

SUMMARY OF MAJOR RESEARCH PROJECTS AT THE EXPERIMENTAL LAKES AREA DURING 2008

Updated April 06, 2009

The level of research activity on site at the ELA during 2008 remained at a level similar to 2007, and close to the historic average. Total on-site research activity for the April through November period was just over 3,200 person-days and involved approximately 105 different researchers representing more than nine different universities, government agencies and private companies. 2008 was the second 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 2008 resulted in research activity of 74 person-days involving eleven different researchers. During 2008, 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. This project will come to a close this season with the removal of the control structure. The long-term, ecological research (LTER) program continued, with limited support from core funding. On-site meteorological monitoring, with support from Environment Canada, moved into its 40th consecutive year. ELA Lake 227 was experimentally fertilized with phosphorus for the 40th consecutive year. A short-term study looking at the sub-lethal effects of instantaneous pressure changes on the internal organs of fish was carried out on Lake 382. The BFR enclosure study, looking at bioavailability, bioaccumulation, and toxicity of a suite of additive and reactive brominated flame retardants (BFR) continued this summer with DecaBDE being added to the enclosures.

A DFO/University-based study investigated the relative uptake of waterborne and dietary mercury by forage fish.

The following is an attempt to summarize the status of most major research projects by providing some information about their purposes, designs and, where possible, significant results. It should be noted, however, that data analyses are ongoing and most of the results provided here are preliminary. These projects are grouped under several broad category headings.

Note:

Using information provided by research project leaders and other ELA staff, Mark Lyng compiled this summary. The summary is intended as an overview of research activities at the ELA during 2008. 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.

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LONG-TERM MONITORING AND CLIMATIC FACTORS

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

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

LONG-TERM ECOLOGICAL RESEARCH (LTER) AND DATA MANAGEMENT

Principal Investigators

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

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

Project Description and Goals

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

There are three objectives for the project:

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

Summary of the work carried out during 2008

Long-term records of meteorology and hydrology of the Lake 239 basin were maintained. Meteorological variables (air temperature, precipitation, wind speed and direction, PAR, bright sunshine and evaporation) were monitored daily. The 3 inflowing streams and outflow of Lake 239 were monitored for volume of flow (continuous record) and chemical composition (weekly). The five core lakes (114, 224, 239, 373, and 442) were again monitored, where possible, for all major disciplines which include: hydrology, water temperature, secchi depth and light extinction profiles, water chemistry, primary production, epilithon, phytoplankton populations, 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 limnological variables (light and temperature profiles, secchi depth) and samples for chemistry, phytoplankton and zooplankton analyses were taken every 2 weeks 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 continually in all LTER lakes. Primary production monitoring was only done on Lake 373, once a month. Sampling of epilithon was only conducted in July and August in littoral zones of LTER lakes 239 and 375, and only for algal taxonomy, C, N, P, chlorophyll a, and stable isotopes (archived). Metabolic sampling was not done. Phytoplankton and zooplankton analyses included identification to species and biomass estimates. Phytoplankton taxonomy and counts were reduced to monthly for Lake 373, and to a single open-water season value, determined from a composite of bi-weekly samples, for Lakes 224 and 442. *Chaoborus* and *Mysis* in lakes 373 and 240 were sampled for comparisons to specific experimental lakes. Mark-recapture work to estimate fish populations occurred in spring and/or fall, depending on the species. Movements of lake trout and white suckers in Lake 373 were studied with acoustic telemetry for the purpose of comparison to those in the aquaculture experimental lake (Lake 375).

The ELA Database continues to be heavily used, both by internal and external researchers as a source of data from ELA. Almost 600 inquiries were made internally. Four stand-alone versions were distributed to external collaborators and three to Environment Canada researchers. Do were provided to 20 external researchers who made 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 2007-8 data. Several new small data sets (e.g. evaporation pan data, ice and snow thickness, YSI temperature/O₂ profiles, etc.) were added. Chemical data from the FLUDEX experiment was archived in the Database, and work is progressing on similarly archiving Hg, DOC and SO₄ budget data from the ELARP experiment. As well, chemistry data from the 2002 helicopter survey of 148 ELA lakes, done by Canadian Wildlife Service (CWS) for Environment Canada, was obtained and is being processed for inclusion the Database to allow for comparisons with previous helicopter surveys done by ELA. Work is almost complete on including historical large and small bodied fish population data in the Database.

Major findings or conclusions

Papers using LTER data:

Summary of ELA Research for 2008

Azevedo, P.A., C.L. Podemski, R.H. Hesslein, S.E.M. Kasian, and D.P. Bureau. 2009. Estimation of waste outputs by a rainbow trout cage farm using a nutritional approach and monitoring of nutrient status of lake water. (in prep)

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.* (In Press; accepted 2008 Jun)

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

Hesslein, R. H., M. A. Turner, D. Guss and M. Lyng. 2009. Distinguishing changes in physical and chemical parameters of a boreal lake due to climate variation and acidification. *Can. J. Fish. Aquat. Sci.* (In Press; Accepted 2008 Dec 18)

Jeziorski, A., N. Yan, A. Paterson, A. DeSellas, M. A. Turner, D. Jeffries, W. Keller, R. Weeber, D. McNicol, M. Palmer, K. McIver, K. Arseneau, B. Ginn, B. Cumming, and J. Smol. 2008. The widespread threat of calcium decline in fresh waters. *Science* 322: 1374-1377.

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.* (In Press; accepted 2008 Sep 30)

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.* (In Press; Accepted 2008 May 21)

Zhang, J., J. Hudson, R. Neal, T. Clair, M. A. Turner, D. Jeffries, P. Dillon, L. Molot, K. Somers, and R. Hesslein. 2009. Long-term patterns of dissolved organic carbon in lakes across eastern Canada: evidence of a pronounced climate effect. *Limnol. Oceanog.* (In Revision 2008 Dec)

Hille, K.A. 2008. Does Aquaculture Impact Benthic Algal Ecology? A study on the effects of an experimental cage aquaculture operation on epilithic biofilms. 326 p. + xii. M.Sc. Thesis. University of Manitoba, Winnipeg, MB

Baulch, H.M, P. Dillon, M.A. Turner, R.H. Hesslein, S.E.M. Kasian. 2008. Lakes as Nutrient Sinks: Does Climate Mediate Nitrogen and Phosphorus Retention?. AGU Chapman Conference on "Lakes and Reservoirs as Sentinels, Integrators, and Regulators of Climate Change". September 8-10, 2008,

Plans for 2009

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. Some methodology changes are expected in order to gain efficiencies. Inter-calibration studies and documentation will be required. A project review meeting is planned for the winter of 2009.

