Biology 109: Ecological Knowledge and Environmental Problem Solving

Huron River Case Study

The causes of excessive algal growth and nuisance algal blooms have been recurrent themes in this course. In the Soap and Detergent case study and in the Lake Washington case study we learned that the underlying problem is usually elevated supplies of phosphorus, which encourage the production and accumulation of algal biomass. Moreover, we learned in the Ore Lake case study that elevated phosphorus in combination with low levels of inorganic nitrogen can promote the growth of cyanobacteria ('bluegreen algae') that form unsightly surface scums, and which can release toxins and deplete dissolved oxygen when they die and decompose.

The City of Ann Arbor, MI has been embroiled in a dispute with State environmental regulatory agencies (alternatively named MDNR, MDEQ, MNRE) over water quality conditions of two man-made lakes along the Huron River: Ford Lake and Belleville Lake. Both impoundments of the river were constructed in the first half of the 20th Century for the purpose of generating hydroelectricity. Both have exhibited nuisance concentrations of cyanobacteria during the summer. However, both lakes are considered to be the most productive warm-water fisheries in the state, with thriving populations of bluegill, bass, perch, walleye, and other species.

State environmental regulators have tended to blame the water quality problems on Ann Arbor because the city operates a wastewater treatment facility (WWTP) that discharges into the Huron River near Dixboro Road, at the eastern, downstream boundary of the city jurisdiction, just 9.5 km (6 miles) upstream from the inlet to Ford Lake (Fig. 1). During the last years of the 20th Century and the first years of the 21st Century, Ann Arbor upgraded its treatment facilities to remove ever-increasing amounts of phosphorus from its discharge water, at ever-increasing expense, but there was no tangible decrease in the frequency or severity of the algal biomass problems in Ford and Belleville Lakes.

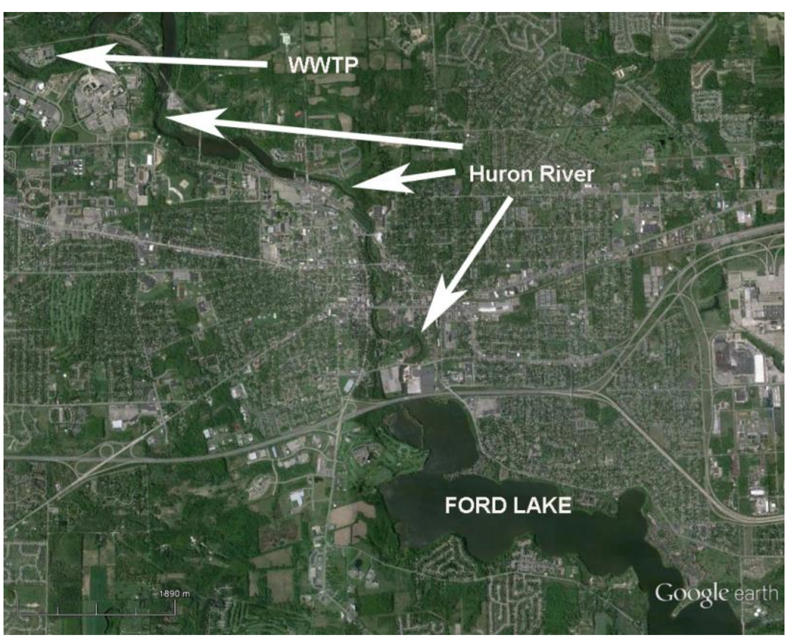

Fig. 1. Google Earth image of Huron River between the Ann Arbor WWTP and inlet to Ford Lake.

In the year 2000, the Washtenaw County Board of Commissioners named me their representative to the Huron River Watershed Council, a non-governmental organization (NGO) that attempts to coordinate environmental initiatives and information pertaining to the Huron River and its various water bodies (http://www.hrwc.org). Ann Arbor city officials then asked me to look into the science underlying the ongoing water quality dispute regarding the Huron River. In 2003, with the help of a grant from the U.S. EPA, my students and I began several years of fieldwork and theory development.

No sooner had we started our study when an accidental experiment called into question the relationship between phosphorus discharged from the Ann Arbor WWTP and algal blooms in Ford Lake. During the Great Northeast Blackout of early August 2003, the Ann Arbor WWTP lost power and discharged a large quantity of minimally treated sewage and a great amount of phosphorus into the Huron River. We documented that it entered the lake as a dramatic pulse over two days. However, no algal bloom developed. When an algal bloom did develop a month later, the lake had already been flushed through by river water (Fig. 2).

