

# **SUMMARY OF MAJOR RESEARCH PROJECTS AT THE EXPERIMENTAL LAKES AREA DURING 1998**

1 December 1998

Renewal and refocusing has continued at the ELA during 1998. A new workshop complex and a new station manager's residence were constructed during the winter, and work is just getting underway on the first phase of a new laboratory complex at the field station. Two positions, including a new research scientist position, were staffed this fall, and three more research scientist positions are scheduled to be staffed over the next few months. Long-term ecological research was given a more independent status within the program, acknowledging the inherent value of the ELA long-term data record on unperturbed systems. Monitoring of lakes recovering from acidification continued, as did an enlarged program of investigation into food chain linkages in lakes of different trophic status. Much of the research effort was again focused on studies examining the effects of reservoirs. The ELA Reservoir Project and the Lake 226 drawdown study were scaled back somewhat, but the new upland flooding project got underway and the enclosure walls for three upland reservoirs were constructed. Several other new research proposals are under development.

Total site use increased significantly over 1997, in part because of winter construction activities. While more than 100 research personnel, representing a number of government agencies, universities, and corporations worked on site during the 1998 field season, the trend was toward fewer individuals, each spending more time on site. Construction activity on site is expected to continue into the spring and resume next fall. The following is an attempt to summarize the status of major projects by providing some information about their purpose, design and, where possible, significant results. It should be noted, however, that data analyses are ongoing and many of the results provided here are preliminary. These projects are grouped under several broad category headings.

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## 1. BIOMANIPULATION AND SYSTEM 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 chain. 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.

### 1.1 Biomanipulation and Fertilization of Lake 227, and Biomanipulation of Lake 110

Lake 227 was fertilized with phosphorus for the 30th consecutive year in 1998. The original 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.

In May of 1993, 40 male northern pike (*Esox lucius*), a piscivorous fish, were added to Lake 227. These fish were transferred from Lakes 222 and 663 at spawning time, when individuals could easily be sexed. An identical transfer of pike to Lake 110 was completed in the spring of 1993. Transfers of pike to Lakes 110 and 227 were undertaken after obtaining approval from the Ontario Ministry of Natural Resources. Major ions, nutrient chemistry, nitrogen fixation, primary production, zooplankton, benthos, and fish populations were examined in both lakes and in reference Lake 240 throughout the study. Changes in background levels of mercury and organochlorines (PCB's) in fishes and other biota were also monitored during the experiment.

During 1997, 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.

In the fall of 1998, as in 1995, 1996, and 1997, Lake 227 was fished to ensure removal of all adult pike. No fish have been caught for several years and we assume that all pike have been removed from the lake. There has been no evidence of pike reproduction.

No fish studies were carried out in Lake 110 during 1998. We believe that some adult pike remain in the lake, but no evidence of pike reproduction has been observed.

### 1.2 Stoichiometry and Food Web Dynamics

During recent years, a joint research undertaking (The Stoichiometry Project), involving DFO and researchers from Arizona State University (ASU)(Dr. James Elser), the University of Texas at Arlington (Dr. Tom Chryzanowski), and the University of Minnesota (Dr. Robert Sterner), have investigated how

changes in zooplankton community structure alter the relative availability of N and P supporting phytoplankton and bacterial production. This research centred on changes in the stoichiometry of N and P in two lakes, artificially-eutrophic L227 and oligotrophic L110, following introduction of piscivores [see 1.1, above].

In 1998, a series of research projects at the ELA provided follow-up to the earlier studies. These studies, largely funded by the United States National Science Foundation (NSF), are headed by Dr. Elser, Dr. J. Urabe of Kyoto University, Dr. Chrzanowski and Dr. J. Grover of the University of Texas, and Dr. Sterner.

### ***1.2.1 Stoichiometric Responses to Food Chain Manipulation***

Sampling of two manipulated lakes (L110, L227) and reference a lake (L240) continued in 1998. These are ongoing studies from a prior NSF project at ELA in which piscivorous pike were added to Lake 110 and Lake 227 [see 1.1, above], and responses of the lower food web were monitored during the ensuing period with an emphasis on stoichiometric parameters.

Both lakes continue to indicate interesting transient dynamics to the manipulations. A new manuscript for the Lake 110 experiment is planned for the period of 1996-1998; this is a follow-up to a published paper (Elser et al. 1998) reporting the potential existence of stoichiometric constraints on food web dynamics in Lake 110 given its very high seston C:P ratios. Data analysis for the Lake 227 experiment for the period of 1992-1996 is underway and a manuscript summarizing the spectacular re-organization of the Lake 227 ecosystem during 1996's *Daphnia* bloom is in preparation.

### ***1.2.2 Testing the Light:Nutrient Hypothesis***

A large, mesocosm experiment was conducted in ELA Lake 239. This experiment involved the establishment of 18 enclosures (1-m diameter, 4-m depth) that were subjected to a 3 x 3 factorial manipulation of light intensity and nutrient supply. The experiment is testing the "light:nutrient hypothesis", which states that light:nutrient balance is a key parameter affecting seston C:P stoichiometry and thus food web dynamics in pelagic ecosystems.

A large suite of ancillary and core limnological parameters were measured in each enclosure on a 6-day sampling schedule over a 10-week period. These included light extinction, inorganic nutrient dynamics, bacteria and protozoa abundance, phytoplankton and zooplankton abundance and species composition, seston C:N:P ratios, zooplankton C:N:P ratios, light vs. nutrient limitation of algae, DOC vs. nutrient limitation of bacteria, grazing and nutrient recycling rates by macrozooplankton, and C:P food quality of seston for *Daphnia* growth.

Samples from this experiment are being processed and data should be available for analysis this winter.

### ***1.2.3 Microbial indicators of biological integrity and nutrient stress***

Dr. Chrzanowski and Dr. Grover are examining several chemical and biological variables that may not only provide broadly applicable approaches to understanding the biological consequences of nutrient loading in aquatic systems, but may also provide a means of predicting the resulting community structure. The indicators being examined are seston C:N:P ratio, species level responses of algae to nutrient bioassays, community level responses of bacteria to nutrient bioassays, community structure of algae, community structure of bacteria, and the estimated ratio of algal to bacterial specific growth rates.

During 1998, technical staff (1.5 persons) were on site from 15 May through 28 August. Principle investigators (2) were on site for approximately 25 days each. During the period from 15 May to 28 August, Lakes 227 and 239 were each sampled bimonthly. Data on physical limnology (light, temperature, and dissolved oxygen profiles) were collected for each sampling interval. Epilimnetic water

samples were collected synoptically with data on physical limnology. Water samples are being analyzed to determine dissolved nutrient loads (C, N and P species). Particulate fractions of the water are being analyzed to establish seston C:N:P ratios. Fifteen nutrient bioassays were conducted (7 for L239, 8 for L227). Growth of bacteria in L239 were found to be limited by availability of C, N and P, whereas growth of bacteria in L227 was limited primarily by availability of C and N. Patterns of substrate utilization suggest that bacterial communities in the lakes respond differently to substrate availability and may be separated by ordination analyses.

The University of Texas research team plans to replicate their sampling effort through the summer of 1999. No new experimental studies or manipulations are planned.