Don McNicol (Canadian Wildlife Survey of EC) is planning another helicopter survey in the ELA region during the fall of 2009. Also, in the early summer Russ Weeber (also of CWS) is planning another food chain survey in the ELA region. Both of these endeavours provide opportunities for ELA researchers, and the LTER program in particular.

The ELA Database will continue to be updated with new data and applications. It is expected that the Database will now include maps, provided by OMNR, which show the historical logging activities in ELA lake watersheds.

Specific Ancillary Studies

Meteorological Monitoring

The ELA is the site of long-term monitoring of meteorological variables via a station (met site) that uses equipment provided by the Meteorological Service of Canada (MSC) of Environment Canada and is operated by ELA staff. Ken Beaty, with assistance from Mark Lyng, Ray Pambrun, and others, has primary responsibility for this facility and data are contributed to the MSC national climate database. Established in June of 1969, this site is now in its 39th year of continuous monitoring. Meteorological variables (air temperature, precipitation, wind speed and direction, bright sunshine and evaporation) were monitored daily again in 2007. A larger building to house the expanding instrumentation on site was constructed this year.

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

Canadian Air and Precipitation Monitoring Network (CAPMoN)

ELA personnel, under the direction of Ken Beaty, continued to operate a CAPMoN station at the ELA met site in 2007. The CAPMoN program (http://www.msc.ec.gc.ca/capmon/index_e.cfm), which monitors both atmospheric and precipitation chemistry at a network of sites across Canada, is funded and coordinated by Environment Canada. The ELA site, which has been operating since the 1980's, monitors ground-level ozone, SO₂ and HNO₃ in the atmosphere, Cl, SO₄, NO₃, Na, NH₄, Ca, K, Mg, pH, and mercury in precipitation. It has frequently been used as a baseline reference for sites in eastern Canada.

Canadian Network Isotopes in Precipitation (CNIP)

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

SEISMIC MONITORING STATION

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

small network of stations installed in northwestern Ontario and is expected to remain in place for up to 5 years.

LAKE 239 SURFACE ENERGY BALANCE STUDY

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Purpose

The Climate Research Division of Environment Canada is currently developing a 1-dimensional dynamic lake module for use in its land surface modelling research programme that includes both the dynamics of epilimnion deepening/retreat, as well as the impact of DOC concentration on transparency. In support of this research, an instrumented raft was deployed on Lake 239 in July 2007 and has been in continuous operation ever since.

Description

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

Preliminary Results

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.

Outlook for 2009

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.

Aquatic Ecosystem Recovery Study

Principal investigators

Fisheries and Oceans Canada

Kenneth Beaty, Alain Dupuis, David Findlay, Dr. Raymond Hesslein, Dr. Wolfgang Jansen, Susan Kasian, Stephen Page, Dr. Michael Paterson, Ken Sandilands, and Dr. Michael Turner (scientist in charge)

Purpose

Large numbers of lakes in southeastern Canada and in northeastern United States have not yet recovered from anthropogenic acidification. Despite substantial reductions in the release of acidifying emissions acid deposition continues to exceed critical loads across large portions of eastern Canada. This causes acidification to continue and threatens the biodiversity of the aquatic ecosystems in these regions. For example, chemical models of Environment Canada predict that about one quarter of the lakes in eastern Canada outside of the Sudbury area will still be acidified after 2010. About 76,000 lakes will remain chemically damaged (i.e., their pH will remain below 6 even though they could be expected to have pHs higher than 6), even with full implementation of the Canada – USA Air Quality Agreement. Moreover, integrated assessment models have predicted that about 160,000 Canadian fish populations will remain at risk.

The 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, ELA researchers embarked on a major program of investigating the effects of acidification on lakes of the Boreal Shield. 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.

At the start of our recovery study, comparatively little was known about the ability of aquatic ecosystems to recover from chronic acidification, although much was known about the impacts of acidification. As a result, our studies of the natural potential of boreal forest lakes to recover from acidification have been particularly relevant.

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.

Funding

In 2008/9 Dr. Dean Jeffries was the primary Environment Canada (EC) partner. Funding for the ecosystem recovery research studies was obtained primarily from a memorandum of understanding between D. Jeffries (National Water Research Institute – EC) and M. Turner. Both DFO and EC provided support for its researchers' salaries and for the ELA platform.

Research & monitoring activities

During 2008 pH was unregulated in Lake 302S for the eighth year. Funding from D. Jeffries enabled us to continue monitoring several physical (hydrology, temperature, and transparency), chemical (nutrient and ionic chemistry) and biological (phytoplankton and zooplankton) properties in the pelagic zone. A midsummer pelagic profile was also collected in Lake 223. As has been the case for several years, resource limitations prevented us from conducting sampling in the littoral zone.

Preliminary results

A summary report of the L302S study is currently being prepared and will be available later in 2009. Our preliminary general conclusion is that the experimental ecosystem demonstrated substantial resilience recovering from the major stress of being acidified to pH 4.5. Although for many properties the hysteresis seen earlier during recovery was primarily a lag rather than an alternate endpoint, some properties remain disturbed (e.g., the phytoplankton remains unexpectedly dominated by Dinoflagellates, which had been predominant during the severe acidification phase). Moreover, some keystone taxa, such as the crayfish, remain absent.

Before generalizing this conclusion to eastern North America, it is important to remember that despite the severity of this experimental perturbation (to pH 4.5), in several respects the acidification was much less severe than that occurring elsewhere. For example, in aquatic ecosystems of eastern North America, both the terrestrial portions of the watersheds have also been acidified, and regional biological refugia for recolonization have been lost.

