

SUMMARY OF MAJOR RESEARCH PROJECTS AT THE EXPERIMENTAL LAKES AREA DURING 2009

The level of research activity on site at the ELA during 2009 remained at a level similar to 2008, and close to the historic average. However, activity levels continued with the declining trend that we have seen for the last several years. Total on-site research activity for the April through November period was just over 3,500 person-days and involved approximately 116 different researchers representing a total of 11 different universities, government agencies and private companies.

Last Year, 2009, was the third season of operation under the Memorandum of Understanding with Environment Canada. This Agreement 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 2009 resulted in research activity of 100 person-days (up 35% from last year) involving 18 different researchers. During 2009, both the Cage Aquaculture study and the METAALICUS study were in monitoring and recovery status, resulting in research activity levels lower than previous experimental years. It was another season of minimal sampling for the ELA Reservoir Project (ELARP), which has undergone experimental, seasonal flooding each year since 1993. The project is now in recovery and the control structure is being removed. The long-term, ecological research (LTER) program continued. On-site meteorological monitoring, with support from Environment Canada, moved into its 41st consecutive year. ELA Lake 227 was experimentally fertilized with phosphorus for the 41st consecutive year. The brominated flame retardants (BFR) enclosure study, looking at bioavailability, bioaccumulation, and toxicity of a suite of additive and reactive BFR continued this summer with DecaBDE being added to the enclosures.

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 and Mike Paterson compiled this summary. The summary is intended as an overview of research activities at the ELA during 2009/10. 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 | 3 |
| Long-Term Ecological Research (LTER) and Data Management..... | 3 |
| Meteorological Monitoring | 5 |
| Canadian Air and Precipitation Monitoring Network (CAPMoN)..... | 5 |
| Canadian Network Isotopes in Precipitation (CNIP)..... | 5 |
| Lake 239 Surface Energy Balance Study..... | 7 |
| Ecosystem Recovery | 8 |
| The Aquatic Ecosystem Recovery Study | 8 |
| Habitat Alteration and Ecosystem Productivity | 10 |
| Fertilization of Lake 227 | 10 |
| Reservoir Impacts and Possible Mitigation | 11 |
| Experimental Lakes Area Reservoir Project (ELARP)..... | 11 |
| Impacts of Stream Diversion | 12 |
| The Impact of Dry Conditions on Boreal Lake Ecology and Hydrology..... | 11 |
| Mercury Loading and Bioaccumulation | 14 |
| Mercury Experiment to Assess Atmospheric Loading in Canada and the United States (METAALICUS)..... | 14 |
| Long-term quantification of net wet and dry mercury deposition at the remote Experimental Lakes Area, NW Ontario..... | 17 |
| Enclosure Studies of Brominated Flame Retardants | 19 |
| Fate and effects of a brominated flame retardant, decabromodiphenyl ether, in aquatic ecosystems | 19 |
| Environmental Impacts of Aquaculture | 24 |
| Impacts of Cage Aquaculture on Lake Ecosystems..... | 24 |
| Assessment of fitness effects of enhanced growth rate in rainbow trout in nature..... | 30 |

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.

1. LONG-TERM ECOLOGICAL RESEARCH (LTER) AND DATA MANAGEMENT

Project 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.

Principal Investigators: K. Beaty, A. Dupuis, D. Findlay (emeritus), D. Guss, S. Kasian, M. Lyng, K. Mills (emeritus), M. Paterson, K. Sandilands, M. Stainton.

All principal investigators are ELA/DFO staff.

Summary of the work carried out during 2009.: Long-term records of meteorology and hydrology of the Lake 239 basin were maintained. Meteorological variables (air temperature, precipitation, wind speed and direction, PAR (photosynthetically available radiation), 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, phytoplankton populations, zooplankton, and fish. There were some reductions in monitoring effort due to resource limitations. Some discipline specific monitoring continued in other lakes to maintain long-term records.

Measurements of physical limnological variables (light and temperature profiles, secchi depth) and samples for chemistry, phytoplankton and zooplankton analyses were taken every 2 weeks

Summary of ELA Research for 2009

through the open water season in all lakes and twice over winter (shortly after ice-on and before ice-off) in Lakes 239 and 373. Surface water temperature was measured continuously in all LTER lakes. Primary production monitoring was only done in Lake 373 and the ^{14}C method was replaced with continuous in-situ monitoring of algal metabolism (CO_2 and O_2). Epilithon communities were not monitored. Phytoplankton and zooplankton analyses included identification to species and biomass estimates. Phytoplankton were sampled and counted biweekly from Lake 239. In Lakes 373, 224 and 442 samples were taken biweekly, but composites were made to determine a monthly count. *Chaoborus* and *Mysis* in Lake 373 were sampled for comparisons to specific experimental lakes. With the exception of Lake 442, 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 (Lake 375).

Don McNicol (Canadian Wildlife Survey of EC) conducted another helicopter survey in the ELA region to study long-term water chemistry trends. In the early summer, Russ Weeber (also of CWS) conducted a food chain survey in the ELA region with assistance from DFO staff.

The ELA Database continues to be heavily used, both by internal and external researchers as a source of data from ELA. Over 500 inquiries were made internally. Three stand-alone versions of the database were distributed to external collaborators at Canadian universities and five to Environment Canada researchers. Data were provided to 16 external researchers who made formal written requests. 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 2008-9 data. A few new small data sets (e.g. snow depth, evaporation pan readings, etc.) were added as well as all data concerning epilithon research (M. Turner) at the ELA. The Database also obtained maps, provided by OMNR, which show the historical logging activities in ELA lake watersheds. Raw and processed chemical data (e.g. budgets etc.) from the ELARP experiment (from V. St. Louis, University of Alberta) was archived in the Database. M. Mackay (Environment Canada) provided meteorology data from the instrumented raft in Lake 239.

Major findings or conclusions: A numerical model is being developed to simulate the vertical distribution of heat and dissolved oxygen in Lake 375, a lake impacted by an experimental aquaculture operation. The research question to be addressed is whether the decrease in hypolimnetic oxygen concentration over the course of the experiment is related to factors associated with the aquaculture operation, or with factors associated with physical mixing of the lake. Long-term monitoring data from the meteorological station, Lake 375 and Lake 239 is being used to calibrate and validate the model.

Data collected from long-term and whole ecosystem experiments at the ELA are being used to provide critical parameter values for the development of various dynamic ecosystem models. The main project, to improve the design of ecosystem monitoring programs for Manitoba reservoirs, is being conducted in close association with Manitoba Hydro and the Province of Manitoba.

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, the Real Property camp manager, 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 41st year of continuous monitoring. Meteorological variables (air temperature, precipitation, wind speed and direction, bright sunshine and evaporation) were monitored daily again in 2009. 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 2009. The CAPMoN program (http://www.msc.ec.gc.ca/capmon/index_e.cfm), which monitors both atmospheric and precipitation chemistry at a network of sites across Canada, is funded and coordinated by Environment Canada. The ELA site, which has been operating since the 1980's, monitors ground-level ozone, SO₂ and HNO₃ in the atmosphere, Cl, SO₄, NO₃, Na, NH₄, Ca, K, Mg, pH, and mercury in precipitation. It has frequently been used as a baseline reference for sites in eastern Canada.

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

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 (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.

Publications and presentations:

Publications using LTER data:

Baulch, H.M., M.A. Turner, D.L. Findlay, R.D. Vinebrooke and W.F. Donahue. 2009. Benthic algal biomass – measurement and errors. *Can. J. Fish. Aquat. Sci.* Vol 66(11): 1989-2001.
Findlay, D.L. C.L. Podemski and S.E.M. Kasian. 2009. Aquaculture impacts on the algal and bacterial communities in a small boreal forest lake. *Can. J. Fish. Aquat. Sci.* 66(11): 1936-1948.

Helmus, M.R., W. Keller, M.J. Paterson, N.D. Yan, C.H. Cannon and J.A. Rusak. 2010. Communities contain closely related species during ecosystem disturbance. *Ecology Letters* 13: 162-174.

Hesslein, R.H., M.A. Turner, D. Guss and M. Lyng. 2009. Separating the effects on water chemistry of climate variation and experimental manipulation in the long-term acidification and recovery of lakes. *Can. J. Fish. Aquat. Sci.* 66(11): 1864-1874.

Summary of ELA Research for 2009

Parker, B.R., D.W. Schindler, K.G. Beaty, M.P. Stainton, and S.E.M. Kasian. 2009. Long-term changes in climate, streamflow, and nutrient budgets for first-order catchments at the Experimental Lakes Area (Ontario, Canada). *Can. J. Fish. Aquat. Sci.* 66(11): 1848-1863.

Paterson, M.J., C.L. Podemski, W. Findlay, D.L. Findlay, A. Salki. Zooplankton responses to changes in phytoplankton, hypolimnetic oxygen, and predation by *Mysis* and fish in a whole-lake experiment on the effects of cage aquaculture. Submitted to *Can. J. Fish. Aquat. Sci.*

Plumb, J.M. and P.J. Blanchfield. 2009. Performance of temperature and dissolved oxygen criteria to predict habitat use by lake trout (*Salvelinus namaycush*). *Can. J. Fish. Aquat. Sci.* 66(11): 2011-2023.

Shurin, J., Winder, M., Adrian, R., Keller, W., Matthews, B., Paterson, A., Paterson, M., Pinel-Alloul, B., Rusak, J., Yan, N. Environmental stability and lake zooplankton diversity- contrasting effects of chemical and thermal variability. *Ecology Letters*: in press.