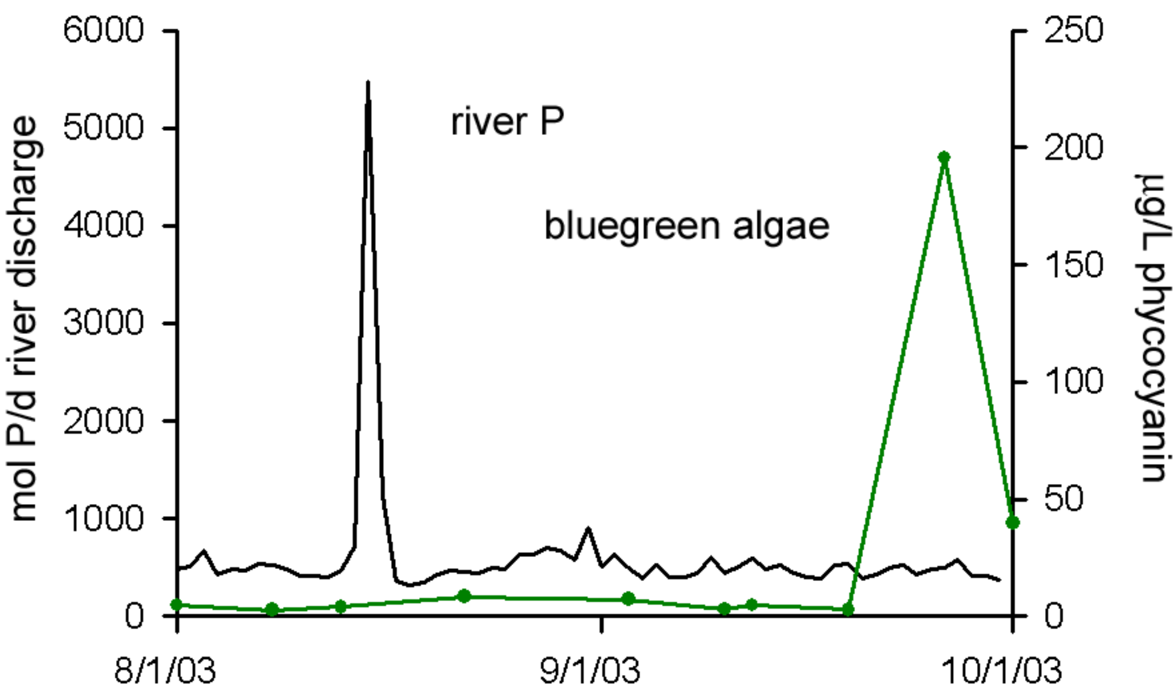

Fig. 2 Daily mass of phosphorus supplied to Ford Lake by the Huron River and concentration of phycocyanin (a pigment specific to cyanobacteria) in Ford Lake. The time lag between accidental discharge of phosphorus during the Great Blackout and appearance of an algal bloom was 40 days, the same as flushing time for Ford Lake at that time of year.

An alternative explanatory theory was that the real problem was the way that the Ford Lake dam was being managed. Henry Ford built the dam in 1932 to supply electricity to his Willow Run factory, which during World War II became the largest factory building in the world, producing B-24 Liberator heavy bombers. Turbines at the dam were designed to draw water from the surface of the lake. The impoundment is operated as ‘‘run of the river,’’ ensuring that outflow matches inflow and that surface height does not change. There are flood gates at the base of the dam to release water in an emergency, but those gates are typically kept closed in order to generate a maximum amount of electricity. Ford Motor Company transferred ownership of the dam to the Charter Township of Ypsilanti in the mid-1970s, and the Township continued to operate the original turbines and generators, selling electricity to Detroit Edison.

Like Ore Lake, Lake Washington, Lake Michigan, and many other lakes in the Temperate Zone, Ford Lake develops thermal stratification during the summer. The surface water warms and floats on top of a cooler, deeper layer. In Ford Lake, the deeper water stagnates and loses all of its dissolved oxygen over time. Water is released only from the surface warm layer. As soon as oxygen becomes depleted in the deep water, nitrate starts to be lost, as well. Anaerobic bacteria can use nitrate as an alternative terminal electron receptor for respiration. When both oxygen and nitrate are fully depleted, the deep water sediments start to release large quantities of phosphate that had previously been held in the mud by the 'iron trap' (review Lake Washington).