#### **1.2.4 Student Projects**

A variety of sampling efforts and experiments were performed by Paul Frost, ASU PhD student. These studies are a part of his PhD thesis studies investigating factors associated with the C:N:P stoichiometry of benthic communities in ELA lakes. Data are being processed.

An undergraduate research project was performed by Craig Herbold (University of Southern California) investigating the possibility of intra-specific facilitation of growth of *Daphnia* via stoichiometric feedbacks. Data from this project are still being processed.

#### **1.2.5 Ancillary studies**

Several side projects of various kinds were also performed in 1998. Of particular note are experiments using lake water from Lake 239, Lake 240, and Lake 979, in which researchers tested for actual P-limitation of *Daphnia* given the quality of available seston. Preliminary data indicate a positive response of *Daphnia* growth to P supplementation when the animals were raised on seston from Lake 239 and Lake 240 (high seston C:P lakes), but no response to P when fed seston from Lake 979 (a low seston C:P lake). If these data hold up, they will be the first direct evidence for P-limitation of zooplankton growth in nature.

### **1.3 Nutrient Cycling and Food Chain Effects**

Dr. Jeff Hudson, a Killam Postdoctoral Fellow at the University of Alberta, carried out several studies relating nutrient cycling to food chain effects. His objectives were to:

- 1) Examine the effect of nutrient cycling on primary production in ELA lakes.
- 2) Examine the effect of piscivorous and planktivorous fish on nutrient cycling in ELA lakes and lakes in Alberta
- 3) Examine the effect of carbon, nitrogen and phosphorus stoichiometry on nutrient cycling in ELA lakes and lakes in Alberta.

Sampling was carried out on a number of ELA lakes during late summer. Samples and data are still being analyzed and results may be available this winter.

Currently, there are no plans to continue this research in 1999.

### **1.4 Biomanipulation of Lake 221**

Lake 221 is the site of a biomanipulation experiment that started in 1987 when 123 northern pike were transferred to this lake from nearby Lake 222. Water chemistry, primary productivity, phytoplankton

populations, zooplankton, zoobenthos, and fish populations were studied in Lake 221 before and after pike addition. The Recovery phase of the experiment started in 1994 when approximately 80% of the northern pike were removed from this lake. Netting continued in 1995, 1996 and 1997. The presence of several younger fish in the 1997 catch indicated that the pike are reproducing in this lake. Water chemistry, phytoplankton, and zooplankton populations were monitored again in 1998, but no fish studies were conducted.

The Lake 221 ecosystem underwent significant changes during the initial 5 years following pike introduction. Yellow perch populations, pearl dace populations, total zooplankton biomass, and phytoplankton biomass were significantly reduced. Two populations (Chaoborus and bacteria) benefited from the introduction of pike. Overall, Lake 221 shifted from having a plankton-supported food web to having one supported by bacteria. Monitoring of the lake has continued through 1998 to address the key question whether such a lake ecosystem can reach a new equilibrium and, more importantly for management, can this new equilibrium be sustained. Lake 221 results, to date, suggest that this is possible. In Lake 221 the zooplankton, phytoplankton, and bacteria have been stable over the past 5 years, and there has been no significant change in major nutrients.

### **1.5 Experimental Cropping of Lakes**

The lake whitefish populations of Lakes 258, and 305 were experimentally fished to simulate a pulse commercial fishery in 1981 and 1982. Recovery of these populations has been monitored by over-night sets of gill nets one to two nights per year since the initial cropping. Reference Lakes 259 and 468 are also monitored using similar netting techniques. In 1998, only Lakes 259 and 468 were fished. Data from these reference lakes are used to interpret lake whitefish data from other ELA experiments.

### **1.6 Effects of Macrophyte Removal on Pike Populations**

Lake 191 at the Experimental Lakes Area is the site of a macrophyte (aquatic plant) removal experiment to determine the change in northern pike production when half of the macrophytes present in the littoral zone are removed.

After two years of background study, macrophyte harvesting was initiated in 1996. A mechanical harvester removed fifty percent of the macrophytes present in the lake by August 1996 and the cut areas have been maintained during 1997 and 1998. Changes in water chemistry and all trophic levels in the lake are monitored during the study.

The primary changes that occurred after cutting have involved fish populations. The population structure and abundance of northern pike changed almost immediately after harvesting began. Total abundance has decreased and abundance of age 0 (young of the year) northern pike has also decreased. Few age 0 pike were present in the cut areas. Larger, intermediate-sized northern pike were displaced from littoral areas to deeper water, and their abundance has markedly declined. Abundance of prey species, yellow perch and pumpkinseed, have steadily increased. This has led to changes in the species structure of zooplankton because of increased grazing by plantivorous pumpkinseed and yellow perch. This has resulted in a size shift in the phytoplankton community towards smaller species. The major changes observed in 1998 were further increases in the abundance of small yellow perch and decrease in abundance of northern pike.

The study will continue in 1999, probably with funding from additional sources. Macrophytes will be harvested for the fourth year and impacts documented on the water chemistry, fish, and other biota of the lake.

## **2. PHYSICAL PERTURBATIONS**

This section includes experimental studies in which some physical aspect of the ecosystem has been manipulated. In most cases, this has involved experimental alteration of the water level, as a simulation of what typically occurs during the creation and operation of reservoirs. In Canada, these reservoirs are generally created primarily for generation of hydroelectricity. Many cause flooding over large areas of northern wetland and forest land.

### **2.1 Experimental Lakes Area Reservoir Project (ELARP)**

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 GHG's carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>) to the atmosphere.

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 byproducts of the decomposition of the flooded vegetation in the peatland are CO<sub>2</sub> and CH<sub>4</sub>. Mobilization of MeHg within the flooded ecosystem and release to the atmosphere of CO<sub>2</sub> and CH<sub>4</sub> 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 Wetland 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 1996, 1997, and again in 1998, the 979 wetland was flooded for the fourth, fifth and sixth consecutive summers. While the system was studied less intensively, GHG emissions and MeHg mass-balance budgets were monitored.

#### **2.1.1 Greenhouse Gas Emissions**

Dr. Vincent St.Louis from the University of Alberta, and Amy Partridge, a student from the University of Manitoba, in collaboration with Drs. John Rudd and Carol Kelly (Department of Fisheries and Oceans), continued to study greenhouse gas fluxes and rates of peat decomposition in the ELARP reservoir during 1998. The researchers measured fluxes of CO<sub>2</sub> and CH<sub>4</sub> diffusing from the surface water of the reservoir, as well as fluxes of these gases in bubbles ebullating from the bottom of the reservoir. These studies showed that five years after the initial flooding of the peatland, rates of decomposition and fluxes of GHGs are still elevated, at times reaching levels not previously observed.

To determine the extent to which decomposition of peat contributed to this flux, they systematically incubated in the laboratory flooded peat from the reservoir, as well as peat collected from an unmanipulated reference peatland. They found that flooded peat not only decomposed faster at the flooded peatland than the reference peat collected, but that flooded peat produced proportionately more

CH<sub>4</sub> than did unflooded peat. This is important because CH<sub>4</sub> is a much more potent GHG than CO<sub>2</sub>. This study will be published in the upcoming year.