Turner, M.A., D.L. Findlay, H.M. Baulch, L.M. Armstrong, S.E. M. Kasian, D.K. McNicol and R.D. Vinebrooke. 2009. Benthic algal communities: recovery from experimental acidification. *Can. J. Fish. Aquat. Sci.* 66(11): 1875-1891.

Winder, M., J.E. Cloern. Does the terrestrial phenology concept apply in water? Submitted to *Phil. Trans. Royal Soc*

Zhang, J., J. Hudson, R. Neal, T. Clair, M. A. Turner, D. Jeffries, P. Dillon, L. Molot, K. Somers, and R. Hesslein. 2010. Long-term patterns of dissolved organic carbon in lakes across eastern Canada: evidence of a pronounced climate effect. *Limnol. Oceanog.* 55(1) 30-42.

Presentations using LTER data:

Cummings, B.F., M.T. Moos, K.R. Laird. 2010. Extending the record of reference conditions at lake 239: A paleolimnological perspective. Canadian Society of Limnology Meetings, Winnipeg. Jan. 2010.

Findlay, D. & S.E. Kasian. The relationship between climatic variables and phytoplankton community structure in a small boreal shield lake. Canadian Society of Limnology Meetings, Winnipeg. Jan. 2010.

Prowse TD, de Rham L, Dibike Y, Harder S, Callaghan T, Saloranta S. 2009. A Lake Monitoring and Modelling Network for Climate Change Studies. Poster Presentation at ArcticNet 2009 Annual Scientific Meeting. Dec 8-11, 2009, Victoria, BC.

Shurin, J.B. M. Winder, R. Adrian, W. Keller, B. Matthews, A.M. Paterson, M.J. Paterson, B. Pinel-Alloul, J.A. Rusak, N.D. Yan. 2010. Environmental stability and lake plankton diversity – contrasting effects of chemical and thermal variability. Canadian Society of Limnology Meetings, Winnipeg. Jan. 2010.

Plans for 2010: The intention is to continue the LTER monitoring, within resource limitations, so that as many long-term records of natural variation in boreal shield lakes as possible can be maintained. Further methodology changes or newer instrumentation for data collection are expected in order to gain efficiencies. Inter-calibration studies and documentation will be required.

Data will continue to be loaded into the ELA Database as it becomes available.

2. LAKE 239 SURFACE ENERGY BALANCE STUDY

Project goals: 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 in July 2007 and has been in continuous operation ever since.

Principle investigators:

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

Summary of work carried out in 2009: While the ELA database contains more than 30 years of meteorological, hydrological, and hydrochemical data for Lake 239, 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. 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 findings and conclusions: Given our successful simulation of the open water season (reported on last year) for L239, this year's efforts will focus largely on an analysis of the ice – cover season.

Plans for 2010: We fully anticipate that our raft will continue to operate at ELA for the next 5 years at least. A manuscript intended for *Limnology and Oceanography* examining the thermal response of dissolved organic carbon variability in a small boreal shield lake is expected to be submitted this year. In addition, we intend to enhance our model with an ice component, enabling continuous multi – year simulation.

ECOSYSTEM RECOVERY

3. Acidification Recovery Study

Project goals: Despite substantial reductions, acid deposition continues to exceed critical loads across large portions of North America and large numbers of lakes in southeastern Canada and the northeastern United States have not yet recovered from anthropogenic acidification. Unexpected delays in recovery of many lakes appear to have been caused by several factors, including:

- Nitrogen oxide emissions have not been reduced as much as sulphur emissions;
- Some of the buffering components in precipitation have declined;
- Acidifying substances are still being released from previously acidified watersheds;
- Some of the buffering potential in the watersheds has been exhausted by prior acidification;
- Acidification is often only one of a suite of stressors, which includes climate change and related factors such as calcium decline;
- Expectations for the recovery of aquatic ecosystems have often been incorrect and overly optimistic.

To better understand the natural recovery potential of boreal lakes, ELA researchers and colleagues have been studying several ecosystems that had previously been experimentally acidified. Beginning in 1974, several lakes (223, 114, and 302) and a wetland (239 Fen) were acidified using various experimental designs. This program provided scientific evidence that was instrumental in the development of the 1991 Canada-US Clean Air Act.

The general goal of our acidification recovery studies has been to evaluate the ability of boreal forest lakes to recover from acidification without deliberate intervention in the recovery process. To achieve our general goal we have been studying the ability of two experimental lakes to recover from acidification in terms of their physical, chemical and biological properties; although the principal experimental system was Lake 302S, we have continued limited study of Lake 223. Following years of experimental acidification, we relaxed their target pH, and eventually allowed pH to be unregulated. (Note that in 1999 we added lake whitefish to Lake 302S to facilitate ecosystem recovery.) In addition to better defining the nature of recovery of boreal forest lakes from acidification, the policy implications of our studies include indirect testing of the suitability of current acidifying emissions standards.

The goals of our study support the Federal, Provincial and Territorial governments' commitment to the recent Canada-Wide Acid Rain Strategy for Post-2000. This research supports DFO's 1986 Policy for the Management of Fish Habitat by enhancing Canadians' ability to mitigate acid-related threats to the productive capacity of fish habitats. Our research will also contribute to the upcoming Canadian Acid Rain Assessment.

Principal investigators:

Fisheries and Oceans Canada

Ken Beaty, Alain Dupuis, David Findlay, Dr. Raymond Hesslein, Susan Kasian, Stephen Page, Dr. Michael Paterson, Ken Sandilands, Dr. Michael Turner

Environment Canada

Dr. Dean Jefferies, Dr. Don McNicol, Russ Weeber.

University of Manitoba

Lynn Frazer

Summary of work carried out in 2009: In 2009/10, Dr. Don McNicol and Russ Weeber of Environment Canada (EC) surveyed lakes in the ELA area for water chemistry, food web structure, and birds as part of a long term study of acidification recovery in lakes across Canada. A summary report of the lake survey is currently being prepared. Lakes 302 and 223 were not monitored in 2009. Lynn Frazer completed her M.Sc. thesis wherein she reconstructed the response of littoral and pelagic cladoceran assemblages to acidification of lakes 302N and 223.

Publications

Baulch, H. M., M. A. Turner, D. L. Findlay, R. Vinebrooke, W. Donahue, and L. Hendzel. 2009. Is chlorophyll appropriate as a measure of biomass in benthic algal studies? *Can. J. Fish. Aquat. Sci.* 66 (11): 1989-2001.

Frazer, L.V. 2009. Paleolimnological reconstruction of cladoceran community reassembly following experimental manipulation of two boreal shield lakes. M.Sc. thesis. University of Manitoba, Winnipeg, MB.

Hesslein, R.H., M.A. Turner, D. Guss and M. Lyng. 2009. Separating the effects on water chemistry of climate variation and experimental manipulation in the long-term acidification and recovery of lakes. *Can. J. Fish. Aquat. Sci.* Vol 66(11): 1864-1874.

Phillips, I. D., R. D. Vinebrooke, and M. A. Turner. 2009. Experimental reintroduction of the crayfish species *Orconectes virilis* into formerly acidified Lake 302S (Experimental Lakes Area, Canada). *Can. J. Fish. Aquat. Sci.* 66 (11): 1892-1902.

Turner, M.A., D.L. Findlay, H.M. Baulch, L.M. Armstrong, S.E.M. Kasian, D.K. McNicol, and R.D. Vinebrooke. 2009. Benthic algal communities: recovery from experimental acidification. *Can. J. Fish. Aquat. Sci.* 66 (11): 1875-1891.

Vinebrooke, R.D., M. A. Turner, D. L. Findlay, and M. J. Paterson. 2009. Removal of treatment effect negates biodiversity-ecosystem function relationships: Evidence from a 20-year lake experiment. *Can. J. Fish. Aquat. Sci.* 66 (11): 1903-1909.

Plans for 2010: Monitoring of the recovery of L302S will continue in 2010.

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.

4. FERTILIZATION OF LAKE 227

Project goals: 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 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.

Principal investigators:

Michael Paterson, David Findlay, Michael Stainton (DFO)

Lewis Molot (York University), Derek Muir (Environment Canada), Sherry Schiff (Waterloo), David Schindler (University of Alberta), Susan Watson (Environment Canada)

Summary of work carried out in 2009: Lake 227 was fertilized with phosphorus for the 41st consecutive year in 2009. 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 2009, 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 2009.

Publications:

Clasen, J.L. and Suttle, C.A. 2009. Identification of Freshwater Phycodnaviridae and Their Potential Phytoplankton Hosts, Using DNA *pol* Sequence Fragments and a Genetic-Distance Analysis. *Appl. Environ. Microbiol.* **75**: 991-997.

Plans for 2010: 2010 marks the first year of a 3-year project being on L227 led by Drs. Lewis Molot (York University), David Schindler (University of Alberta), Sherry Schiff (Waterloo), Derek Muir (EC), Susan Watson (EC), and others. The proposal for this study was previously circulated to ELA Management Board members and received approval in December 2009. The project seeks to build on the long history of research in Lake 227 by undertaking a whole-lake addition of NaSO₄. The applicants hypothesize that varying sulfate (SO₄) levels in eutrophic lakes across Canada account for much of the chemical and biological variation in lake responses. They predict that SO₄ regulates internal P and iron (Fe) loading from sediments and that variations in Fe and P affect the formation of nuisance cyanobacterial blooms. The experiment will also examine how variations in SO₄ regulate methylmercury (MeHg) formation rates. Additions of NaCl to enclosures will explore the potential impact of the sodium (Na)

additions made in concert with SO_4 and will provide information on the potential impacts of road salt in Canadian lakes.

