SUMMARY OF MAJOR RESEARCH PROJECTS AT THE EXPERIMENTAL LAKES AREA DURING 2007

March 10, 2008

The level of research activity on site at the ELA during 2007 was considerably less than earlier years, but remained at a level similar to 2006, and close to the historic average. Total on-site research activity for the April through November period was just under 3,000 person-days and involved approximately 102 different researchers representing more than nine different universities, government agencies and private companies.

2007 was the first full season of operation under the newly signed agreement with Environment Canada. This Memorandum of Understanding sees Environment Canada participate as a partner with DFO in supporting the ELA facility and in conducting research on site. Environment Canada's presence at the ELA for 2007 resulted in research activity of 57 person-days involving twelve different researchers. This activity resulted in a participation level of 2% of the total site usage.

During 2007, the experimental phase of the Cage Aquaculture study was in its fifth year, with research activity levels similar to those of 2006. The METAALICUS study was in its seventh year of ecosystem-scale, experimental manipulation, but with a significant drop in level of on-site sampling activity. It was an "off" season of sampling for the ELA Reservoir Project (ELARP), 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 39th consecutive year. ELA Lake 227 was experimentally fertilized with phosphorus for the 39th consecutive year. A Lake 240 enclosure study, looking at bioavailability, bioaccumulation, and toxicity of a suite of additive and reactive brominated flame retardants (BFR) commenced this summer.
Another DFO/University-based study investigated the potential effects of an experimental cage aquaculture operation on eplithic biofilms. 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, designs and, where possible, significant results. It should be noted, however, that data analyses are ongoing and most of the results provided here are preliminary. These projects are grouped under several broad category headings.

Note:

Using information provided by research project leaders and other ELA staff, Mark Lyng compiled this summary. The summary is intended as an overview of research activities at the ELA during 2007. In most cases, the results provided are preliminary and subject to revision. 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.

TABLE OF CONTENTS

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 ELA. 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.

Activities in 2007:

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 L373 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.

The steel flume at the Lake 239 outflow was replaced in August. Studies were undertaken to assess the ability to remotely access hydrology sites. Two Maxstream radios will be tested in the lab, over winter, to assess downloading capabilities from hydrology data loggers. Progress was made to remotely access information(discharge, level, water temperature and conductivity), in real time, from the Lake 239 outflow station.

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 2005-6 data. Work progressed on getting fish population data into the Database, as well as some additional meteorological/hydrological sets (e.g. snow depth). Experimental data from the FLUDEX experiment was archived in the Database. Further enhancements were made to the Retriever application to incorporate more data sets into the long-term reporting and data analyses options

Major Findings or Conclusions:

Several papers that will be submitted to the ELA anniversary edition of CJFAS made extensive use of the LTER data. For example:

Baulch, H.M., M.A. turner, D.L. Findlay, R.D. Vinebrooke, W. Donahue, L.L. Hendzel. Benthic algal biomass: what are we measuring? (submitted)

Enache, M., A. Paterson, B.F. Cumming. Changes in diatom assemblages from 40 reference lakes from the Experimental Lakes Area (northwestern Ontario, Canada): Assessment of the likely role of climate change. (submitted)

Findlay, D.L., T. Chrzanowski, S.E.M. Kasian, L.L. Hendzel. Phosphorus availability controls DOC utilization by bacteria in small boreal lakes. (submitted)

Hesslein, R.H. Michael A. Turner, Douglas Guss, Mark Lyng.2007. Distinguishing changes in physical and chemical parameters due to climate variation versus experimental acidification of a lake. (submitted).

Phillips, I., R.D. Vinebrooke, and M.A.Turner. Reintroduction of a functionally important crayfish species (Cambaridae: Orconectes virilis) to recovering post-acidification 302S: Implications for ecosystem restoration. (submitted)

Plumb, J. and P.J. Blanchfield. Habitat preference and boundaries for lake trout (Salvelinus namaycush) in a small boreal lake (submittted)

Schindler, D.W., B.R. Parker, K. Beaty, M.P. Stainton, S. Kasian. Long-term changes in weather, climate, precipitation and stream output at the Experimental Lakes Area. (submitted)

Turner, M.A., D.L. Findlay, H.M. Baulch, L.M. Armstrong, S.E.M. Kasian, D.M. Mcnicol, R.D. Vinebrooke. Recovery from acidification of benthic algal assemblages in a boreal shield lake. (submitted)

Vinebrooke, R.D., M.A. Turner, D.L. Findlay, M.J. Paterson. Removal of treatment effect negates biodiversity-function relationships: evidence from a 20-year experiment. (submitted).

Xenopolous, M.A., W.J. Edwards, D.A. Culver, D.W. Schindler. The ultraviolet radiation environment experienced by phytoplankton: the role of vertical transport processes. (submitted)

Xenopolous, M.A., P.R. leavitt, D.W. Schindler. Ecosystem level regulation of boreal lake phytoplankton by ultraviolet radiation

A master's thesis was completed using long term data from both Lakes 239 and 373:

Plumb, J.M. 2006. Climate-mediated changes in habitat use by lake trout (Salvelinus namaycush). M.Sc. Thesis, University of Manitoba, Department of Zoology. pp. 206.

Presentations:

The following presentations were made at the 2007 American Fisheries Society Meeting:

K.H. Mills, S.E.M. Kasian, K.G. Beaty, M.E. Lyng, S.J. Page1, D.L. Findlay, and M.J. Paterson. Long-term Trends in Pristine Lakes at the Experimental Lakes Area, Canada.

K.H. Mills, S.M. Chalanchuk, D.J. Allan, V.P. Palace, P.J. Blanchfield1, & K.A. Kidd
A Whole-Lake Experiment to Assess the Impacts of an Endocrine Disruptor on a Lake Trout Community.

K.H. Mills, C.L. Podemski, P.J. Blanchfield, D.L. Findlay, M.J. Paterson, & M.A. Turner . A Whole-Lake Experiment to Assess the Impacts of Rainbow Trout Cage Culture in a Small Lake: Lake Trout Enhancement?

Long-term Data Sets Requested by External Researchers:

Stand-alone versions of the ELA Database were distributed to 6 collaborating researchers so that they could conduct their own data queries. In addition, there were 20 other requests for specific data from national and international researchers.

Plans for 2008:

The intention is to continue the LTER monitoring so that long-term records of natural variation in boreal shield lakes can be maintained. A recent partnership agreement with Environment Canada (EC), for operation of the field station and research at the ELA has made funding more secure. It is hoped that EC researchers will eventually expand the long-term monitoring activities into new areas not yet identified..

Specific Ancillary Studies:

Meteorological Monitoring

The ELA is the site of long-term monitoring of meteorological variables via a 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 39^{th} year of continuous monitoring. Meteorological variables (air temperature, precipitation, wind speed and direction, bright sunshine and evaporation) were monitored daily again in 2007. A larger building to house the expanding instrumentation on site was constructed this year.

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 2007. 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, SO_2 and HNO_3 in the atmosphere, Cl, SO_4, NO_3, Na, NH_4, 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 (^{18}O, 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.

ECOSYSTEM RECOVERY & CALCIUM DECLINE

Project goals

The first goal is to better understand the phenomenon of calcium decline in boreal aquatic ecosystems in terms of its possible causes and potential ramifications. This joint research will provide part of the scientific basis needed to set clear ecosystem objectives for both the protection and the restoration of viable fish habitat of Canada's inland waters. The research will also provide both for a better understanding of the potential risks for healthy ecosystems and for identification of those habitats that are especially sensitive in order that habitat managers can take special precautions to protect these habitats if warranted. For example, this research may enable DFO to assess whether the declines of aqueous calcium that are occurring in broad regions of Canada represent a special issue of concern that affects the development of recovery strategies for species at risk. Another research objective will be to identify indicators of these ecosystem risks.