The peat incubations determined rates at which peat decomposes in anaerobic conditions such as those commonly found in reservoirs. However, pieces of peat may break off floating peat islands in reservoirs, and fall into the aerobic water column. Amy Partridge completed a 4<sup>th</sup> year honours project to test the hypothesis that peat decomposes faster aerobically than anaerobically. She did enclosure experiments in which she incubated in the lake both pieces of peat and chunks of peat. She found that pieces of peat dispersed in aerobic water decomposed at the same rate as peat decomposing anaerobically in a chunk. However, she found that pieces of peat acidified the water, leading to a shift in the carbonate equilibrium and proportionally more dissolved CO<sub>2</sub> than observed in the water with the chunk of peat. Amy plans to publish her results.

### **2.1.2 Methylation of Mercury**

Monitoring of MeHg production and mass balances has continued under the direction of Drs. Rudd and Kelly. While MeHg concentrations in the 979 reservoir remained elevated, MeHg mass-balance budgets indicate that mercury methylation rates have slowed dramatically, although they remain above pre-flooding levels. Concentrations of MeHg in the flooded peat, where most of the newly produced MeHg has been sequestered, are nearing pre-flood levels.

The drop-off in MeHg concentrations while GHG emissions remain relatively constant is of interest. At the outset of this study, the research team hypothesized that GHG fluxes and MeHg concentrations would be linked over time. Most of the flooded vegetation has now decomposed, which means that current gas fluxes are being supported more by peat decomposition. The researchers now believe that methylation must be linked more to decomposition of vegetation (which had slowed considerably 5 years after initial flooding), but not linked as strongly to peat decomposition. This has important implications for interpreting gas fluxes in older reservoirs, which often remain high after many decades, while mercury in fish decreases after 1 to 2 decades. The ELARP research team has recommended that fish be removed prior to and just after reservoir flooding, so that the top of the food chain is not exposed during the periods of highest methylating activity.

The experimental reservoir will continue to be flooded each summer, but the experiment has entered a long term monitoring phase and the reservoir will not be studied during 1999 and 2000. Funding is in place for the year 2001, when changes in GHG fluxes and MeHg cycling/bioaccumulation will be studied again.

### **2.1.3 Methylmercury uptake by Tree Swallow Nestlings**

Monitoring of the tree swallow (*Tachycineta bicolor*) population nesting adjacent to the experimental reservoir (L979) has continued since the Experimental Lakes Area Reservoir Project (ELARP) began in 1992. The primary objective of this research is to determine if increased rates of MeHg production in the reservoir results in bioaccumulation of MeHg in birds to levels that affect their reproductive success.

This work is conducted by Dr. Vince St. Louis and a graduate student, Pauline Gerrard, from the University of Alberta. Over the last seven years, they have monitored 11 nestboxes on Lake 979 and 24 nestboxes on various reference lakes and wetlands. In an effort to study the rates and effects of MeHg uptake in tree swallows nesting around the experimental reservoir, they measure growth parameters after hatching, as well as total Hg (THg) concentrations in roughly half of the nestlings before they fledge. Since the majority of Hg in tree swallows is MeHg, they are able to compare MeHg concentrations in the tree swallows to those measured in Diptera, their primary food source, emerging from their respective lakes.

Following experimental flooding of the wetland in 1993, concentrations of MeHg in the dipteran flies had increased up to 3-times pre-flood levels by 1995. Their emergence resulted in a large increased flux of MeHg from the reservoir, and they were a major food source for many species of insectivorous songbirds, such as tree swallows, during the avian breeding season. THg burdens in tree swallows nesting around the reservoir increased immediately after flooding and, by 1997, reached levels that were double pre-flood measurements. In 1996 and 1997, the researchers also began analyzing four main target tissues (brain, liver, muscle, and feathers) for THg bioaccumulation. THg levels in the feathers show highly-elevated concentrations, where Hg is bound and molted annually. THg concentrations in the tissues remained relatively low and will be directly compared to those published for similar toxicity studies.

During the summer of 1998, the University of Alberta researchers continued to monitor reproductive parameters and collect eggs and nestlings for analyses of THg accumulation. They also collected dipteran emergence for biomass estimates and analysis of MeHg. They will continue this work through 1999 and complete an eight-year data set on the tree swallows nesting in the area.

Goals for the completion of this project include:

- continued collection of dipteran emergence for biomass estimates and analyses of MeHg in the summer of 1999;
- continued monitoring of the reproductive success of swallows breeding near the experimental reservoir and reference sites;
- continued collection of tree swallow eggs and nestling tissues for analyses of THg accumulation;
- analyses of tissues collected in 1998 and 1999;
- calibration of the proportion of THg in individual tissues that is MeHg;
- summarizing all Hg analyses and avian reproductive parameters collected to date; and
- Scientific publication of findings.

The data obtained from this study will provide a novel input to the whole-ecosystem mathematical model of mercury cycling in reservoirs currently being developed by Reed Harris of Tetra Tech Inc.. Most mercury models do not consider the potential export of mercury out of the aquatic system, and how much of the exported MeHg then bioaccumulates in terrestrial organisms.

#### **2.1.4 "Bioreporter" Project**

In a related project, the use of a genetically engineered "bioreporter" to measure the bioavailability of inorganic mercury in lake water is being tested. Inorganic mercury is turned into MeHg, which is more toxic, by bacteria that carry out methylation. The inorganic mercury must enter the bacterial cells to become methylated, but a lot of mercury in aquatic systems is bound to particles and DOC, and so is not bioavailable for methylation. The bioreporter system, which is a strain of bacteria that produces light when mercury enters its cells, allows scientists to quantify bioavailability. The ELA part of this work has been done by Karen Scott, who is a graduate student in Microbiology at the University of Manitoba. She has continued to measure bioavailability of mercury, testing and refining use of the Bioreporter system in natural waters.

## **2.2 Lake 226 Drawdown Study**

The purpose of the Lake 226 experiment is to study the impacts of winter, water level drawdown, simulating the water level fluctuations in a northern hydroelectric reservoir. The lake has been studied for one year prior to drawdown (1994), for three years after and during drawdown (1995, 1996, and 1997), and for one year after recovery from drawdown (1998).

In the winter of 1994-95 the water level was reduced by 2 m below natural levels. Approximately 30% of the lake water volume was removed, resulting in a decrease of about 11% in lake surface area. The lake rose during the spring and early summer by about 0.5 m, but the level stayed relatively constant during the summer and fall at about 1.5 m below natural levels, as runoff into the lake was approximately balanced by evaporation. In the winters of 1995-96 and 1996-97 the water level was reduced by 3 m below natural levels. The lake rose during the spring and summer of 1996 and 1997 due to snow melt and summer rains. Lake elevation at freeze-up in 1996 and 1997 was approximately 0.8 m below natural levels. The lake was not drawn down in the winter of 1997-98 and natural lake elevations were achieved early in the summer of 1998.

The following impacts of drawdown have been observed on Lake 226. The water column of Lake 226 has remained mostly unchanged, or only slightly impacted, by winter water level drawdown. Epilimnion depths, suspended sediment levels, and light penetration were unchanged. Oxygen may be showing decreases since drawdown, at least in late winter, when concentrations in March after drawdown (1996 and 1997) were less than before drawdown. Nutrient concentrations, primary production, chlorophyll concentrations, and phytoplankton populations were not significantly affected by drawdown. Zooplankton populations, including Chaoborus, also have not been dramatically affected by drawdown.

