Why Scale Matters in Freshwater Studies: From Laboratory Bottles to Entire Lakes

Ben Van Bastelaere, Jamie Dearnley, Vince Palace, Gregg Tomy

University of Manitoba

Introduction

Fresh water is our planet's most essential, yet finite, resource. Increasingly, anthropogenic activities and their consequences are encroaching on pristine freshwater systems. Now more than ever, accurate and reliable data is required to protect freshwater systems and inform impactful management decisions. Limnology, the scientific study of fresh water bodies, incorporates physical, chemical, and biological aspects which are naturally studied over an array of scales. These range from small bottle assays in labs, to entire watershed experiments and exposures. It is important to evaluate the benefits and drawbacks of different scales of study: from highly replicable but unrealistic laboratory studies to highly realistic full lake studies with low replicability. Here, the drawbacks, benefits, and practicalities of the different experimental approaches are explored.

Lab Studies

Benefits

- **High replicability**
- Low cost
- Easily test multiple variables, gradients and treatments
- Shorter duration
- Less confounding variables

A lab study investigating the effect of oil on chlorophyll levels in lake water. Photo credit: K. Perry

Drawbacks

- **Low realism**
- Predominantly focuses on individuals rather than populations and ecosystems
- Lacks many aspects of a whole aquatic ecosystem that can lead to erroneous conclusions
- Lacks atmosphere-water interactions
- Founder effect causing a lack of diversity in laboratory populations/colonies

Mesocosm Studies

Benefits

- Moderately replicable while including some intertrophic interactions
- Lower cost than whole lake studies
- Allows for smaller areas of cleanup that would not be possible at a whole lake scale. For example, oil spill remediation studies (as seen in the photo to the right)

The Experimental Set-up of a Mesocosm Study. Photo credit: Freshwater Oil Spill Remediation study

Drawbacks

- Lacks lake stratification
- Limits diversity and rare species
- Can not incorporate the highest trophic levels (predators)
- Limited migration
- Low mortality compared to natural populations

Whole Lake Studies

Benefits

- **Highly realistic**
- Simultaneous exposure to all species and factors within the system
- Incorporates all natural, known and unknown, lake processes
- Incorporates population dynamics
- Greater spatial and temporal scale
- Allows ecosystem to reach equilibrium which can take years

A diagram of a contaminant point-source in a whole-lake study. Photo credit: L. Hayhurst

Drawbacks

- **Low replicability**
- High costs per study
- Each lake is unique, results in one lake may not be the same in another
- Time, the length of the study often exceeds graduate students' tenure
- Direct causality and mechanisms can be difficult to determine

Case Study: Silver Nanoparticles

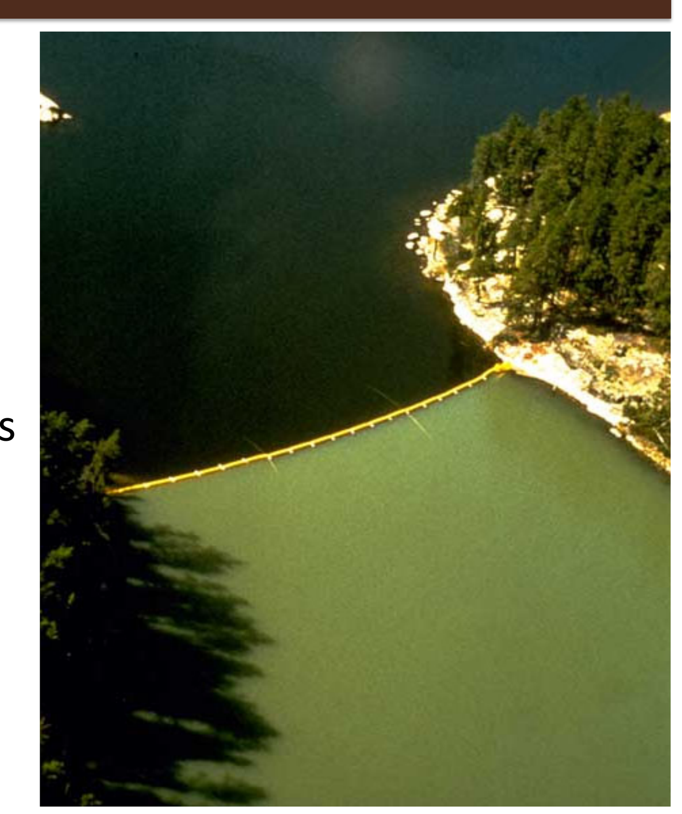
- Silver nanoparticles (AgNPs) exposure in a laboratory setting to freshwater algae model organism *Chalmydomonas reinhardtii* demonstrated acute toxicity by means of photosynthesis inhibition that could not be explained by Ag^+ ions alone, suggesting AgNPs may play a role themselves in toxicity (Navarro et al. 2008)
- This was contradicted by a whole lake study in which phytoplankton communities were largely unaffected by the addition of AgNPs likely due to natural processes having a much stronger effect on community changes than individual toxicity (Conine et al. 2018).

A plume of silver nanoparticles. Photo credit: D. Rearick

- This whole lake study further accurately demonstrated the degree of bioaccumulation of silver nanoparticles up the trophic levels and bottom up control, from phytoplankton to Northern Pike and Perch.