The second general goal is to conduct monitoring to assess whether the properties of natural lake ecosystems can recover to their original states when acidic inputs are reduced. Although atmospheric emissions of acidifying substances have declined, chemical and especially biological recoveries are not happening as initially expected. As a result of this research both DFO and EC will obtain additional scientific knowledge about whether diminished acid inputs will enable the natural recovery of acidified lakes to re-establish healthy and productive ecosystems. For example, EC will be able to use this new knowledge to better characterize the nature and extent of physical and chemical recovery and better characterize the nature and extent of physicochemical and biological recovery endpoints. These are important elements of the next Canadian Acid Rain Science Assessment required by the federal-provincial Canada-Wide Acid Rain Strategy. EC will also be able to use this new knowledge to evaluate and, if necessary, modify existing policies with respect to aquatic acidification and controls on the emissions of acid precursors.

Names and affiliations of principal investigators

Michael Turner (DFO, team leader), Ken Beaty (DFO), Dave Findlay (private), Ray Hesslein (DFO), Wolfgang Jansen (North South Consultants), Dean Jeffries (EC), Mark Lyng (DFO), Stephen Page (DFO), Mike Paterson (DFO), Iain Phillips (SK Watershed Authority), Dave Schindler (U. Alberta), Norm Yan (York U.)

Brief description of the work carried out

To achieve the first general goal we are pursuing three objectives in 2007: (a) studying the temporal dynamics and chemical mass balances of calcium in boreal watersheds in order to understand the possible causes of recent aqueous declines seen in the region using the ELA database. (b) Conducting a preliminary survey of a small number of ELA lakes to act as a baseline for the future evaluation of the sensitivity of aquatic biota to declining calcium. (c) Carrying out a pilot mesocosm study as a preliminary bioassay of the calcium demand of mussels that appear to be declining in some ELA lakes.

To achieve the second goal we studied the recovery of several physicochemical and biological properties of the ELA Lake 302 South, which previously experienced several years of experimental acidification to pH 4.5, and has now recovered in terms of pH. The specific research objectives in 2007 have been to: monitor outflow hydrology and lake level; during the open-water period sample the pelagic zone for temperature, photosynthetically active radiation and water chemistry (nutrients and ions), phytoplankton and zooplankton composition; and at the beginning and end of the ice-covered period, sample the mid-lake station for water chemistry. In addition rapid assessment monitoring of zoobenthos populations was carried out in L302 and in reference lakes.

Listing of any significant findings or results to date, including preliminary results of note

Data are still being analysed, although preliminary surveys confirmed that major declines or extirpations of mussels have occurred in some lakes of the ELA region, coincident with the recent decline in aqueous calcium concentrations at the ELA. Aqueous calcium is declining in many lakes of the boreal forest ecozone in eastern Canada, a phenomenon sometimes linked to acidic deposition and forestry practices. Similarly during the last decade concentrations have declined in lakes at the Experimental Lakes Area (ELA) in northwestern Ontario for reasons that we are exploring. During this time mussels have disappeared from the littoral zone of an ELA lake that was once home to an abundant population of mussels (*Pyganodon grandis grandis*). Populations of mussels and snails also appear to have declined in a nearby lake. In contrast, zooplankton populations in ELA lakes seem unaffected based upon our preliminary analyses. In this context we are studying calcium dynamics of ELA watersheds during the last 4 decades to understand the underlying processes. For example, in the unlogged and low acid depositional region of the ELA, declining inputs via precipitation and temporary increases from forest fires have affected calcium dynamics. In the longer term we would also like to explore the potential ramifications of declining aqueous calcium for aquatic ecosystem integrity. For example, we hypothesize that declining calcium could weaken the coupling of littoral and pelagic subecosystems reducing littoral productivity, which is key to fish productivity. As a result, declining aqueous concentrations of calcium could be inducing the syndrome of aquatic osteoporosis in which ecosystem biodiversity and function are impaired, potentially putting the health and productivity of a large number of aquatic ecosystems at risk. This would be an unintended outcome of reducing atmospheric acid emissions for those regions where declining aqueous calcium is linked to decreasing acid deposition.

Plans for 2008 and beyond

Provisional plans are to continue the monitoring in 2008 and to expand upon the preliminary Ca decline research conducted in 2007 though these plans are dependent upon the availability of funding.

Recent or pending publications, including graduate theses

Presentation at 30th Congress of the International Association of Theoretical and Applied Limnology (Montreal 12-18 Aug 2007). Aquatic Osteoporosis: Are Declining Calcium Concentrations Impacting the Integrity of Boreal Aquatic Ecosystems? Michael Turner, David Schindler, Norman Yan, Dean Jeffries, Michael Paterson, Diane Malley, and Raymond Hesslein. Five publications stemming from the earlier study of ecosystem recovery are being prepared for the ELA special issue of CJFAS.

Summary of ELA Research for 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.

LAKE 239 SURFACE ENERGY BALANCE STUDY

Murray MacKay, Paul Bartlett
Climate Research Division, Science and Technology Branch, Environment Canada

Chris Spence
Hydrology and Arctic Laboratory, Environment Canada

Ken Beaty, Mark Lyng, Stephen Page
Fisheries and Oceans Canada

Purpose

The Climate Research Division of Environment Canada is currently developing a 1-dimensional dynamic lake module for use in its land surface modelling research programme that includes both the dynamics of epilimnion deepening/retreat, as well as the impact of DOC concentration on transparency. In support of this research, an instrumented raft was deployed on Lake 239.

Description

While the ELA database contains more than 30 years of meteorological, hydrological, and hydrochemical data for this reference lake, sufficient radiation data to drive and evaluate the model has generally not been collected. To address this, an instrumented raft was deployed on July 7, 2007 and operated continuously since then (Fig. 1). An aluminum mast and cross-arm assembly mounted two Eppley PSP pyranometers (one facing up, the other facing down) for incoming and outgoing shortwave radiation, an upward facing Eppley PIR pyrgeometer for incoming longwave radiation, a downward facing Apogee IRR-P infrared temperature sensor for lake surface temperature, and a Met-One 013-A wind speed sensor. Data were logged every 10 minutes to a Campbell Scientific CR10 datalogger, which was continuously charged through a solar panel mounted on the mast. Other meteorological data required to run the model were taken from the ELA meteorological station located within the watershed a few hundred metres away. Lake temperature profiles were taken manually at least twice per day during July and approximately bi-weekly after that until the lake turned over in November.

Preliminary Results

Because net shortwave radiation is of paramount importance for the dynamics of boreal lakes, the performance of the simple albedo parameterization used in the model is compared with an observed estimate for July based on the pyranometers in Fig. 2. It can be seen that the simple scheme performs very well in general, apart perhaps for very low sun angles near sunrise and sunset, when insolation is weak (though the observations themselves must be regarded as suspect under these conditions).

Fig.3 compares observed and simulated surface temperatures for July 8 – October 17. In general the model simulates surface temperature very well. Fig. 4 compares selected observed and simulated temperature profiles throughout the simulation. It can be seen that the model also captures the evolution of the thermal profile reasonably well – in particular the seasonal deepening of the thermocline.

Outlook for 2008

We fully anticipate that our raft will continue to operate at ELA for the next 5 years at least. In July 2008 we intend to move the platform to L626 or L373 in support of a proposed diversion experiment lead by Ken Beaty, Paul Blanchfield, Chris Spence, and Michael Turner. A manuscript intended for *Limnology and Oceanography* entitled “Modelling the thermal response of dissolved organic carbon variability in a small boreal shield lake” is currently under preparation.

