SUMMARY OF MAJOR RESEARCH PROJECTS AT THE EXPERIMENTAL LAKES AREA DURING 1996

1 December 1996

1996 has been a year of "downsizing" and consolidation for ELA staff and research programs. A number of long-term staff are in the process of closing off research programs in anticipation either of early retirement or of moving to alternative employment. Three major research programs (Long Range Transport of Atmospheric Pollutants, Sustainable Fisheries Initiative, Green Plan Toxic Chemicals) are in their final year of assured funding. Projects funded under these programs are attempting to consolidate and summarize long-term results. Researchers working on the ELA Reservoir Project are also summarizing and writing results from the first five years of this study.

Nonetheless, a broad range of ecological studies were conducted at the Experimental Lakes Area and on samples taken at the ELA. While site use was reduced significantly, close to 150 research personnel representing a number of government agencies, universities, and corporations worked on site during the 1996 field season. The following is an attempt to summarize the status of major projects by providing some information about their purpose, design and, where possible, major results. It should be noted, however, that data analyses are ongoing and many of the results provided 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 five 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 28th consecutive year in 1996. 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, 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 have been 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 1996, 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 1996, as in 1995, Lake 227 was heavily fished to remove all adult pike. Fewer than 25 pike were netted and removed, all during the early stages of the fishing effort. All netted fish were several years of age and showed signs of food deprivation. There was no evidence of pike reproduction. This lake will be monitored again in 1997 to determine the success of the pike removal. Any additional adult pike which can be found will be removed.

1.1.1 The Stoichiometry Project

During recent years, a joint research undertaking (The Stoichiometry Project), involving DFO and researchers from Arizona State University (Dr. James Elser), the University of Texas at Arlington (Dr. Tom Chryzanowski), and the University of Minnesota (Dr. Robert Sterner), 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 1996, studies, led by Dr. Sterner, focussed primarily on oligotrophic Lake 110. Daphnia populations in this lake had not responded as anticipated to the introduction of the piscivorous pike in 1993. Using enclosures within Lake 110, the research team investigated the relationships of Daphnia populations to nutrient levels to determine if this lack of population response was attributable to nutrient limitations on algal growth.

Funding for follow-up work in 1997 is still undetermined. Once all work is completed on Lake 110, the introduced pike will be netted and removed from the lake.

1.2 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, an fish populations have been 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. Water chemistry, phytoplankton, and zooplankton populations were monitored in 1996.

1.3 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 by similar netting. This monitoring continued in 1996. Data from reference lakes are used to interpret lake whitefish data from other ELA experiments.

1.4 Northern Pike Project - Macrophyte Removal

The purpose of this experiment is to evaluate the impact of littoral zone alteration on recruitment, growth, and change in productivity of a northern pike population. Currently funded under the federal Sustainable Fisheries Initiative, this project, in 1996, progressed to the stage of experimental manipulation.

After two years of background monitoring in 1994 and 1995, 50% of the macrophytes (large aquatic plants) in the littoral zone of Lake 191 were removed during summer 1996 using a mechanical harvester. The effects of this removal on resident fish populations, especially northern pike, are evaluated using mark-recapture studies. Young-of-the-year northern pike are intensively censused. Water chemistry, phytoplankton, and zooplankton are monitored each year of study. Macrophyte populations are censused in August of each year for species composition, biomass, and area coverage. In the areas harvested, approximately 98% of the macrophyte biomass was removed.

Nearby Lake 165 was monitored as a reference lake for this experiment.

Fish impact results for 1996 are still being assessed. However, catches of adult pike, both before and after macrophyte harvesting were lower than in previous years. This may be a result simply of differing climatic conditions in 1996.

2. PHYSICAL PERTURBATIONS

2.1 Experimental Lakes Area Reservoir Project (ELARP)

In June 1993, following 2 years of background study, ELA Lake 979, a small wetland system, was flooded to a depth of more than a metre. Mobilization of methyl mercury within the flooded ecosystem and release to the atmosphere of CO_2 and CH_4 in response to the flooding were monitored intensively. A non-flooded wetland system (ELA Lake 632), was monitored as a reference. Following winter drawdown, flooding of 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 methyl mercury and in release of the greenhouse gases were observed in response to flooding.

With the first phase (5 years) of the experiment completed, 1996 was devoted primarily to data analyses and scientific paper writing. These publications should soon begin appearing in the scientific literature.

After impoundment of Lake 979, concentrations of phosphorus, nitrogen, and dissolved organic carbon increased as a result of decomposition of flooded terrestrial organic matter. In the first year of impoundment, mean bacterial biomass increased 10X and individual bacterial cell volumes increased 2X over pre-flooding averages. Phytoplankton production and biomass decreased to approximately 25% of pre-flooding levels. Zooplankton biomass and production by Cladocera increased 10X and zooplankton community composition changed from dominance by small-sized *Bosmina longirostris* (Müller) to dominance by large *Daphnia rosea* Sars emend. Richard. In the first year of impoundment, production by Cladocera usually exceeded phytoplankton ^{14}C productivity suggesting that the main pathway of carbon flow to secondary producers shifted from an autochthonous to an allochthonous base derived from flooded terrestrial vegetation. In the second year of flooding, bacterial biomass decreased and phytoplankton biomass was higher than in the two previous years of study. It is currently unclear to what extent the high densities of zooplankton were used by fish. Shifts in zooplankton size indicate that fish predation was not intense, possibly because of low oxygen concentrations over the newly flooded peat.

During 1996, the 979 wetland was flooded for the fourth consecutive summer. Monitoring continued on the reservoir for methyl mercury and a range of limnological parameters, largely through funding support from Manitoba Hydro. No greenhouse gas monitoring was carried out. Current plans for 1997 are to continue as in 1996, but meetings are scheduled during winter 1996/97 to plan activities for 1997 and beyond. Discussions to date have included proposals for an upland flooding study as a comparison for the ELARP

A research paper by Trish Sellers *et al*, published in the journal *Nature* in April, 1996, described how methylmercury in lakes can be decomposed by sunlight. This important finding from the ELARP project received considerable media attention.