The nearshore zone of Lake 226 has been severely affected by drawdown, in almost all respects studied. Macrophytic vegetation has decreased significantly since drawdown. Epilithic algal communities have also changed significantly. Benthic macroinvertebrates in the near shore zone have declined significantly. In contrast, in the profundal zone, benthic invertebrates increased or maintained their abundance.

The nearshore zone of the lake was classified for substrate type and slope. Substrate information was combined with lake whitefish position information during the spawning season and derived from tagging information. The nearshore substrates most utilized by these fish all included large and small cobble. Depths of presumed spawning ranged down to 4.4 m. Eggs were located at one of these sites in the fall of 1997 by a cooperative SCUBA diving sampling effort of DFO and OMNR.

Complete year class failures of lake whitefish were observed after both 2 and 3 m drawdowns. Actual egg deposition must, therefore, have been only in the shallow parts of the nearshore zone. The total abundance of lake whitefish decreased significantly both before and after drawdown, due to 2-3 naturally weak year classes before drawdown and year class failures following drawdown. Estimates of survival were quite constant for all sample periods except for the winter of 1996-97, when survival estimates were significantly smaller. The abundance of forage fish did not change after drawdown.

The lake will not be drawn down over the winter of 1998-99, as researchers continue study of the lake during recovery from drawdown. Rather, the water level will be allowed to continue at natural levels until the spring of 1999. Anticipated funding from new sources may permit continued studies during 1999 and beyond in which the lake level is experimentally adjusted to different levels.

### **2.3 Upland Flooding Experiment**

The purpose of the Upland Flooding Experiment is to study the greenhouse gas and mercury impacts of flooding forested upland areas. This experiment is a sequel to the ELA Reservoir Project (see 2.1, above). Three forested uplands of different moisture types and located in the watershed of ELA Lake 458 (Roddy Lake), will be flooded in June 1999 to create simulated hydroelectric reservoirs.

During 1998, extensive work was carried out to prepare the sites for the experiment. Vegetation and soil cover were removed to expose the bedrock along the downhill margins of the three selected areas. Dikes that will contain the water were then constructed directly on the exposed bedrock. The vegetation on the areas enclosed by the dikes has been left undisturbed and pre-flood monitoring has commenced in these areas.

The three areas will be flooded by pumping water from nearby Lake 468, which is low in mercury and dissolved organic carbon. Flushing rates will be equalized among the reservoirs by maintaining pumping rates proportional to reservoir volumes. GHG fluxes before and after flooding will be measured at all three sites. Carbon dioxide, methane and nitrous oxide will be monitored. Fluxes will be compared to the previously flooded boreal wetland and to existing hydroelectric reservoirs to determine the potential greenhouse gas contribution of global freshwater reservoirs. The production of MeHg from flooded soils and the bioaccumulation of MeHg through the food chain will be measured in the experimental reservoirs. Mitigation strategies that will have direct planning application will be developed.

**Study schedule and plan**

**1998-99:** dam construction, background data collection including site characterization of vegetation, mercury inventories in soils and vegetation, carbon inventories, and set up of pump and piping water supply system hydrological network completed

**1999-00:** year 1 of flooding, measurement of GHG emissions and mercury dynamics

**2000-01:** year 2 of flooding, study of GHG emissions and mercury dynamics; mitigation mesocosm studies

**2001-02:** year 3 of flooding, study of GHG emissions and mercury dynamics; year 2 of mitigation mesocosm studies

The three areas to be flooded are: a moist forest (Site 1), a dry forest (Site 2), and a very dry forest with areas of exposed bedrock (Site 3). The approximate sizes of each of these impoundments are as follows:

Site	Area (ha)	Mean depth (m)	Volume (10 <sup>4</sup> m <sup>3</sup> )	Dike length (m)
1	0.61	1.0	0.61	190
2	0.70	1.2	0.84	130
3	0.71	1.0	0.71	350

Reservoirs will be filled by pumping water from Roddy Lake. Outflow water from all sites will drain back to Roddy Lake. Water will be pumped using a diesel-powered unit. A double-walled, fuel storage tank will be installed at the field site, complete with fail-safe systems to detect fuel leaks.

Water renewal times of approximately 2 weeks during the open water season are anticipated. Dikes have been constructed of gravel, sealed to bedrock with plastic (for dikes 1 m in height or less) and with wood construction sealed to bedrock with cement and plastic (for dikes greater than 1 m in height). Maximum dike height and reservoir depth would be approximately 2 m.

No chemical or physical substances will be experimentally added to Roddy Lake or to any of the impoundments. Rather, naturally occurring substances only will be monitored as part of the experiment.

### **2.3.1 Impact of Reservoir Creation on Greenhouse Gas Fluxes from Forested Uplands.**

Reservoirs created for hydroelectric power have recently been identified as sources of greenhouse gases (GHG), including methane (CH<sub>4</sub>) and carbon dioxide (CO<sub>2</sub>), to the atmosphere. Following flooding plants die and stop taking up atmospheric CO<sub>2</sub> via photosynthesis. In addition, bacteria mineralize carbon stored in plants and soils to CO<sub>2</sub> and CH<sub>4</sub>, which then flux to the atmosphere. The long-term impact of reservoir creation on GHG emissions should be related to the amount of organic carbon stored in ecosystems prior to flooding. In the northern Boreal landscape, where many Canadian reservoirs are developed, carbon stores range from large in peatlands to small in pockets of ridge-top forests.

The three boreal upland catchments being experimentally flooded range in their degree of organic carbon stores. A study by Elizabeth Joyce of the University of Alberta will focus on the decomposition of this flooded organic carbon with two major objectives:

- 1) to investigate biogeochemical processes controlling initial rates of decomposition and GHG production in the flooded catchments with varying stores of organic carbon, and
- 2) to compare these initial rates with those measured in a previously flooded experimental wetland with large stores of organic carbon in peat.

Pre-flood data for 1998 show that methane is being oxidized in all catchments, the moist forest, the dry forest and the driest forest. Respiration (plant and soil), indicated by an increase in CO<sub>2</sub>, is occurring in all chambers over a 30-minute period. Pre-flood gas flux data will continue to be collected until experimental flooding occurs in mid-June 1999. 10 types of vegetation will be collected and deposited within the catchments before flooding in order to monitor rates of decomposition.

### **2.3.2 Effects of Reservoir Creation on Mercury Methylation Rates**

The Upland Flooding Experiment has been designed to test the hypothesis that methylmercury (MeHg) and greenhouse gas production in reservoirs is related to the amount of carbon stored in the reservoir. Three sites have been chosen to represent three different types of upland forests. These types are a moist forest (Site 1: jack pine stands, with *Sphagnum* and *Ledum*), a dry forest (Site 2: thick jack pine stands with some birch and alder), and a very dry forest (Site 3: jack pine stands with exposed bedrock outcrops). Each of these sites has different amounts of organic matter stored in the vegetation and soils.

The specific research objective of Britt Hall, from the University of Alberta, is to determine, using a whole ecosystem mass balance approach, if Hg methylation rates increase, and therefore lead to increased MeHg concentrations in fish. Inputs (precipitation, throughfall, and inputs from the source lake) and storage (vegetation and soil) of MeHg and inorganic Hg will be measured and subtracted from the amount of MeHg and inorganic Hg leaving the system (via run off, groundwater, outflows from reservoirs, and photodegradation).