Case Study: Nutrient Control

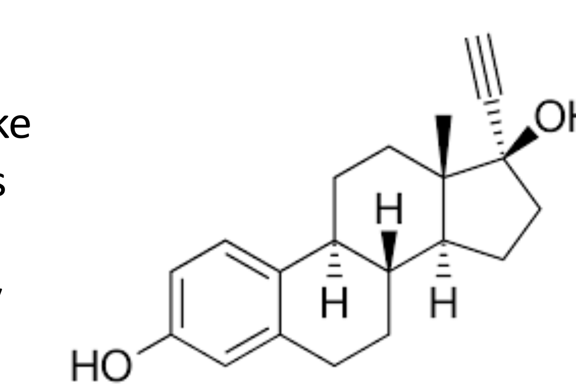
- Nutrient control research is important in negating and explaining detrimental algae blooms. Controversy has been prevalent in this branch of aquatic research stemming from studies at improper scales
- Initially, eutrophication was thought to be carbon controlled due to bottle experiments showing evidence of carbon limitation. These experiments neglected water-atmosphere interaction providing sufficient carbon in a whole lake setting. (D W Schindler 1977)
- More recently, there is continuing controversy over whether just phosphorous alone, or nitrogen and phosphorus together, should be controlled to limit eutrophication of water systems. Much of these controversies stem from smaller scale studies negating time it takes, up to 17 years, for a lake to reach a steady state in terms of nitrogen concentration (D W Schindler)



Half of this lake (top) received additional nitrogen and carbon, while the other half (bottom) received additional nitrogen, carbon, and phosphorus which caused eutrophication. Photo credit: Experimental Lakes Area

Case Study: Synthetic Estrogen

- Laboratory studies demonstrated estrogen causes adverse reproductive effects in fish (Parrott and Blunt 2005)
- In the second year of a whole lake addition study, fathead minnow populations were nearly eliminated completely, lake trout declined following a collapse of their food source, but pearl dace populations remained similar to reference lake populations, likely due to their increased lifespan. (Kidd et al. 2007)
- Estrogen exposure was less evident in larger fish, likely due to estrogen concentrations being 2-5 time lower in deeper portions of the stratified lake that larger fish preferred (Palace 2009)
- In laboratory studies, negative physiological effects were demonstrated in zooplankton and phytoplankton at environmentally relevant concentrations. In contrast, the whole lake study no declines in abundance were observed in algal, microbial, zooplankton, and benthic invertebrate communities (Kidd 2014).
- Factors such as inter-trophic relations between fathead minnow and lake trout, lake stratification affecting estrogen exposure, as well as the time it took for populations to begin declining, demonstrate how the study of synthetic estrogen could have only been done on a whole lake scale to retain validity.



Synthetic estrogen, 17-ethinylestradiol

University of Manitoba

References:

Conine, Andrea L., Daniel C. Rearick, Michael J. Paterson, Marguerite A. Xenopoulos, and Paul C. Frost. 2018. "Addition of Silver Nanoparticles Has No Long-Term Effects on Natural Phytoplankton Community Dynamics in a Boreal Lake." *Limnology and Oceanography Letters* 3 (4): 311–19.

Kidd, Karen A., Paul J. Blanchfield, Kenneth H. Mills, Vince P. Palace, Robert E. Evans, James M. Lazorchak, and Robert W. Flick. 2007. "Collapse of a Fish Population after Exposure to a Synthetic Estrogen." *Proceedings of the National Academy of Sciences* 104 (21): 8897–8901.

Kidd, Karen A., Michael J. Paterson, Michael D. Rennie, Cheryl L. Podemski, Dave L. Findlay, Paul J. Blanchfield, and Karsten Liber. 2014. "Direct and Indirect Responses of a Freshwater Food Web to a Potent Synthetic Oestrogen." *Philosophical Transactions of the Royal Society B: Biological Sciences* 369 (1656).

Navarro, Enrique, Flavio Piccapietra, Bettina Wagner, Fabio Marconi, Ralf Kaegi, Niksa Odzak, Laura Sigg, and Renata Behra. 2008. "Toxicity of Silver Nanoparticles to Chlamydomonas Reinhardtii." *Environmental Science and Technology* 42 (23): 8959–64.

Palace, V. P., R. E. Evans, K. G. Wautier, K. H. Mills, P. J. Blanchfield, B. J. Park, C. L. Baron, and K. A. Kidd. 2009. "Interspecies Differences in Biochemical, Histopathological, and Population Responses in Four Wild Fish Species Exposed to Ethynylestradiol Added to a Whole Lake." *Canadian Journal of Fisheries and Aquatic Sciences* 66 (11): 1920–35.

Parrott, Joanne L., and Beverley R. Blunt. 2005. "Life-Cycle Exposure of Fathead Minnows (Pimephales Promelas) to an Ethinylestradiol Concentration below 1 Ng/L Reduces Egg Fertilization Success and Demasculinizes Males." *Environmental Toxicology* 20 (2): 131–41. https://doi.org/10.1002/tox.20087.

Schindler, D. W., G. J. Brunskill, S. Emerson, W. S. Broecker, and T.-H. Peng. 1972. "Atmospheric Carbon Dioxide: Its Role in Maintaining Phytoplankton Standing Crops." *Science* 177 (4055): 1192–94.