In 2010, the proponents will examine the effects of NaSO_4 and NaCl in a series of enclosure experiments in Lake 227. Results from these experiments will be used to set a target SO_4 concentration in a whole-lake experiment to begin in 2011. At present, it is expected that SO_4 will be added once only in 2011. Additions of P to L227 will continue as in past years. Monitoring of mercury in small fish in L305, which is downstream from L227, will also begin in 2010.

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.

5. EXPERIMENTAL LAKES AREA RESERVOIR PROJECT (ELARP)

Project Goals: 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.

Principal Investigators (2009):

Michael Paterson, Ken Beaty, Alain Dupuis, Stephen Page (DFO)

Vincent St. Louis (University of Alberta)

Summary of work carried out in 2009: In June, 1993, following two years of background studies, the outflow of ELA Lake 979 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. Each year since 1993, Lake 979 has been repeatedly drawn down in late fall and reflooded in May.

Lake 979 was not flooded in 2009 and the removal of the dam structure was initiated. Monthly sampling of zooplankton, phytoplankton, nutrients, and mercury (Hg) was undertaken.

Major findings or conclusions: Preliminary analyses suggest that nutrient and methyl mercury levels are already returning to near background levels in L979. Results from L979 are being used in the development of models to predict the impacts of reservoir construction and management in northern Manitoba by Stephen Page.

Publications or presentations:

Publications:

Demarty, M., Bastien, J., Tremblay, A., Hesslein, R.H., and Gill, R. 2009. Greenhouse Gas Emissions from Boreal Reservoirs in Manitoba and Quebec, Canada, Measured with Automated Systems. *Environmental Science & Technology* **43**: 8908-8915.

Hall, B.D., Cherewyk, K.A., Paterson, M.J., and Bodaly, R.A. 2009. Changes in methyl mercury concentrations in zooplankton from four experimental reservoirs with differing amounts of carbon in the flooded catchments. *Canadian Journal of Fisheries and Aquatic Sciences* **66**: 1910-1919.

Presentations:

Page, S.J. R.H. Hesslein, M. Paterson, G. Swanson, D. MacDonald. 2010. Modeling ELA reservoir studies and the relevance to Manitoba reservoirs. Canadian Society of Limnology Annual meetings, Winnipeg MB Jan 2010.

Paterson, M.J. and others. 2010. Effects of experimental changes in water level at the Experimental Lakes Area (ELA), Canada. Manitoba-Israel Water experts Symposium, Israel. Jan 2010.

Rudd, J.W.M., V. St.Louis, C.A. Kelly. 2010. Long term emissions of greenhouse gases from peatland reservoirs has likely been underestimated. Canadian Society of Limnology Annual meetings, Winnipeg MB Jan 2010.

Plans for 2010: Removal of the dam structure and restoration of the outflow area of L979 will continue in 2010. Monthly sampling of nutrients, water chemistry, and zooplankton will also be undertaken.

IMPACTS OF STREAM DIVERSION

6. THE IMPACT OF DRY CONDITIONS ON BOREAL LAKE ECOLOGY AND HYDROLOGY

Project Goals: The purpose of the study is to quantify the impacts of drier conditions on the evaporative and thermal regimes and ecology of small boreal lakes.

Principal Investigators:

Beaty, Ken DFO
Blanchfield, Paul DFO
Spence, Christopher EC

Research team: Cruz-Font, Liset & Shuter, Brian (U. of Toronto), Enders, Eva (DFO), Hesslein, Ray & Page, Stephen (DFO), Mackay, Murray (EC), Mills, Ken & Chalanchuk, Sandy (DFO), Paterson, Michael & Dupuis, Alain (DFO), Tate, Lori (DFO), Turner, Michael (DFO)

Funding sources or support organizations:

Environment Canada and Fisheries and Oceans Canada

Summary of work carried out in 2009: The proposed study involves the diversion of all upstream water entering an ELA 4th order lake (Lake 626) to simulate both a climate-warming scenario (loss of connection to upstream inputs) and a physical manipulation (water withdrawal). The proposed study will occur in two phases. The first phase will compare and contrast the evaporative regime, limnology and fish ecology of the experimental (Lake 626) and reference (Lake 373) lakes for three open water seasons (2008-2010) to establish differences between the lakes. The second phase is proposed to last for three years (2011-2013) and involves direct manipulation of the upstream inputs to Lake 626. In year three of the study, hydraulic structures will be added to Lake 627, immediately upstream of Lake 626, to permit the diversion of inflow from Lake 627 (which also receives inflow from Lakes 429 and 628). The water will be diverted around Lake 626 and will subsequently flow into Lake 625 (the lake downstream of Lake 626). These structures will allow the research team to manipulate the upstream inputs to Lake 626 and simulate dry conditions for the open water season of years four to six.

In 2009, the thermal regime of each lake was measured with an Onset TidBit thermistor string installed early in the open water season. The evaporative regime was estimated using meteorological sensors installed at three levels above the lake on a floating platform, deployed at the same time as the thermistor string. In 2009, water chemistry and zooplankton community composition of the study and reference lakes and watersheds was sampled bi-weekly. Further, samples of major taxonomic groups were taken at the end of summer for stable isotope analyses to determine trophic status and pathways of energy transfer. Spring and fall trap-netting occurred, to determine the abundance and growth of small-bodied fish (minnows) and lake trout. We implanted acoustic telemetry transmitters into lake trout to determine the spatial and pelagic distribution of this species. In addition, collaborators from the University of Toronto implanted lake trout with sensors that measure tail-beat frequency to determine activity levels of fish in the study and reference lakes. Volume and chemistry of runoff from the local watersheds of each lake was sampled.

Major findings or conclusions: Reference baseline evaporation and thermal data were collected from Lake 626 and Lake 373 in 2009, permitting direct comparisons. Bi-weekly sampling for water chemistry and zooplankton from 2008 continued through 2009 from both lakes. A late summer collection of all trophic levels were taken for stable isotope analyses and are now being processed. Hydrological reconnaissance surveys and mapping of the watershed occurred as well as construction of an outflow weir and recording lake level station on Lake 626. New topographic mapping was completed in April 2009. Wells were installed in a wetland tributary to Lake 626 to establish if it contributed runoff to Lake 626. In 2009 we acquired funding for the first two phases of diversion channel construction, which involved the installation of a new culvert where the diversion channel meets Pine Road (complete) and clearing and grubbing of the diversion channel from Lake 627 to the Pine Road (to complete by 31 March 2010).

Publications and presentations:

Blanchfield, P.J., Tate, L.S., Plumb, J.M., Acolas, M.-L., and Beaty, K.G. 2009. Seasonal habitat selection by lake trout (*Salvelinus namaycush*) in a small Canadian shield lake: constraints imposed by winter conditions. *Aquatic Ecology* **43**: 777-787.

Cruz-Font, L., B.J. Shuter, P.J. Blanchfield, L.S.Tate. 2010. Monitoring the depth distribution of lake trout in two lakes with different food webs. Canadian Society of Limnology Meetings, Winnipeg. Jan. 2010.

Plans for 2010: Both lakes are fully instrumented and a full year of baseline data collection was completed in 2009. Plans are to conduct another year of background study in 2010 and acquire funding for the final phase of diversion channel construction. A group meeting is being planned for early 2010.

MERCURY LOADING AND BIOACCUMULATION

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

Project Goals: 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. 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 ended in 2007. The experiment is now examining recovery from elevated mercury deposition.

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.

Principal investigators:

Michael Paterson, P. Blanchfield, C. Podemski, K. Sandilands, Lee Hrenchuk (DFO)

Reed Harris (Reed Harris Consulting, Toronto)

M. Amyot, Université de Montréal, Montréal, QC

C. Babiarz, U. of Wisconsin, Madison, WI

B. Branfireun, C. Oswald, U. of Toronto, Toronto, ON

C. Gilmour, Smithsonian Institute, MD

H. Hintelmann, Trent University, Peterborough, ON

C. Kelly, R & K Research Inc., Saltspring Is., BC

D. Krabbenhoft, USGS, Madison WI

Summary of ELA Research for 2009

S. Lindberg, Oakridge National Laboratory, Oakridge, TN

J. Rudd, R & K Research Inc., Saltspring Is., BC

V. St.Louis, J. Graydon, U. of Alberta, Edmonton, AB

M. Tate, USGS, Madison WI

Summary of work carried out in 2009: Lake 658 is a small (8.4 ha), low productivity, headwater lake on the Canadian Shield. Mercury additions with different isotopic signatures were applied to the lake, upland and wetland at a target rate of $22 \mu\text{g m}^{-2} \text{yr}^{-1}$ (^{202}Hg , ^{200}Hg and ^{198}Hg) each year from 2001, with additions to the terrestrial system ending in 2006 and additions directly to the lake surface ending in 2007. 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. Mercury was added to the Lake 658 ecosystem. The study is now following recovery of the Lake 658 ecosystem.