A research team from McGill University, led by Dr. Tim Moore, also carried out mercury cycling studies on the 632 reference wetland during 1996.

2.2 Lake 979 Littoral Impact Study

The lake 979 littoral impact study connects the experimental flooding of the 979 wetland (as part of the ELARP, No. 2.1, above) with the creation of new aquatic habitat, its colonization by biota, and the use of these potential extra food resources by forage and predaceous fish. The study can be regarded as a mirror image of the Lake 226 Drawdown experiment (No. 2.3, below).

All field work has now been completed. Work to process samples and analyze results is continuing, but some preliminary results can be outlined.

Nutrient status parameters measured in phytoplankton before and after flooding in the open water of Lake 979 revealed that phosphorus (P) deficiency decreased, whereas nitrogen (N) deficiency increased, probably because of increased nutrient mobilization (primarily P) from the flooded zone. Nutrient mobilization from the flooded zone into the main area of the lake was measured starting in 1994. Most sites in the flooded zone were primarily P deficient; several areas were more N deficient than P deficient during the summer, which suggested spatially highly variable nutrient mobilization. Nitrogen deficiency in the N deficient areas was satisfied by N fixation. Total epiphytic biomass (carbon) growing on herbaceous plants in the flooded zone will be estimated from nutrient composition data.

The flooding of Lake 979 shoreline provided benthic (bottom dwelling) macroinvertebrates with a variety of new niches to exploit. As a consequence, invertebrate emergence from the new shorelines increased almost 10-fold from the year before flooding (1992: mean emergence of Chironomidae was $\approx 700.m^{-2}$) to the year following flooding (1993: mean emergence of Chironomidae was $\approx 6200.m^{-2}$). Emergence of insects from aquatic habitats can be used as a rough measure of the productivity of those habitats. Emergence doubled in 1994 to $\approx 12000.m^{-2}$, a rate that was maintained in 1995 ($\approx 14000.m^{-2}$). Emergence from the open-water area of the lake has remained relatively stable ($\approx 1100\text{-}2100.m^{-2}$) during the period 1992 to 1995. Species composition of emerging Chironomidae changed after flooding, moreso in the newly flooded peatland zone than in the open-water area. Artificial substrate samplers that were placed into the newly flooded peat shorelines to measure colonization by benthic invertebrates also revealed high numbers of invertebrates after flooding. Thus, newly flooded peat shorelines apparently provide ideal conditions for colonization by invertebrates.

Preliminary results of studies of the food web of Lake 979 indicate that periphyton is the major carbon source for the benthic invertebrate community of the lake. Of the four species of fish present in the lake, white sucker appear to be at the top of the food chain; white sucker are primarily zooplanktivorous in Lake 979. Links between fish and rapidly expanding macroinvertebrate populations have not yet been established.

Dace were cultured in pens over the open-water area of the lake and over the newly flooded peat zone. Dace in the newly flooded zone exhibited noticeably lower growth, probably as a result of severe depression of oxygen concentrations in the peat.

2.3 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 hydroelectric reservoir. The lake has been studied for one year prior to drawdown (1994) and for two years following drawdown (1995 and 1996).

In the winter of 1994-95, the water level was reduced to 2 m below natural levels. This drawdown was achieved by blasting the natural outlet channel. Precautions were taken to avoid fish mortalities during blasting by using reduced charge sizes, and by removal of all large fish from the bay adjacent to the outlet combined with the installation of a fish barrier at the head of the bay. No fish mortalities were observed. Approximately 30% of the lake 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 winter of 1995-96 the water level was reduced to 3 m below natural levels. This drawdown was achieved by siphoning water through four 4" plastic pipes. The lake rose during the spring and summer due to snow melt and higher than average summer rains. Lake elevation at fall 1996 freeze-up was approximately 0.8 m below natural levels.

Preliminary indications are that the following impacts occurred in the lake as a result of water level drawdown. Approximately 10% of surface area of the lake has been dry in the summer and the productivity of this portion of the lake was lost to fish populations, although in 1995, a warm summer resulted in the total number of emerging insects from the lake being only slightly reduced after drawdown. Standing stocks of benthic macroinvertebrates decreased in the shallow littoral zone of the lake. There has been reproductive failure of lake whitefish in the lake in both years of drawdown, probably due to the exposure of incubating eggs after spawning. Acoustically tagged fish were followed during the 1995 and 1996 fall spawning seasons and time of spawning, spawning sites and substrate used for spawning has been identified. Analysis of stable isotopes of carbon and nitrogen indicated that lake whitefish were feeding mainly on food from the pelagic food chain, perhaps mostly Chaoborus. Submerged vegetation declined dramatically after drawdown although terrestrial vegetation began to invade the exposed shores. Littoral algal production decreased due to loss of habitat and to an increased sedimentary character of the communities; spatial variability increased. Increased resuspension of fine sediments was less noticeable than expected. Phytoplankton species composition was unaffected although total biomass increased due to increased abundances of chrysophytes and dinoflagellates. Bacteria also appear to have increased.

The lake is being drawn down to 3 m below natural levels in the winter of 1996-97, using the siphon pipes installed last year. Monitoring of the lake in the 1997 summer field season will depend on funds available. Funding is currently provided through the Sustainable Fisheries Initiative.

2.3.1 Nearshore Mapping in Lake 226

The purpose of this work was to provide estimates of habitat loss effected by drawdown as a model of reservoir operation by hydroelectric utilities. Lake 226 nearshore habitat was mapped in two separate surveys, before and immediately after drawdown, to determine the availability of habitat under two different hydraulic regimes. Using a fetch distance model, the change in wave parameters before and after drawdown were estimated, as well as correlations between hydraulic energy, slope, and substrate type. All work was completed by spring, 1996.

2.3.2 Nutrient Status of Benthic Algae

The relative nutrient status of benthic algae and pelagic algae in ELA lakes has been unknown until now. This study, as an adjunct to the Lake 226 drawdown, attempted to compare these two communities within the same lake. Staffing uncertainties and funding limitations prevented this work from continuing in 1996.