In 1998, Britt collected pre-manipulation data to quantify the MeHg and inorganic Hg inputs to and outputs from the three sites in their non-flooded states. She measured MeHg and total Hg (THg) concentrations in precipitation (collected at the ELA Met site), throughfall (collected in each of the three sites), and run off. Litterfall samplers were also set to determine an annual flux of MeHg and THg from the litter.

Pre-flood data show that precipitation is a source of both MeHg and THg to each of the sites. Concentrations of MeHg and THg in throughfall were greater than those in precipitation, suggesting that wet deposition removes particle-bound Hg from the forest canopies. Methyl Hg concentrations in the moist site were greater than concentrations in the dry site, which in turn were greater than concentrations in the very dry site. The pre-flood data set will be augmented using 1999 spring runoff and groundwater data.

During the summer of 1999, MeHg and THg concentrations in ten vegetation tissues will be determined and litterbags will be used to measure the change in MeHg and THg concentrations over time in each of the newly flooded reservoirs. Britt will continue to measure inputs and output and fluxes of MeHg and THg after flooding. Mass balance budgets will be constructed for each site and compared to one another, as well as to the Experimental Lakes Area Reservoir Project's (see 2.1, above) six-year-old wetland reservoir (L979). The results from the research comparing MeHg cycles in different forest reservoirs will be used to calibrate a mercury model to help develop knowledge that will further our predictive abilities of the behaviour of MeHg in flooded ecosystems. Increased predictive abilities will, in turn, facilitate development of mitigation strategies for the impacts of future reservoir creation.

### **3. NATURAL VARIABILITY, UV RADIATION, AND CLIMATIC FACTORS**

In order to objectively assess 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.

#### **3.1 Long-Term Ecological Research**

In 1998, the Long-Term Ecological Research (LTER) project was formally established to co-ordinate the hydrological, chemical, and biological monitoring of long-term reference lakes at the ELA. Goals of the project are to provide an envelope of expected natural variability against which experimental results can be assessed, and to provide reliable estimates of the effects of region-wide perturbances resulting from global stressors such as climate change, atmospheric contaminant loading and stratospheric ozone depletion.

The project will monitor two groups of lakes. The first is a core set of reference lakes that will be protected against experimental manipulation for the long-term. The core lakes will have good historical records, be typical of lakes in the ELA, and be monitored by as many disciplines as possible for full ecosystem coverage. The second set of lakes will be monitored for a shorter, fixed period of time for the purposes of contributing to discipline-specific, reference data sets, answering specific questions or expanding the range of type of lake or biological community.

Final decisions have not yet been made about the long-term sets of lakes, but an LTER monitoring program continued in 1998. Five lakes (114, 224, 239, 373, and 442) received full-discipline coverage that included measurements for hydrology (where feasible), secchi depth and water temperature, water chemistry, primary production, periphyton, phytoplankton, zooplankton, and fish. Discipline-specific monitoring continued for fish populations in lakes 259 and 468 and for hydrology in Lakes 240, 470, and 302. Additional activities included a survey to find a high DOC lake to include in the reference set, and studies to determine the best standard protocols for long-term monitoring.

### ***3.1.1 Impact of Natural Disturbances on the Lake 239 Watershed***

Long-term hydrological, meteorological, and chemical monitoring in the calibrated catchments of this watershed continued during 1997. Portions of the watershed were perturbed by a major forest blow-down in 1973, and by forest wildfires in 1974 and 1980. This and other ELA watersheds have been subjected to extremes of precipitation over the monitoring period. The monitoring is intended to evaluate long-term effects of these and other natural perturbations on the lake ecosystems, and to calibrate other hydrological studies at the ELA. The watershed has been continuously monitored for 30 years. No chemical additions are made.

## **3.2 Direct and Indirect Effects of Ultraviolet Radiation**

Over the past several years, a research group from the University of Alberta, led by Dr. David Schindler, has carried out a variety of studies focusing on the effects on lakes and streams of ultraviolet-B (UV-B) radiation. These studies have examined the role of dissolved organic carbon (DOC) as a shield against UV-B in freshwater systems.

During 1998, aspects of this work were continued at the ELA by University of Alberta graduate students. They investigated the effects and interactions of UV radiation and DOC on algal populations in limnetic and littoral zones of lakes.

### ***3.2.1 Importance of Near-surface Thermoclines in Combination with UV Radiation in Boreal Lakes***

Shallow, near-surface thermoclines form under hot and windless conditions and can retain the plankton under photoinhibitory irradiances, including ultraviolet (UV) radiation, for prolonged periods of time. As a result of climate change and acidification, the concentration of dissolved organic carbon (DOC), an important attenuator of solar radiation in lakes, is reduced, lowering underwater UV-B attenuation. The objective of this study, by University of Alberta Ph.D. candidate, Marguerite Xenopoulos, was to examine the combined effects of high UV penetration and shallow secondary thermoclines on phytoplankton and other trophic levels.

Particular attention was placed on the combination of very high incident UV and still weather, when planktonic organisms are held isolated in a shallow layer of high UV radiation. Such conditions have been found to be particularly detrimental to some phytoplankton species. Near-surface thermoclines can occur on up to  $\frac{3}{4}$  of summer days in small lakes of the Experimental Lakes Area. The effects of such short-term, high intensity, UV exposure on survival of organisms and on photoinhibition of photosynthesis have not yet been investigated.

Four ELA lakes were selected to investigate phytoplankton production on calm days with high incident UV; these lakes, chosen for differences in lake size, water clarity and physico-chemical properties, are Lake 224, Lake 225, Lake 305 and Lake 227. Hobo-Temp temperature data loggers were installed *in situ* to monitor temperature changes in the lakes. Photosynthetically active radiation (PAR) was determined daily with a Li-Cor quantum sensor and incident UV radiation by means of UV-A and UV-B sensors. Time-series experiments were conducted during the summer of 1998. Storms punctuated the beginning and the end of the sampling period. A storm is defined here as a meteorological forcing that stimulates vertical mixing (i.e. cold front, rainstorm, windstorm). Sampling was continued under anticyclonic weather conditions characterized by more stable thermal stratification and warm weather until the next storm. Primary and bacterial productivity were measured in the mixing layer and in the sublayer. Preliminary results indicate a reduction of 10-50% in near-surface primary production in periods of very low mixing and high UV.

This work will continue in 1999, with the following preliminary objectives:

- 1) To investigate vertical distribution and productivity of the plankton under ice in combination with high incident UV (2 intense weeks between mid-March and mid-April, depending on ice thickness)
- 2) To develop a method measuring UV-B induced DNA damage, in the water column, using flow-cytometry which enables us to quantify the optical properties of individual phytoplankton cells (especially when near-surface thermoclines occur)
- 3) To compare plankton sinking rates under different light regimes (PAR only, UVB enhanced etc.)

Possible study lakes: L224, L225, L305, L227, L239, L302, L114, L226.

### **3.2.2 Effects of UV Radiation on littoral Algal Communities**

Lake acidification is known to reduce concentrations of dissolved organic carbon (DOC) that can serve as a shield to reduce penetration of UV radiation into the water column. University of Alberta graduate student, Elise Watkins, began a study investigated the effects of UV radiation on algal communities inhabiting the littoral zone of ELA Lake 302, a system in the late stages of recovery from experimental acidification (see section 4.2, below). No results of this graduate study are available yet.