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.* (In Press; accepted 2008 Jun)
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- Jeziorski, A., N. Yan, A. Paterson, A. DeSellas, M. A. Turner, D. Jeffries, W. Keller, R. Weeber, D. McNicol, M. Palmer, K. Mclver, K. Arseneau, B. Ginn, B. Cumming, and J. Smol. 2008. The widespread threat of calcium decline in fresh waters. *Science* 322: 1374-1377.
- Phillips, I. D., R. D. Vinebrooke, and M. A. Turner. 2009. Reintroduction of crayfish to a recovering acidified lake: ecological restoration or invasion? *Can. J. Fish. Aquat. Sci.* (In Press; accepted 2008 April)
- 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.* (In Press; accepted 2008 September)
- 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.* (In Press).

Plans for 2009

Dr. Michael Paterson will become responsible for this project as of the next fiscal year with the departure of Michael Turner from DFO in June 2009, though currently plans are to continue monitoring the recovery of L302S.

HABITAT ALTERATION AND ECOSYSTEM PRODUCTIVITY

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

FERTILIZATION OF LAKE 227

Rationale

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

Research Activities

Lake 227 was fertilized with phosphorus for the 40th consecutive year in 2008. 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 2008, 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 2008 and this program will continue in 2009.

Publications and Presentations

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

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

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

RESERVOIR IMPACTS AND POSSIBLE MITIGATION

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

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

This work is now winding down, but data analyses are ongoing.

EXPERIMENTAL LAKES AREA RESERVOIR PROJECT (ELARP)

Objectives

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

Historical Summary

In June, 1993, following two years of background studies, the outflow of a ELA Lake 979 and its surrounding wetland was dammed, and the water level raised 1.4 meters to flood 14 hectares of peatland. Direct by-products of the decomposition of the flooded vegetation in the peatland are CO₂ and CH₄. Mobilization of MeHg within the flooded ecosystem and release to the atmosphere of CO₂ and CH₄ in response to the flooding were monitored intensively. A non-flooded wetland system (ELA Lake 632), was monitored as a reference. Following winter drawdown, flooding of Lake 979 was repeated in summer and fall of 1994 and 1995, as detailed studies continued in both wetland systems. In all three years, dramatic increases in MeHg and in release of the GHG were observed in response to flooding.

During the open-water periods of 1996 through 1998, the 979 wetland was experimentally flooded, but the system was studied less intensively. GHG emissions and MeHg mass-balance budgets were monitored. In 1999, and again in 2000, the system was flooded, but no ecosystem monitoring was conducted. During the open water period of 2001, the system was flooded once again and a regular monitoring program was carried out. Flooding was repeated in 2002, 2003, 2004, and 2005, but only minimal general monitoring was conducted. In 2006, the reservoir was flooded and regular monitoring, similar to that done in 2001, was conducted.

Monitoring in 2008

Lake 979 was flooded and hydrologically monitored. Monthly sampling of Zooplankton, Phytoplankton, and nutrients was performed.

Future of the Study

The system will not be flooded in 2009, and as required by the ELA operating agreement, the existing dam will be removed and the natural flow regime restored.

THE IMPACT OF DRY CONDITIONS ON BOREAL LAKE ECOLOGY AND HYDROLOGY

Purpose

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

Principal investigators

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

Collaborators

DFO: Hesslein, Ray, Page, Stephen, Mills, Ken, Chalanchuk, Sandy & Majewski, Andy,
Paterson, Michael, Dupuis, Alain, Tate, Lori, Turner, Michael DFO
EC: Mackay, Murray

Funding sources or support organizations

Environment Canada and Fisheries and Oceans Canada

Description

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 two open water seasons (2008-2009) to establish differences that exist between the lakes. The second phase is proposed to last for three years (2010-2012) and involves direct manipulation of the upstream inputs to Lake 626. In year two 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 three to five.

The thermal regime of each lake will be measured with an Onset TidBit thermistor string installed early in the open water season. The evaporative regime will be estimated using meteorological sensors installed at three levels above the lake on a floating platform, which will be deployed each open water season at the same time as the thermistor string. Each year, water chemistry and zooplankton community composition of the study and reference lakes and watersheds will be sampled bi-weekly. Further, samples of major taxonomic groups will be taken annually for stable isotope analyses to determine trophic status and pathways of energy transfer. Spring and fall trap-netting will be used to determine the abundance and growth of small-bodied fish (minnows) and lake trout. Acoustic telemetry will be used to determine the spatial and pelagic distribution of lake trout.

Significant findings to date:

2008 was the first year of data collection on Lake 626. Reference baseline evaporation and thermal data were collected from Lake 626, as well as bi-weekly sampling for water chemistry and zooplankton. A late summer collection of all trophic levels were taken for stable isotope

analyses. Fish population sampling occurred in the spring and fall and 13 lake trout were implanted with pressure-sensing acoustic transmitters and their spatial and pelagic distribution monitored. We documented littoral habitat types using digital imaging during SCUBA surveys. 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 will be completed by April 2009. Similar data collections occurred in reference Lake 373, and in addition a floating climate tower was built at the end of the season.

Current status of the study, including future plans

Both lakes are fully instrumented and ready for the first full year of baseline data collection in 2009. Funding will determine if the diversion channel will be built in 2009.

MERCURY LOADING AND BIOACCUMULATION

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

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

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

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

Background and Rationale:

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

As a result of the above complications interpreting field data, an experiment was designed to use stable mercury isotopes to examine the effect of mercury loading on methylmercury (MeHg) production and concentrations in biota. METAALICUS involves the addition of stable, non-radioactive, mercury isotopes to a whole ecosystem to see if there is a response in fish mercury

concentrations. Pilot scale studies began in 1999 and the full scale experiment began at Lake 658 in 2001. Mercury has been added to the Lake 658 ecosystem each year since 2001. Mercury additions to the terrestrial system ended in 2006, while mercury additions directly to the lake surface ended in 2007. The experiment is now examining recovery from elevated mercury deposition.

