Canada's Experimental Lakes

In remote Ontario, a network of lakes is dedicated to bold ecological manipulations. Research there has helped explain algal blooms and acid rain. As the unique outdoor lab turns 40, some wonder whether it is past its prime

In 1966, fisheries scientist Waldo Johnson had a big idea. Algal blooms were plaguing Lake Erie, and the Canadian government had created the Freshwater Institute to study the problem. Johnson, as the new director, proposed to pollute several small lakes intentionally to figure out exactly what was going on. If researchers manipulated the entire lake ecosystem, he argued, they might be able to mimic what happens in nature and find some answers.

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Hear more about how ELA's lakes are altered and probed on *Science*'s podcast.

The government agreed, setting aside dozens of remote lakes for research. The world-renowned facility that resulted, the Experimental Lakes Area (ELA), changed the face of freshwater ecology, ushering in an era of what researchers there call "extreme science."

Over the decades, ELA researchers and collaborators from around the world have conducted more than 50 massive experiments, including building dams and setting up fish farms. In a practice that would surely raise eyebrows elsewhere, they have dumped toxic metals, synthetic hormones, and other pollutants into pristine lakes. "Everyone has the same reaction: 'I can't believe they let you do that,'" says ELA's chief scientist Michael Paterson, a zoologist with Canada's Department of Fisheries and Oceans (DFO), which runs the facility. "We use these lakes the way medical researchers use white mice."

ELA was pivotal in fingering phosphorus from detergents as the culprit in algal blooms, and experiments in lakes there provided compelling evidence of the harm caused by acid rain. U.S. and Canadian environmental policies were forged in part on the strength of ELA's science. "It's hard to overstate the impact they've had," says James Elser of Arizona State University (ASU), Tempe.

"...the single most powerful image in the history of limnology."
—JAMES ELSER

Forty years later, ELA still hosts first-rate science, say many ecologists. With $13 million of infrastructure, finely characterized lakes, and decades of baseline data, the site can tackle problems few others can. All is not rosy, however. Researchers complain that government bureaucracy has long limited the lab's full potential, although this may change with a new arrangement for funding. Half of the staff scientists there are nearing retirement, and recruiting top talent can be a challenge. As ELA celebrates its 40th birthday, even some of the lab's old hands wonder aloud whether the place is due for some rejuvenation.

Young blood

In many ways, the stars were aligned when Johnson sketched out plans for the outdoor lab, which became useful for studying much more than eutrophication. In 1967, a pair of technicians was sent out to find an area with many lakes of various sizes, remote enough to be pristine yet within 300 kilometers of Winnipeg, where the Freshwater Institute was located. Flying by plane and helicopter, the technicians named hundreds of lakes, simply giving them sequential numbers. Eventually, 46 lakes in 17 small watersheds were selected.

The setting is ideal. The lakes and sur-

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Probing below. Floating traps collect aquatic insects on lake 375, part of the research infrastructure at ELA.

rounding pine forests rest on granite bedrock, so there is little groundwater, which means the lake chemistry is relatively simple to study. And the diversity of the lakes' sizes and depths makes for an exceptionally versatile ecological lab.

Limnologist Jack Vallentyne, hired from Cornell University, was put in charge of assembling a crack team of scientists. He recruited respected experts from Japan, Poland, Italy, and other countries, as well as "hot, young blood," as he called the younger members of the team. In his bid to persuade scientists to move to Winnipeg and endure long, cold winters, Vallentyne touted the opportunity to do whole-lake experiments on a scale unmatched anywhere else.

In what turned out to be a strategic move, Vallentyne put a young limnologist, David Schindler of Trent University in Peterborough, Canada, in charge. In the summer of 1968, Schindler set up a field camp with a few trailers and got to work. (Schindler is a member of *Science*'s board of reviewing editors.)

ELA's original mission was to examine the problem of eutrophication. The pressing question in the late 1960s was which nutrient triggers excessive algal growth. Studies in small tanks done elsewhere had yielded conflicting data. Some scientists thought the culprit was phosphorus, principally in detergents and sewage; others thought it might be nitrogen from fertilizer and sewage, or carbon, or perhaps even trace metals.