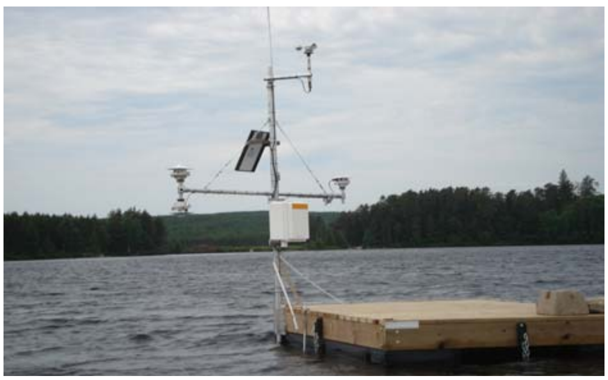

Fig.1 Environment Canada’s instrument raft on Lake 239 at the ELA

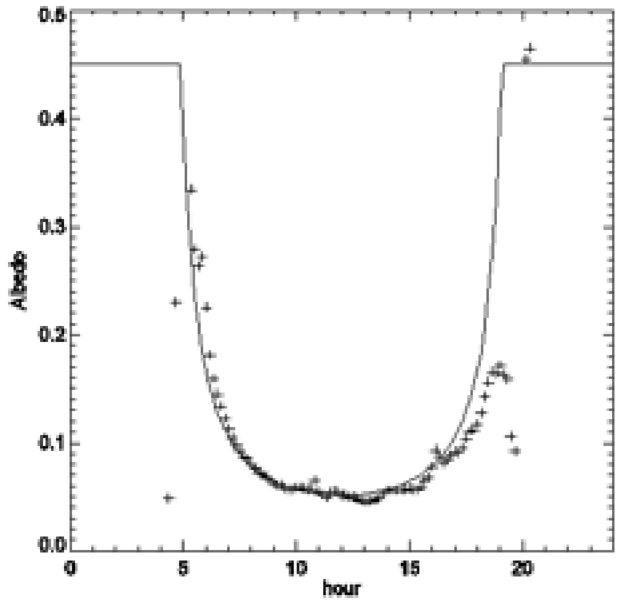

Fig. 2 Average July diurnal cycle for lake albedo: computed (solid), observed mean value 8 – 31 July, 2007 (crosses).

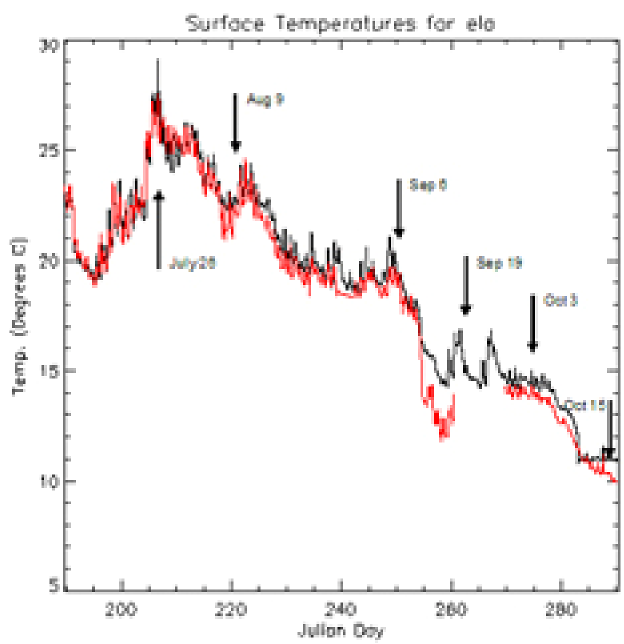

Fig. 3 Observed (red) and simulated (black) lake surface temperature for Julian day 189 (July 8) – Julian day 290 (Oct 17). Also indicated are the approximate times when simulated and observed temperature profiles are compared in Fig. 4.

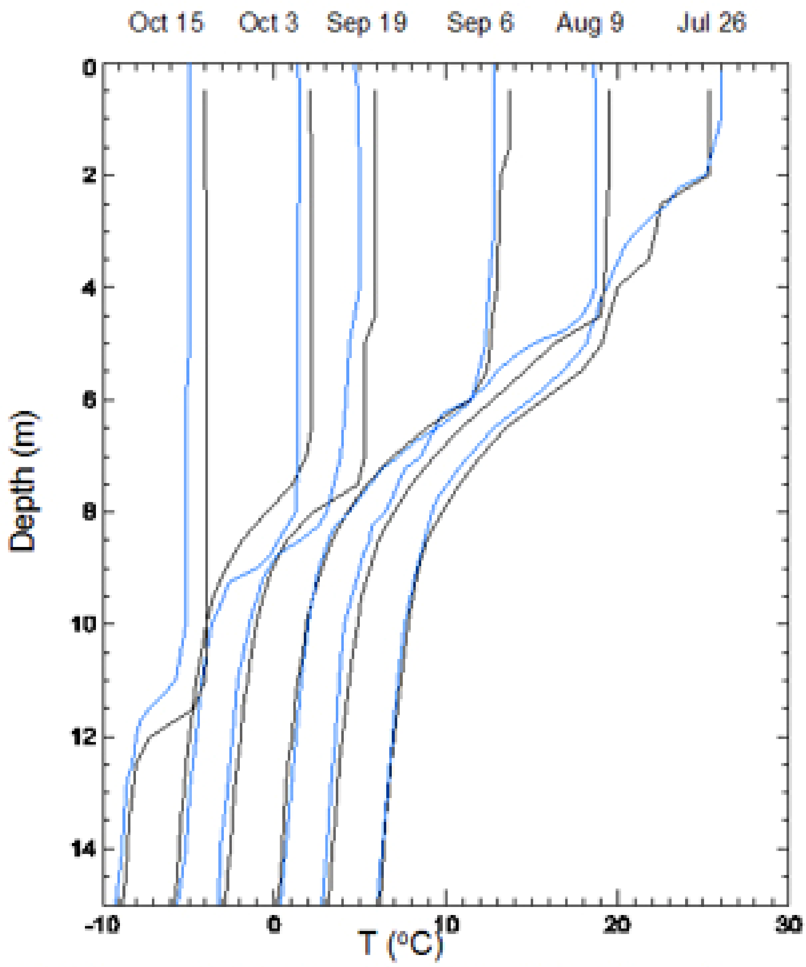

Fig. 4 Observed (blue) and simulated (black) morning temperature profiles from surface to 15m depth. Successive profiles are staggered by 3 degrees Celsius to aid in viewing.

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.

Summary of ELA Research for 2007

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 39th consecutive year in 2007. 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 2007, 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 2007 and this program will continue in 2008. Diane Orihel of the University of Alberta (supervisor David Schindler) may undertake enclosure experiments exploring the effects of additions of NaSO4 on phosphorus recycling from L227 sediments.

Publications and Presentations

Molot, L.A., G. Li, D. L. Findlay & S.B. Watson. Iron regulation of bloom forming cyanobacterial abundance in freshwaters. Submitted to Nature.

Li, G., L.A. Molot, S.A. Miller, D.L. Findlay, S.K. McCabe and S.B. Watson. Effects of UVB exposure on phytoplankton in eutrophic lakes. Submitted to Canadian Journal of Fisheries & Aquatic Sciences.

D. W. Schindler, R.E. Hecky, D.L. Findlay, M.P. Stainton, B.R. Parker, M.Paterson, M. Lyng, S. Kasian. Controlling Eutrophication by Controlling Nitrogen Input: Results of a 37 Year Experiment. Submitted to Science.

