Experimental Lakes Area:
Canada's Outdoor Freshwater Laboratory

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The Experimental Lakes Area (ELA) is located in extreme western Ontario, near the town of Kenora. Kenora lies north of Lake of the Woods (at the Northwest Angle of the Canada-U.S.A. border) and about 200 km east of Winnipeg, Manitoba. The landscape surrounding Kenora is fractally mottled with glacial lakes of all shapes and sizes and connected by portages. In the 1960s, scientists selected this slice of boreal forest for a series of bold experiments in large-scale freshwater ecosystem manipulation.

Climate and geology

At an elevation of 410 m, Kenora's climate is characterized as humid continental, with cold winters and warm summers. Mean annual rainfall is 565.3 cm and mean annual snowfall is 164.1 cm. Normal maximum and minimum temperatures for January are -11.4° C and -20.5° C; for July, 24.4° C and 14.9° C. [GC14]

Geologically, the region belongs to the Superior Province, one part of the larger Precambrian Canadian Shield (a/k/a Laurentian Plateau). Bedrock of the ELA is predominantly igneous/metamorphic units of (a) massive granodiorite to granite and (b) foliated tonalite, dated to the Neo- to Mesoarchean (2.5 to 3.4 Ga). [OGS91]

In much more recent times, the region was overlain by ice sheets during the Wisconsin glaciation. When the ice retreated, about 13,000 years ago, Lake Agassiz formed from the meltwater, leaving sediment deposits. The crust rebounded differentially, leaving uplifted areas; lake wave action scoured some of these clean to bedrock. [ODLF65] Just such conditions were ideal for a suite of experimental lakes.

Responding to a problem

The story of the ELA's inception is told by [Vallentyne00]. It came about in response to concerns by the two governments and the International Joint Commission (IJC) about transborder flows of water contaminants. As part of the research initiative, Canada set up the Freshwater Institute (FWI) in Winnipeg in 1966 to study the biological side of the causes and controls of water pollution. FWI researchers would work under the direction of the Fisheries Research Board (FRB); although funded by the government, the FRB consisted of university-based scientists and set its own agendas. The FRB's history of excellence in research (reaching back to 1898) was key to recruiting scientific talent.

The research team understood the need for field research, as opposed to lab work, to understand the pollution problem. At the time, less than 1% of freshwater organisms had been cultured in the lab for longer than a generation;

at any rate, it was not possible to maintain any natural aquatic community for a significant amount of time.

The lakes

The team sought a tightly clustered group of lakes not too far from Winnipeg, but in an area with little human settlement. Perhaps most importantly, they were looking for lakes situated directly on granite bedrock, rather than glacial till, so that the confounding effects of groundwater movement would be minimal.

To that end, the team extended a logging road and set up a field station; beginning with topographic maps and continuing with aerial surveys, they selected 58 small, deep headwater lakes and their watersheds out of the hundreds within a 15 km radius of the station. The ecosystems of the lakes themselves were to be the experimental subjects.

Only the larger lakes in the region had been given names by geographers (e.g., Winnange and Eagle Lakes to the north and Dryberry Lake to the south), so the scientists assigned 3-digit numbers to all the water bodies and wetlands.

The lakes that the scientists designated for research are deep (up to 20 m) and clear. The range of total dissolved solids is 3 to 140 mg/l, with a mean of 36 mg/l. Chemically, they are dilute, with conductivities in the range of 11 to 161 µmho/cm, with a mean of 29 µmho/cm. Secchi depths range from 1 to 5 m, with some up to 10 m. Thermal stratification and mixing are the rule: most of the study lakes are monomictic or dimictic. However, Lake 111 is clearly monomictic. Lake drainage orders range from 1 to 52.

Water renewal (flushing) times vary greatly from year to year, depending on precipitation. However, the range for these lakes is from <0.1 to >10 years. By contrast, pollutants are flushed from Lake Ontario over a period of 25-30 years; for Lake Superior, the period is 500-600 years. [Vallentyne00], [ELA09d], [ELA10b], [ELA10c]

These lake ecosystems are relatively low in diversity, particularly at the top of the food web. In most lakes, primary production is represented by chrysophyte (so-called golden) algae. Rotifers and small crustaceans like *Diaptomus minutus* and *Bosmina longirostris* dominate the zooplankton; it is conjectured that these are less susceptible to visual predators in the clear lake waters. Benthic invertebrates include crayfish (in the form of *Orconectes virilis*, native here), amphipods (like *Hyalella azteca*), and chironomids. In a typical lake, its fish community would be made up of several species of minnows, the algal-feeding White Sucker (*Catostomus commersonii*), and a top predator like Northern Pike (*Esox lucius*) or Lake Trout (*Salvelinus namaycush*). In some smaller lakes, the top level of the aquatic trophic web is occupied by Yellow Perch (*Perca flavescens*) or Lake