ELA is a low deposition area for mercury, with approximately $2\text{-}7 \mu\text{g m}^{-2} \text{yr}^{-1}$ of wet mercury deposition (2000-2006). The low mercury deposition rate at ELA means that adding the equivalent of about $1/6^{\text{th}}$ of a teaspoon (approximately 12.5 g) of mercury per year increased wet Hg deposition to the 52 ha Lake 658 ecosystem (lake and watershed) by approximately 5 fold. This addition resulted 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. 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 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. As noted, mercury is no longer being added. During 2000, public information meetings were conducted in Dryden and Kenora to discuss the project with the public. 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.

Major findings and conclusions (2009): Following cessation of loading, concentrations of inorganic ^{202}Hg dramatically decreased in the water column of L658 beginning in 2008. The resulting concentrations of total mercury in Lake 658 surface waters are now within ranges observed in natural lakes. Lake spike continued to be detected as methylmercury in surface and hypolimnetic waters in 2008. Samples from 2009 and are still being analysed.

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 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. In 2008 and 2009, mercury levels in fish declined slightly but remained within the range of values seen in 2006-7.

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. 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.

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.

Publications and presentations:

Publications:

Clarisse, O., Foucher, D., and Hintelmann, H. 2009. Methylmercury speciation in the dissolved phase of a stratified lake using the diffusive gradient in thin film technique. *Environmental Pollution* **157**: 987-993.

Lehnherr, I. and Louis, V.L. 2009. Importance of Ultraviolet Radiation in the Photodemethylation of Methylmercury in Freshwater Ecosystems. *Environmental Science & Technology* **43**: 5692-5698.

Presentations:

Blanchfield, P.J., Paterson, M.J., Tate, L.S., Orihel, D.M., Van Wallegghem, J.L.A., Rudd, J.W.M., Harris, R., and Hintelman, H. The response of fish mercury levels to changes in inorganic mercury loading. 9th International Conference on Mercury as a Global Pollutant, 7-12th June, 2009, Guiyang, China. (Oral)

Blanchfield, P.J., M.J. Paterson, C. Podemski, J. Graydon, H. Hintelmann, R. Harris. 2010. How will changes in atmospheric mercury emissions affect bioaccumulation of methyl mercury in aquatic food webs? Results from the METAALICUS project. Canadian Society of Limnology Meetings, Winnipeg. Jan. 2010.

Hrenchuk, L.E., P.J. Blanchfield, M.J. Paterson, and H.H. Hintelmann. Modelling the uptake of newly deposited mercury by yellow perch (*Perca flavescens*). Canadian Society of Limnology Meetings, Winnipeg. Jan. 2010.

Hrenchuk, L.E., Blanchfield, P.J., Hintelman, H., and Paterson, M.J. Uptake dynamics of newly-deposited mercury in a boreal aquatic food web. 9th International Conference on Mercury as a Global Pollutant, 7-12th June, 2009, Guiyang, China.

Plans for 2010: There will be no mercury additions to the lake in 2010 and the ecosystem is in the recovery stage. Detailed monitoring of site conditions, mercury concentrations, and the fate and transport of mercury will be continued.

Lake Restoration:

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 downstream Winnange lake will also be monitored every second year. In 2005, 2006, and 2007, trace amounts of lake isotope were identified in a few yellow perch collected close to the Lake 658 outflow. Concentrations were highest in 2007, but still accounted for <6%, on average, of the total amount of Hg detected in perch.

In 2008 and 2009, Environment Canada sampled Winnange Lake as part of their contaminants monitoring program. We were able to sub-sample these fish for analyses of stable mercury isotopes, in addition to our annual collection of yellow perch. Fish were categorised based on whether mercury isotope levels were above detection (>1% of ambient [Hg]), above quantification (between 0.5-1% of ambient [Hg]), or below detection limits (<0.5% of ambient [Hg]). Of the 56 fish sampled in 2008, representing four species, none contained detectable levels of mercury isotope (Table 1). Two fish had levels of isotope that were above quantification and this was from the isotope added directly to the surface of Lake 658. Average concentrations of isotopes were all below detectable or quantifiable levels.

8. Long-term quantification of net wet and dry mercury deposition at the remote Experimental Lakes Area, NW Ontario.

Project Goals: The biogeochemical cycling of mercury at the remote and relatively pristine Experimental Lakes Area (ELA) has been followed since 1990. We have been quantifying, in the open, *net* wet deposition of total mercury (THg; all forms of Hg in a sample) and methylmercury (MeHg; a toxic form of Hg that bioaccumulates through food webs) at the ELA since 1992. This has now become one of the longest records of *net* wet THg and MeHg loadings at a given site globally. In addition to wet deposition, there is also dry deposition of Hg to watersheds. Although dry deposition loadings can be quite significant, they are very difficult to quantify. We have been quantifying dry deposition of Hg in two ways at the ELA. First, since 1998, we have been using the difference between *net* loadings of THg and MeHg in the open and the *net* loadings of THg and MeHg under forest canopies (throughfall) to quantify the dry deposition of Hg to canopy foliage. Included in these measurements is the quantification of litterfall deposition of Hg to the forest floor because studies suggest that a large portion of the Hg in foliage results from the uptake a gaseous Hg from the atmosphere. Our historical studies have shown that forest canopies can add up to 5 times more THg and MeHg to watersheds than precipitation in the open. Second, since 2005, we have been quantifying atmospheric concentrations of gaseous elemental mercury (GEM), reactive gaseous mercury (RGM) and particulate Hg (pHg) using automated Tekran speciation units, which allow us to also model dry deposition of Hg to the region. We have found that RGM and pHg concentrations at the ELA are on average very low. Concentrations of GEM are on average ~1.4-1.5 ng/m³ at the ELA, but can fluctuate quite dramatically daily, seasonally and during periods when forest fires are burning nearby. There are currently no equivalent datasets that have historically quantified wet and dry deposition of THg and MeHg while also monitoring atmospheric concentrations of GEM, RGM and pHg. Our work at the ELA in 2009 continued building this important and unique long-term dataset.

Principal Investigators:

Dr. Vincent St.Louis (professor, University of Alberta)

Dr. Jennifer Graydon (post doctoral fellow, University of Alberta)

Summary of work carried out in 2009:

The majority of our atmospheric Hg research is conducted at the ELA meteorological site (Atmospheric Environment Service designation: Rawson Lake Station) ~0.5 km from the ELA base station. At this site, in 2008 we deployed automated collectors to continue building our long term record of *net* THg and MeHg wet deposition in the open and under forest canopies. Our Tekran air speciation units are also deployed at the meteorological site. We also continued to monitor the Hg isotopes applied to the METAALICUS watershed as they make their way through the vegetation pools (i.e., forest canopies and ground vegetation) since the last spike application in 2006.

In early May 2008, we erected a new building at the ELA Environment Canada CAPMoN Meteorological Station to house the Tekran 2537/1130/1135 system. The instruments were turned on in mid-May, following EC protocols and practices, to continue the long-term collection of concentration data for gaseous elemental mercury (GEM), reactive gas phase mercury (RGM) and particle associated mercury (PHg) that began back in 2005. In 2009, a summer assistant (Justin Shead) was hired again by the METAALICUS CARA program between May-October to check the site daily for logistical issues and to ensure that the instrumentation was functioning properly. These included checks on: 1) the performance of the zero air source, 2) the level of carrier gas, 3) the functioning of the 1130/1135 system, 4) a steady power supply to the system, 5) the computer to ensure that data was downloading correctly, and 5) the performance of the standard addition unit. The principle investigators (Vincent St.Louis and Jennifer Graydon) also checked the functionality of the instrumentation daily from the University of Alberta through a remote internet connection to the Tekran 2537/1130/1135 system computer. Data were regularly downloaded both onto an external hard drive and onto computers at the University of Alberta. Every two weeks, the soda lime trap at the inlet to the 2537A was changed, whereas monthly, we changed out all the RGM and PHg glassware and filters located in the 1130 and 1135 systems, and the sample filters at the back of the 2537A inside the building. Quarterly maintenance calibrations were conducted on the 2537A to verify the permeation rate of the instrument. Overall, we ensured that the instrumentation was in good working condition and appropriate repairs are conducted. The data files have input into the Environment Canada RDMQ program for the final QA/QC of the results.

In May 2008, six automated wet deposition collectors were removed from the METAALICUS watershed where they had resided since 2001. The collectors were cleaned and re-deployed at the ELA Environment Canada CAPMoN Meteorological Station to quantify open and throughfall fluxes of THg, MeHg and other chemical parameters such as pH and SO_4^{2-} . Two collectors were deployed in the open, whereas two were deployed under jack pine canopies and two under birch canopies to quantify throughfall fluxes. Standard type-B rain gauges were deployed next to each automated collector. We also deployed two litterfall collectors next to each automated collector under the forest to quantify litterfall fluxes of Hg. This sampling protocol allowed for direct measurements of wet and dry deposition on a routine basis at the ELA using the "direct method" (estimate of dry deposition = throughfall + litterfall – open loadings). In 2009, samples were collected from the automated collectors during the open-waters season (May-October) once there was enough deposition volume for THg and MeHg analyses. There were ~15 such collection events during the summer of 2009. If it did not rain for a period of two weeks, collection containers in each automated collector were replaced with clean ones to prevent sample contamination. All samples collected for THg have already been analysed, as have all the general chemistry samples. MeHg samples will be analysed very soon. The automated collectors were shut down in late October. To determine a net load of THg, MeHg

and general chemistry during winter, integrated snowpack core samples will be collected at maximum snowdepth in late February 2010. Once we have all the concentration data, we will calculate loadings at the various sites. All THg and MeHg samples are being analysed in the internationally calibrated University of Alberta Low Level Mercury Analytical Laboratory, whereas all chemistry samples are being analysed at the Freshwater Institute Department of Fisheries and Oceans) water chemistry analytical laboratory.