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.

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 (CO_2) and methane (CH_4) to the atmosphere.

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 CO_2 and CH_4. Mobilization of MeHg within the flooded ecosystem and release to the atmosphere of CO_2 and CH_4 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. In 2006, the reservoir was flooded and regular monitoring, similar to that done in 2001, was conducted.

Monitoring in 2007

Lake 979 was flooded, but no monitoring except hydrology, was undertaken.

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. At this time, no funding is available to carry out these repairs. Although we anticipated that 2007 would be the final year of sampling, we continued to flood the peatland in the hope that new funding might be obtained. The decision on whether to flood in 2008 is still under review.

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.

Publications and Presentations

Hall, B.D., K.A. Cherewyk, M.J. Paterson, R.A. Bodaly. Changes in methyl mercury concentrations in zooplankton from four experimental reservoirs with differing amounts of carbon in the flooded catchments. To be submitted to Canadian Journal of Fisheries and Auatic Sciences.

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.

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 sulfur 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, an experiment was designed to use 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. Mercury additions to the terrestrial system ended in 2006, while mercury additions directly to the lake surface continued in 2007. 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 onto the lake surface as sources of MeHg to fish.

Participants:

Principle Investigators:

Michael Paterson, DFO Winnipeg, and Reed Harris, Tetra Tech Inc., Toronto

Other DFO Winnipeg Investigators:

P. Blanchfield, C. Podemski, K. Sandilands

Other Investigators:

M. Amyot, Université de Montréal, Montréal, QC
C. Babiarz, U. of Wisconsin, Madison, WI
B. Branfireun, U. of Toronto, Toronto, ON
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
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 target rate of 22 µg m^{-2} 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 2-7 µg m^{-2} 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.

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 period was granted in February 2004. Permission to continue adding mercury to the ecosystem for the 2007-2009 period was granted in February 2007.

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) Mercury additions continued directly to the lake surface. First synthesis paper describing METAALICUS results from 2001-2003 published in peer reviewed literature (see Harris et al. 2007 in Publications section at end of this document).
- (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 2000-2006, 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 2007, some of the terrestrial pilot-scale studies done from 1999-2006 were continued or expanded to gain additional knowledge:

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

In 1999 a small-scale (600 m2) forested plot study was initiated to provide an early assessment of the possible responses of Hg loading to upland catchments. These studies have continued to the present and show a steady migration of the isotope spike into the soil profile during the four years of successive spike additions (different isotope each year). These results suggest that more recent mercury deposition to terrestrial soils can eventually be expected to be incorporated into runoff and transported down gradient. 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 ^{202}Hg 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).

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 Hg(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 receive mercury additions enriched with ^{200}Hg, ^{198}Hg, and ^{202}Hg respectively. In each case the annual application rate was approximately 22 µg m^{-2} yr^{-1} in terms of the total amount of mercury being added. Isotope applications to the upland and wetland were completed in 2006. Isotope applications directly to the lake surface have occurred each year from 2001 through 2007. Isotopes are being applied directly to the lake by mixing from a boat at a depth of 0.7 m, over a series of 9 applications during the ice-free season.

Results from the Lake 658 Ecosystem:

Mercury applied directly to the lake surface ("lake spike") was clearly observed as inorganic ^{202}Hg each year from 2001-2006 (no 2007 surface water results are available yet).

Concentrations of total mercury increased in surface waters in a sawtooth pattern during the period of additions, and declined in the months between additions The resulting concentrations of total mercury in Lake 658 surface waters have to-date been within ranges observed in natural lakes. Lake spike has also been measured as methylmercury in surface and hypolimnetic waters since the first season (2001).

Lake spike has been detected in Lake 658 surface sediments since the summer of 2001. The concentration of lake spike Hg in sediments continued to climb through 2006, reaching roughly 20% of total Hg in the top 2 cm of sediments by September 2006. No 2007 sediment Hg results are available yet. Upland and wetland spike Hg in sediments remain at or below analytical detection limits of 1% of total Hg. Lake spike Hg became less available for methylation as it aged in L658 sediments. In the first year of spiking, almost 10% of lake spike Hg was found as MeHg in sediments. This percentage has declined through time during the study. By 2006, the percent of lake spike Hg as MeHg was similar to the long-term average for ambient Hg in sediments, roughly 3%.

Changes in Hg bioavailality with age in sediments may be driven by the partitioning of Hg to solids. Partition coefficients for lake spike Hg were initially much lower than for ambient Hg (log Kd of 10^3 vs. 10^5), but by late 2004, partitioning of ambient Hg and lake spike Hg were similar.

The concentrations of Hg and MeHg in sediment pore waters relative to overlying waters can be used to estimate the direction and magnitude of diffusive fluxes. The comparisons show that littoral sediments are a source of both ambient and lake spike MeHg to the water column of L658. These data also show that one route of delivery of spike Hg to sediments is through diffusion from overlying water. These findings were only possible through the use of stable Hg isotopes.

Within weeks of adding mercury to the lake surface in 2001, some of the lake spike began to appear as methylmercury at low concentrations in biota in the lower food web (zooplankton, benthos). In every season following the first year of mercury addition, a detectable amount of lake spike has been found in young-of-year (YOY) yellow perch. By August 2006, slightly more than one-third of the mercury in yellow perch was ^{202}Hg added originally to the lake surface. Muscle biopsy results for northern pike have revealed detectable levels of lake spike since 2002 and now are present at greater concentrations than forage fish. Both terrestrial and wetland spikes have been detected in all forage fish species; however, the concentrations of added spike mercury are near detection levels. 2007 fish mercury results are not yet available.

METAALICUS researchers working in the terrestrial (upland and wetland) compartments of the Lake 658 ecosystem assembled an initial mass budget of mercury added to the upland during the first two years of study. This was discussed in the 2004 *Summary of Major Research Projects at the ELA.* A key finding was that only a small amount (1%) of mercury added to the terrestrial system was detected in runoff. The implication is that the terrestrial system imposes a time lag on the delivery of atmospheric Hg deposition to lakes via runoff. This is important because runoff is the dominant source of ambient mercury to Lake 658. In order to achieve the METAALICUS goal of understanding whole-ecosystem response to a loading increase, and predicting future conditions to possible load reductions, continued monitoring of the terrestrial fluxes is essential and planned.

Overall, the full-scale METAALICUS studies at Lake 658 indicate that when mercury is added to the lake surface directly, the conversion to methylmercury in sediments, and bioaccumulation in the food web begins quickly, within weeks. Concentrations of lake spike in biota represented a relatively small fraction of the total amount of methylmercury in fish during the first season, but have increased with time as noted above. In terms of mercury added to the terrestrial system, little has been exported to the lake to-date. It is not clear whether mercury concentrations in fish have not yet stabilized in response to the changing mercury loads directly to the lake surface. We cannot yet say what the eventual response of fish mercury concentrations will be following a change in mercury loading.