Sooner or later, a cold front would cause the lake to mix, partially or completely, stirring all that released phosphate throughout the lake. No nitrate accompanies the phosphate, however, and the result is a recipe for massive production of nitrogen-fixing cyanobacteria of the species *Aphanizomenon flos-aquae* (Fig. 3).

Fig. 3. *Aphanizomenon* bloom, Ford Lake, July 2004.

More Inductive Reasoning

If the nuisance algal blooms in Ford Lake were being caused by *internal* sources of phosphorus, it seemed there were at least two possible ways to seek a solution: (1) find a way to reduce the release of phosphate from the mud and therefore reduce the total amount of algal biomass that could be produced, or (2) prevent the loss of nitrate and thereby change the species composition of the algae that would be produced. Higher ratios of nitrogen to phosphorus would not favor cyanobacteria, according to theory developed by Professor Val Smith (Ore Lake Case Study).

One way to accomplish both (1) and (2) would be to force Ford Lake to mix throughout the summer rather than to develop thermal stratification. But how could that be accomplished? Ford Lake is 4 square kilometers (1000-acres) in area and on average 4.3 meters (14 feet) deep.

Remember those flood gates at the bottom of the dam? What if they were opened during the summer and deep water was discharged? You surely would not want to do that after anoxia developed, or you would kill thousands of fish below the dam and become very unpopular in downstream communities. But if the discharge was started early enough, before oxygen became depleted, maybe the lake could be forced to mix and the detrimental conditions would never establish. Of course, the experiment would cost Ypsilanti Township a literal revenue stream by diverting water away from the hydroelectric turbines. How much revenue? That would depend on how much water was needed, and what the contract with Detroit Edison specified for dollars paid per kilowatt-hour generated.

A theory relevant to this problem involving lake physics is called 'The Theory of the Mixed Layer' (Niiler and Kraus 1977), but remember that science involves both the creation and testing of theory. What was needed were empirical data to test and refine the theory as it applied specifically to Ford Lake. Even rough calculations indicated that the experiment would likely cost the Township many thousands of dollars in lost revenue. But, local citizens on the Township's Water Conservation Advisory Committee (WCAC) invited me to make a public presentation to the Township Board of Trustees (elected, governing representatives) in October 2005, and the Trustees voted unanimously to permit manipulation of their lake the following summer (2006). They instructed the dam operator to comply with instructions to open the flood gates at requested times and for requested discharge volumes.

Theoretical calculations suggested that 300,000 cubic meters of water would have to be discharged from the base of the dam every day to keep the lake in a mixed condition. That rate was tried for one week in June 2006, and the results were as predicted. But to make sure we were not releasing more water than was needed, we tried 150,000 cubic meters per day for a week in July, and that was clearly not enough. So we resumed discharge of 300,000 cubic meters per day in late July, and the lake never developed a bluegreen bloom that summer. Instead, it produced diatoms, a type of algae that sink rather than float, and the water remained transparent.

The following year, 2007, was designated a control year. There was no selective discharge from the flood gates, and the lake reverted to its former nuisance condition by late summer, becoming carpeted with *Aphanizomenon*.

In 2008, we discharged 300,000 cubic meters per day from the base of the dam from late June to August and the lake looked great. People would boat out from their docks to tell us that they had lived on the lake for 30 years or more and it never looked so good.

I proposed another control year in 2009, but the Board of Trustees refused. They said they were convinced that they now knew how to manage the lake themselves to keep it in the condition that their citizens enjoyed. It cost them several tens of thousands of dollars in lost revenue each summer, but they and their constituents thought it was worth the expense (Fig. 4).

Fig. 4. Ford Lake August 2002 (left) and August 2008 (right).

Why was another Control Year desirable?

When you conduct a whole-lake or whole-ecosystem experiment, you have to realize that no one year is exactly like any other in terms of temperatures, rainfall, wind, etc. It is also possible that different events might occur within the ecosystem, such as construction activities, floods, tornadoes, etc. In the case of the Huron River, a very substantial change occurred in 2008 that would have national implications in terms of environmental policy and regulation.

In 2007, the Ann Arbor City Council voted to institute a municipal ordinance that prohibited the application of lawn fertilizer containing phosphorus unless chemical analysis demonstrated that the soil was phosphorus-deficient. Prior evidence had indicated that most soils in southeast Michigan do not require additional phosphorus to promote the growth of turf grass. In early 2008, Matt Naud, environmental coordinator for Ann Arbor, phoned to inform me of the passage of the ordinance, and then he asked if I thought it would be possible to measure any effect of the ordinance on the phosphorus content of the Huron River. After all, he said, the goal of the ordinance was to reduce phosphorus runoff into the Huron River from the city's landscape, but they had no idea if it would do any good. He said the City Council had acted on the basis of limited information suggesting that perhaps a 22% reduction could be achieved. He called me because I was in possession of the most comprehensive set of data about Huron River chemistry as a result of the project I had recently been conducting. I replied that scientists usually try to estimate whether they could detect a predicted response *before* conducting a major experiment, but that I would make some calculations and get back to him.