Major findings or conclusions (2009): Samples and data are currently being analyzed.

Plans for 2010: The tekran air speciation units will continue to run at the met site as described above through 2010. The automated precipitation collectors will be uncovered and re-deployed in May 2010 and will be sampled through the end of October 2010.

Publications and presentations:

Graydon, J. A., St. Louis, V. L., Hintelmann, H., Lindberg, S., Sandilands, K. A., Rudd, J. W. M., Kelly, C. A., Hall, B. D. and Mowat, L. D. 2008. Long-term wet and dry deposition of total and methyl mercury in the remote boreal ecoregion of Canada. *Environmental Science & Technology*, 42(22), 8345-8351.

Graydon, J. A., St. Louis, V. L., Hintelmann, H., Lindberg, S. E., Sandilands, K. A., Rudd, J. W. M., Kelly, C. A., Tate, M. T., Krabbenhoft, D. P. and Lehnher, I. 2009. Investigation of uptake and retention of atmospheric Hg(II) by boreal forest plants using stable Hg isotopes. *Environmental Science & Technology*, 43(13), 4960-4966.

ENCLOSURE STUDIES OF BROMINATED FLAME RETARDANTS

9. Fate and effects of the brominated flame retardant “decabromodiphenyl ether” in a boreal lake mesocosms.

Project goals : Since the 1960s, polybrominated diphenyl ethers (PBDEs) have been used as flame retardants in commercial and household products, including electronics, building materials, upholstery fabric, and foam furniture. Large quantities of PBDEs are synthesized each year; for example, the global production of PBDEs in 2001 was estimated to be over 67, 000 metric tons. PBDEs are now ubiquitously found in air, water, fish, birds, marine mammals, and people.

PBDEs are a family of chemicals that have a diphenyl ether structure with 1 to 10 bromine (Br) atoms. Congeners of PBDEs differ in the number and position of Br atoms. Congeners with 1, 2, and 3 Br atoms are referred to as “mono-BDE”, “di-BDE”, “tri-BDE”, etc. The congener with 10 Br atoms, “deca-BDE” is called BDE-209 (Figure 1). Three commercial products of PBDEs have been synthesized: PentaBDE (mostly tetra- to hexa-BDEs), OctaBDE (mostly hexa- to nona-BDEs), and DecaBDE (mostly deca-BDE).

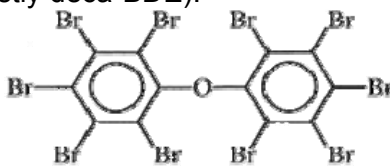


Figure 1. Structure of BDE-209

Studies have established that PBDEs are endocrine disruptors , developmental neurotoxins, and possible carcinogens. All PBDE products have been shown to disrupt the thyroid hormone

system, as a consequence of their structural similarity to the thyroid hormone thyroxine (T₄). In general, lower-brominated PBDE congeners are more readily absorbed and more toxic. Within the last decade, the use of PentaBDE and OctaBDE was banned in several countries (including Canada, USA, and members of the European Union) because of concerns about the toxicity of lower-brominated congeners. The PentaBDE and OctaBDE products have recently been targeted for global elimination under the Stockholm Convention (May 2009).

As a result of the bans on lower-brominated PBDEs, DecaBDE became the most widely used PBDE product. However, the use of DecaBDE has since been banned in Sweden, the European Union, and several US states. In addition, after negotiations between the US Environmental Protection Agency and three major chemical companies, DecaBDE will largely be phased out of the US marketplace by 2013. The continued use of DecaBDE in Canada is controversial because of its potential to break down into more toxic metabolites. Whereas degradation of DecaBDE into lower-brominated congeners has been clearly demonstrated under laboratory conditions, the extent to which this process occurs in the natural environment is largely unknown. In our 3-year field study (2007-2009), we examined the fate and effects of DecaBDE in large, in-lake mesocosms at the Experimental Lakes Area. Our study addresses three main questions:

Question 1. Debromination of DecaBDE in the Aquatic Environment

One of the greatest uncertainties regarding the fate of DecaBDE is the extent to which this chemical is degraded in the environment. Half-lives of DecaBDE estimated from laboratory studies vary by orders of magnitude. Our study determines, for the first time, debromination rates of DecaBDE under natural field conditions. This information is critically needed for risk assessments of DecaBDE.

Question 2. Bioaccumulation of DecaBDE and its Degradation Products by Aquatic Biota

PBDE concentrations have been widely measured in fishes, birds, and marine mammals. Unfortunately, levels of PBDEs in abiotic media have only rarely been reported in conjunction with those in biota, and therefore, little information is available on the bioaccumulation of PBDEs. In our experiments, we are examining the bioaccumulation of DecaBDE and its breakdown products in a typical littoral food web, including seston, periphyton, zooplankton, benthic invertebrates, and a common forage fish species.

Question 3. Toxicity of DecaBDE and its Degradation Products to Freshwater Fish

Laboratory-based experiments suggest that PBDEs are potentially toxic to fish. Various studies have shown that PBDEs significantly inhibit EROD activity in the fish liver, lower plasma levels of thyroxine, reduce sperm counts and body condition, and cause behavioral changes, such as activity levels, fright response, and predation rate, in larval killifish. Our study evaluates the toxicity of DecaBDE, and its potential breakdown products, on an important forage and game fish species, the yellow perch (*Perca flavescens*).

Listing of major participants and their affiliations

| | | |
|-------------------------------|--------------------------------------|--|
| Derek Muir | Research Scientist, Section Chief | Aquatic Ecosystem Protection Research Division Environment Canada Burlington, Ontario |
| Project Collaborators: | | |
| Bradley Park | Biologist | Freshwater Institute, Fisheries & Oceans |

Summary of ELA Research for 2009

| | | |
|------------------|-----------------------|---|
| | | Canada Winnipeg, Manitoba |
| Colin Darling | Chemical Technologist | Aquatic Ecosystem Protection Research Division Environment Canada Burlington, Ontario |
| Alain Dupuis | Aquatic Biologist | Freshwater Institute, Fisheries & Oceans Canada Winnipeg, Manitoba |
| Bernard LeBlanc | Research Technician | Freshwater Institute, Fisheries & Oceans Canada Winnipeg, Manitoba |
| Diane Orihel | PhD Student | Department of Biological Sciences University of Alberta Edmonton, Alberta |
| Vince Palace | Research Scientist | Freshwater Institute, Fisheries & Oceans Canada Winnipeg, Manitoba |
| Michael Paterson | Research Scientist | Freshwater Institute, Fisheries & Oceans Canada Winnipeg, Manitoba |
| Gregg Tomy | Research Scientist | Freshwater Institute, Fisheries & Oceans Canada Winnipeg, Manitoba |

Summary of work carried out in 2009:

Experiment A: This experiment began in Sep 2007, when four 10-m diameter mesocosms at the south end of Lake 240 were treated with different doses of a DecaBDE technical product (DE83R from Great Lakes Chemical Corp.; “control”: 0 g, “low”: 0.023 g, “medium”: 0.21 g, and “high”: 1.9 g). Because of ice damage in spring 2008, the mesocosms were removed, but an underwater fence was erected around the site of “high” mesocosm. We continued to sample the sediments at this “high” site twice per year (May 15 and Oct 7, 2008; Jun 1 and Oct 14, 2009).

Experiment B: In June 2008, the four 10-m diameter mesocosms (originally from Experiment A) were installed in the northwest corner of Lake 240. On Jun 18, 2008, we added different doses of DecaBDE to the mesocosms (“control”: 0 g, “low”: 0.039 g, “medium”: 0.28 g, and “high”: 2.3 g). Wall strips were installed for periphyton colonization, and age 1+ yellow perch from Lake 240 were stocked in each mesocosm (30 fish/mesocosm). We sampled water, suspended particles, sediments, periphyton, zooplankton, and fish from the mesocosms during the 2008 open water season. The mesocosms were again shifted by ice during the winter, but sediment samples were collected from the undisturbed areas of the mesocosms on May 27, 2009.

Experiment C: Because the mesocosms from Experiment B had shifted during the winter, they were moved back to their original positions in late May 2009. On Jun 11, 2009, some of the mesocosms were re-treated with DecaBDE; the “low” mesocosm was spiked with a “high” dose (2.3 g)(because sediment BDE-209 concentrations from this mesocosm were not significantly different from those in the control mesocosm), and the “medium” mesocosm was spiked with the same “medium” dose (0.25 g). The “control” and the “high” mesocosms were not re-treated with DecaBDE. The mesocosms were re-stocked with age 1+ yellow perch (30 fish/mesocosm) on

June 17, 2009. Samples of water chemistry, zooplankton, and periphyton were collected in mid-Jul, early Sep, and mid-Oct. Water and sediment samples were collected during the Jul and Oct sampling events. At the final sampling in Oct, samples of benthic invertebrates were collected using light traps and an Ekman dredge, and we attempted to remove all fish from the mesocosms using minnow traps, gill nets, and a seine net. Yellow perch were also collected from Lake 240 at the time of stocking (Jun) and final sampling (Oct).