In a now-famous experiment (*Science*, 24 May 1974, p. 897), the team divided Lake 226 with a plastic curtain and added phosphorus to one half. When it turned a distinctive murky green, they had their answer. It was an aerial photograph from this experiment that largely persuaded policymakers to phase out phosphorus from detergents. "I think that's the single most powerful image in the history of limnology," Elser says. When Schindler took the results—and the photo—to government hearings in Canada and the United States, he put ELA on the map as a hub of innovative, policy-relevant research.

Next, Schindler tackled one of the most contentious issues of the day, acid rain. In a series of experiments conducted between 1976 and 1988, researchers added sulfuric and nitric acid, pollutants that lead to acid rain, to Lake 223 and others. The results showed that the pristine ecosystem began to suffer at significantly less acidic conditions than electric utilities maintained. They also demonstrated harm cascading through the food web, with plankton species disappearing and fish not reproducing—as had been seen in lakes already damaged by acid rain. One of the key contributions of ELA, points out ecologist Gene Likens of the Cary Institute of Ecosystem Studies in Millbrook, New York, was that it provided experimental evidence that helped convince skeptics of observational studies. Schindler and his colleagues were also able to perform experiments showing that lakes would slowly recover when the pH returned to normal.

Rising star. David Schindler, shown in 1979 and today, was ELA's first director. Many credit ELA's reputation to his 2 decades of leadership.

Once again, Schindler made the rounds of government offices and congressional hearings in Canada and the United States with his data and images—this time starving trout whose prey had died and species that had vanished. Although ELA was by no means alone in studying acid rain, many say Schindler's ability to communicate science in simple, homespun terms—he appeared widely on television and in newspapers and magazines—helped spark stricter regulations on power plants. In 1990, the U.S. Congress passed major amendments to the Clean Air Act that helped reduce acid rain (*Science*, 6 November 1998, p. 1024).

They were heady times. The federal government and other funders were generous, and the researchers who flocked to the site each summer were essentially given free rein. True, there were a few rules, Schindler recalls. For example, once an experiment ended, the lake had to be restored to its original condition. Other than that, "in the early days, we could do pretty well what we pleased," he says. The camaraderie was strong. "It was nirvana when I got there," recalls John Rudd, who first arrived at ELA as a graduate student in 1972. Researchers worked full-time, brainstorming late into the night. "We lived our science together, week after week," says Rudd.

Ecology's supercollider

But change was afoot. In 1979, the Fisheries Research Board, which had been run mostly by university scientists, was dissolved; the Freshwater Institute and ELA were transferred to DFO. The move put department officials, not scientists, in charge and eventually had a large impact on the direction of the research, says Schindler.