Experimental Objectives:

METAALICUS is designed with the following overall objectives:

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

Participants:

Principle Investigators:

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Other DFO Winnipeg Investigators:

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International Advisory Panel:

J. Munthe, Swedish Environmental Research Institute (IVL).
E. Swain, Minnesota Pollution Control Agency
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Study Description:

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

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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 respectively). The power of using isotopes lies in the ability to follow the newly deposited mercury separately from background mercury. Applying mercury with different isotopic signatures to the upland, wetland and lake also allows us to determine the relative contributions of these sources to fish mercury levels. Mercury has been added to the Lake 658 ecosystem each year since 2001 with additions to the terrestrial system ending in 2006 and additions directly to the lake surface ending in 2007. 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 experiment is being carried out in two phases. Phase I involved pilot and baseline studies in 1999-2000, to prepare for Phase II. The ELA Management Board approved Phase I studies at the February 1999 and February 2000 meetings. Final approval of the full-scale experiment for 2001 through 2003 was obtained in March 2001. Permission to continue adding mercury to the ecosystem for the 2004-2006 period was granted in February 2004. Permission to continue adding mercury to the ecosystem for the 2007-2009 period was granted in February 2007. As noted, mercury is no longer being added.

Milestones:

- (1999-2000) Two years of pilot scale experiments; pre-addition background monitoring of candidate lakes. The Lake 658 ecosystem was selected for study.
- (2001-2006) Six years of whole-ecosystem isotope additions to the lake surface. Terrestrial Hg additions were completed in 2006
- (2001-2007) Seven years of mercury additions directly to the lake surface.
- (2008-2009) Monitoring of mercury concentrations and cycling until conditions return to pre-addition levels.

Public Consultation:

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

Pilot Scales Studies:

Pilot-scale studies from 1999-2004 were described in the *Summaries of Major Research Projects at the ELA* for 2000-2006, based on results available at the time. These included:

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

In 2007, some of the terrestrial pilot-scale studies done from 1999-2006 were continued or expanded to gain additional knowledge:

Results from the Lake 658 Ecosystem:

Mercury applied directly to the lake surface (“lake spike”) was clearly observed as inorganic ²⁰²Hg each year from 2001-2007. Concentrations of total mercury increased in surface waters in a sawtooth pattern during the period of additions, and declined in the months between additions. In 2008, concentrations of inorganic ²⁰²Hg dramatically decreased in the water column of L658. The resulting concentrations of total mercury in Lake 658 surface waters have to-date been within ranges observed in natural lakes. Lake spike has also been measured as methylmercury in surface and hypolimnetic waters since the first season (2001).

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 ²⁰²Hg added originally to the lake surface. Muscle biopsy results for northern pike have revealed detectable levels of lake spike since 2002 and now are present at greater concentrations than forage fish. Both terrestrial and wetland spikes have been detected in all forage fish species; however, the concentrations of added spike mercury are near detection levels. In 2008, methyl mercury levels in fish and other biota 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. This was discussed in the 2004 *Summary of Major Research Projects at the ELA*. A key finding was that only a small amount (1%) of mercury added to the terrestrial system was detected in runoff. The implication is that the terrestrial system imposes a time lag on the delivery of atmospheric Hg deposition to lakes via runoff. This is important because runoff is the dominant source of ambient mercury to Lake 658.

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.

2009 Field Season:

There will be no mercury additions to the lake in 2009 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 in 2009.

Lake Restoration:

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

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

Impact on Downstream Lakes:

Based on pilot-scale studies and our knowledge of the behaviour of mercury in ELA lakes, most of the added mercury will be bound to particles (soils, peat, sediments) in the Lake 658 ecosystem or returned to the atmosphere in the long term. Mercury in the Lake 658 outflow enters a very large downstream lake (Winnange Lake, approximately 1000x larger than Lake 658). Monitoring is being carried out in Winnange Lake to verify that the food web is not impacted by the Lake 658 experiment. From 2001-2007, concentrations of the three different mercury isotopes added to the Lake 658 watershed were quantified in two species of Winnange Lake fish (northern pike and age 1 yellow perch). None of the experimentally-added mercury to Lake 658 was detected in Winnange Lake fish in 2003 (2001 sampling was prior to our first additions of mercury isotope). In 2005, 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, 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, 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.

Table 1. The number of fish captured from Winnange Lake and analyzed for isotopic mercury that was added to Lake 658 and its watershed as part of the METAALICUS project. The number of fish observed to have detectable levels of isotopic mercury and the % contribution to total fish mercury concentrations is shown.

Fish species	Number of fish sampled	Number of fish with Hg isotope above detection level (>1% of ambient)	Maximum % of isotope (isotope/ambient)

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Yellow perch (age 1+)	30	0	0.6%
Northern pike	1	0	0.9%
Lake whitefish	10	0	-
Lake trout	15	0	-

2008 Publications:

Clarisse,O., Foucher,D., and Hintelmann,H. 2008. Methylmercury speciation in the dissolved phase of a stratified lake using the diffusive gradient in thin film technique. Environmental Pollution **ASAP**.

Graydon,J.A., St.Louis,V.L., Hintelmann,H., Lindberg,S.E., 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 and Technology **42**: 8345-8351.

Mitchell,C.P.J., Branfireum,B.A., and Kolka,R.K. 2008. Spatial characteristics of net methylmercury production hot spots in peatlands. Environmental Science and Technology **42**: 1010-1016.

Orihel,D.M., Paterson,M.J., Blanchfield,P., Bodaly,R.A., Gilmour,C.C., and Hintelmann,H.H. 2008. Temporal changes in the distribution, methylation, and bioaccumulation of newly deposited mercury in an aquatic ecosystem. Environmental Pollution **154**: 77-88.

Relative Uptake of Waterborne and Dietary Mercury by Forage Fish

Purpose

To quantify the relative contributions of dietary and waterborne mercury (Hg) to tissue mercury levels in yellow perch (*Perca flavescens*).

