fish harvest. The transect ran along the 15 m isobath and had sites located directly beneath the cage, at the cage edge, and at 1 m, 3 m, 5 m, 10 m, 15 m, 20 m, and 45 m from the cage centre. In spring 2006, additional sites were added at 70 and 1000 m from the cage. These sites were added because data collected along the transect in November 2005 indicated that overall benthic invertebrate abundance had been reduced along the entire length of the 45 m transect.

Core samples were collected by a Kajak-Brinkhurst corer. The water on top of each core was removed by siphoning and a pH probe was used to measure the pH of the sediments at 1 cm, 2 cm, 3 cm and 4 cm of depth within the core. The top 0-1, 1-2 and 2-4 cm of sediment were extruded from five replicate cores from each station in May and in October. Pore-water was collected via filtration and ammonia concentration was measured using an ion selective electrode. An additional 4 cores from each station were similarly sectioned and the sediment frozen for later analysis of carbon, nitrogen, phosphorus and metals content. From each station, 10 replicate cores were collected and preserved for enumeration of benthic invertebrates.

To estimate the overall contribution of nutrients released from sediments affected by fish wastes to P and N loading to the lake 375, Dr. Paula Azevedo has initiated a project to measure nutrient fluxes from sediments at two locations in L375. Major factors affecting the fluxes, such as oxygen level, temperature, potential redox and conductivity, are being investigated. Using intact cores, the soluble reactive phosphorus, total dissolved phosphorus, total phosphorus, ammonia, nitrate and nitrite and total dissolved nitrogen fluxes were measured under aerobic

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and at low oxygen ($DO \leq 4$ ppm) water conditions and at various temperatures. Concentration changes of solutes in the overlying water as a function of time will be used as a direct measure of solute fluxes across the sediment-water interface. Water sampling from triplicate core incubations were collected at regular intervals for up to 156 hours from the time the incubation started. As sediment chemistry (total carbon, total nitrogen and total phosphorus, Mg, Ca and Fe) and benthic community characteristics may vary among sampled stations and through the incubation time, its effect on the nutrient fluxes across the sediment and water interface will be determined. For this purpose, cores will analyzed for total carbon, total nitrogen and total phosphorus, and sieved and analyzed to determine benthic community characteristics (macrobenthos abundance).

Energy Transfer to the Native Food Web

Little is known about the effects of cage culture on the native food web. The main objective of this component of the study is to assess whether the aquaculture fish feed or trout faeces are being used as a novel energy source by the Lake 375 biota. To achieve this, we are examining the carbon, nitrogen, and sulphur stable isotope signatures of invertebrates and fish collected before and after the introduction of cage aquaculture into L375. Adding to the 2002-2004 collections, aquatic invertebrates, macrophytes and periphyton were collected in August from L375 and the upstream reference lake, L373. All invertebrates were sorted into families and frozen. Zooplankton and *Mysis* were collected monthly from May through October. Samples of fish were collected in the spring and fall of 2006. Samples will be processed in winter 2006/2007.

Wild Fish

We continued our yearly sampling of fish populations in Lake 375 and two reference lakes, as in previous years. White sucker, slimy sculpin, and cyprinid populations were sampled in the spring and fall with trap nets. Lake trout were sampled in the fall with trap nets and short sets of small-mesh gillnets. Almost all fish were returned live to each lake. Each white sucker and lake trout was anaesthetized, weighed, measured, and marked before release. A few fin-rays were removed for age determinations from a representative sample of each species. Each cyprinid or slimy sculpin was anaesthetized and measured. Data collected in the spring and fall are still being analyzed, but trends that first emerged in 2005 continued in 2006.

The barrier fence on the outflow of Lake 375 was inspected over the course of the field season to ensure that no escaped rainbow trout (experimental or accidental) could move downstream to Manomin Lake. As a result of very high water levels in the spring, the fence was extended to ensure that escapees had no wetted channel through which to migrate into the outflow.

We continued to maintain three radio-linked acoustic fish positioning systems (VRAP, Vemco, Nova Scotia) that continually monitor the movements of acoustically-tagged fish in study Lake 375 (two systems) and reference Lake 373 (one system). We augmented the data collected using the automated positioning systems with the use of multiple passive receivers which record date and time, depth, and unique fish identifier numbers.

Most of the transmitters implanted in the initial year of the study 2002 were no longer functioning due to loss of battery power. New transmitters were implanted into wild fish to continue monitoring distribution and movements of native fish species. New tags have been implanted into Lake trout and white suckers and we also released an additional 10 rainbow trout with active transmitters into the experimental lake prior to the harvest of caged fish.

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We again examined cyprinid abundance and size-distributions through monthly minnow trapping at the cage site, at littoral sites around Lake 375, and at similar sites in Lake 373. Samples of minnow species from each site were preserved for stable isotope analysis and other measures.

Sampling at Commercial Farms

An important component of our work is making the linkage between research at the ELA and observations in the “real world”. In 2006, we have made significant strides in connecting this project to observations at commercial farms in Canada. During the ice-free seasons of 2006, water chemistry, zooplankton and phytoplankton samples were collected at two commercial farms monthly. Additionally, four farms have cooperated to allow us to make the first measures of waste feed at commercial farms in Canada. We have also measured accumulated wastes and collected sediments and zoobenthic samples along transects at six commercial farms in Lake Huron and also at the largest trout farm in Canada, located in Lake Diefenbaker, Saskatchewan. In all cases, analysis is underway.

Presentations and Publications

Corben Bristow has successfully defended his MSc thesis at the University of Ottawa. Rebekah Rooney successfully defended her MSc thesis at the University of Manitoba, and Marilyn Kullman also successfully defended her MSc thesis at the University of New Brunswick.

Marilynn Kullman’s first scientific manuscript has been accepted for publication (see below) and she is currently preparing a second manuscript to be submitted in December 2006. Corben Bristow has submitted one manuscript for review and is currently working on two other manuscripts. Paula Azevedo is about to submit one manuscript detailing the waste loading from the farm in 2003 and 2004 and has another manuscript underway. Two manuscripts detailing impacts to sediment and benthos are in preparation. A general manuscript reviewing overall project results from the first two years is also in preparation.

- M.A. Kullman, C.L. Podemski and K. A. Kidd. 2007. A Sediment Bioassay to Assess the Effects of Aquaculture Waste on Growth, Reproduction, and Survival of *Sphaerium simile* (Say) (Bivalvia: Sphaeriidae). *Aquaculture*. In press.

Plans for 2007

If our research proposal to ACRDP for an additional year of funding is successful, the project will continue with another year of fish production next year, otherwise we will shift our focus to an examination of ecosystem recovery. Impending retirements and lack of staff renewal will pose challenges for us to continue to produce the quantity of data of previous years, particularly in the areas of water and sediment chemistry and primary production. Dr. Paula Azevedo is in her second year of an NSERC Visiting Fellowship with the Freshwater Institute and this Fellowship will end mid-November 2007, which will reduce our ability to continue to model waste outputs and nutrient release. We have had 2 new M.Sc. students join our research team in 2006. Kelly Hille will work on the effects of the cage on periphyton communities. Michelle Wetton’s thesis work will focus on the relationship between organic loading and benthic impacts and will incorporate field samples at the ELA and at a commercial farm in Lake Huron, as well as mesocosm experiments to be conducted at the FWI.