2.4 Impact of Disturbances on the Lake 239 Watershed

Long-term hydrological. Meteorological, and chemical monitoring in the calibrated catchments of this watershed continued during 1996. 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 28 years. No chemical additions are made.

Annual precipitation in 1996 proved to be the greatest yet measured (in excess of 970 mm through mid November) at the ELA during more than 27 years of record. One storm event in August produced 95 mm of rain at the meteorological station, and more than 167 mm was recorded at a rain gauge two km away during the same event. August 1996 was the wettest August (177.5 mm) on record at the ELA Met station.

Also in 1996, the record-late Lake 239 ice-out date of May 17, combined with the ice-on date of November 14, resulted in the shortest ice-free period (181 days) on record for the ELA.

Among the scientific results from this long-term study was a major paper by Schindler et al, published in *Limnology and Oceanography* (Vol. 41(5): 1004-1017) in 1996. This paper provides an update on ELA monitoring of the effects of climatic warming on boreal lakes and streams.

3. Acidification and Recovery

Acidification of aquatic ecosystems by anthropogenically-derived acidic precipitation has been widely recognized for almost two decades as a widespread environmental problem in many parts of eastern Canada, the northeastern United States, Scandinavia, and elsewhere. While certain legislative and regulatory measures have already been adopted to alleviate this problem, considerable uncertainty remains about the ultimate effectiveness of these measures and about the ability of natural ecosystems to spontaneously recover from significant acidification once acidic input has been reduced. The following six experimental studies are intended to provide legislators and managers with answers to remaining questions about the effectiveness of current control measures and the probable nature of ecosystem recovery from acidification.

3.1 Monitoring Recovery of the Lake 239 Wetland from Acidification

Simulated acid rain, composed of sulphuric and nitric acids, was added to a 2.66 ha portion of a small fen in the Lake 239 watershed from 1983 through 1990. Additions were made at monthly intervals during each ice-free season. The purpose was to evaluate effects of the simulated acid rain on wetland chemistry, vegetation, and downstream chemical exports (to Lake 239).

Beginning in 1991, no further acid additions were made, but monitoring of hydrology, outflow chemistry and plant growth continued through 1995 to evaluate the recovery of this wetland system.

In 1996, no funds were available to continue this monitoring, and the study has now been discontinued.

3.2 Recovery of Lake 223 from Acidification

Lake 223 is the site of an acidification-recovery experiment that commenced in 1976. The surface waters of this lake were acidified using sulphuric acid from 1976 through 1983. The experiment provided ground-breaking evidence of the adverse impact of acid on the lake food chain, even at pH levels of 5.0 or higher. This evidence was instrumental in spurring international legislation for the control of anthropogenic sulphur oxide emissions to the atmosphere.

In 1996, Lake 223 was monitored for the final year in the final stage of pH recovery that started in 1984. Water chemistry, phytoplankton, zooplankton, zoobenthos, and fish populations have been monitored each year. No acid has been experimentally added since 1993. The mean lake pH in 1996 was 6.7, identical (for the third consecutive year) with the lake pH prior to any acid additions.

The chemical recovery of Lake 223 from the experimental acidification that was conducted from 1976 to 1983 is now complete. Biological recovery has lagged chemical recovery significantly during the pH recovery phase of the experiment. Lake trout recruitment increased in 1996, but total lake trout abundance is still only 50% of the number present prior to acidification. The species composition of phytoplankton and zooplankton in the lake is gradually reverting to a state found prior to acidification.

A 1996 paper by Findlay and Kasian (*Can. J. Fish. Aquat. Sci.* **53**: 856-864) describes the effect of incremental pH recovery on the phytoplankton community of this lake.

DFO funding for this work will not continue beyond the current fiscal year.

3.3 Recovery of Lake 302S from Acidification

Background

The Lake 302S whole-lake experiment is important to understanding the ability of aquatic ecosystems to recover naturally (i.e., without human intervention) from anthropogenic acidification. This experiment differs from, and is complementary to, the Lake 223 experiment because of Lake 302S' more severe acidification.

The lake is finishing its fifth year of recovery from acidification to pH 4.5 during 1996. The target pH has remained at 5.8 since 1994, compared to 5.1 in 1992 and 1993. Complete ecosystem analysis continued as in past years, including: hydrology, water chemistry (plus metals), and most components of the pelagic and littoral food webs.

This productive experiment has contributed >56 primary publications (published, in press or in preparation), 5 graduate theses and 25 ancillary publications since 1985. The future of this experiment is in doubt, however, because of DFO's withdrawal of support for LRTAP research (see below).

Preliminary 1996 Conclusions

Simple reduction of acid inputs, by itself, is insufficient to (initially) restore the chemical and biological composition and functioning of the ecosystem at this intermediate pH (5.8). Neither geochemical nor biological recovery are proceeding along their acidification trajectories so that the lake is recovering to a state that differs from that prior to acidification. Decreasing the lake's pH below 5 may also have impaired the lake's ability to recover from acidification compared to those less severely acidified, although this is uncertain.

Geohemical recovery is both incomplete and prolonged. Recovery was often incomplete until certain threshold values were achieved (e.g., nitrogen), or was prolonged (e.g., carbon), or previously unobserved features were seen (e.g., iron and internal alkalinity generation). The lake's arguably most important biogeochemical property, its ability to generate akalinity internally, remains impaired. Internal reacidification has been regularly observed, as a result, the efficiency of acidifying substances is greater during the recovery period. Some of this hysteresis may be related to chemical changes that are mediated biologically, e.g., sulfate reduction and nitrification, and have possibly been impaired by insufficient supplies of reduced carbon. Concentrations of most metals remain elevated or have increased during the recovery period; continued increases in iron concentrations may be linked to these periods of internal reacidification.