Principal Investigators

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Special funding sources/support organizations

ELA Graduate Fellowship Fund, EPRI

Study Description

We conducted a replicated experiment to determine the relative uptake of dietary and waterborne mercury to levels of mercury in fish. The experiment took place in large tanks

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located at Lake 658 at the ELA in August and September 2008. Prior to the initiation of the experiment, zooplankton were collected from Lakes 658 and 240 by towing a zooplankton net horizontally behind a boat. Approximately 2 kg of zooplankton (wet weight) were collected and subsequently made into fish food pellets. In early August, twelve 160 L fiberglass tanks with lids, two 500 L reservoir tanks with lids, and one water pump with hoses were transported from the main ELA camp to Lake 658. The tanks were set up on land at the east end of Lake 658 near Winnange Lake and each was assigned one of four treatments: clean water + clean food; clean water + spike Hg food; spike Hg water + clean food; spike Hg water + spike Hg food. Winnange Lake provided the clean water and Lake 658 the spike Hg water (enriched stable mercury isotope had been added to the lake in previous years as part of the METAALICUS experiment). Signs providing basic information about the experiment and contact information for the ELA and OMNR were posted at the site, and Fisheries and Oceans labels were placed on the tanks.

In early August, 20 age-0 yellow perch, collected from Lake 240, were placed in each tank. The experiment then ran for 4 weeks, with two crew members visiting the site each day. Fish were fed gradually each day over the course of 5 hours, and uneaten food was siphoned out of the tanks. Prior to its use in the tanks, lake water was pumped from each lake daily into the reservoir tanks and allowed to sit overnight. Separate pump hoses were used for each lake, and the pump body was flushed with Winnange Lake water for 5 minutes after exposure to Lake 658 water. The drains from each tank were connected to one discharge hose that emptied into Lake 658, meaning that all water used in the experiment eventually ended up in Lake 658. This was done to avoid contamination of Winnange Lake with spike Hg from Lake 658. Tanks were drained to half each day and re-filled with water from the reservoirs. Water was sampled weekly for total mercury and methylmercury from one tank of each treatment and from each reservoir tank. Any fish mortalities were removed on a daily basis. Fish were sacrificed at the end of the experiment with an overdose of tricaine methanesulfonate (MS-222) anesthetic, processed for basic biological data, and frozen in individual Whirl Pak bags.

Preliminary results

Several fish from the spike Hg water + spike Hg food treatment were processed and sent for Hg analysis along with samples of spike food and Lake 658 zooplankton in November 2008. Preliminary results show detectable levels of spike Hg in all samples.

Plans for 2009

The rest of the samples collected in 2008 will be processed and analyzed in the winter of 2009. There are no plans to continue this experiment at the ELA in 2009.

ENCLOSURE STUDIES OF BROMINATED FLAME RETARDANTS

Assessments by Environment Canada (2005) and by the UK Environment Agency (2007) have concluded that further studies are needed on BFRs, especially on highly brominated forms such as BDE209. Both assessments found that BDE209 is persistent but that more science was needed to assess bioaccumulation and toxicity. A key question is whether BDE209 debromination is significant under realistic environmental conditions thus resulting in the availability of more bioavailable and toxic congeners. There is growing evidence that BDE209 is

bioaccumulating, e.g. detection in herring gull eggs in the Great Lakes (Gauthier et al. 2007; Law et al ET&C 2006) although the pathways are not clearly defined. The combination of widespread distribution in the environment (including in remote regions), and presence in tissues of top predators (including sensitive life stages such as eggs) makes BDE209 a high priority for further study.

Fate and effects of a brominated flame retardant, decabromodiphenyl ether, in aquatic ecosystems

Principle Investigators and Collaborators

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Brad Park, Fisheries & Oceans Canada
Michael Paterson, Fisheries & Oceans Canada
Gregg Tomy, Fisheries & Oceans Canada

Special funding sources or support organizations

This study is funded by Environment Canada's Chemicals Management Plan. Fisheries & Oceans Canada provides in-kind support. DO is supported by NSERC, Alberta Ingenuity Fund, and the University of Alberta.

Purpose of the study

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 (Bromine Science and Environmental Forum 2003). PBDEs are "additive" flame retardants, meaning they are not chemically bound to polymers, and therefore, may leach from products into the environment. In fact, PBDEs are now ubiquitously found in air, water, fish, birds, marine mammals, and people (Hites 2004). PBDEs are even accumulating in remote areas, such as the Arctic, indicating they can be transported long distances in the atmosphere (de Wit et al. 2006). Concerningly, levels of PBDEs in the environment have increased over the last four decades (de Wit 2002). In North America, PBDE concentrations in the environment and people have increased exponentially with a doubling time of approximately 5 years (Hites 2004). PBDEs are a family of chemicals that have a diphenyl ether structure with anywhere between 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).

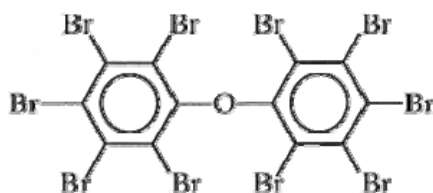


Figure 1. Structure of BDE-209

Three technical products of PBDEs have been synthesized: PentaBDE (mostly tetra- to hexa-BDEs), OctaBDE (mostly hexa- to nona-BDEs), and DecaBDE (mostly deca-BDE). Because of concerns about the toxicity of lower-brominated congeners, the use of PentaBDE and OctaBDE were banned in Canada, the USA, and the European Union. Consequently, DecaBDE became the most widely used PBDE product in North America and Europe. In 2008, the European Union and several US states banned DecaBDE, but DecaBDE continues to be used in Canada. Studies have established that PBDEs are endocrine disruptors, developmental neurotoxins, and possible carcinogens (Darnerud 2003). All PBDE products have been shown to disrupt the thyroid hormone system, as a consequence of their structural similarity to the thyroid hormone thyroxine (T_4) (Vonderheide et al. 2008). In general, lower-brominated PBDE congeners are more readily absorbed and more toxic (Birnbaum and Staskal 2004).

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.