Major findings and conclusions (2009):

Question 1

Concentrations of BDE-209 in surface sediments from the original “high” site (Experiment A) typically exceeded 1000 ng/g dw, which is 2-3 orders of magnitude greater than those at the control site, but is within the range of BDE-209 concentrations observed globally in freshwater sediments (Hites 2004). Concentrations of nona-BDEs were significantly higher in sediments collected 13 months after DecaBDE treatment, in comparison to those collected after 1 and 4 months, indicating that debromination of DecaBDE was occurring in sediments over time, or that sediments were accumulating nona-BDEs produced elsewhere in the mesocosms. Several octa-BDE congeners were detected in sediments collected after 1 and 4 months, and hepta- and hexa-BDEs were also observed after 13 months.

After the mesocosms were moved across the lake to the new site and re-treated with DecaBDE (Experiment B), average BDE-209 concentrations of sediments collected in July 2008 were 13, 215, and 998 ng/g dw in the low, medium, and high mesocosms, respectively. As expected, these average BDE-209 concentrations are roughly proportional to the doses of DecaBDE applied to the mesocosms. However, BDE-209 concentrations of sediments in the low mesocosm were not significantly different from those in the control mesocosm. Debromination of DecaBDE occurred rapidly in Experiment B, for surface sediments in the medium and high mesocosms contained detectable levels of DecaBDE breakdown products (nona- through to penta-BDEs) as soon as 1 month after DecaBDE treatment. Strips of wall material suspended in the mesocosms in 2008 (Experiment B) were analyzed 1 and 4 months after the mesocosms were treated with the DecaBDE commercial product. Wall strips collected from the medium and high mesocosms had detectable levels of BDE-209 and some breakdown products (hexa- to octa-BDEs). All wall strips had high ambient concentrations of lower-brominated BDEs unrelated to the DecaBDE treatment, which likely originated from the plastic manufacturing process. No data is yet available for samples collected in 2009 (Experiment C).

Question 2

Some zooplankton and fish samples collected from the mesocosms in 2008 (Experiment B) have been analyzed for PBDE concentrations. In samples collected 1-3 months after DecaBDE treatment, BDE-209 (deca-BDE) was not detected in zooplankton or fish, but breakdown products of DecaBDE were detected in both zooplankton (nona- to hexa-BDEs) and fish (nona- to tetra-BDEs). Unusually high concentrations of BDE-15 (di-BDE) were measured in zooplankton, but this preliminary result requires further investigation. No results are available on PBDE levels in biota collected in 2009 (Experiment C).

Question 3

In mid-Oct 2008, 10 fish were sampled from each mesocosm (Experiment B) and analysed for growth and histology. There was no apparent effect of BDE exposure on growth, thyroid epithelial cell size (an indicator of thyroid disruption), or gonad developmental stage. Fish from 2009 (Experiment C) have not been yet been analysed for growth and histology. No results are available on liver deiodinase enzyme levels of fish from Experiment B or C.

Overall Summary

In summary, DecaBDE added to mesocosms in Lake 240 was rapidly and extensively debrominated. Breakdown products of DecaBDE accumulated in sediments and biota. No

deleterious effects of BDE exposure on growth or reproduction were observed in yellow perch stocked in the mesocosms.

Plans for 2010: No further sampling or experiments are planned for 2010. The four mesocosms, as well as the underwater fence around the old high site, will be removed from Lake 240 this summer.

Publications and presentations:

Orihel D., D. Muir, C. Darling, A. Dupuis, M. Paterson, B. Le Blanc, V. Palace, B. Park, G. Tomy. Fate of decabromodiphenyl ether added to in situ mesocosms at the Experimental Lakes Area. *63rd Canadian Conference For Fisheries Research*, Winnipeg, Canada, 7-9 January, 2010 (oral presentation).

Orihel D., D. Muir, C. Darling, A. Dupuis, M. Paterson, B. Le Blanc, V. Palace, B. Park, G. Tomy. An in situ mesocosm study to examine the fate and effects of decabromodiphenyl ether. *SETAC North America 30th Annual Meeting*, New Orleans, USA, 19-23 November 2009 (oral presentation).

Orihel D., D. Muir, C. Darling, A. Dupuis, M. Paterson, V. Palace, B. Park, G. Tomy. Debromination products of decabromodiphenyl ether detected in sediments and periphyton of DecaBDE amended mesocosms. *12th International Conference on Chemicals and the Environment*, Stockholm, Sweden, 14-17 June 2009 (poster presentation).

Orihel D., D. Muir, C. Darling, A. Dupuis, V. Palace, B. Park, M. Paterson, G. Tomy. Debromination of decabromodiphenyl ether: evidence from a field experiment. *SETAC Europe 19th Annual Meeting*, Göteborg, Sweden, 31 May - 4 June 2009 (poster presentation).

Tomy G., D. Orihel, B. LeBlanc, B. Rosenberg, D. Muir, C. Darling, A. Dupuis, M. Paterson, V. Palace, B. Park. Bioaccumulation of decabromodiphenyl ether and its metabolites: a mesocosm study. *11th Annual Workshop on Brominated Flame Retardants*, 19-20 May 2009 (oral presentation).

Orihel D., D. Muir, C. Darling, A. Dupuis, V. Palace, B. Park, M. Paterson, G. Tomy. Fate of decabromodiphenyl ether added to mesocosms in a boreal lake: preliminary sediment results. *SETAC North America 29th Annual Meeting*, Tampa, Florida, 16-20 November 2008 (poster presentation).

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.

10. Impacts of Cage Aquaculture on Lake Ecosystems

Project goals: This whole ecosystem study has been developed to assess the environmental and ecological impacts of cage aquaculture under current industry practices. The study is

determining the impacts of aquaculture on water quality, primary production, sediments and native invertebrate and fish communities. A mass balance approach and the measurement of stable sulfur, carbon and nitrogen isotopes is being used to trace the movement of aquaculture-related waste materials in the ecosystem. Originally planned for three years, in 2004 the project received approval for an additional four years of funding from the Aquaculture Co-operative Research and Development Program (ACRDP). The project has just completed its second year of recover after the cessation of fish farming and this was the last year for which we have research funding. At the time of writing it is unclear if we will be able to continue the project past March 2010.

Principal Investigators:

Cheryl L. Podemski, Ken H. Mills, Michael Paterson, Michael Turner, Paul J. Blanchfield, Ray Hesslein, Lori Tate, Dave Findlay, Paula Azevedo, Alain Dupuis(DFO)

Karen Kidd, Shelley Wellman (University of New Brunswick at St John)

Michelle Wetton, Kelly Hille (University of Manitoba)

Dominique Bureau (University of Guelph)

Contributors:

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

Summary of work carried out and major findings in 2009:

Limnology: On a monthly basis, samples for water quality analysis were collected along depth profiles in the centre buoys of L375 and L373. 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. As we have consistently found no difference in values between the two stations, sampling at the farm station was discontinued in 2009 to conserve costs. 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. On a monthly basis, a YSI multi-parameter probe was used to construct depth profiles for temperature, oxygen, pH, conductivity, turbidity, and fluorescence at stations placed along the north-south axis of the lake. Secchi depths were also determined at each station.

In March of 2009, we measured oxygen profiles under ice in Lake Manomin near the L375 outflow due to concerns that the manipulation of L375 might have downstream effects on dissolved oxygen concentrations and therefore adversely affect wild fish populations in Manomin.

Phytoplankton and Bacteria: Phytoplankton was sampled from the main basin of Lake 375 in 2009. Ice-free phytoplankton averaged biomass 473 mg m^{-3} , similar to biomass estimates in reference years 2001-02 (394 and 443 mg m^{-3} , respectively) and Lake 373. During the years of cage operation overall biomass increased by 4x, with large spring blooms in excess of 16x background. In 2009 there was no spring bloom and biomass averaged 300 mg m^{-3} . A maximum biomass 1600 mg m^{-3} occurred in late May early June. Summer phytoplankton biomass averaged 530 mg m^{-3} with an average fall biomass of 230 mg m^{-3} .

The spring phytoplankton community was dominated by *Pseudoanabaena galeata* (cyanobacteria). By late May early June dominance shifted to chrysophytes (*Uroglena volvox*, *Chrysochromulina laurentiana*, and *Mallomonas tonsurata*). Chrysophytes remained dominant throughout the remainder of the year. In September *Snowella lacustris* and *Chroococcus turgidus*, cyanobacteria, became co-dominant with the existing chrysophytes. With the accept

ion of *Pseudoanabaena galeata* (cyanobacteria) in the spring Lake 375 was compositionally similar to reference Lake

Littoral Periphyton: The purpose of this portion of the study was 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). Due to the retirement of Michael Turner, this component was discontinued in 2009.

Zooplankton: In 2009, we continued to collect samples to estimate the abundance, biomass, and species composition of zooplankton and invertebrate predators (primarily *Mysis relicta*) in Lake 375 and reference Lake 373. These organisms are important food for fish and also act as indicators of changes in water quality. Zooplankton samples were collected at the deep station in both the north and south basins of L375 on a biweekly basis. Samples were collected in L375 from the epilimnion and the hypolimnion at each station using a double-barreled net. A tube sampler was used to collect samples from six locations located around L373. *Mysis* were collected monthly in L373 and L375 at least one hour after sunset using a 0.75m diameter net. Samples were collected on a transect located along the long axis of each lake; there was a total of 11 stations in L375 and 8 stations in L373.