Some uneven biological recovery is occurring, albeit in the absence of fish other than pearl dace, but symptoms of a biocoenotic disturbance remain. Biotic composition and function remain highly variable, with littoral and pelagic recoveries differing compositionally and functionally. Recovery of biological diversity is uneven: diversity is recovering in phytoplankton, but not in zooplankton or fish (constrained by the absence of natural invading populations). Phytoplankton biomass, which had earlier achieved all-time maxima due to dinoflagellate blooms, is returning to preacidification levels. In contrast, epilithic algal biomass remains low, and annual blooms of littoral filamentous green algal are variable in occurence and generally low in abundance. Phytoplankton productivity remains unaffected by the change in pH in contrast to epilithic productivity, which remains disrupted. Algal nutrition has shifted: planktonic phosphorus deficiency continues, while nitrogen deficiency increased due to decreasing ammonia levels; carbon limitation of benthic algae, which was aggravated by acidification, persists. The macrophyte community does not appear different during recovery from those in nearbye reference lakes. Annual zooplankton abundance and biomass are fluctuating considerably, consistent with a further decline in zooplankton diversity. Chironomid emergence appears to be returning to preacidification levels, while littoral Cladocera continue to flourish, possibly due to the absence of littoral fish predation. A population of pearl dace that survived the acidification period regained its reproductive ability.

With the impairment of chemical recovery, the stage is only partially prepared for biological recovery. In some cases, the chemical mileu of the lake is less favourable during recovery than before. In addition, complex interactions between biological and chemical properties make prediction of recovery of ecosystem properties difficult.

Plans for 1997

Recovery from acidification remains a priority of the Government of Canada (e.g., DOE), is poorly understood (see paucity of recovery papers in Water, Air, and Soil Pollution Vol. 85, 1995). Recovery will also be an important issue in eastern North America for several decades (see time trend analysis papers in same volume) as well as in the remainder of the planet as acidification in Asia and the southern hemisphere continues.

Our ability to continue this experiment in 1997 and beyond remains unknown because DFO has formally withdrawn its support of LRTAP initiatives beyond the 1996/97 fiscal year. It is unclear whether the ELA will be able to obtain sufficient financial support external to DFO to maintain the necessary experimental additions, let alone continue the ecosystem recovery studies or to initiate new research. Our efforts to secure external financial support have also been hampered by the external perception of DFO's policy towards freshwater research. For example, K. L. Sumner (on behalf of the The Richard and Jean Ivey Fund) declined to support future Lake 302S research because he found it "difficult … to feel confident about DFO's ability to maintain a viable freshwater program, especially in what appears to be the absence of any strategic policy for its conduct. … [T]here is no policy direction and commitment on the part of governments for the quality of our freshwater resources." Consequently, our plans for further research and continued monitoring have been compromised both by DFO's withdrawal of support and by external perception of its policies.

In the event that we are unsuccessful in obtaining future funding for this experiment, we will be forced to terminate this experiment; this is an irreversible step. We would accelerate biological recovery of the foodwebs in Lake 302S by removing the curtains partitioning the southern and northern basins of the lake, allowing fish populations from the north to reestablish in the south.

If we are successful in obtaining support, then we will probably maintain the target pH at 5.8 to assess whether recovery can proceed beyond that already seen, so as to determine whether human intervention is needed to restore the ecosystem to its original state. We would continue many of the ecosystem measurements as in previous years, except where downsizing has compromised our abilities. Our additional plans, pending funding, include: determining whether the availability of reduced carbon is controlling the rate of recovery of internal alkalinity generation; analysis of the interaction of recovery from acidification with global change (specifically the interaction with increased UV_b and CO_2; see paper by Schindler *et al*, 1996, *Nature* 379:705-708); examination of the effects on biological populations of long-term stress; further analysis of the potential for dinoflagellate blooms to be toxic to biological populations during acidification and recovery (see section 3.6, below); and developing strategies for foodweb reconstruction.

3.4 Recovery of Lake 302N from Acidification

Lake 302N is the northern basin of Lake 302, separated from the south basin (described in 3.3, above) since 1981 by vinyl curtains. Experimental loading of $NaNO_3$, Na_2SO_4 and HCl were made during 1992 and 1993, along with additions of H_3PO_4 at a rate of 1:10 P:N, as part of a study to define the role of phosphorus supply in the lake's internal generation of alkalinity. The water pH was maintained at 5.4 during those years.

The experiment served to demonstrate that phosphorus additions can stimulate internal alkalinity generation, thereby serving as a potentially cost-effective remediation strategy. Concern for increased risk to the fish populations dictated that experimental additions be stopped and that the recovery of the lake be monitored.

During 1996, this lake basin was in the third year of partial recovery from these additions. As in 1994 and 1995, a limited amount of concentrated HCl was added to prevent the pH from rising above the target value of 5.8. Monitoring of various limnological parameters continued. The populations of lake whitefish and other organisms in this basin also serve as potential seed populations for the restocking of Lake 302 South.

3.5 Acid Phosphatase Activity in the Epilimnia and Metalimnia of Lakes 302S and 302N

It has been shown that Al-organic P complexes increase in temperate lakes as lake water pH decreases, and the literature suggests that phosphatase activity should increase in order to compensate for reduced availability of organic P. Three previous years of data (1991, 1992 and 1995) from Lake 302 has shown acid phosphatase activity to be higher than alkaline phosphatase activity under acidic conditions.

No resources were available to continue this work in 1996.

3.6 Causes of Fish Kills in Acidified Lakes 302S and 302N

In 1989, a fish kill was reported in Lake 302 South. A similar fish kill apparently occurred in Lake 302 North in 1993. Since both basins are acidified and often dominated by blooms of freshwater dinoflagellates, a research project was initiated by researchers at the University of Western Ontario to investigate causes of these events. Dr. Charles Trick heads this team.

Experiments performed in 1994 and 1995 tested the hypothesis that the fish kills were due to activities of, or toxins stored in, the dinoflagellates. This work concluded that the causative agent for the fish kills was probably a bacterium associated with the freshwater dinoflagellate, *Peridinium*.