Using our existing data from baseline years 2003 to 2005, a student, Julie Ferris and I calculated that by sampling once a week at multiple sites we would have a 90% chance of being able to detect a 25% change in average phosphorus concentration from the baseline values. We actually published the prediction before making any field measurements (Ferris and Lehman 2008).

From 2008 to 2010 my students and I measured phosphorus and other chemical properties of the Huron River at weekly intervals from May to September each year. After just the first year it became apparent that phosphorus concentrations were reduced, but not nitrogen, silica, or other analytes. This is exactly what one might expect of a management scheme that specifically targeted phosphorus and nothing else. We reported the results in various forums and published the work (Lehman et al. 2009; Lehman et al. 2011). In Fall 2008 I was invited to testify about our findings to the Michigan House environmental committee chaired by then-representative Rebekah Warren of Ann Arbor. Her committee introduced a bill to limit application of phosphorus-containing lawn fertilizer state-wide, and it was adopted by both the House and the Senate, then signed into law by Governor Jennifer Granholm in the final lame duck session of the State Legislature before she left office. That legislation has proved to be a model for similar regulations in other states.

So there was the scientific problem. Phosphorus concentrations had declined in the Huron River starting in 2008, the first year in which we experimentally manipulated Ford Lake for the entire summer. The citizens of Ypsilanti Township and their elected representatives were not willing to risk letting Ford Lake revert to its former condition just to test a scientific theory that nuisance blooms were controlled by internal processes rather than the amount of phosphorus supplied by the Huron River. The lake was in an improved state and the underlying cause was of distinctly secondary interest. But the situation was completely unsatisfactory from a scientific perspective because there were at least two alternative theories about the lake's improved condition. Did the lake improve in 2008 (Fig. 4), and in subsequent years as it turned out, because Ann Arbor had reduced the amount of phosphorus it was transporting downstream, or because the lake was being artificially mixed? A pragmatist might argue that it makes no difference what is responsible for the desired outcome, and maybe both theories deserve some credit.

By this time, you should understand that the Scientific Method does not permit you to declare that a theory is correct, or that multiple theories all deserve some credit for being correct. The Scientific Method only permits you to prove that a theory is wrong, if indeed it is wrong.

Although the Ypsilanti Board of Trustees did not want to participate in the scientific adventure of annihilating one hypothesis or other, there was at least one other possibility. We could wait for a drought, a drought severe enough to deprive Ford Lake of the 300,000 cubic meters per day needed to sustain the artificial mixing. Recall that the lake is regulated as 'run of the river' so the Township is not permitted to draw down the lake level. If too little water enters the lake, the total discharge has to be curtailed. Analysis of river discharge measurements made and archived by the U. S. Geological Service (USGS) suggested that in any nine year period there was a 50% chance that drought conditions might reduce river flow to less than 300,000 cubic meters per day for several weeks during the summer.

In 2012 our patience was rewarded as the upper Midwest experienced its second worst drought in the last 35 years. There was too little water flowing in the Huron River to permit the flood gates to operate at 300,000 cubic meters per day, and the gates remained closed all summer. We sampled the Huron River that summer and demonstrated that phosphorus concentrations remained at the reduced level established from 2008 to 2010, so if reduced river phosphorus was responsible for improved conditions in Ford Lake, there should NOT be a nuisance bloom of algae that summer.

By late June, the lake entered a prolonged period of thermal stratification and dissolved oxygen concentrations 8 meters below the surface dropped to zero for almost the entire month of July. But at the very end of July a cold front caused the lake to mix temporarily and the large quantities of phosphate released into the deep water were stirred throughout the lake. A large bloom of *Aphanizomenon* immediately ensued in early August (Fig. 5).