We are examining the fate and effects of DecaBDE in aquatic mesocosms at the Experimental Lakes Area. Our experiment addresses three questions:

Question 1. Debromination of DecaBDE in the Aquatic Environment (Muir, Orihel, Darling)

One of the greatest uncertainties regarding the fate of DecaBDE is the extent to which this chemical is degraded in the environment (Vonderheide et al. 2008). While it has been suggested that degradation of DecaBDE in the environment is minimal (e.g., Hale et al. 2006), evidence is growing that DecaBDE can be degraded to lower-brominated congeners by several pathways. Recent laboratory studies have demonstrated that DecaBDE can be degraded by light (Eriksson et al. 2004, Soderstrom et al. 2004, Ahn et al. 2006b), sediment minerals (Keum and Li 2005, Ahn et al. 2006a), anaerobic microbes (Gerecke et al. 2005, He et al. 2006, Tokarz et al. 2008), and by fish (Stapleton et al. 2004, Tomy et al. 2004, Stapleton et al. 2006). Half-lives of DecaBDE in natural sediments vary by orders of magnitude in different experiments, from 40-60 hours (Soderstrom et al. 2004), 150 days (Ahn et al. 2006b), to 14 years (Tokarz et al. 2008). Our experiment will determine, for the first time, debromination rates of DecaBDE under natural field conditions. This information is critically needed for risk assessments of DecaBDE (Environment Canada 2006).

Question 2. Bioaccumulation of DecaBDE and its Degradation Products by Aquatic Biota (Tomy, Paterson, Dupuis)

PBDE concentrations have been widely measured in fishes, birds, and marine mammals (de Wit 2002, Hites 2004). 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 (Vonderheide et al. 2008). The available evidence does suggest that PBDEs are bioaccumulated by aquatic biota, and some congeners may be biomagnified in food webs. For example, bioaccumulation factors of selected PBDE congeners are on the order of 10^7 for lake trout in the Laurentian Great Lakes (Streets et al. 2006) and trophic magnification factors in the Lake Winnipeg food web range from 1.5 to 10.4 for different PBDE congeners (Law et al. 2006). In our experiment, we will examine 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 (Palace, Park)

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 (de Wit 2002). Exposure to PBDEs has lowered plasma levels of thyroxine in juvenile lake trout (Tomy et al. 2004), reduced sperm counts and body condition of male fathead minnows (Muirhead et al. 2006), and caused behavioral changes, such as activity levels, fright response, and predation rate, in larval killifish (Timme-Laragy et al. 2006). Our study will evaluate the toxicity of DecaBDE on an important forage and game fish species, the yellow perch (*Perca flavescens*). We will examine the effect of DecaBDE exposure, under natural field conditions, on thyroid and gonad histology, liver deiodinase enzyme levels, and daily growth rates (as inferred from otolith increment widths).

Brief description of the work carried out

Experiment A

In August 2007, four 10-m diameter mesocosms were installed at the south end of Lake 240, ELA (z = 2.6 m). Strips of wall material were hung from the center of each mesocosm for periphyton colonization. On September 6, 2007, a single dose of DecaBDE was added to three mesocosms (“low”: 0.023 g, “medium”: 0.21 g, and “high”: 1.9 g). The fourth mesocosm (“control”) did not receive DecaBDE. To apply the treatment, wet sediment was fortified with a DecaBDE technical product (DE83R; Great Lakes Chemical Corp) and sprayed over the water surface of the mesocosms. Approximately 1 month after treatment, yellow perch (*Perca flavescens*) were captured from Lake 240 and stocked in each mesocosm (at a density of 30 fish/mesocosm). Prior to stocking, fish were measured, weighed, and marked with an elastomer dye. An initial sample (n = 10 fish) was collected at the time of stocking. In October 2007, we sampled water, suspended particles, sediments, periphyton, zooplankton, and benthic invertebrates (*Ephemeroptera*) from the mesocosms. During the winter, we attempted to capture fish under ice, but achieved only a low sample size. Unfortunately, strong winds during spring melt in 2008 dislodged the base of the mesocosms from the lake bottom. In May 2008, we collected sediment cores and periphyton strips from all mesocosms, and were able to capture a few marked fish from the “low” mesocosm. In early June, we removed the mesocosms and moved them to a new location in Lake 240 (see Experiment B). The center of each mesocosm was marked with an underwater float, and an underwater fence (constructed from vapor barrier and wooden posts) was installed around the site of the “high” mesocosm. We sampled the sediments at the original site of the “high” mesocosm site in October 2008.

Experiment B

In June 2008, four 10-m diameter mesocosms (originally from Experiment A) were installed in the northwest corner of Lake 240, ELA (z = 2.3 m). Strips of wall material were hung from the center of each mesocosm for periphyton colonization. On June 18, 2008, we added a single dose of DecaBDE to three mesocosms (low: 0.039 g, medium: 0.28 g, and high: 2.3 g). The fourth mesocosm (control) did not receive DecaBDE. We followed a similar protocol for applying the DecaBDE treatment as in Experiment A, except this time we fortified freeze-dried sediment. On July 15, 2008, we captured age 1+ yellow perch from Lake 240 and stocked the mesocosm (at a density of 30 fish/mesocosm). An initial sample (n = 16 fish) was collected at

the time of stocking. In early July, mesocosms were also stocked with eggs (2250 eggs/mesocosm) of a common mayfly species native to Lake 240 (*Hexagenia* sp.). In July and October 2008, we sampled water, suspended particles, sediments, periphyton, and zooplankton in mesocosms. We collected yellow perch (n = 10 per mesocosm) in October 2008.

Listing of any significant findings or results to date

Question 1 (Muir/Orihel/Darling)

To date, we have analyzed PBDE concentrations in sediments, and preliminarily conclude that:

- DecaBDE added to in-lake mesocosms degraded to at least hepta to nona-BDEs within months in both mesocosm experiments
- Degradation occurred more rapidly in summer, when penta and hexa-BDEs were observed as soon as 1 month after DecaBDE addition
- DecaBDE breakdown products in sediments accumulated over time, with concentrations increasing up to 10-fold over 3 to 5 months
- Congener patterns of octa- and nona-BDEs in both mesocosm experiments were similar to those recently observed in natural lake sediments (Kohler et al. 2008)

Question 2 (Tomy/Paterson/Dupuis)

No results to report to date.