Dr. Schindler has been seeking funding and collaborators for two proposed experimental studies using ELA lakes. One would examine the role of allochthonous DOC in lakes by experimentally reducing the DOC entering a lake, either through stream diversion or by digestion of the incoming DOC. The second study would experimentally deepen the mixed layer and thermocline of a lake and examine the effects of a diminished hypolimnetic volume. Both of these experiments would mimic effects observed in ELA lakes during a two-decade period of climatic warming, and would provide a preview of what might be expected in many boreal lakes in response to global warming.

### **3.3 Effects of UV-B Radiation on a Pelagic Community**

A research team from the University of Winnipeg, consisting of Drs. Rod Bollman, Judith Huebner, and Donna Young, plus three student research assistants, spent nine days in June and eight days in July-August at the ELA. They completed a pilot project intended to develop a research protocol and to field-test equipment to be used in a two month study at ELA during the 1999 field season. The focus of the study is to try and estimate the impact of ultraviolet-B (UV-B) radiation on the pelagic community of a lake. During the two field trials, the study lake was selected, gear modified, and several new experiments planned. The lake selected was 224. The timing of the 1999 study will include a month before and a month after the summer solstice.

Three different experiments were developed during the field trials. The first involved placing six limnocorrals (2 metres wide by 1 metre deep) into an area of the lake subjected to the longest sunny period of the day. Three limnocorrals were covered with a 'lid' of mylar plastic, which blocked 90% of the UV-B radiation, suspended 10 cm above the corral (to allow for air exchange and prevent heat build-up). The other three corrals were designed in a similar fashion, but the mylar was replaced with a clear plastic that transmitted >90% of the incident UV-B radiation. The team monitored changes in the UV-B levels, water temperature, dissolved oxygen concentrations, and the aquatic community (algae, *Daphnia pulex*, and, in some enclosures, fathead minnows). Results are still being analyzed. The second experiment involved the suspension of two (1 metre wide by 1 metre deep) limnocorrals made of fine-meshed netting. One was covered with mylar and the other with clear plastic. Fathead minnows were placed in each of the corrals and survival was monitored. The final experiment involved the placement of two metal frames into shallow water (0.5 m deep). Each frame had two-litre plastic bags suspended at 0.5

metres, 0.25 metres and at the surface. The upper surface of one frame was covered with mylar; the other was left open. *Daphnia pulex* were placed in each bag and survival recorded daily. Results are being analyzed and will be reported at a later date.

### **3.4 Metalimnetic and Hypolimnetic Chlorophyll Peaks**

For the third consecutive summer, Dr. F.J. DeNoyelles, Jr. and Dr. David Graham of the University of Kansas conducted summer surveys of several ELA lakes to evaluate the magnitude and status of metalimnetic and hypolimnetic chlorophyll maxima attributable to concentrations of algae and photosynthetic bacteria at distinct depth strata.

This work is a follow up to extensive studies of these peaks conducted at the ELA by Dr. DeNoyelles and other researchers during the 1970's and 1980's. Results from lakes at the ELA will be compared to those from artificial lakes in Kansas and other sites much further south. Similar work is being conducted for the Coldwater Lakes study area near Atikokan, Ontario.

## **4. RECOVERY OF AQUATIC ECOSYSTEMS FROM ACIDIFICATION**

### **Background**

“The Canadian ‘story’ of aquatic acidification and recovery is far from complete” (1997 Canadian Acid Rain Assessment, V. 3, p. v). Although human-caused acidification of aquatic ecosystems has been recognized as a concern for almost three decades, it remains a widespread environmental problem of our planet, e.g., in Canada, northeastern United States, Scandinavia, and more recently in southeast Asia. Canadian regions of concern include many parts of eastern Canada, northeastern Alberta and northwestern Saskatchewan.

Recovery from acidification will be an important issue in Canada for several decades (see time trend analysis papers in *Water, Air, and Soil Pollution (WASP)* Vol. 85, 1995). Although certain legislative and regulatory measures have already been adopted in an attempt to alleviate this problem, considerable uncertainty remains about the ultimate effectiveness of these measures. The expected rate of recovery is not occurring in many lakes of eastern Canada. So there is now concern about the abilities of our lakes to recover from significant acidification once acidic inputs have been reduced. We also realize that many important features of recovery remain poorly understood (see paucity of recovery papers in same *WASP* volume).

As a result, our whole-lake experiments are important to understanding the ability of aquatic ecosystems to recover naturally (i.e., without human intervention) from anthropogenic impacts (i.e., acidification). The Lake 223 and 302S studies represent lakes recovering from different degrees of acidification; namely, moderate and severe, respectively.

An important goal of our whole-lake and related studies is to provide habitat managers and legislators with answers to questions about both the effectiveness of current emission control measures and the probable nature of ecosystem recovery from acidification. As well, our experiments have been productive, contributing many scientific articles, graduate theses and other publications since their inception.

## General Findings

The principal good news of our research is that the simple reduction of acid inputs, by itself, can result in some degree of ecosystem recovery. Unfortunately simple reduction of acid inputs has been insufficient to (initially) fully restore the chemical and biological composition and functioning of the experimental ecosystems at any intermediate stage of pH recovery. As a result, our previously acidified lakes (Lakes 223 and 302S) are recovering to states different than their pre-acidification state; i.e., neither geochemical nor biological recovery is proceeding along its acidification path so that there is hysteresis in the recovery process.

This finding appears partly to depend on the severity of the acidification. For example, reducing a lake's pH below 5, as in the case of Lake 302S, impaired the lake's biogeochemical ability to buffer itself against acid inputs, further increasing the hysteresis. As a result, the efficiency of acidifying substances is greater during the recovery period than it was during acidification, and current emission regulations may be insufficient to protect many of our lakes.

Full understanding of the recovery potential of our aquatic ecosystems will be difficult because interactions between biological and chemical properties are complex (e.g., see our 1998 minnow mesocosm study). As well, with the impairment of chemical recovery, the stage is prepared incompletely for biological recovery, which has also been impeded in our experimental lakes. In some cases, the chemical milieu of the lakes has been even less favourable during recovery than it was before.

Despite varying degrees of pH recovery, symptoms of a biocenotic disturbance often remain. For example, biological diversity remains lower in some populations in both lakes. As a result, biotic composition and function can be variable, with littoral and pelagic recoveries often differing compositionally and functionally. Recovery of biological diversity has been uneven: diversity is recovering rapidly in phytoplankton, but less so in zooplankton and fish (constrained in part by the absence of natural invading populations). As a result, biological structure and function are often different than was seen during the acidification phase, i.e., prior to the major changes caused by acidification. Biological surprises have been common during the recovery phase, as populations invaded previously empty niches, with attendant trophic consequences. Biological recovery in acidified lakes can not be considered to be a simple function of species recolonization.

## Funding Challenges

Our ability to continue the recovery experiments remains uncertain because of the cessation of the Long Range Transport of Acidic Pollutants program (LRTAP), which had funded our acidification studies through the 1996/97 fiscal year. It remains unclear whether we will be able to obtain sufficient financial support to continue the ecosystem recovery studies or to initiate important new research. In 1997 and 1998 we continued the limited acid additions required (in Lake 302S), and continued biological and chemical sampling (albeit at a reduced level), but at a considerable cost to ELA's A-base budget.