Over the course of the experiment, large scale changes in the zooplankton community have not been evident. In 2006 and 2007, slight increases in total zooplankton biomass were observed, but these were within the range of variation in the reference lake, L373. In contrast, we have observed large decreases in densities of *Mysis* since 2006. These decreases are most likely the result of declines in hypolimnetic oxygen concentrations and increased susceptibility to predation by fish.

Sediments and associated biota: 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. We have continued this sampling to the present.

Core samples were collected by a Kajak-Brinkhurst corer. Ten cores were collected at each distance for the purposes of enumerating the benthos. Five cores samples were collected and extruded and the top 2 cm sampled for measurement of sediment chemistry (C, N, P and an ICP scan of metals). An additional 6 samples were collected for the purpose of monitoring porewater chemistry. The water on top of each core was removed by siphoning and a pH probe was used to measure the pH of the sediments. 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.

Over the years of fish production, the profundal benthic invertebrate community of L375 has become noticeably altered. During the first 4 year of fish production, these alterations were spatially restricted to the area immediately under and surrounding the cages, presumably a response to settling solid wastes. Since 2007, the abundance and richness of the community have become significantly depressed along the entire length of the 100m transect and, we believe, over much of the profundal zone. Ostracoda appear to have been extirpated. We

believe that these observations are due to prolonged periods of low oxygen in overlaying hypolimnetic waters that has occurred for both of the last 2 years. Although fish farming has undoubtedly contributed to increased productivity in the lake, and as a result increased sediment oxygen demand, a confounding factor is the incomplete spring turnovers that have occurred in L375 for several years now. In 2008 even the fall turnover was incomplete. The failure of the lake to turn over will significantly contribute to hypolimnetic oxygen deficit. A modeling exercise is currently being undertaken to examine the relative contribution of these factors to the hypolimnetic oxygen deficit.

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 250 μ m sieve and were preserved in 10% formalin. These samples are being processed, but progress is limited by funding and staff availability. The biweekly sampling was reduced to monthly in 2009 due to reduced budget and will not be continued in 2010.

There is considerable interest in learning more about the rate of recovery of sediment after cessation of farming. There is no published information on this issue in freshwater and this types of data might be valuable as we consider fallowing as a mitigative strategy. We will try to continue once per year under cage sampling to track the recovery of sediments, if we can find funding to support the analyses.

Manual Overturn of L375: The decreasing effectiveness of spring and fall overturns in L375 became a concern to the scientific staff on the project. The lack of overturn created a confounding factor that may have resulted from climate change in springs that warm rapidly and create stratification before the lake can overturn, or to some combination of these factors (most likely). This as a problem because it compromises our ability to apply knowledge gained from the L375 project to aquaculture in larger systems such as Lake Huron and Lake Diefenbaker. Commercial aquaculture would not be permitted to occur in small enclosed basins, and hypolimnetic oxygen declines would only be expected to occur in response to fish farm loading in very poorly sited locations — again, which regulators would presumably not agree to license. During our annual meeting in 2008, we discussed the implications of this phenomenon and researchers unanimously voted to attempt to manually overturn the lake in the spring of 2010.

Ice-off occurred on May 4 2009. The following day, we began installation of an aeration system that was composed of a commercial Ingersoll Rand 185 CFM portable air compressor, attached by approximately 700m of high pressure air hose to a circular, floating manifold approximately 55m in diameter. The manifold was anchored in the deep basin of L375 and from the manifold 10, 20m long down-lines were hung leading to 10, 17.5 cm diameter airstones. Each airstone was weighted with a lead diving weight. A second, small compressor was used to power two airstones hung at 10m in the deep portion of the north basin. Temperature and oxygen profiles were collected every day at 1m intervals in both basins. Researchers agreed that we wished only to simulate annual turnover, not to artificially aerate through the ice-free season. It was therefore decided to continue aeration only so long as it took to either obtain oxygen concentrations of 10mg/L at 20m or to have hypolimnetic water reach 6°C and it was at the 6°C decision point that aeration was ceased.

Energy Transfer to the Native Food Web: Little is known about the effects of cage culture on the native food webs of lakes. 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

Summary of ELA Research for 2009

aquaculture into L375. After the graduation of Marilyn Kullmann in 2007, this work has been reduced. During the 2008 and 2009 field season, monthly samples of zooplankton, mysis, chironomids and Heptageniidae mayflies were collected and archived. There were no widespread collections of benthic invertebrates. Dr. Kidd has accepted a new graduate student, Shelley Wellman, who will be completing her MSc requirements at the University of New Brunswick.

This research is following up on the work done by Kullman et al. (2009). In that study, we found that the dissolved and particulate wastes from the rainbow trout cage culture became an important source of energy for fish and invertebrates in Lake 375. This component of the project will assess whether the biota are still using waste from the cage culture or whether they are reverting to in-lake, pre-aquaculture sources of nitrogen and carbon. In this study and in Kullman et al. (2009), we are using naturally occurring stable isotopes of carbon and nitrogen to understand where biota are getting their energy (wastes or in-lake production) and their relative trophic level. Because the feed and wastes from the cage culture were distinct from the carbon and nitrogen present naturally in the lake, we were able to show that cage wastes became an important source of energy for invertebrates and fish. During the recovery phase of the aquaculture experiment, we will continue to measure carbon and nitrogen isotope ratios of food web organisms and assess whether and how quickly the lake's organisms are reverting to pre-aquaculture sources of nutrients.

Once a month from May to September of 2009, invertebrates were collected from the littoral zones of Lake 375 and Lake 373. The taxa collected were the same as in the previous Kullman et al. (2009) study. Fathead minnow (*Pimephales promelas*), pearl dace (*Margariscus margarita*), finescale dace (*Phoxinus neogaeus*), and northern redbelly dace (*Phoxinus eos*) were collected from the littoral zone in Lake 375 and Lake 373 from June to September of 2009; Lake 373, however, did not have fathead minnows.

Kullman's work indicated that the main nutrient sources were the direct consumption of fish fine particulates or larger particulate waste for $\delta^{13}\text{C}$ and through assimilation of dissolved ammonia for $\delta^{15}\text{N}$. However, we would expect the biota are still assimilating aquacultural waste as a novel energy source if sediments rich in aquacultural nutrients remain available to the food web. In other studies, benthic communities and sediment have been shown to take longer to recover than pelagic and littoral zones.

We do not anticipate any follow up field work for this project. The expected completion date for this thesis is early 2011.

Wild Fish: We continued our fish population field sampling in 2009 as we had conducted it in all the previous years of the experiment. We fished trap nets in Lake 375 and reference lakes (224 and 373) in the spring and fall of the year, and supplemented these catches with short sets of small mesh gillnets (to obtain live samples) in the fall during lake trout spawning. Catches of all fish species in Lake 375 were lower in 2009 than the latter years of cage culture and the first year post-cage culture. Catches of fish populations in Lake 224 and 373 were similar to previous years.

We believe that the fish populations of Lake 375 were in a period of transition from the positive responses to cage culture observed during the 4th to 6th years of cage culture and into the first year following cage culture, 2008. We have not fully analyzed the data collected during 2009, but based on observations during our field sampling, abundance of minnows was greatly reduced in Lake 375, abundance of small white sucker was greatly reduced, and condition of lake trout has likely decreased. This is the second year post cage culture and if the subsequent data analyses confirm the changes observed during field sampling, then these changes match the time course of observations of "recovery" of fish populations documented after two other ELA lake fertilization experiments. Increased productivity of fish populations continued into the

first year post fertilization of in these two other experiments, and the “crash” occurred the second year post fertilization. We will not be able to confirm any abundance change for lake trout and white sucker in 2009 based on mark-recapture until sampling is completed in 2010. We project data analyses of 2009 data to be completed by April 2010. However, without additional funding, there are no plans to continue this sampling in 2010 and beyond.

Behaviour of wild and escaped fish: The primary goals of this component of the ELA Aquaculture Project are twofold: (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 have been using a combination of mark-recapture approaches and acoustic telemetry to achieve these goals. 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. There are currently no plans to continue this work in the 2010 field season.

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. Our research suggests that the life expectancy of escapees is on average 2 years, with none surviving longer than four years, so the fence will likely be removed in 2011.

Plans for 2010: The 2009 field season was the last year for which we have funding support. The reduction of our research staff has also added challenges. At this point it is unclear which components of the study will continue into 2010. Although the study of sediment recovery would be of significant utility to understanding the potential of fallowing as a mitigative strategy, we were unsuccessful in a grant application for funding for this work. We will sample sediment chemistry and benthos under the cage and along the distance transect on an annual basis if funding can be found to support analysis costs, but detailed analysis of the process of sediment recovery will not be possible.

It is unlikely that the Northern Ontario Aquaculture Association will be agreeable to partner in an ACRDP grant application for 2010 and beyond. Several members of the association have stated that they have seen no evidence that science is improving the regulatory environment for the industry and, in fact, regard parts of the new proposed guidelines (the sediment guidelines) as a significant step backwards. They have clearly indicated that they will not make further financial contributions to science programs until such time as they see an incorporation of new science in the regulatory environment. Unfortunately, it appears that our research has little demonstrated ability to influence regulators, despite the participation of regulatory agencies in our annual review meetings and the participation of several of our researchers as technical consultants for the guideline harmonization effort. The ACRDP program, which has been our major supported for this research project, requires a minimum cash contribution from an industry partner in order for a project to receive any funding. We receive no A-Base funding from DFO to undertake any of this project and this likely means that the L375 project will end in March 2010.