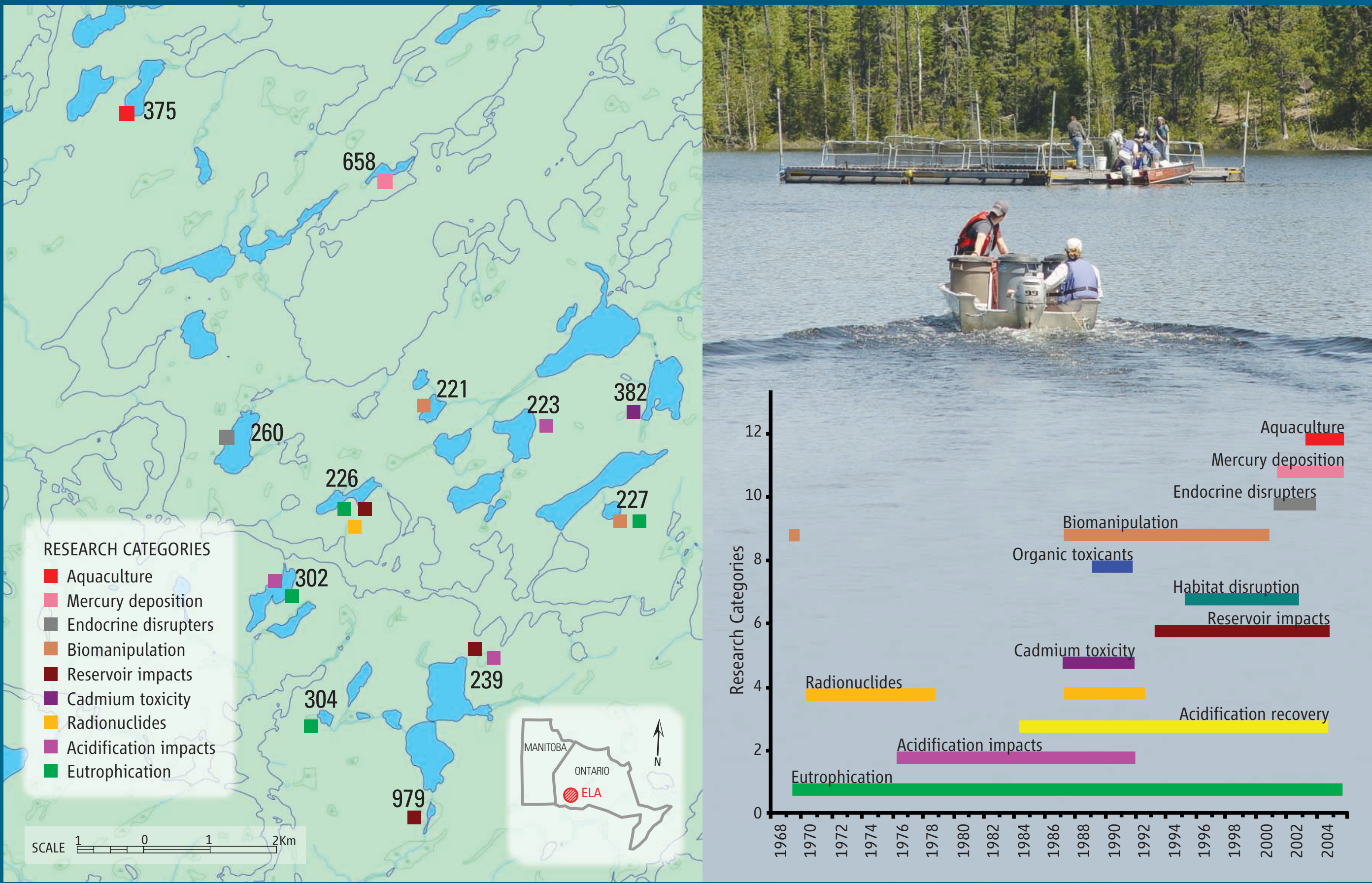
DFO's primary focus was on marine rather than freshwater issues, and ELA gradually lost its favored status. Raising funds for experiments became increasingly hard. "We'd always fall through the cracks," Schindler recalls. Fed up, he left for the University of Alberta, Edmonton, in 1989.

Also at about that time, a few officials with the province of Ontario began to look askance

Dam impact. Flooding wetlands showed that reservoirs can release greenhouse gases and mercury.

CREDITS (TOP TO BOTTOM): D. F. BRAKKE; (INSET) UNIVERSITY OF ALBERTA CREATIVE SERVICES; DFO

WHOLE–ECOSYSTEM EXPERIMENTS



Full palate. For 40 years, researchers have conducted a broad range of experiments in 58 lakes reserved for research (some shown above). Among others, they have manipulated food webs; examined the effects of habitat disruption, such as removal of lake vegetation; and studied the impact of caged aquaculture.

at ELA's practice of dosing the lakes with one pollutant after another. One example in particular sticks in the craw of Robert Hecky, who took over as director after Schindler.

ELA scientists had been adding cadmium, a metal released from smelters and coal-fired power plants, to Lake 382 to see whether provincial regulations were tight enough to protect aquatic organisms. A few years after Schindler left, Ontario's then–minister of environment halted that work, forbidding ELA scientists from adding any more cadmium. "They threatened to shut down the whole ELA if we didn't stop," recalls a still-outraged Hecky—despite the fact that power plants were emitting greater concentrations of cadmium on a regular basis. Hecky says he soon realized that plans to add polychlorinated biphenyls to the lakes weren't going to fly, either.