Whitefish (*Coregonus clupeaformis*). Most lakes also support avian predators, among them diving feeders (Common Loon [*Gavia immer*] and Common Merganser [*Mergus merganser*]), Ring-billed Gull (*Larus delawarensis*), occasional raptors (Bald Eagle [*Haliaeetus leucocephalus*] and Osprey [*Pandion haliaetus*]), Belted Kingfisher (*Megaceryle alcyon*), and smaller insectivores like Tree Swallow (*Tachycineta bicolor*). Also, in most lake ecosystems we can find aquatic mammals, such as North American Beaver (*Castor canadensis*) and various mustlelids like American Marten (*Martes americana*) and Fisher (*M. pennanti*). [ELA10a]

Whole-lake manipulation

The ELA's relative remoteness from large Canadian cities (Kenora is more than 20 hours away from Toronto by car), lack of groundwater effects, and abundance of small lakes (most between 5 and 50 ha) makes it possible to conduct the long-term, wide-scope, whole-lake experiments that the facility has become known for.

¶ Project METAALICUS (Mercury Experiment To Assess Atmospheric Loading in Canada and the United States) was initiated in 2001. Investigators sought to understand how mercury deposited from the atmosphere makes its way through the ecosystem and is accumulated as organic mercury in fish. For each of six years, an incremental 12.5 g of mercury was added, as three different radioisotopes, to the watershed of Lake 658: ^{198}Hg to an upstream wetland, ^{200}Hg to the surrounding forest, and ^{202}Hg directly to the water. Although early results showed immediate uptake by Yellow Perch of the isotope that was released in the water, the research team is continuing to monitor the slow progress of the forest-distributed metal from the upland, through soils, and into the lake. [ELA06a], [Stokstad08]

¶ From 2003 to 2007, Lake 375 was host to a 760-m^3 nylon cage stocked each year with Rainbow Trout (*Oncorhynchus mykiss*) fingerlings, in a joint project with the Ontario Aquaculture Association and Meeker Aquaculture. From two years before production to three years after, Lakes 375 and 373 (a control), were monitored for changes in water chemistry, sedimentation, algal production, animal communities, and other variables. Radio transmitters were implanted into resident Lake Trout and White Suckers so that their movements could be tracked. There is some indication that minnows in the lake benefited indirectly from waste from the fish farm. [ELA09a], [DFO11]

¶ Natural and artificial estrogen, taken as a birth control measure, is excreted by humans and passes untreated by wastewater treatment plants into downstream rivers and lakes. From 2001 to 2003, experimenters added the hormone 17α-ethynylestradiol (EE2) to the waters of Lake 260 in concentrations on the order of parts per trillion (approx. 5 ng/l). During the treatment period and for the two years of monitoring that followed, they observed a recruitment failure of Fathead

Minnow (*Pimphales promelas*). Adverse effects on gonadal development were observed in several species of fish; as evidence that the endocrine systems of the fish were being disrupted, elevated levels of the egg protein precursor vitellogenin were observed, at 2,000 (in females) to 9,000 (in males) times reference levels. While no significant changes to the algal, microbial, or zooplankton populations were found during the experimental period, populations of the zooplankton predator *Chaoborus* spp. doubled, perhaps in response to top-down food web effects. [ELA06b]

¶ Experimental Lakes Area teams were leaders in research into the effects of acid rain on lake ecosystems. Sulfuric acid was introduced into Lake 223 starting in 1976. By 1981, the experimental target acidity was reached, pH 5.0 (the natural level is 6.7). Key species, such as the shrimp *Mysis relicta*, crayfish, and Fathead Minnows dropped out of the lake, while the top predator Lake Trout were slowly starving for lack of prey. A controlled recovery phase of the experiment was begun in 1984, allowing the water chemistry to return to pre-treatment levels. pH levels were back to normal, and the Lake Trout slowly bounced back, but extirpated species like Slimy Sculpin (*Cottus cognatus*) have not yet returned.

An even more aggressive, double-basin experiment was conducted in lake 302. Sulfuric acid was added to one half of the lake, eventually lowering the pH to 4.5; in the other basin, nitric acid was added. The nitric acid (HNO_3) proved to be two-thirds as effective as the sulfuric in affecting acidity; this evidence pointed to nitric oxide (NO) emissions from automobiles as an important factor in lake acidification. [ELA04], [ELA09b]

¶ In various experiments, researchers introduced other contaminants into these hectare-sized lab flasks, including aluminum, cadmium, barium, nanosilver, and the organic toxicants chlordane and toxophene. Study goals included understanding the effects on fish and validation of the existing water quality guideline of 0.2 ppb for cadmium. [ELA09c], [ELA12], [Fieldberg14]

It's important to note that at the end of every experiment, each lake is cleaned up and returned to its pre-treatment state. Indeed, an experiment's research objective may include studying how the ecosystem recovers once an artificial input is curtailed, as in the acid rain study above, and as discussed in the next section.