In 1996, the UWO team revisited the questions regarding the environmental control of the toxin levels in Lake 302N and Lake 302S by perturbing the phytoplankton community with nutrients, particularly with iron additions. Iron was deemed the "environmental trigger" in the studies in 1994 and 1995. During experiments in 1996, the team was unable to recreate a fish-kill. Environmental modifications of water samples that had been successful in previous years were non-toxic in 1996. They conclude that the regulation of toxins active against fish is a complicated process that includes climate changes (influencing the phytoplankton species composition), seasonal changes (nutrient consumption over the summer season influences toxin activity), and seasonal/daily precipitation events (that transport iron from the hillslope into the lake and stimulate toxin levels).

In 1996, the UWO researchers have also characterized the taxonomic status of the bacterial isolates and considered the physiological regulation of toxin production using a Daphnia-bioassay system as a surrogate for fish bioassays. This information is contained in a MSc. thesis being prepared by Michael Ray (Dept. of Plant Sciences, University of Western Ontario).

4. MONITORING NATURAL CONDITIONS

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

4.1 Nearshore Fish Habitat Mapping

The purpose of this research was to develop methods that describe the 3-D form of nearshore habitat in detail, and to develop software applications for reconstruction of field data in digital format. Nearshore fish habitat in 5 natural ELA lakes (nos. 164, 165, 373, 377, 442) was mapped to inventory material types by depth class, and to compare the habitat (basin geology, slope, allocthonous/autocthonous materials, zone of deposition) between basins in an area of relatively homogeneous geology. Estimates of wave energy were derived from a new Geographic Information Systems (GIS) Fetch Distance model for predicting properties of waves in lakes. Hydromechanical energy was correlated with substrate and slope maps using GIS.

All work on this project has now been completed and forms the basis of a graduate thesis by Paul Cooley, University of Manitoba.

4.2 Lake Monitoring for LRTAP (Long Range Transport of Atmospheric Pollutants)

Five small ELA lakes (Lakes 224, 239, 305, 373) were monitored for ten years as part of the DFO Long Range Transport of Atmospheric Pollutants (LRTAP) program. The ELA was the LRTAP monitoring site with the lowest loading of atmospheric pollutants of all DFO sites in Canada; hence it provided the baseline for the National Monitoring Programme. Other sites were located in central Ontario, Quebec, and Atlantic Canada. This program was necessary to fulfil Canada's obligations under the current air quality agreement with the United States.

In 1996, no funding was available to continue field monitoring activities under this program. The data from previous years are resident in a relational database and a final report is in preparation. No further work on this project is anticipated.

Two artificially acidified ELA lakes (223 and 302S), and one experimental lake (382) had been sampled for the past five years using the same monitoring methods. The acidified systems have been intensively studied and are now in a state of recovery. Chironomid emergence was monitored in the acidified lakes during 1996, but will probably be discontinued in 1997 because of staffing reductions.

4.3 Nutrient Status Assessment of Selected ELA Lakes

A number of ELA lakes were assayed annually for nutrient status, many for more than 5 consecutive years. Each lake was routinely assayed for alkaline phosphatase activity, nitrogen debt, and nutrient composition ratios. In 1996, staffing uncertainties resulted in this work being cancelled. The status of this program for 1997 remains uncertain.

4.4 Direct and Indirect Effects of Ultraviolet Radiation

A 1996 paper by Schindler *et al*, based on ELA research and published in the journal *Nature* (Vol. 379: 705-708), discussed the ecological consequences of combined climatic warming and lake acidification for UV-B penetration into boreal lakes. This paper attracted international attention and the results received major media coverage in Canada and the U.S.A.

Three experiments and two surveys were completed by Bill Donahue as part of his Ph.D. program, under the supervision of Dr. David Schindler of the University of Alberta. Two of the three experiments (5 weeks each) were completed in enclosures in the east bay of ELA Lake 239. The other study incorporated artificial streams on the outflow of ELA Lake 470 and ran from May until late August.

4.4.1 UV and the Mixed Layer of Boreal Lakes

The first enclosure experiment investigated the interactions of UV radiation and mixed-layer depth, and how this interaction leads to changes in the UV environment in boreal lakes. The second investigated the effects of DOC-UV photochemicals, specifically additions of natural concentrations of H_2O_2, on DOC optics and biological communities in boreal lakes. Several dissolved organic carbon (DOC) parameters were followed throughout the experiments, including changes in absolute removal rates, fluorescence, and absorbance. Biological monitoring included sampling for chlorophyll *a*, bacteria, phytoplankton, and zooplankton. H_2O_2 concentrations were monitored using a modified fluorometric technique.

A survey of 36 lakes and 32 streams in the ELA area was conducted in order to determine relationships between DOC and its optical properties like fluorescence and absorbance and how changes in DOC affect its absorbance of UV radiation.

4.4.2 UV and attached Algal Communities in Streams

Mr. Donahue continued to investigate the role of UV radiation in the structuring and functioning of attached algal communities, including their invertebrate inhabitants, in streams. Six artificial streams were used again in an attempt to look at seasonal-scale changes in naturally-seeded communities related to UV radiation. Biological parameters sampled include chlorophyll *a*, and algal and invertebrate taxonomy and biomass, as well as diel counts of blackfly larvae and diel drift samples of both invertebrates and algae. One very interesting result from this experiment is the evident role of UV radiation in stimulating diurnal emigration of blackfly larvae. Sloughing of algal mats did not occur this year, perhaps as a result of exceptionally high snow-melt and run-off, and high precipitation throughout the summer, and as a result possible changes in nutrient concentrations in the water relative to the two previous very dry summers. It has become evident that streams at ELA do not respond to UV radiation in the same manner as streams in alpine and coastal areas of BC and Alberta. A final experiment next summer will investigate the underlying reasons for these differences.

4.4.3 UV and Epilithic Communities in Lakes

Bill Donahue and Dr. Michael Turner (DFO) completed a survey of epilithic communities in 9 lakes to investigate the role of UV radiation in the structuring of these shallow water communities. Lakes sampled covered a range of DOC concentrations and UV environments, and included previously acidified and eutrophied lakes. This survey is a collaborative effort, involving Dr. Peter Leavitt (University of Regina), Mike Stainton (DFO), and Dr. Kate Duff (University of Alberta).