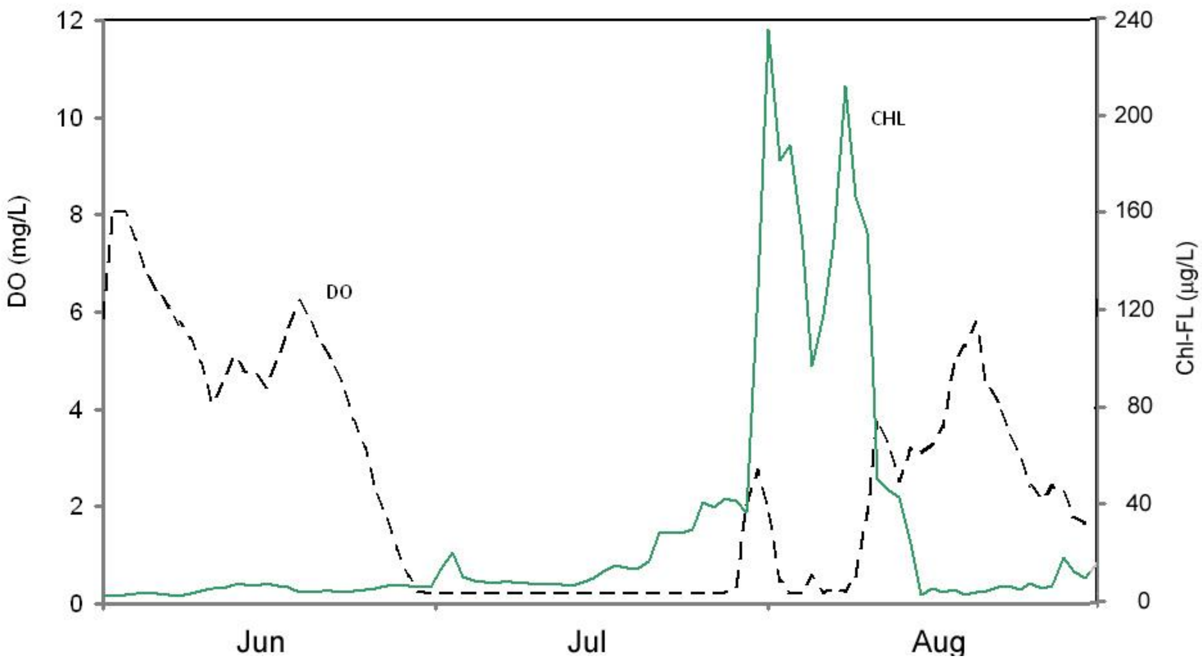

Fig. 5. Concentration of dissolved oxygen (DO) at 8 m depth (hypolimnion= deep layer) in Ford Lake and algal chlorophyll (a proxy for algal biomass) at 3 m (epilimnion= surface layer) during summer 2012.

- What can you conclude from this observation?
- If you had been measuring phosphorus concentrations in the epilimnion of Ford Lake, what change might you have observed coincident with the mixing event that stirred oxygen into the deep water of the lake in late July?
- If you had measured DO at 8 m depth during the summers of 2009, 2010, and 2011, would you expect to see similar prolonged periods of anoxia such as was observed in July 2012?
- What observation(s) would have convinced you that internal lake processes were not responsible for nuisance algal blooms in Ford Lake?

For additional experimental evidence refuting the hypothesis that reductions in river phosphorus were responsible for the improved condition of Ford Lake, see Lehman et al. (2013). For data and analysis of mixing dynamics and dissolved oxygen in Ford Lake from 2008 to 2012 see Lehman (2014).

References

Ferris JA, Lehman JT. 2008. Nutrient budgets and river impoundments: Interannual variation and implications for detecting future changes. Lake and Reservoir Management 24: 273-281.

Lehman JT. 2014. Understanding the role of induced mixing for management of nuisance algal blooms in an urbanized reservoir. Lake and Reservoir Management 30: 63-71.

Lehman JT, Bell DW, McDonald KE. 2009. Reduced river phosphorus following implementation of a lawn fertilizer ordinance. Lake and Reservoir Management 25: 307-312.

Lehman JT, Bell DW, Doubek JP, McDonald KE. 2011. Reduced additions to river phosphorus for three years following implementation of a lawn fertilizer ordinance. Lake and Reservoir Management 27: 390-397.

Lehman JT, Doubek JP, Jackson EJ. 2013. Effect of reducing allochthonous P load on biomass and alkaline phosphatase activity of phytoplankton in an urbanized watershed, Michigan. Lake and Reservoir Management 29: 116-125.

Niiler PP, and Kraus EB. 1977. One-dimensional models of the upper ocean. *In* EB Kraus [ed.], Modelling and prediction of the upper layers of the ocean, p. 143–172. Pergamon.