The nadir came in 1996, when the federal government tried to shut ELA during a round of belt-tightening. Hecky resigned in protest. Scientific societies such as the American Society of Limnology and Oceanography rushed to ELA's defense, and the lab was saved. ELA is secure now, assures Robert Lambe, DFO's regional director in charge of the Freshwater Institute. "It's not in the crosshairs."

But the years have taken a toll, say scientists inside and outside ELA. Old-timers say that DFO grants are smaller and harder to come by now. "The federal money to conduct experiments has dried up," Rudd says. A long-term experiment on flooding of wetlands may have to be shut down if funds to repair the dam can't be found.

The biggest impact has been the decline in staffing; the number of DFO scientists working full-time at ELA has fallen by about half since the early 1990s, to six today. Researchers from other institutions still flock to the lab with the spring thaw, although now it tends to be graduate students and technicians rather than professors who stay the whole summer, Rudd says.

In terms of technological prowess, ELA remains unmatched. Over the years, DFO replaced the dented trailers with comfortable dormitories and a first-rate laboratory. ELA is still "the supercollider of ecology," says Schindler. In a recent experiment to gauge the impact of freshwater aquaculture, for instance, researchers had to build a 12-ton cage on the ice of Lake 375 in –30°C weather. Every spring, starting in 2003, the cage was stocked with 10,000 rainbow trout that had to be trucked in from nearly 1900 km away. There are not many places in the world with ELA's combination of experience setting up big infrastructure and onsite research capacity, as well as detailed background records and reference lakes, notes DFO's Cheryl Podemski, who ran the experiment.

Perhaps the most ambitious experiment of the past decade is METAALICUS (see sidebar, p. 1319), in which researchers added isotopes of mercury to Lake 658 and its watershed for 7 years in a row. The goal is to figure out how the pollutant moves

CREDITS: (MAP/TIMELINE DATA) DFO; (IMAGE) C. PODEMSKI/DFO

Contaminating a Lake to Save Others

LAKE 658, CANADA—Even at the Experimental Lakes Area (ELA), the birthplace of "big" ecological experiments, METAALICUS is ambitious. Over the past 9 years, some 15 principal investigators (PIs) from eight institutions have joined forces at this remote experimental station (see main text) to tease apart how mercury in air pollution cycles through the environment. By adding stable isotopes to Lake 658 and the surrounding watershed, researchers are studying how mercury percolates through soil and into lakes, how microbes make it bioavailable, and the rates at which it accumulates in fish. Already, the $15 million project, formally known as the Mercury Experiment to Assess Atmospheric Loading in Canada and the United States (METAALICUS), has generated policy-relevant results.

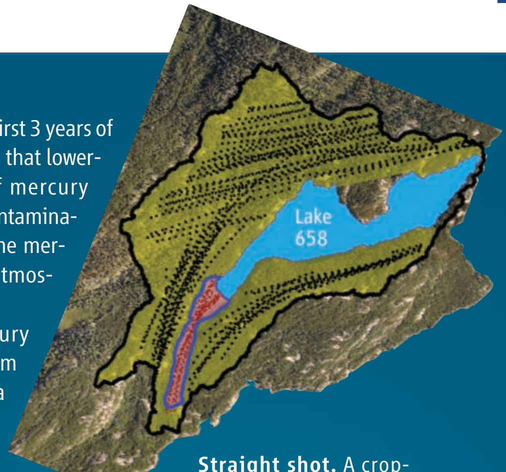
Several attributes made ELA an ideal location for METAALICUS, says one of its leaders, geochemist David Krabbenhoft of the U.S. Geological Survey in Middleton, Wisconsin. For one, the relatively low rates of background deposition to the lake made it easier to detect the tiny amounts of mercury isotopes—just 12.5 grams (a sixth of a teaspoon)—that they added each year. Even more important, the remote location and the history of successful research at ELA lowered the chance of public objections. Just in case, Canadian researchers held public briefings in Dryden and Kenora, the closest towns.