Despite this financial predicament, one of the five principal recommendations of the 1997 Canadian Acid Rain Assessment (V. 3, p. vi) was:

“Whole-lake experimental acidification/recovery research is now funded at an ineffectual level even though recovery is nowhere near complete. A reasonable funding level should be restored and the projects completed.”

This recommendation recognized both the value of our whole-lake experiments for policy development and the fact that our program support (LRTAP) had ended. Although we believe that recovery from acidification of aquatic ecosystems and fish habitat should remain a research priority of the Government of Canada (especially for the Department of Environment and the Department of Fisheries and Oceans) we are now without direct program support. As a consequence, we are seeking additional financial support (preferably from the Government of Canada, but possibly from industry) to continue the most important of these recovery research activities. Such funding will also allow the ELA to fulfill its obligation to continue monitoring its experimentally acidified ecosystems until they have clearly returned to a healthy, natural state.

### Plans for 1999

Our plans for 1999 are dependent on whether we are successful in obtaining financial support for our recovery experiments. If we can maintain at least the markedly reduced funding level of 1998 (hopefully from a source other than ELA A-base funds), our lake-specific plans are as follows:

**Lake 223:** continue to study at a reduced work schedule as in 1998, emphasizing principally the status of the lake trout population, with only a modicum of water chemistry sampling.

**Lake 302S:** maintain the target pH for a second year at 6.1 to assess whether chemical and biological recovery will can proceed beyond that already seen. We would continue many of the ecosystem measurements as in previous years, albeit at a reduced intensity, and except where downsizing has compromised our abilities. This will allow us to determine whether human intervention is needed at this level to restore the ecosystem near to its original state.

**Lake 302N:** continue only minimal chemical and biological monitoring as per our agreement with Ontario.

**Supplementary plans** (sometimes using mesocosms) that would require additional funding include:

- prepare to study the success of controlled reintroduction of lake whitefish to Lake 302S;
- develop strategies for food web reconstruction;
- analyse the potential for interactions with global change (specifically the interaction with increased UV<sub>b</sub> and CO<sub>2</sub>; see paper by Schindler et al, 1996, Nature 379:705-708);
- study the potential for interaction with increased mercury deposition;
- determine whether the availability of reduced carbon is controlling the rate of recovery of internal alkalinity generation (Lake 302S);
- analyse the effects of long-term stress on biological populations.

Recognizing that many analyses of our experiments are still in progress, especially the 1998 observations, here are the highlights of our findings.

## 4.1 Recovery of Lake 223 from Acidification

Lake 223 had been acidified with sulfuric acid from 1976 (pH 6.7) to 1983 (pH 5.1), and was then allowed to recover gradually from 1984 (pH 5.4) to the present time. The purpose of the acidification phase of the experiment was to document chemical and biological changes of progressive acidification. This phase was terminated intentionally before most fish species were extirpated, but at a stage where their elimination was assured had acidification continued. The purpose of the recovery phase has been to document the rate and extent of chemical and biological recovery in a lake that had been acidified

moderately. 1998 was the fourth year of complete pH recovery; pre-acidification pH levels (6.5 – 6.7) had been achieved in 1995.

Biological recovery has lagged pH recovery in Lake 223, and has been variable in character among the biota. Recovery in the phytoplankton, arguably the first group to recover, remains well established. Zooplankton community structure is now similar to that prior to acidification, and even previously extirpated *Mysis relicta* was collected again in 1998, presumably as a result of reinvasion from upstream Lake 224. Lake trout (*Salvelinus namaycush*) abundance is still gradually increasing, but total abundance remains low. White sucker abundance has now decreased to numbers that existed prior to acidification; similarly, growth and condition (fatness) have now returned (increased) to pre-acidification values. The fathead minnow (*Pimephales promelus*) population has similarly returned to former abundance values, although the slimy sculpin (*Cottus cognatus*) remains absent.

#### 4.2 Recovery of Lake 302S from Acidification

The target pH in Lake 302S was raised to 6.1 in 1998, versus previous recovery targets of 5.8 (1994 – 1997) and 5.1 (1992 – 1993); 1998 was the seventh year of recovery from acidification to pH 4.5 with sulfuric acid. Ecosystem analysis included: hydrology, water chemistry (plus metals), and many components of the pelagic and littoral food webs, albeit at lower sampling effort. Unfortunately, some study components (e.g., zoobenthos and toxic algal bloom research) were discontinued.

Geochemical recovery continues to be disturbed. Recovery has sometimes been incomplete until certain threshold values are achieved, e.g., nitrogen and the nitrification process. Occasionally recovery is prolonged, e.g., carbon – dissolved organic carbon production, in part by water renewal considerations. Now and then previously unobserved features are seen, e.g., iron (unexpected increase) and internal alkalinity generation (unexpected suppression).

There are preliminary indications that the lake's ability to generate alkalinity internally may finally be beginning to recover; this conclusion needs confirmation by chemical mass balance analysis. This preliminary analysis is based on the need to add acid to maintain the target pH, although the amounts added are still small compared to the acidification phase. Despite this, internal re-acidification has still been observed. As a result, the efficiency of acidifying substances continues to be greater during the recovery period than it was during acidification. This may have been related to chemical changes that are mediated biologically (e.g., sulfate reduction and nitrification), and were possibly diminished by insufficient supplies of reduced carbon, now possibly being replenished by increasing littoral inputs. Concentrations of most metals are declining but remain elevated during the recovery period; temporary increases in iron may have been linked to periods of internal re-acidification via re-oxidation of previously reduced sulfate.

Biological recovery remains uneven. Algal nutrition shifted: in contrast to continued planktonic phosphorus deficiency, nitrogen deficiency increased back to its pre-acidification state due to decreasing ammonia levels; benthic carbon limitation, which was aggravated by acidification, was diminished in 1997 and 1998 as dissolved inorganic carbon concentrations increased. Phytoplankton biomass, which had earlier achieved all-time maxima due to dinoflagellate blooms during earlier stages of pH recovery, largely returned to pre-acidification levels. In contrast, phytoplankton productivity continued to remain unaffected by changes in pH. On the other hand, epilithic algal biomass and productivity, which had remained low, began to recover with the resurgence in dissolved inorganic carbon concentrations. Although there were unexpected increases in both 1997 and 1998, annual blooms of littoral filamentous

green algae have generally been variable in occurrence, and usually low in abundance, compared to the large blooms that occurred at very low pH.

Annual zooplankton abundance and biomass have fluctuated considerably, consistent with the decline in zooplankton diversity. The zoobenthic situation continues to change. Chironomid emergence was slowly declining to its pre-acidification levels through to 1997 [we have lost our ability to continue these measurements because of personnel downsizing]. In contrast, both Cladocera (e.g., *Daphnia catawba*) and Corixids had continued to flourish in the near shore region (probably due to the absence of fish predation); but in 1997 and 1998 they have basically disappeared (probably due to the resurgence of minnow populations). Tadpoles (*Rana* spp.) are now present again in the near shore region. Crayfish (*Orconectes virilis*) continue to be absent. In contrast, sponges (first seen in abundance in 1997) have continued their surprising appearance in 1998, although their abundance may be lower than in 1997 [Note: sponges were not observed in Lake 302S prior to acidification].