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 food web is not impacted by the Lake 658 experiment. Concentrations of the three different mercury isotopes added to the Lake 658 watershed have been quantified in two species of Winnange Lake fish (northern pike and age 1 yellow perch) in alternate years, commencing in the early summer of 2001. None of the experimentally-added mercury to Lake 658 was detected in Winnange Lake fish in 2003 (2001 sampling was prior to our first additions of mercury isotope). In 2005, small amounts of lake isotope were identified in a few yellow perch that were collected close to the Lake 658 outflow. Data from yellow perch collected from Winnange Lake in 2006 confirmed that only fish near the outflow of Lake 658 accumulated any isotopic mercury. Only mercury added directly to the surface waters of Lake 658 has been detected in Winnange Lake yellow perch, and concentrations are very low, often just at the limit of detection and account for <1%, on average, of the total amount of Hg in fish. The presence of mercury from Lake 658 in Winnange Lake perch appears localized and contributes minor amounts of Hg compared to the burden of Hg already in Winnange Lake fish. In 2007, we collected yellow perch, northern pike and lake trout from Winnange Lake for Hg analyses, which are currently underway. No added isotope was detected in the sediments of Winnange Lake, just offshore of the outflow from Lake 658, sampled in 2005 or earlier. Sediment samples collected in Winnange Lake in 2007 have not been analyzed yet for mercury.

2008 Field Season:

The project team has decided that there will be no mercury additions to the lake in 2008. The Lake is to be considered in the recovery stage. Detailed monitoring of site conditions, mercury concentrations, and the fate and transport of mercury will be continued in 2008.

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.

2007 Publications:

Harris RC, JWM Rudd, M Amyot, C Babiarz, KG Beaty, PJ Blanchfield, RA Bodaly, BA Branfireun, CC Gilmour, JA Graydon, A Heyes, H Hintelmann, JP Hurley, CA Kelly, DP Krabbenhoft, SE Lindberg, RP Mason, MJ Paterson, CL Podemski, A Robinson, KA Sandilands, GR Southworth, VL St. Louis, and MT Tate (2007) Whole-ecosystem study shows rapid fish-mercury response to changes in mercury deposition. Proceedings of the National Academy of Sciences of the United States of America 104(42): 16586–16591

Orihel, D.M., M.J. Paterson, P.J. Blanchfield, R.A. Bodaly, C.C. Gilmour, H. Hintelmann. 2008. Temporal changes in the distribution, methylation, and bioaccumulation of newly deposited mercury in an aquatic ecosystem. Environmental Pollution. In press.

Orihel, D.M., M.J. Paterson, P.J. Blanchfield, R.A. Bodaly, and H. Hintelmann (2007) Experimental Evidence of a Linear Relationship between Inorganic Mercury Loading and Methylmercury Accumulation by Aquatic Biota. Environ. Sci. Technol., 41 (14) : 4952 -4958

Southworth, G., S. Lindberg, H. Hintelmann, M. Amyot, A. Poulain, M.A. Bogle, M. Peterson, J. Rudd, R. Harris, K. Sandilands, D. Krabbenhoft, and M. Olsen (2007) Evasion of added isotopic mercury from a northern temperate lake. Environmental Toxicology and Chemistry 26(1): 53–60.

Van Walleghem, J.L.A., P.J. Blanchfield, and H.H. Hintelmann. 2007. Elimination of mercury by yellow perch in the wild. Environ. Sci. Technol. 41: 5895-5901.

Van Walleghem, J.L.A., P.J. Blanchfield, and H.H. Hintelmann. Rates of mercury elimination by a top predator, *Esox lucius*.(submitted)

ENCLOSURE STUDIES OF BROMINATED FLAME RETARDANTS

Assessments by Environment Canada (2005) and by the UK Environment Agency (2007) have concluded that further studies are needed on BFRs, especially on highly brominated forms such as BDE209. Both assessments found that BDE209 is persistent but that more science was needed to assess bioaccumulation and toxicity. A key question is whether BDE209 debromination is significant under realistic environmental conditions thus resulting in the availability of more bioavailable and toxic congeners. There is growing evidence that BDE209 is bioaccumulating, e.g. detection in herring gull eggs in the Great Lakes (Gauthier et al. 2007;Law et al ET&C 2006) although the pathways are not clearly defined. The combination of widespread distribution in the environment (including in remote regions), and presence in tissues of top predators (including sensitive life stages such as eggs) makes BDE209 a high priority for further study.

FATE AND EFFECTS OF DECABROMODIPHENYL ETHER (DECABDE) IN AQUATIC MESOCOSMS

Collaborators:

Derek Muir, Environment Canada

Summary of ELA Research for 2007

Diane Orihel, University of Alberta

Vince Palace, Fisheries & Oceans Canada

Brad Park, Fisheries & Oceans Canada

Michael Paterson, Fisheries & Oceans Canada

Gregg Tomy, Fisheries & Oceans Canada

Background:

Polybrominated diphenyl ethers (PBDEs) are commonly used as flame retardants in a wide variety of products, including televisions, computers and furniture. PBDEs in consumer products may be released to the environment during their manufacture, service life, and after disposal. Since the 1970s, levels of PBDEs in the environment have been increasing (de Wit 2002). PBDEs are now ubiquitously found in air, water, fish, birds, marine mammals, and people (Hites 2004). The accumulation of PBDEs in wildlife and humans have raised concerns about the safety of these chemicals.

Three commercial PBDE products are manufactured: pentabromodiphenyl ether (PentaBDE; mixture of congeners with 4 to 6 bromine atoms), octabromodiphenyl ether (OctaBDE; mixture of congeners with 6 to 9 bromine atoms), and decabromodiphenyl ether (DecaBDE, mainly composed of BDE-209, a congener with 10 bromine atoms). The number of bromine atoms on the diphenyl ether influences its uptake, bioaccumulation, and toxicity. In general, the lower brominated congeners are more bioaccumulative and toxic (Darnerud 2003, Birnbaum and Staskal 2004). In response to concerns about the toxicity of lower brominated PBDEs, the penta- and octa- commercial mixtures have been banned in several countries.

The continued use of the decabromodiphenyl ether (DecaBDE) product is controversial because of the potential for this chemical to breakdown into the lower brominated congeners, which are more readily absorbed and accumulated by organisms. Laboratory studies have demonstrated that PBDEs can be debrominated by light (Hua et al. 2003, Eriksson et al. 2004), by microbes (Gerecke et al. 2005, He et al. 2006), and in fish (Tomy et al. 2004, Stapleton et al. 2006). Debromination of DecaBDE has been clearly demonstrated to occur under experimental conditions, but whether this process occurs in the environment is less certain (Birnbaum and Staskal 2004). If debromination of DecaBDE is an important process in nature, the formation of more bioaccumulative and more toxic breakdown products could potentially affect the health of humans and wildlife.

Study Objective and Design:

We are examining the fate and effects of decabromodiphenyl ether (DecaBDE) in aquatic mesocosms at the Experimental Lakes Area. The objectives of this study are to determine: (i) the extent to which DecaBDE is debrominated in the natural environment; (ii) the bioavailability and bioaccumulation of DecaBDE to aquatic invertebrates and fish; and (iii) the toxicity of DecaBDE to small fish under realistic conditions. We installed four 10-m diameter mesocosms in a 3-m deep area of Lake 240 in August 2007. On September 26, a single dose of DecaBDE (BDE-209 congener) was added to three mesocosms to achieve nominal sediment concentrations between 240 and 2400 ng/g dw. The fourth mesocosm was not dosed to serve as a control. Approximately 1 month later, 30 young-of-the-year yellow perch (*Perca flavescens*) were stocked in each mesocosm. Samples of water, particles, sediment, periphyton, zooplankton, benthic invertebrates, and fish were collected in October 2007.

Plans for 2008 and 2009:
Fish and mussels will be stocked in May of each year. Samples of water, particles, sediments, periphyton, zooplankton, benthic invertebrates, and fish will be collected on 2-3 occasions in each year. Samples will be analyzed to determine concentrations of BDE-209 and debromination products. Temporal trends in concentrations of each congener will be assessed, and a mass balance will be constructed for each mesocosm. Bioaccumulation factors will be calculated for invertebrates and fish. Toxicity will be assessed in fish by examining biotransformation enzymes and the thyroid hormone system.