Publications:

Summary of ELA Research for 2009

Blanchfield, P.J., Tate, L. and C. Podemski Survival and behaviour of rainbow trout (*Oncorhynchus mykiss*) released from an experimental aquaculture operation. Canadian Journal of Fisheries and Aquatic Science 66: 1976-1988.

Findlay D, C.L. Podemski and S.E.M Kasian. Aquaculture Impacts on the Algal and Bacterial Communities in a small Boreal Forest Lake. Canadian Journal of Fisheries and Aquatic Science 66 (11): 1936-1948.

Kullman, M.A., K.A. Kidd, C. L. Podemski P.J. Blanchfield and M. Paterson 2009. Assimilation of Freshwater Salmonid Aquaculture Waste by Native Aquatic Biota Canadian Journal of Fisheries and Aquatics Sciences 66 (11): 1965-1975.

Rooney, R. and C. L. Podemski 2009. Effects of an experimental rainbow trout (*Oncorhynchus mykiss*) farm on invertebrate community composition. Canadian Journal of Fisheries and Aquatic Science 66 (11): 1949-1964.

Rooney, R. and C. L. Podemski 2009. Freshwater rainbow trout (*Oncorhynchus mykiss*) farming affects sediment and pore-water chemistry. Marine and Freshwater Research. *In press*.

Seckar, D. Interactions between *Chaoborus* spp. and *Mysis relicta* and their impact on pelagic crustacean zooplankton in mesocosms at the Experimental Lakes Area. M.Sc. thesis. University of Manitoba.

Paterson, M.J., C.L. Podemski, L. Wesson, A. Dupuis. Effects of changes in hypolimnetic oxygen, phytoplankton, and fish predation on the Opossum Shrimp (*Mysis relicta*) in a lake with an experimental freshwater cage aquaculture operation. Submitted to Can. J. Fish. Aquat. Sci.

Paterson, M.J., C.L. Podemski, W. Findlay, D.L. Findlay, A. Salki. Zooplankton responses to changes in phytoplankton, hypolimnetic oxygen, and predation by *Mysis* and fish in a whole-lake experiment on the effects of cage aquaculture. Submitted to Can. J. Fish. Aquat. Sci.

P.A. Azevedo, C.L. Podemski, R.H. Hesslein, S.E.M. Kasian, D.L. Findlay and D.P. Bureau Estimation of waste outputs by a rainbow trout cage farm using a nutritional approach and monitoring of lake water quality.

Presentations:

Dupuis, A., M. Paterson, R. Hesslein, C. Podemski. 2010. dissolved oxygen dynamics during an experimental aquaculture operation in a small boreal lake : a modeling approach. Canadian Society of Limnology Annual meetings, Winnipeg MB Jan 2010.

Kullmann, M. K.A. Kidd, C.L. Podemski, M.J. Paterson, P.J. Blanchfield. 2010. assimilation of freshwater salmonid aquaculture waste by native aquatic biota. Canadian Society of Limnology Annual meetings, Winnipeg MB Jan 2010.

Mills, K.H., S.M. Chalanchuk, D.J. Allan, C.L. Podemski. 2010. Lake trout enhancement: a by-product of rainbow trout cage aquaculture. Canadian Society of Limnology Annual meetings, Winnipeg MB Jan 2010.

Paterson, M.J., D. Findlay, C. Podemski, L. Wesson, A. Dupuis, A. Putt, P. Blanchfield, L. Tate. The effects of an experimental rainbow trout cage farm on the plankton community of a freshwater lake. Freshwater Cage Culture Environmental Forum II, Sudbury, Ont. June 9-10, 2009.

Podemski, C.L., P. Azvedo, P.J. Blanchfield, D. Findlay, K.A. Kidd, M. Kullmann, K.H. Mills, M.J. Paterson, R. Rooney, M. Wetton. 2010. Effects of net pen aquaculture on a lake ecosystem: results from the ELA aquaculture project. Canadian Society of Limnology Annual meetings, Winnipeg MB Jan 2010.

11. Assessment of fitness effects of enhanced growth rate in rainbow trout in nature.

Project goals: Corporations in Canada are proposing the use of engineered fish strains for aquaculture, yet significant concern exists regarding potential environmental impacts that may arise should they escape from production facilities, enter ecosystems, and compete with indigenous species. Laboratory assessments of risk are currently associated with high uncertainty due to difficulties in extrapolating experimental data to scenarios in nature. One research approach with minimal risk is to utilize non-genetic growth modification, generating animals that can serve as surrogates that mimic the physiology and behaviour of engineered organisms to a large extent, but are not genetically modified and thus do not afford any long-term risk to the environment. This approach has the potential to provide real-world fitness and impact data regarding risks of genetically engineered aquatic organisms.

The main goal of the proposed research is to determine the survival and potential ecological effects of growth-enhanced rainbow trout in a natural environment.

Principal Investigators:

Robert Devlin, DFO, Centre for Biotechnology Regulatory Research, West Vancouver, BC

Paul Blanchfield, DFO, Freshwater Institute, Winnipeg, MB

Wendy Tymchuk, DFO, West Vancouver, BC

Mike Paterson and Alain Dupuis, DFO, Freshwater Institute, Winnipeg, MB

Richard Moccia, University of Guelph, Guelph, ON

Summary of work carried out in 2009:

The study is comprised of three components:

1. Ongoing lab trials in West Vancouver and BC lakes: Wild and domesticated strains of rainbow trout have been assessed in the laboratory for growth rate, and basic behavioural characteristics. To extend these findings to the field, we intend to assess the behaviour and survival of the strains in natural lake environments. A 3D acoustic tag system (HTI, Seattle, USA) has been acquired and was field deployed in 2009 to test its functionality in the research lakes. The system performed well, providing sub-meter resolution of fish position over at least a 0.3-0.5 km range. These tests validate the use of this or similar systems for assessing behaviour in real time in these lakes, and in the ELA lakes planned for this study and described below.
2. University of Guelph laboratory trials: Much of the information presently available on differences between wild and domestic growth-enhanced rainbow trout is from studies at the West Vancouver lab. These studies use strains of fish that are different from those available in Ontario. Because we are required to use strains of rainbow trout from Ontario in the ELA study, it was determined that an important addition to this study would be laboratory trials of domestic and wild strains of rainbow trout from Ontario. This lab study will allow us to better predict the fitness differences between strains (naturalized vs. domestic) and growth modification (domestic vs. growth-enhanced to mimic transgenic). We are collaborating with Dr. R. Moccia at the University of Guelph to oversee this portion of the study. Since completely wild strains of rainbow trout are not indigenous in Ontario, we will use “de-domesticated” or “naturalized” fish. Much effort in 2009 was devoted to finding strains of rainbow trout in Ontario that could be

Summary of ELA Research for 2009

used for the ELA portion of this study. Appropriate fish were located and transported to the Alma research station, University of Guelph. This study has yet to proceed because of a delay in acquiring permission from the company supplying the bovine growth hormone (Posilac™, Monsanto Corporation). In the interim, growth rate of the wild and domestic trout under varying rations is being investigated.

3. ELA study: The first year of background data on Lakes 303 and 304 were collected. This included standard ELA field sampling for water chemistry and limnological variables. Monthly phytoplankton and zooplankton samples were identified and enumerated. Late summer phytoplankton, zooplankton, benthos and fish samples are being processed for stable isotope analyses. Outflow areas examined for installation of barrier fences to prevent fish escapes.

Major findings or conclusions (2009):

1. Ongoing lab trials in West Vancouver and BC lakes: Validation of HTI 3D acoustic tag tracking system.
2. University of Guelph laboratory trials: Fish strains located and food ration laboratory trials are proceeding.
3. ELA study: A full year of background data collected.

Plans for 2010:

1. Ongoing lab trials in West Vancouver and BC lakes: In June of 2010, domestic and wild trout will be tagged and transferred to lakes in central BC. The HTI acoustic tag system will be deployed to track their behaviour during June, July and August.
2. University of Guelph laboratory trials: We anticipate receiving permission to acquire the growth hormone in 2010. The present delay is a result of changes in company structure, and therefore new permission and agreements are being sought. We plan to proceed with the growth-enhanced laboratory trials of Ontario strains of rainbow trout at the Alma facility in 2010.
3. ELA study: It is anticipated that 2010 will be another year of background data collection on Lakes 303 and 304. In addition, we plan to install the barrier fences and conduct feasibility studies on the use of telemetry to monitor fish movements in these lakes. If the Guelph laboratory trials proceed quickly, there is the possibility for a pilot study at ELA in 2010. The study would be undertaken using few animals (~25 - 100 fish per treatment group). Each lake would receive fish from all four treatments: 1) wild; 2) domestic; 3) growth-enhanced wild; and, 4) growth enhanced domestic. Fish would be marked individually and assessment of the survival of different groups would be examined in the fall following several months of growth, as well as in subsequent years. Data collected would include growth rate, survival effects, age of maturation, fertility and fecundity. Fish will also be sampled to assess body morphology, stomach contents (to assess whether prey selection has been altered), body condition factor and composition (proximate analysis of energy reserves), and gene expression and endocrinology profiles. We will also examine the impact to the native food web and energy flow in Lakes 303 and 304 as a result of these fish introductions.

Publications: None at this time specifically relating to this project.