Phosphorus and lake eutrophication experiments

The most headline-worthy research to come out of the ELA, as well as the earliest, concerned the role of phosphorus as a contributor to cultural (accelerated, anthropogenic) eutrophication. Scientists (and the policy-makers they advised) in the 1960s-1970s pondered the following questions:

- Is phosphorus the key nutrient responsible for algal and cyanobacterial blooms, or is the limiting factor carbon (the "Lange-Kuentzel-Kerr" hypothesis), nitrogen, or a trace nutrient?
- Can already eutrophied lakes be recovered by reducing phosphorus inputs? Or rather, will phosphate lake sediments continue to produce eutrophic conditions once the external sources are curtailed?

A series of moon shot-scale experiments settled these questions. First, Lake 226, which is shaped like a figure-8 leaning to the east, was divided at its narrow point by a vinyl-nylon sea curtain into two basins of approximately equal size, each with a surface area of 8 ha and containing 500,000 m^3 of water. Beginning in late May 1973, both basins were fertilized with carbon (as sucrose) and nitrogen (as sodium nitrate); in addition, only the northeast basin received phosphorus (as phosphoric acid). By early September, the CNP-treated basin bloomed with the cyanobacterium *Anabaena spiroides*, while the other basin's phytoplankton levels were unchanged. A stunning aerial photograph of the two-parted lake, colored green and black, has been widely reproduced.

Experiments at nearby Lake 227 established that surface-water carbon was not a necessary condition for algal blooms; rather, at least some carbon was taken up from the atmosphere. Also, researchers observed no significant increase in sedimentary phosphorus.

And a multi-year study at Lake 304 served to answer the question of recovery after eliminating the artificial fertilizer. Chlorophyll-a levels were measured monthly during 1968-1970 as a baseline. In 1971 and 1972, carbon, nitrogen, and phosphorus were pumped into the system, raising chlorophyll levels into the range generally defined as eutrophic (30 mg/l); the peak was seen in September 1972, at 115 mg/l. The next year, artificial inputs of carbon and nitrogen continued while phosphorus was eliminated. As a result, monthly chlorophyll levels dropped to 22 mg/l and lower.

These clear-cut research findings, suitable for both ecology textbooks and presentations to policy-makers, accelerated legislative and regulatory efforts to control point-source phosphorus pollution. Today, phosphorus compounds are widely banned or restricted as ingredients in cleaning products sold to consumers in the developed world. [Schindler74], [Vallentyne00], [Schindler06], [Molles08, pp. 416-417], [Stokstad08]

Funding and the power environment

As with any publicly-funded research initiative, the ELA has changed hands several times with respect to its controlling body; at the same time, plentiful funds have come and gone. As noted above, initially it was under the Fisheries Research Board (FRB). While the FRB received money from Fisheries and Oceans Canada (DFO)[1], it was largely autonomous. The first organizational change came in 1969, when the minister made a change to the employment relationship. Thereafter, FRB employees would be public servants, subject to more bureaucratic procedures. Then, in 1973, the FRB was relieved of direct control of the labs. In 1979, the Fisheries Research Board Act dissolved the FRB altogether; thereafter, the labs would be units of DFO. In the 1980s and 1990s, the consequences of the reorganization were staff attrition, overwork, and reduced morale, as reported by [Vallentyne00], a first-hand observer.

A round of budget belt-tightening in 1996 threatened to shutter the labs. Yet, research continued at the lakes into the new century, even though DFO's emphasis was on marine, not freshwater systems. [Stokstad08] Finally, in May 2012 (after other attempts by various Liberal and Conservative governments to transfer the ELA to a university or other research organization), DFO announced that funding for the facility would be discontinued after the fiscal year ending March 2013. [Hoag12]

Fortunately for the labs, a deal was struck in September 2013 to transfer the ELA to the International Institute for Sustainable Development (IISD), which in turn is funded by the United Nations. The provincial governments of Ontario and Manitoba, along with DFO, will provide money during a transition period. [Owens13] Earlier this year, trilateral agreements among Canada, Ontario, and IISD formalized the transfer and scientists returned to work for the 2014 field season. [IISD14], [Fieldberg14]

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1 Since the 1960s, Fisheries and Oceans Canada has undergone several name changes. For simplicity, this paper uses today's name and abbreviation throughout.

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