References

Birnbaum, L.S. and Staskal, D.F. 2004. Brominated flame retardants: cause for concern? *Environmental Health Perspectives* 112, 9-17.

Darnerud, P.A. 2003. Toxic effects of brominated flame retardants in man and in wildlife. *Environment International* 29, 841-853.

De Wit, C.A. An overview of brominated flame retardants in the environment. *Chemosphere* 46, 583-624.

Eriksson J., Green N., Marsh G., Bergman A. 2004. Photochemical decomposition of 15 polybrominated diphenyl ether congeners in methanol/water. *Environmental Science & Technology* 38, 3119-3125.

Gerecke, A.C., Hartmann, P.C., Heeb, N.V., Kohler H.P.E., Giger, W., Schmid, P., Zennegg, M., Kohler, M . 2005. Anaerobic degradation of decabromodiphenyl ether. *Environmental Science & Technology* 39, 1078-1083.

He, J.Z., Robrock, K.R., Alvarez-Cohen, L. 2006. Microbial reductive debromination of polybrominated diphenyl ethers (PBDEs). *Environmental Science & Technology* 40, 4429-4434.

Hites, R.A. 2004. Polybrominated diphenyl ethers in the environment and in people: a meta-analysis of concentrations. *Environmental Science & Technology* 38, 945-956.

Hua, I., Kang, N., Jafvert, C.T., Fabrega-Duque, J.R. 2003. Heterogeneous photochemical reactions of decabromodiphenyl ether. *Environmental Toxicology and Chemistry* 22, 798-804 .

Stapleton, H. M., Brazil, B., Holbrook, R.D., Mitchelmore, C.L., Benedict, R., Konstantinov, A., Potter, D. 2006. In vivo and in vitro debromination of decabromodiphenyl ether (BDE 209) by juvenile rainbow trout and common carp. *Environmental Science & Technology* 40, 4653-4658.

Tomy, G.T., Palace, V.P., Halldorson, T., Braekevelt, E., Danell, R., Wautier, K., Evans, B., Brinkworth, L., Fisk, A.T. 2004. Bioaccumulation, biotransformation, and biochemical effects of brominated diphenyl ethers in juvenile lake trout (*Salvelinus namaycush*). *Environmental Science & Technology* 38, 1496-1504.

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 will be 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 fifth and final year of fish production. We will now proceed to monitor 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
- Lori Tate, Freshwater Institute, Fisheries & Oceans
- Dave Findlay, Freshwater Institute, Fisheries & Oceans
- Laurie Wesson, Freshwater Institute, Fisheries & Oceans
- Paula Azevedo, Freshwater Institute, Fisheries & Oceans
- Adam McFee, Freshwater Institute, Fisheries & Oceans
- Karen Kidd, University of New Brunswick at St John
- Marilynn Kullman, MSc candidate, University of New Brunswick at St John
- Corben Bristow, MSc candidate, University of Ottawa
- 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

Summary of ELA Research for 2007

Contributors:

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

2007 Study Activities and Preliminary Results

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 07, 2007, 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. Unfortunately the fish appeared to be very stressed from the trip, with mortalities evident in the truck. Overnight 2998 fish perished. As a result a second shipment of 3500 fish were received on May 28, 2007. These fish were in very good conditions, and total mortality over the summer was 209 fish, or 2.2%. Fish were harvested on Oct 29, 2007. Fish remained healthy throughout and no antibiotic use was required. Total feed usage over the production cycle was approximately 11290 Kg. Estimated total production of trout was 8762 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. In general, waste feed appears to be minimal; only a single pellet was collected this year.

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 (1-10m) and analyzed for all forms of phosphorus and nitrogen. Sediment traps were collected weekly in both basins to 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.

In 2003, the addition of the fish farm to Lake 375 increased the net load of carbon, nitrogen and phosphorus to this system by two, three and six times, respectively. Feed usage in 2007 was the highest yet, with 11290 kg fed as compared to the previous maximum of 11124 kg in 2005. Epilimnetic suspended N and suspended P measures were elevated from historically recorded concentrations in 2004 and this trend continued in 2005, particularly during spring and fall mixing periods. Much of the particulate chemistry from 2006 and all from 2007 is unavailable due to analysis delays in the FWI analytical laboratory resulting from retirements.

Phytoplankton and Bacteria:

As in all previous years of this project phytoplankton and bacteria were sampled bi-weekly from the deep stations in the north and south basins throughout the ice-free season in 2007 using an integrated sampler. Dave Findlay, the individual responsible for this portion of the project, retired from DFO in 2007 and as a result no samples from this year have been analyzed. We plan to have samples analyzed on a contract basis for the remainder of the project, however, this represents a significant increase in costs to the project and as a result the number of samples analyzed may have to be reduced.

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 2005 due to the retirement of Len Hendzel.

Littoral Periphyton:

The purpose of this portion of the study is to monitor epilithic biofilms for potential impacts on the littoral zone in response to the aquaculture operation. Principal investigators included Ms. Kelly Hille (University of Manitoba Graduate Student Candidate) and Dr. Michael Turner (Canadian Dept. of Fisheries & Oceans Research Scientist). The research was performed in partial fulfilment for a MSc. degree in Biological Sciences for Ms. Kelly Hille at the University of Manitoba. Financial support for the project was provided by NSERC, UMGF, DFO-Academic Partnership Funds, the ELA Graduate Scholarship and the ACDRP.

From 2001-2007 SCUBA divers collected metabolic and particulate samples from the middle littoral zone of the experimental and reference lakes as part of a Before-After-Control-Impact (BACI) experimental design.

We had hypothesized that these cumulative P inputs from the farm could enhance epilithic productivity given the relatively high dissolved inorganic carbon concentrations present in the experimental lake. Phosphorus stocks in the experimental lake have increased slowly as a result of both food waste and fish excretion. However, we have observed little metabolic response (photosynthesis or respiration) in the epilithon. Algal composition, has changed from a primarily diatom dominated assemblage to one dominated by cyanobacteria, although we are still determining the role of farm nutrients in this shift. With this shift, increases in a cyanobacterial toxin, microcystin, were possible; however, an increase has not been observed.

We postulated that increased available P would decrease the epilithic carbon (C) to P ratio (<C: P), indicating improved food quality, which appears to have occurred. Finally, we tracked the $\delta^{15}N$ signal in the lake's epilithon to determine whether the marine fishmeal was affecting the nitrogen dynamics of littoral biofilms. The results of this are still pending though the fishmeal signal has been increasing.

Currently, the 2007 data are being compiled and analyzed, the thesis writing process has begun, and completion is planned for the summer of 2008. Research objectives for 2008 are still under discussion.

Periphyton trays:

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 2007. 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. Due to the retirement of Dave Findlay, these samples have not been analysed..

Zooplankton:

In 2007, 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 in L375. 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 0.75m diameter net. Samples were collected along a transect along the long axis of each lake; there was a total of 11 stations in L375 and 8 stations in L373.

Samples from 2007 have not yet been processed. Over the three year of fish production from which zooplankton data have been analyzed, large scale changes in the rotifer and crustacean zooplankton community are not evident. In 2006 and 2007, lerge declines in abundances of *Mysis* were observed.

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, 21m) in both basins of L375 and in the reference lake (L373). Samples were collected at 11m 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 250μm sieve and were preserved in 10% formalin. These samples are being processed, but progress is limited by the limited funding and staff available for this work.