Question 3 (Palace/Park)

No results to report to date.

Current status of the study, including any plans for 2009 and beyond

Experiment A

We will continue to monitor sediments of the original “high” mesocosm site in 2009. Sediment cores will be collected in May and October 2009 and analyzed for PBDE concentrations.

Experiment B

We will continue to monitor all four mesocosms in 2009. Water, particles, sediments, periphyton, and zooplankton will be sampled in May, July, and October, 2009 and analyzed for PBDE concentrations. Benthic invertebrates will be sampled in October 2009. Yellow perch will be re-stocked in the mesocosms in June 2009, collected in October 2009, and analyzed for PBDE concentrations and toxicity end-points (i.e., thyroid and gonad histology, liver deiodinase enzyme analysis, and daily otolith increment measurements). Mesocosms will be removed in summer 2010.

Experiment C

We will examine the effect of different methods of sample storage on PBDE determination. In 2009, 12 sediment cores will be collected from Lake 240 and treated with freeze-dried sediment fortified with DecaBDE technical product. Sediment cores will be incubated at 20°C and under ultra-violet light for 30 days. After this incubation period, the top 1-cm of each core will be collected in glass jars and stored in darkness: (i) at room temperature (20°C); (ii) in the fridge (4°C), or in the freezer (-10°C). Each storage treatment will have four replicate samples

[alternatively, each sample could be homogenized, sub-sampled, and each subsample subjected to a different storage condition]. Samples will be stored for 4 months, and then analyzed for PBDE concentrations.

Publications

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, November 16 - 20, 2008, (poster presentation).

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ENVIRONMENTAL IMPACTS OF AQUACULTURE

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

Impacts of Cage Aquaculture on Lake Ecosystems

Purpose

This whole ecosystem study has been developed to assess the environmental and ecological impacts of cage aquaculture under current industry practices. The study will determine the impacts of aquaculture on water quality, primary production, sediments and native invertebrate and fish communities. A mass balance approach and the measurement of stable sulfur, carbon and nitrogen isotopes will be used to trace the movement of aquaculture-related waste materials in the ecosystem. Originally planned for three years, in 2004 the project received approval for an additional four years of funding from the Aquaculture Co-operative Research and Development Program (ACRDP). The project has just completed its sixth year, which was the first year of recover after the cessation of fish farming. We are about to enter the final year of this study.

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2008 Study Activities

Limnology:

On a monthly basis, samples for water quality analysis were collected along depth profiles in both the north and south basin of the lake. Also on a monthly basis, but on alternate weeks (resulting in biweekly sampling), depth-integrated samples were collected from the epi, meta,

and hypolimnion at the same stations. As we have consistently found no difference in values between the two stations, sampling at the farm station will be 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. Sediment traps were collected weekly in both basins to determine sedimentation rates of carbon, nitrogen, and phosphorus. On a biweekly basis, a YSI multi-parameter probe was used to construct meter by meter depth profiles for temperature, oxygen, pH, conductivity, turbidity, and fluorescence at 12 stations placed along the north-south axis of the lake. Secchi depths were also determined at each station.

Secchi depth decreased over the years of fish farming, with lowest values typically observed directly after spring turnover. The first year of recovery was 2008. Spring 2008 Secchi depths were again quite low, but by mid-summer, Secchi depth values had recovered to pre-farming values.

In March of 2008, 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. Dissolved oxygen under ice has not reduced over the 5 years of fish production.

Phytoplankton and Bacteria:

As in all previous years of this project, phytoplankton and bacteria were sampled bi-weekly from the deep stations in the north and south basins throughout the ice-free season in 2007 using an integrated sampler. Samples for both 2007 and 2008 are being analyzed and the data is not yet available.

A manuscript describing changes in water chemistry and in the pelagic algal community has been accepted for publication by the Canadian Journal of Fisheries and Aquatic Sciences for publication in 2009.

Littoral Periphyton;

No field work was conducted in 2008

Zooplankton:

In 2008, 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.

Mysis and zooplankton samples from 2008 have been counted and processed. Zooplankton data from 2008 are still being entered in the ELA zooplankton database. 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 the loss of suitable habitat for *Mysis*.

Periphyton trays:

Discontinued in 2008.

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 settleable 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. 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 in creased sediment oxygen demand, a confounding factor is the incomplete spring turnovers which have been observed to occur in L375 for several years now. In 2008 even the fall turnover was incomplete. The failure to turnover will significantly contribute to hypolimnetic oxygen deficit. A modeling exercise is currently being undertaken by Alain Dupuis, a new biologist recently hired, 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 250µm sieve and were preserved in 10% formalin. These samples are being processed, but progress is limited by the limited funding and staff available for this work. The biweekly sampling may be discontinued in 2009 due to reduced budget.

A manuscript describing the effects of the L375 farm on sediment chemistry has been accepted for publication by the Canadian Journal of Fisheries and Aquatic Science in 2009. A second manuscript discussing impacts to the benthic community will be submitted in the next month.

Energy Transfer to the Native Food Web:

Little is known about the effects of cage culture on the native food web. The main objective of this component of the study is to assess whether the aquaculture fish feed or trout faeces are being used as a novel energy source by the Lake 375 biota. To achieve this, we are examining the carbon, nitrogen, and sulphur stable isotope signatures of invertebrates and fish collected before and after the introduction of cage aquaculture into L375. During the 2008 field season, monthly samples of zooplankton, mysis, chironomids and Heptageniidae mayflies were collected and archived. There were no widespread collections of benthic invertebrates.

A manuscript discussing the stable isotope work has been accepted by the Canadian Journal of Fisheries and Aquatic Sciences for publication in 2009.