Fathead minnows (*Pimephales promelas*), finescale and northern redbelly dace (*Phoxinus* spp.) and young white suckers (*Catostomus commersoni*) have recently reappeared and flourished in the lake, presumably by 'upstream' movement from Lake 302N. Pearl dace (*Semotilus margarita*), which had survived the acidification phase, now have several year classes present in the lake. A surprising evaluation of the effects on food web structure of the reappearance of these minnows is presented in section 4.2.1, below. Slimy sculpin (*Cottus cognatus*), as in Lake 223, and lake whitefish (*Coregonus clupeaformis*) remain absent from the fish assemblage.

Swallows returned again to the shoreline of Lake 302S as in previous years, but for the first time during the recovery phase, were successful in their nesting attempts. The reasons for the previous impairment continue to remain unknown, although previous research suggests that calcium insufficiency and metal toxicity in food were not the causes.

#### **4.2.1 Effects of Omnivorous Minnows on the Littoral Food Web**

Cyprinid minnows (fathead minnows (*Pimephales promelas*), finescale and northern redbelly dace (*Phoxinus* spp.)) have recently reappeared in the recovering acidified Lake 302S, which had previously been rendered almost fishless during experimental acidification. Several concomitant changes in various littoral communities suggested to Dr. Rolf Vinebrooke (University of Alberta) and Dr. Michael Turner (DFO) that recolonization by cyprinid minnows could play a key role in the biological recovery of anthropogenically acidified lakes. They hypothesized that omnivorous cyprinid minnows would suppress both acid-tolerant invertebrates and nuisance epiphytic filamentous green algae, facilitating biological recovery within the shallow littoral area.

They tested this hypothesis by conducting a minnow enclosure/exclosure experiment using nine 4-m<sup>2</sup> littoral corrals in Lake 302S during July and August 1998. Preliminary results show that minnows suppressed microcrustaceans and epiphytic herbivores (i.e. chironomid spp.), which in fact resulted in increased epiphytic filamentous algal biomass. Their unexpected findings suggest that biological recovery in acidified lakes should not be considered to be a simple, direct, positive function of species recolonization. Future areas of related study should involve testing the food-web effects of deliberate reintroduction of previously extirpated organisms (i.e. amphipods, crayfish, and tadpoles) into Lake 302S.

### **4.3 Recovery of Lake 302N from Acidification**

Funding constraints caused ELA researchers to terminate this experiment in 1997. The purpose of the Lake 302N experiment at that time had been to test whether phosphorus additions, by stimulating algal

growth, would stimulate internal alkalinity generation, and thereby serve as a potentially cost-effective remediation strategy. Details of this study were provided in previous reports.

Although there were no chemical or acid additions during 1998, the pH appears to have been somewhat lower than is natural. Only essential monitoring of chemical and biological parameters was continued.

The populations of lake whitefish and other organisms in this basin serve as potential seed populations for the restocking of Lake 302 South.

## **5. PERSISTENT TOXIC SUBSTANCES**

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.

In addition, these experimental studies with persistent toxicants provide an opportunity to determine the physiological bases of ecosystem effects, thereby identifying indicators of stress at lower (physiological, histological) levels of biological organization. Once identified, these indicators can be extremely useful for the assessment and remediation of environmental problems.

Apart from methylmercury research as part of reservoir studies (Section 2), ELA studies of such toxic substances have been relegated in recent years to long-term monitoring of system recovery (see 5.1 and 5.2, below). A research proposal is now being developed that would experimentally add trace amounts of mercury stable isotopes to a lake and its terrestrial catchment to establish the relationship between atmospheric deposition of inorganic mercury and fish MeHg concentrations. If this project is approved and funded, background field studies would begin in 1999. Experimental work would begin in 2001.

### **5.1 Organochlorines and Poly-Aromatic Hydrocarbon Study**

The purpose of this study was to evaluate the effects of chlordane, toxaphene, and a dibenzofuran on lake trout and white sucker populations in Lake 260. It formed the basis for a Ph.D. thesis completed by Peter Delorme (University of Manitoba) in 1994.

In 1988 and 1989, low concentrations of each compound were injected into the bodies of adult lake trout and white sucker. These individuals were recaptured over a series of years to evaluate changes in spawning efficacy, through egg incubation experiments, and changes in the annual survival of the injected individuals. Non-injected individuals were monitored each year as reference fish for the injected fish. Most of the injected individuals have been removed from the population for analysis of residue in their tissues.

No sampling was done in the lake during 1998. The lake trout population in Lake 260 will still be monitored periodically to determine if any of the injected individuals remain in the population. Only two injected individuals were captured in 1997; both had been injected with the "control" substance (corn oil),

originally used to evaluate the effects of injecting the solution without the toxicant in 1988. No individuals that had been injected with chlordane, toxaphene, or dibenzofuran have been recaptured since 1995..

## 5.2 Cadmium Addition to Lake 382

Between 1987 and 1992, trace amounts of cadmium were experimentally added to the surface waters of Lake 382. The purpose was to test the adequacy of existing guidelines for protecting against chronic cadmium contamination effects in real aquatic ecosystems. Levels of cadmium in Lake 382 were gradually raised each ice-free season so that approximately 200 nanograms per litre ( $\text{ng.L}^{-1}$ ) were present during the summers of 1991 and 1992. This is still almost 2 orders of magnitude below the Canadian drinking water standard, but at a level where biological impacts would probably occur if the treatment were chronically maintained. By the end of 1992, a total of 7 kg of cadmium had been added to Lake 382. Most of this has moved into the lake sediments. No cadmium has been added since 1992, but monitoring continued through 1996 to observe responses to the "zero discharge strategy".

Since 1996, no funding has been available to continue the detailed monitoring. Dr. Diane Malley, the study coordinator, has retired from DFO. Basic chemical parameters (nutrients and DOC) and plankton populations were monitored monthly again in 1998. No fish sampling has been done for two years. The current plan calls for periodic cadmium monitoring to continue, but not on an annual basis.

## 6. ENDOCRINE DISRUPTING CHEMICALS (EDC'S)

Humans are producing and releasing to the environment a number of chemicals which are structurally similar to naturally occurring endocrine substances or hormones. There is considerable evidence to suggest that some of these manufactured chemicals may imitate the natural hormones and, under certain conditions, disrupt normal endocrine functioning in a number of species. Can these chemicals, when present in lakes and streams, disrupt the endocrine functioning of fishes? If so, what are the potential consequences?

No experimental work of this type has been conducted at the ELA to date. However, in 1998, planning and pilot studies have been initiated in preparation for a proposed whole-lake experiment with an EDC at the ELA. If this project is approved and funded, background field work would probably begin in 1999 and the experimental work would commence in 2000.

### **Note:**

*This summary was compiled by John Shearer, using information provided by research project leaders and other ELA staff. Where appropriate, the names of principal external investigators, graduate students, and their affiliations are noted. However, many aspects of most major projects are being conducted by DFO Experimental Lakes Area staff, most of whom have not been specifically mentioned. The summary is intended as an overview of research activities at the ELA during 1997. 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.*