4.5 Sediment Records of Climatic Change

Dr. Kate Duff, a Post-Doctoral Fellow with Dr. David Schindler, University of Alberta, is reconstructing from sediment cores the recent histories of chironomid emergence in the ELA area in an attempt to correlate these changes with recent regional climate changes. Attempts will then be made to infer historical changes in climate and communities from these calibration data.

4.6 Metalimnetic and Hypolimnetic Chlorophyll Peaks

Dr. F.J. DeNoyelles, Jr. and Dr. David Graham of the University of Kansas conducted a late summer survey of several ELA lakes to evaluate the magnitude and status of metalimnetic and hypolimnetic chlorphyll maxima attributable to concentrations of algae and photosynthetic bacteria at distinct depth strata. They plan to return to the ELA in 1997 to expand this study and are submitting a grant proposal for U.S. funding support.

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 also planned for the Coldwater Lakes study area near Atikokan, Ontario.

5. PERSISTENT TOXICANTS

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. We require some controlled experimentation in real ecosystems 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.

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 PhD 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.

The lake trout population in Lake 260 is still monitored each year to determine how many of the injected individuals remain in the population. Only two injected individuals were captured in 1996; 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 were recaptured in 1996.

5.2 Cadmium Addition to Lake 382

Many metals, including cadmium, are recognized as persistent toxicants within aquatic ecosystems. While concentration guidelines currently exist for the protection of aquatic species and habitats, there is little quantitative information available about the adequacy of these guidelines for protecting against chronic contamination effects in real ecosystems. The deliberate release of cadmium into the environment is now prohibited in Ontario, but quantities of this metal are still being released as a bi-product of the combustion of fossil fuels and the smelting of metals. As part of the study of long-range transport of atmospheric pollutants (LRTAP), cadmium additions to Lake 382 were initiated in 1987. Levels of cadmium in Lake 382 were gradually raised each ice-free season so that approximately 200 nannograms per litre ($ng.L^{-1}$) 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. No cadmium has been added since 1992, but monitoring has continued.

Funding

In 1996/97, the experiment received 85.4 K funding from the Green Plan Toxic Chemicals Program. 1996/97 is the last year of the present Green Plan Toxic Chemical program and the termination of known funding for the study. There are no plans to continue this whole lake study past March 1997, although publication of the data will continue for several subsequent years.

Sampling and Experimentation

Since no Cd was added to Lake 382 in 1996, it served as the fourth year of observing responses to the "zero discharge strategy". Samples were collected to determine fate of Cd in water and suspended sediments, crayfish, and macrophytes. Populations of phytoplankton and zooplankton were monitored biweekly; crayfish, once in early summer, and fish in the spring and fall were monitored for possible effects from Cd. Water chemistry was also monitored.

Sediments were sampled lake-wide through the ice (21 cores) in March 1996 in cooperation with Whiteshell Nuclear Research Establishment personnel in a design similar to that used by M. Stephenson in 1989. The purposes are to determine if the Cd inventory is declining, if the vertical distribution of Cd in core profiles is changing, and to observe if there has been a focusing of Cd from littoral and metalimnetic sediments to hypolimnetic sediments.

Because of declining funding and personnel, a number of parameters monitored in previous years were not monitored in 1996, including primary production, fish (for Cd accumulation and effects), and littoral benthos.

Since no resident mussels were found in the lake, the availability of Cd to these organisms was measured by introducing mussels from nearby Lake 104 in cages into two different substrates (sand and organic) in Lake 382 and into reference Lake 240. Mussels were introduced in June and sampled in July, August, and October. Changes in Cd tissue burdens and the metal-binding protein, metallothionein, are being compared in mussels from these lakes with those in control mussels from Lake 104.

Innovation

Large sediment traps (2 m diameter grain funnels) for bulk collection for geochemical characterization were modified so that suspended sediment in the trap fell into a collection bottle that opened and closed briefly on a timed basis. This solved a problem noted in 1995 when it was suspected that sediment in the shallower traps was “washed-out” of the trap by turbulence.

Results

Water concentrations of Cd in 1996 were somewhat lower than in 1995, but the whole column concentration in mid-October was about the same in the two years. Cd concentration under the ice on 25 Mar 1996 was 13 ng/L at 1 m water depth and 20-26 ng/L in the remainder of the water column. The epilimnetic concentration remained at 12-17 ng/L until fall turnover when it rose slightly by mid-October when the whole water column was about 20 ng/L. Concentration in the metalimnion was slightly higher than in the epilimnion, usually 20-25 ng/L, and in the hypolimnion (11 m water depth), was 20-30 ng/L, climbing to about 40 ng/L in the fall.

Concentrations of Cd in lake trout and white sucker in 1995 either levelled off or rose slightly. Cd concentrations in the lake trout remained high at ~11µg/g wet wt in the posterior kidney and ~7.5 µg/g wet in the liver. These concentrations were not significantly different from those in 1994, and represent a levelling off or small decline. In white sucker, Cd continued to increase in tissues and reached 15 µg/g wet wt in posterior kidney and 4 µg/g wet wt in liver. The increasing accumulation of Cd in the white sucker is attributed to its bottom-feeding habit of white sucker. The maintenance of high Cd levels by lake trout was not expected and raises questions about the relative contributions of pelagic vs. benthic organisms to the lake trout food chain in this lake.

Information on heavy metal ligands in sediment was obtained using near-infrared spectroscopy. Heavy metals (Cd, Zn, Cu, Pb, Ni, Mn, and Fe) in sediment cores from three littoral and metalimnetic locations were "predicted" by near-infrared reflectance spectroscopy. The detection of the metals in this region of the electromagnetic spectrum is hypothesized to be due to the association of the metals with organic matter. Results from principal component analysis of the spectral and chemical data were interpreted as indicating that all 7 metals were associated with the same organic complex (containing spectrally-identifiable protein, cellulose, oil), but that less of the Cd in the sediments could be explained by this organic complex probably because Cd has a much shorter geochemical history in Lake 382 that the other metals.