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 the 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 15m isobath and had sites located directly beneath the cage, at the cage edge, and at 1m, 3m, 5m, 10m, 15m, 20m, and 45m from the centre. In spring 2006, additional sites were added at 70 and 100m 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 45m 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 1cm, 2cm, 3cm and 4cm of depth within the core. The top 0-1, 1-2 and 2-4cm 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. Porewater ammonia was the first variable to show detectable changes less than 4 months after farm operations begun in May 2003. By September 2004, the area of sediment exhibiting significantly elevated pore-water total ammonia expanded from within the perimeter of the farm to 5 m from its edge. In November 2007, pore-water ammonia continued to be elevated immediately under the farm; however, the effects were now detectable up to 10m away. An additional 4 cores from each station were similarly sectioned and the sediment frozen for later analysis of carbon, nitrogen, phosphorus and metals content. Retirements in the FWI analytical laboratory have lead to significant delays in completion of particulate chemistry analysis and therefore the 2006 dataset is still far from complete. Samples for analysis of metals were sent to a contract laboratory and are as a result complete. In November 2006, copper and zinc were both elevated up to 10m from the farm, compared with background levels from 100m away (I don't have any 2007 data as of yet for this). From each station 10 replicate cores were collected and preserved for enumeration of benthic invertebrates and samples up to the spring of 2007 have been processed.

Over the four years of fish production, the benthic invertebrate community under and around the cage has become noticeably altered, presumably as a result of settleable solid wastes. The abundance and richness of the community in this area has become significantly depressed and only chironomid larvae in the tribe Chironomini and nematodes are present in small numbers. The affected area is spatially restricted; in November 2005, samples collected from 25m away form the edge of cage the community resembled the community collected 45m away. However along the entire length of the transect the Ostracoda had almost completely disappeared. This observation resulting in a lengthening of the sampling transect to 100m in the spring of 2006. Even with these additional sites added (70m, 100m) during the spring and fall transect of 2006, there were no individuals of Ostracoda found at these distances from the farm. By the spring transect of 2007, the Ostracoda had completely disappeared from all sites along the transect. The lake-wide benthic collections in L375 and L373 will allow us to determine if this change is associated with proximity to the farm or is occurring basin-wide. Two manuscripts discussing the changed in sediment chemistry and benthos over the first 2 years of fish production are expected to be submitted for publication before spring 2008.

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 initiated a project to measure nutrient fluxes from sediments 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 and at low oxygen water conditions (DO $\leq$ 4 ppm) and at various temperatures. Water sampling from triplicate core incubations were collected at regular intervals for up to 156 hours from the time the incubation started. In 2008 Dr Azevedo shifted her focus to the use of peepers to continue this work. Retirements in the FWI analytical laboratory have lead to significant delays in completion of particulate chemistry analysis and the work form 2006 has not yet been finalized. Dr. Azevedo has been working on manuscript discussing waste production from the farm and a second manuscript discussing the nutrient mass balance of the lake in the 4th and 5th years of fish production. Both manuscripts are currently on hold awaiting data from the chemistry lab.

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. After the graduation of Marilynn Kullmann in 2007, this work has been reduced somewhat. During the 2007 field season, monthly collections of zooplankton and mysis continued as did collections of chironomids. There were no widespread collections of benthic invertebrates. Dr. Kidd may take on a graduate student in 2008-2009 to study recovery, but this is contingent upon her finding a student with NSERC support. A manuscript discussing the stable isotope work is almost finalized and should be submitted before spring 2008.

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. Trapnet catch-per-unit-effort of minnow species (fathead minnow, pearl dace, and redbelly dace) increased in 2005, a trend that first started during the second year of cage culture. Condition (fatness) of lake trout increased in 2004, and this continued in 2005 and 2006. Lake trout growth, as measure by size at age, increased initially in young trout in 2004 and by 2005 this trend was apparent in trout up age 9. In 2006, growth (as measure by size at age) was the highest ever measured in this population and this continued in 2007. There were, however, two notable changes that occurred in 2007. First, we confirmed for the first time, using our mark-recapture estimates, that lake trout abundance is increasing in Lake 375, and that this has been caused by a combination of increased annual survival and recruitment. Second, lake trout condition decreased slightly from the exceptionally high 2006 value, reversing the almost linear increase in condition observed during the previous year of cage culture, but the 2007 value is still much higher than prior to the years of cage culture. Abundance of cyprinids (minnows) and white sucker remained as high as 2006, well elevated above pre-cage-culture values. Further analyses of the 2007 data are ongoing and will be reported in a primary publication to be submitted in spring 2008.

We have been using a combination of mark-recapture approaches and acoustic telemetry to achieve the goals of: (1) to determine whether freshwater aquaculture operation influences native fish distribution, behaviour and habitat availability; and, (2) to examine the survival and behaviour of escaped fish. We examine 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. Since 2002, we have deployed radio-linked acoustic positioning and telemetry (RAPT) systems that continually monitor the movements of acoustically-tagged fish in the study lake (L375; two systems) and the reference lake (L373; one system). We augment the data collected using the RAPT systems with the use of multiple passive receivers which record date and time, depth, and unique fish identifier number.

Early data showed greater CPUE of some minnow species at the cage site compared to a littoral site. Data from 2006 shows much higher catches of minnows in the littoral site for all species and overall we have observed little evidence of greater growth by fish attracted to the cage site. An intensive mark-recapture study carried out in 2006 showed catches of minnows to be about 20-fold higher in the littoral areas of Lake 375 (>19 000 fish) compared to equal effort at the cage site (~1 000 fish).

In the spring of 2007, 3 new transmitters were implanted into lake trout. Over the course of the study so far, we have telemetry data from 30 lake trout and 16 white sucker from Lake 375 and 25 lake trout and 14 white sucker from Lake 373. We observed no evidence of attraction to the cage site by lake trout during the first several years of the study (2002-2004); however, spatial distributions of tagged lake trout in 2005 show a marked increase in presence at the cage site. We also implanted and released 10 rainbow trout with active transmitters into Lake 375 prior to the harvest of caged fish. In total, we have telemetry data from 46 rainbow trout. Rainbow trout tend to have low survival, with few fish surviving past two years. Most escaped fish show affinity to the cage site that tends to decrease after harvest each year. Some rainbow trout are not associated with the cage. Two of the rainbow trout "escapees" we released into Lake 375 in past years were recaptured in 2007 and both have shown excellent growth. A fish released in 2004 gained 3.1 kg over a 2.6 y period and one released in the fall of 2006 gained 2.2 kg over a ~1-y period.

We continue to maintain the integrity of the barrier fence on the outflow of Lake 375 to ensure that no escaped rainbow trout (experimental or accidental) could move downstream to Manomin Lake.

Sampling at Commercial Farms

An important component of this project has been sampling at commercial farms to ensure the relevance of ELA science. In 2006, we sampled at several commercial farms and this work was continued in 2007. During the ice-free season of 2007, water chemistry, zooplankton and phytoplankton samples were collected at three commercial farms monthly. Those three farms have also cooperated with the measurement of waste feed. Michelle Wetton, a new graduate student under the supervision of Dr. Podemski, has measured the amount of sedimenting wastes along a distance transect at two of the commercial farms as well as the ELA farm. She has also been adding waste from a land-based facility, at rates determined from her field observations, to laboratory mesocosms containing Lake Huron sediment and cultured invertebrates (*Chironomus riparus, Hyalella azteca, Sphaerium simile,* and *Tubifex tubifex*). The purpose of those experiments is to measure the dose response of invertebrate growth and survival to waste additions. Our data from sampling at commercial farms in 2006 is almost complete. Currently there are no plans to continue Lake Huron work beyond 2007 due to budget restrictions.