Wild Fish:

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

Fish populations of Lake 375 continued their positive responses to cage culture in 2008 even though this was the first year of post-culture recovery. This was not unexpected based on the results of previous whole-lake fertilizations studies conducted at the ELA. We conducted field studies of the fish populations of Lake 375 in the spring and fall of 2008, similar to previous years.

There is a one year lag in forming abundance estimates for lake trout in Lake 375 and reference lakes because of the mark-recapture methodology that we use. We can now confirm that the abundance of lake trout in Lake 375 during the fifth year of cage culture, 2007, was more than twice the number before the experiment started in this lake. We can also confirm that the increased abundance in this lake was caused by a combination of increased annual survival of all lake trout in the lake, and increased recruitment during the five years of cage culture. Most of the increase in abundance is due to increased recruitment.

Lake trout growth and condition remained higher than pre-cage-culture. This was not surprising because abundance of cyprinids, young-of-the-year white sucker, and slimy sculpin continued to be higher than pre-cage-culture values.

Behavior 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, behavior, and habitat availability; and, (2) to examine the survival and behavior 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.

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

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

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

A manuscript describing the behavior and survival of escapees from the L375 farm has been accepted for publication by the Canadian Journal of Fisheries and Aquatic Science in 2009.

Sampling at Commercial Farms:

No sampling occurred in 2008.

A manuscript from our waste feed monitoring project of 2006/7 at ELA and 3 commercial sites is currently in preparation, and a technical report describing the results of the Lake Huron benthic sampling in 2006 is also currently in preparation.

Plans for 2009:

In the final two years of this project, our focus has shifted to monitoring ecosystem recovery. We will continue to monitor water chemistry on the same schedule but will discontinue sampling the second station directly beside the cage to reduce our analysis budget.

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 along the distance transects in spring and fall of 2009, but detailed analysis of the process of sediment recovery will not be possible.

Currently the primary question is whether or not any components of the project will be able to continue past 2009. Clearly there would be significant value in continuing Ken Mill's work on the wild fish population to see for how long after the cessation of fish farming the lake continues to support increase lake trout growth, survival and reproduction. Additionally, because sediment quality and benthic invertebrates are poised to become quite influential in the regulation of fish farming activities in Ontario, gaining a better understanding of sediment recovery would also be of significant value.

It is very 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 harmonized 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 a significant improvement in regulation. 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 the past 6 years, 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. We shall therefore have to look to other funding sources. Unfortunately the current economic climate is not favorable for scientific funding and this may mean that the L375 project will end in March 2010.

Effects of Seismic Exploration

The oil and gas industry in Canada has increased their use of explosive-based seismic exploration in the arctic to levels not seen since the 1970s. There is concern regarding these activities because the instantaneous pressure changes (IPC) produced in the water column from the detonation of explosives can have harmful effects on fish. Damage to soft tissues such as the swimbladder can occur from the negative peak pressure expanding these tissues beyond their elastic capacities and resulting in rupture. This can lead to direct mortality or injury and secondary infection. While there are some studies examining the effects of IPC on fish, these assessments have largely been limited to effects identified through gross in-hand examinations immediately after the explosions.

Sub-Lethal Effects of Instantaneous Pressure Changes on the Internal Organs of Fish

Principle Investigators:

Dr. Vince Palace (DFO)
Danielle Goddard (University of Manitoba)

Purpose

It is well documented and acknowledged by industry and regulators that the use of explosives under ice in fish bearing waters is potentially harmful to fish (Wright and Hopky 1998; Capp 2004). Because of the recognized risks of IPCs, the Department of Fisheries and Oceans (DFO) has established a *Guideline for the Use of Explosives In or Near Canadian Fisheries Waters*. These guidelines outline that maximum peak pressure not exceed 100 kPa in order to protect fish. However, the 100 kPa value was derived from the literature and represents an LD50 value (ie. lethal dose to 50% of exposed fish), (DFO Winnipeg, Personal communication). Additionally, the limited data used to develop the 100 kPa guideline were collected in the 1970s. Today's technology is capable of measuring pressure changes in resolution and accuracy orders of magnitude better than in the 1970s, and can be used in the collection of scientifically defensible data required to derive new guidelines for Canadian waters.

Approach

In order to provide scientifically defensible data regarding the guideline IPC, lake trout (*Salvelinus namaycush*) and white sucker (*Catostomus commersoni*) were captured under the ice using short gill net sets (max. 20 minutes) from Lake 382 at the Experimental Lakes Area. After capture, the fish were held in nylon mesh cages away from the eventual site of detonations. Eight (8) fish were exposed to individual IPCs of approximately 20, 50, 70 and 120 kPa by being held in cages in the vicinity (10-15 m away) of detonations. After each detonation, each fish was examined for gross external pathologies and removed from the area of detonation and again held in a cage for another 24 hours. After 24 hours each fish was euthanized and tissues were preserved to examine gross internal pathologies and microscopic damage. To generate the IPCs required for this experiment, explosive charges were deployed using a remote loading pole from the overlying ice surface. The charges were deployed 1-2 m deep in the sediments. Cages were held 10-15 meters from the site of detonation and midway between the lake bottom and the ice platform. IPCs were monitored for each detonation using seismographs and 3 hydrophones.

Preliminary Results

Preliminary gross pathological findings have shown evidence of swimbladder damage in swimbladder bearing fish near the current *Guideline*. At the present time, histopathological examination of tissues (liver, kidney, intestine) in both swimbladder and non-swimbladder bearing fish is being undertaken. Pending publications include a masters thesis and a possible DFO technical report.

Plans for 2009 and beyond

The detonation of explosives in Lake 382 has the potential to harm resident fish not recruited for the experiment either directly or indirectly. Direct harm could be done to fish that happen to be in the vicinity when detonations are performed. Follow up population monitoring,

similar to that done by Dr. Ken Mills for the past several decades on Lake 382, will be performed to monitor for this possibility. Indirect damage to resident fish could arise from sediment mobilization resulting from the detonations. Lake 382 has been historically treated with low concentrations of the metal cadmium. To assess the remobilization of sediment from detonations, concentrations of Cd will be monitored in resident fish. Follow up monitoring of Lake 382 will be undertaken for the next 2 years.

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