Post-experimental Monitoring of Lake 382

Recommendations were made for a minimum on-going sampling program to meet the needs of the ELA Agreement. It was recommended that sampling take place in the fall at the time of the fish population study:

a. annual fall sampling of water at turnover when a single (replicated) sample represents the entire water column. Whole water sample is to be concentrated and analyzed for Cd concentration;
b. annual fall sampling of sediment in the southwest bay because these highly organic sediments contain the highest littoral Cd concentrations. Sediments are to be sampled at 1-1.5 m water depth by a snorkel diver using hand-held 5 cm i.d. Plexiglas cores (5 replicates). Slices 0-5 cm and 5-10 cm are to be analyzed for Cd concentration;
c. every two years, 6 lake trout and 6 white sucker, are to be analyzed for Cd in liver and kidney.

Scientific Value of Lake 382

Although there are no plans for further study of Lake 382, it represents a valuable scientific resource for long-term monitoring of recovery of an aquatic ecosystem from known loading of Cd. The redistribution of Cd within the sediments of the lake, the feedback of Cd from the sediments to the water column, the burial of Cd within the sediments, and the loss of Cd from the system in outflow, insect emergence, and predation and grazing by terrestrial animals can all potentially be studied in this system. It has attracted the interest of paleolimnologists and geochemists as a system with a known level of contamination by Cd and only Cd. Furthermore, the lake provides a unique opportunity to observe the recovery of the biota, particularly lake trout, white sucker, crayfish, and perennial macrophytes, from Cd contamination.

Scientific Productivity

A group of five manuscripts (Findlay et al.; Holoka and Hunt; Lawrence et al.; Malley a; and Stephenson et al.) describing the experimental design and history, fate of Cd in abiotic compartments, and effects on phytoplankton will appear in the Canadian Journal of Fisheries and Aquatic Sciences August 1996 issue. Several other manuscripts on aspects of the experiment were published (Malley 1996; Malley et al. 1996; Stephenson et al. 1996). Additional manuscripts are in preparation or under revision (Currie et al.; Stewart; Wesson; Malley b). Results of studies on Cd in the laboratory were or will be published (Kislalioglu et al. 1996; McNicol et al. 1996; and Scherer et al. (accepted). A number of presentations with data from Lake 382 or associated Cd work were made at conferences or are planned for 1997.

The Lake 382 experiment is one of the case studies in Freshwater Ecosystems in the DFO national report "Chemical Contaminants in Canadian Aquatic Ecosystems: An Assessment of their Effects on Fish, Fish Habitat, and Fisheries Resources" due to be released in 1997.

Publications

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presence of other metals. Can. J. Fish. Aquat. Sci. (submitted).
- Wesson, L.J., J.F. Klaverkamp, and C. Ranson. Cytosolic distribution of Cd, Cu, and Zn, and metal-binding proteins in two species of fresh water fish in response to waterborne Cd exposure (in prep).

Presentations

- Malley, D.F. Multi-generational exposure of the crayfish *Orconectes virilis* to low levels of cadmium in a whole lake experiment: Metal concentrations and population parameters. Abstract for Department of Fisheries and Oceans Green Plan Toxic Chemicals Program Wrap-up Conference, Ottawa, 28-31 January 1997
- Malley, D.F., J. Delaronde, L.J. Wesson, and S. Friesen, and P.C. Williams. Exploring heavy metal - organic matter associations in sediments in Lake 382 using near-infrared reflectance spectroscopy and principal component analysis. Abstract for Department of Fisheries and Oceans Green Plan Toxic Chemicals Program Wrap-up Conference, Ottawa, 28-31 January 1997
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- Stewart, A.R. and D. F. Malley. Effect of a metal mixture (Cu, Zn, Pb and Ni) on cadmium bioavailability and accumulation by the freshwater macrophyte *Eriocaulon septangulare*. Poster at 17th Annual Meeting of SETAC, Washington, D.C., 17-21 November 1996.

5.3 Effect of Metal Mixtures on Availability of Cadmium to Eriocaulon

During the summer of 1995 (July 13 - September 27) the effect of metal mixtures on the availability of Cd from the sediment to *Eriocaulon* was examined in a field experiment. The effect of metal mixtures on the availability of Cd to the rooted macrophyte *Eriocaulon septangulare*, was determined by spiking natural sediment taken from a sheltered bay in Roddy Lake (468). The metals were mixed with the sediments at the ELA field station. The spiked sediment was put into 1' x 2' plastic planter trays with the plants, and placed in 0.5 m of water along the shore in the Roddy bay. Several kilograms of left-over sediment were put into bags, frozen, and returned to the Freshwater Institute for future experiments in the laboratory. As planned, the experiment consisted of 4 treatments and 2 replicates. Enough metal was added to raise background sediment Cd six times (in all 4 treatments), and Cu, Zn, Pb and Ni, two (treatment 2), four (treatment 3) and six times (treatment 4). Approximately 34.2 mg of Cd, 85.5 mg Cu, 769.5 mg Zn, 307.8 mg Pb, and 119.7 mg Ni was added in total to the contained sediments.

No additional field studies were conducted during 1996. The planter trays containing the spiked sediment were removed from the lake in the spring of 1996 and transported to a hazardous waste facility for disposal.

Laboratory analyses of the metal concentrations in the sediments and plants were carried out during 1996. This work forms part of a PhD thesis by Robin Stewart, Botany, University of Manitoba.

6. RADIONUCLIDES AND GROUND WATER

Researchers from the Environmental Sciences Division of the Whiteshell Laboratories of Atomic Energy of Canada Limited (AECL), Pinawa, Manitoba, had been conducting studies at the ELA in recent years, largely in support of their waste fuel management program. During 1995, research funds for continuation of these studies were severely limited, and most of the ongoing AECL work at the ELA was discontinued.

In 1996, no resources were available for the AECL research projects in ELA lakes. Only some collaborative work on Lake 382 (see 5.2 above) was carried out. Given the current downsizing of AECL research operations and the uncertainty surrounding the future of AECL's Whiteshell facilities, no AECL work is anticipated at the ELA in 1997.