Presentations and Publications

There are two MSc thesis and 9 journal publications currently in preparation. At the 2007 Aquaculture Association of Canada meeting, Paul Blanchfield, Ken Mills, Mike Paterson, Michelle Wetton and Cheryl Podemski presented 6 papers from the project. Dominique Bureau presented some of the work that he has been doing with Paula Azevedo to model waste outputs of the farm at the Chile-Canada Workshop on Science and Technology, and Ken Mills and Cheryl Podemski also presented papers at a special session of aquaculture impacts at the 2007 Aquatic Toxicity Workshop.

<u>Submitted manuscripts</u>

Bristow, C., A. Morin, R.H. Hesslein, C.L. Podemski. Delivery of cage aquaculture phosphorus to the epilimnion of a lake during the initial three years of operation.

Bristow, C.E., R.H. Hesslein, and C.L. Podemski. A mass balance model for phosphorus dynamics in boreal shield lakes with cage aquaculture.

DFindlay, D.L., Cheryl L. Podemski and Susan E.M. Kasian. 2007. Aquaculture impacts on the microbial communities in a small boreal forest lake. (submitted).

Rooney, R. and C.L. Podemski. Effects of an experimental rainbow trout (Oncorhynchus mykiss) farm on sediment and benthos of a freshwater lake: Part I changes in sediment and pore water chemistry. (submitted)

Rooney, R. and C.L. Podemski. Effects of an experimental rainbow trout (Oncorhynchus mykiss) farm on sediment and benthos of a freshwater lake: Part II changes in invertebrate community composition.(submitted)

Blanchfield, P.J., L. Tate, C.L. Podemski. Survival and distribution of rainbow trout released from an experimental aquaculture operation (submitted)

Blanchfield P.J., L Tate and C.L. Podemski 2007. Survival and distribution of farmed rainbow trout released from an experimental aquaculture operation. Aquaculture Canada 2007, Annual Meeting of the Aquaculture Association of Canada, September 23- 26, Edmonton, Alberta.

Bureau, D.P., P.A. Azevedo, and C.L. Podemski. 2007. Predicting waste outputs from fish culture operations: the Canadian experience. Chile-Canada Workshop on Science and Technology. "Bioproducts and Processes: Environmental, Scientific and Economic Impacts". Santiago, Chile, October 8-10, 2007.

Mills, K.H, S.M. Chalanchuk, D.J. Allen, P.J. Blanchfield, and C.L. Podemski. 2007. Impact of rainbow trout culture in a small lakes; lake trout enhancement. Aquaculture Canada 2007, Annual Meeting of the Aquaculture Association of Canada, September 23- 26, Edmonton, Alberta.

Paterson, M., D. Findlay, C.L. Podemski, L. Wesson, C. Bristow, and P. Azevedo. The effects of an experimental trout cage farm operation on nutrients and the phytoplankton community of a freshwater lake. Aquaculture Canada 2007, Annual Meeting of the Aquaculture Association of Canada, September 23- 26, Edmonton, Alberta.

Podemski, C.L. and R. Rooney. 2007. Assessment of the benthic effects of freshwater commercial net-pen aquaculture Aquaculture Canada 2007, Annual Meeting of the Aquaculture Association of Canada, September 23- 26, Edmonton, Alberta.

Podemski C.L., R Rooney, P Azevedo and M. Wetton. 2007. Development of benthic changes at an experimental freshwater aquaculture facility. Aquaculture Canada 2007, Annual Meeting of the Aquaculture Association of Canada, September 23- 26, Edmonton, Alberta.

Wetton, M. and C.L. Podemski Effects of aquaculture organic waste loading on benthic invertebrates. Aquaculture Canada 2007, Annual Meeting of the Aquaculture Association of Canada, September 23- 26, Edmonton, Alberta.

Podemski, C.L. R. Rooney, D. Findlay, H.H. Mills, P Azevedo, M. Kullman, K.A. Kidd, M. Paterson, P.J. Blanchfield, L. Tate, R. Hesslein and M. Wetton. 2007. Environmental impacts of freshwater cage aquaculture: Overview of results from the ELA whole-lake aquaculture experiment. 34th Aquatic Toxicity Workshop, Halifax, NS.

Mills, K.H, C.L. Podemski, P.J. Blanchfield, S.M. Chalanchuk, D.J. Allan. 2007. A whole-lake experiment to assess the impacts of rainbow trout culture; lake trout enhancement. 34th Aquatic Toxicity Workshop, Halifax, NS.

Plans for 2008:

In the final two years of this project, our focus will shift to monitoring ecosystem recovery. The reduction of our research budget by over 40% as well as retirements and lack of staff renewal will create a very significant challenge to continuing to produce the high quality data of previous years, and the level of detail of our investigations will necessarily be reduced rather significantly. Dr. Paula Azevedo's Fellowship ends March 31, 2008, and this will end our work on mass balancing and nutrient release from sediments. Ken Mills will be retiring soon and he is currently not planning to have another field season; as of yet no one has been identified to continue the monitoring of fish populations. We will continue to monitor water chemistry on the same schedule but may discontinue sampling the second station directly beside the cage to reduce our analysis budget. Michelle Wetton and Kelly Hille have completed all field work for their graduate degrees. It is currently unclear if Michael Turner will continue sampling of the littoral zone in 2008. Although the study of sediment recovery would be of significant utility to understanding the potential of fallowing as a mitigative strategy, we do not have the funds to support a graduate project to study benthic recovery in detail; however, we will sample sediment chemistry and benthos along the distance transect in spring and fall of 2008 and 2009.

AQUACULTURE IMPACT ON LITTORAL ECOLOGY

Study Description

The purpose of the study is to monitor epilithic biofilms for potential impacts on the littoral zone in response to the experimental rainbow trout aquaculture operation started at the Experimental Lakes Area in 2003.
Principal investigators included Ms. Kelly Hille (University of Manitoba Graduate Student Candidate) and Dr. Michael Turner (Canadian Dept. of Fisheries & Oceans Research Scientist).
The research was performed in partial fulfilment for a MSc. degree in Biological Sciences for Ms. Kelly Hille at the University of Manitoba.
Financial support for the project was provided by NSERC, UMGF, DFO-Academic Partnership Funds, ELA Graduate Scholarship and the ACDRP.

Activities and preliminary results

From 2001-2007 SCUBA divers collected metabolic and particulate samples from the middle littoral zone of the experimental and reference lakes as part of a Before-After-Control-Impact (BACI) experimental design.
We had hypothesized that these cumulative P inputs from the farm could enhance epilithic productivity given the relatively high dissolved inorganic carbon concentrations present in the

experimental lake. Phosphorus stocks in the experimental lake have increased slowly as a result of both food waste and fish excretion. However, we have observed little metabolic response (photosynthesis or respiration) in the epilithon. Algal composition, has changed from a primarily diatom dominated assemblage to one dominated by cyanobacteria, although we are still determining the role of farm nutrients in this shift. With this shift, increases in a cyanobacterial toxin, microcystin, were possible; however, an increase has not been observed. We postulated that increased available P would decrease the epilithic carbon (C) to P ratio (<C: P), indicating improved food quality, which appears to have occurred. Finally, we tracked the $\delta^{15}N$ signal in the lake's epilithon to determine whether the marine fishmeal was affecting the nitrogen dynamics of littoral biofilms. The results of this are still pending though the fishmeal signal has been increasing.

Plans for 2008

Currently, the 2007 data are being compiled and analyzed, the thesis writing process has begun, and completion is planned for the summer of 2008. Research objectives for 2008 are still under discussion.