METAALICUS was years in the planning. After a 3-year pilot project at ELA, the researchers first added isotopes in June 2001, trickling ^{202}Hg throughout this 8.3-ha lake by boat. Depositing the other two isotopes—^{198}Hg onto an adjoining wetland and ^{200}Hg onto the surrounding forest—proved far more challenging. In a nail-biting maneuver, a crop-duster had to fly low overhead repeatedly, precisely spraying an extremely dilute mist of mercury. Had a droplet of either ^{198}Hg or ^{200}Hg drifted into the lake, it would have confounded the findings.

Within 2 months, ^{202}Hg was detected in fish. In a paper published in September 2007 in the *Proceedings of the National Academy of Sciences*, the team reported that mercury levels rose by a third in young yellow perch over the first 3 years of the experiment. This suggests that lowering industrial emissions of mercury should quickly reduce fish contamination in lakes where most of the mercury falls directly from the atmosphere to the water.

The final doses of mercury were added to the ecosystem last year. Earlier this fall, a crew of technicians was busy looking for signs of isotopic mercury trickling through the forest soil. Monitoring will continue for several more years to figure out the rate at which the forest soils release mercury after it lands from the atmosphere. "It's slow, but we can't tell you whether it's 20, 100, 1000 years" for the isotopes to make their way into the lake, says biogeochemist Cindy Gilmour of the Smithsonian Environmental Research Center in Edgewater, Maryland, a co-PI on a new $570,000 U.S. National Science Foundation grant to explore the question. The work is crucial, Krabbenhoft notes, because it will provide insights into the impact that past mercury emissions will have on future fish generations.

METAALICUS is not only the largest experiment in ELA's history, but it is also the first that has moved beyond lake manipulation, ELA's original mandate, to manipulation of the surrounding terrestrial ecosystem as well. "Broadening the perspective beyond lakes adds a lot," says Stephen Carpenter of the University of Wisconsin, Madison, and would be an effective way to maximize the scientific potential of ELA. "They need to think really, really big." **–E.S.**



Straight shot. A crop-duster applied different isotopes of mercury (black dots) to the upland forest (green) and wetland (red).

through the ecosystem and builds up in fish. The final dose of mercury was added in 2007, and now team members are keeping tabs on water quality and aquatic life.

Next?

Other experiments at ELA have finished their active phase as well. In 2007, all the fish were removed from the aquaculture operation for the last time. Now researchers are watching to see how the lake returns to its natural state. That's also the case with ELA's endocrine disrupter study. Over 3 years, researchers added synthetic hormones to Lake 260 to study the effects of birth-control pills in wastewater. At hormone concentrations currently found in municipal wastewater, minnow populations crashed, they found, in the first ecosystem-scale study to show the impact of these pollutants on fish populations.

But now, for the first time in ELA's storied history, no major lake manipulations are on docket. Part of the reason no big manipulations are planned is that half of the staff scientists are about to retire, says Paterson, who is "terrified" of the looming brain drain. But he is heartened by a new alliance with Environment Canada that he hopes will bring new funds to ELA and enable scientists to broaden the scope of their research again.

Trickle down. Researchers are tracking how mercury in the forest flows into Lake 658.

One key issue ELA ought to be immersed in is climate change, Paterson concedes. In fact, Rudd and Schindler tried to sell the idea of studying climate change to DFO in the 1990s, but there was no interest, they say; DFO officials felt it wasn't within the department's mandate. "For the first time, there's a major widespread problem that's going on that we're not [studying] at ELA," says Rudd, who retired in 2002 but continues to work on METAALICUS. ASU's Elser and others say ELA could have been more aggressive since then. "It helps to have senior leadership that can knock heads," Elser says.

Schindler agrees that the lab needs an infusion of fresh blood, especially someone with a bold vision for ELA's future who will battle the bureaucracy for funds. Recruiting the best and brightest isn't easy, however; government salaries aren't competitive with those at top universities, and DFO can't even offer start-up funding to set up new labs. But with three positions that will need to be filled, Paterson will soon be sifting through resumés. With any luck, he might find another Schindler in the bunch—somebody who can set the course for the next 40 years.

–ERIK STOKSTAD

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