7. STUDIES IN, AND LINKAGES WITH, TERRESTRIAL CATCHMENTS

7.1 Impact of Elevated Nitrogen Deposition on Forested Catchments

The enrichment of the atmospheric nitrogen (N) pool from the burning of fossil fuels has caused a large increase of atmospheric N deposition to terrestrial and freshwater ecosystems in North America and Europe. The long-term impact of elevated N deposition is not well known, but it is a suspected causal factor in lake acidification, forest decline, and the eutrophication of estuaries. Understanding the links between forested catchments and lakes is particularly important with elevated N deposition because uptake of excess N by forests will initially protect downstream ecosystems. However, this buffering capacity is limited , so it is important to define the critical loads of N that will not exceed buffering capacity.

A research team from the University of Waterloo (led by Dr. Sherry Schiff and PhD candidate Sebastien Lamontagne), in cooperation with DFO, are conducting an experimental addition of nitrogen to small boreal forest catchments located in the watershed of Lake 302 at the Experimental Lakes Area. In combination with traditional methods, the researchers are developing new isotopic techniques to study the internal cycling of nitrogen in the catchments.

The objectives of this study are twofold:

1. to quantify the pools, fluxes, and the internal cycling of nitrogen in the ELA upland catchments prior to, and following, the experimental addition of nitrate, and
2. to develop new stable isotope techniques to study N-cycling in forested catchments.

Work Realized in 1996

i) Second year of $NaNO_3$ addition:

Forty kg $N.ha^{-1}.y^{-1}$ as $NaNO_3$ were added to upland catchment U3. This nitrate was labelled with the stable isotopes ^{15}N ($300^0/_{00}$) and ^{18}O ($30^0/_{00}$). Catchments U1, U2, and U8 were monitored as reference systems (U8 is also a long-term reference for similar catchments in the Atikokan LTER project). Runoff volume and chemistry was monitored continuously from April to mid-October. In U1 and U3, bedrock and forested subcatchments were monitored from May to October. After two years of N addition, catchment U3 still efficiently retains N (93%).

ii) N-Mineralization:

Under pristine conditions, most N needed for plant growth is obtained by internal recycling of organic N. In addition, increase in nitrification (conversion of ammonium to nitrate) is believed to be a good indicatior of the onset of “nitrogen saturation” of a forest. N mineralization in forest and in thin bedrock soils was measured monthy in the treated catchment and in one of the reference catchments. There was a net loss of nitrate from forest soils in U3. Plant uptake, denitrification, conversion to ammonium and immobilization in soil have been identified as potential mechanisms responsible for the rapid removal of the added N.

iii) Vegetation growth:

The growth (diameter at breast height) of 20 jack pine, 20 black spruce, and 20 black spruce saplings is being followed in catchments U1, U2, and U3. Thus far, no difference in growth rates has been observed. In the same catchments, the yearly radial growth of 10 colonies of the moss *Racomitrium microcarpon* is followed using photographs.

iv) Denitrification

Denitrification is the process by which NO_3^- in soils is converted to N_2 or N_2O gas. The U of Waterloo researchers showed that the conditions required for denitrification mostly occur under the snowpack and in early spring. More detailed denitrification measurements under the snowpack are presently under way.

v) Isotopes:

Plant and soil samples are collected twice a year in catchments U1, U2, and U3 for C:N ration and ^{15}N isotopic content. The ^{15}N signature will be used as a tracer to determine storage of the added nitrate. Work is ongoing in the laboratory to further develop the methodology to measure the ^{18}O content of nitrate. The significance of the latter assay is that “natural” nitrate (i.e. arising from nitrification) has a much different ^{18}O signature than pollution or fertilizer nitrate. In this study, the researchers plan to use the ^{18}O signature of runoff nitrate from U3 to determine the retention efficiency of the nitrate experimentally added to the catchment.

Ongoing Work

Presently, the University of Waterloo team is investigating the ELA long-term deposition record in collaboration with DFO scientists. In many areas of the world, the volatilization of ammonia applied as fertilizer and from manure is a major cause of acid rain. Although most of the prairie landscape is not acid-sensitive, bordering areas such as the Canadian Shield can be. Preliminary analysis suggests that the ELA has been receiving higher than expected N deposition for some time, with a peak occurring during the drought of the 1980”s. Research is underway to determine the origin of this N and the mechanisms regulating its emission and transport.

Long-term Prospects

Much of the adverse impact of elevated N deposition is expected to occur upon long-term exposure. The University of Waterloo researchers are planning on continuing the N addition experiment to catchment U3 for the next 10 years. The form of N added may be changed to include a larger acidity component. During most years, to limit cost, monitoring of the catchments would not be as extensive as in the initial phase. Full-scale studies would take place after 5 and 10 years. Meetings with DFO scientists to prepare the project are scheduled to take place in the winter of 1997.

7.2 Contribution of Forest Litterfall to Lake Nutrient Inputs

In conjunction with a catchment-scale study of the effectiveness of current Ontario forest harvesting buffer strip guidelines on fish habitat, P, N, and C inputs to lakes via litterfall from the forest edge were being measured at the Coldwater Lakes Experimental Watersheds (near Atikokan) and the Experimental Lakes Area in northwestern Ontario. This study is currently funded under the federal Sustainable Fisheries Initiative, which is slated to end in March, 1997.

At the ELA, P inputs from 100 year old and fire regeneration jack pine stands along the shores of Lake 239 are being investigated. In the summer of 1995, pans containing distilled water were set out in two pairs of transects from the water's edge to the centre of the lake, at distances of 0, 1, 3, 9, 30, 90, and 250 m from shore. Samples were collected at two-day intervals from mid-May to mid-October, and filtered through 1.2 μm filters. After identification of large particles, filters and filtrate were analysed for total P, N, and organic C. This work was continued in 1996, using the same techniques. No analysis of the results has been done because of staffing reductions.

Litterfall collection began in the summer of 1995 at the Coldwater Lakes Experimental Watershed. No OMNR staff were available to do this collection at the Coldwater Lakes in 1996, and the work was discontinued at that site.

Note:

This summary was compiled by John Shearer*, using information provided by research project leaders and other ELA staff. It is intended as an overview of research activities at the ELA during 1996. 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.*