

Paleolimnology can provide the missing long-term perspective in ecotoxicology research

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Aquatic ecosystems are exposed to a plethora of environmental contaminants released through human activities over the long term, and yet most ecotoxicology research is conducted on short timescales that may not adequately capture complex ecological responses. In relatively rare cases, regional limnological monitoring records and whole-ecosystem experiments document physico-chemical and ecological trends over decades, but even these valuable datasets may not be of sufficient duration to characterize baseline conditions and natural variability, which are needed to determine if/when important ecological changes have occurred in response to contaminant exposure. We argue that a new approach is needed that integrates the principles of ecotoxicology with paleolimnological techniques, which takes advantage of physical, chemical, and biological proxies preserved in dated sediment cores to reconstruct lake histories over decadal, centennial, and millennial timescales, thus providing the missing long-term perspective (Figure 1).

Lake sediments are a sink for many contaminants of interest, including metals and persistent organic pollutants. Consequently, there is a long tradition of incorporating paleolimnological techniques into investigations on the sources and chemical cycling of contaminants in the environment (Blais et al. 2015). In addition to a well-constrained historical record of geochemical inputs (the “stressor” or “dose” record), sediments also preserve the “response” variables in the form of fossil remains of a number of key aquatic biota from multiple trophic levels (Smol 2008). This includes many commonly used model organisms in ecotoxicology, especially *Daphnia* (zooplankton) and Chironomidae (aquatic insects) larvae. This historical archive of ecotoxicological information has traditionally been under-utilized, but “paleo-ecotoxicology” is gaining prominence as a valuable tool to examine the ecological consequences of long-term exposure to environmental contaminants (e.g., Thienpont et al. 2016).

We believe that improved collaboration and flow of information among paleolimnologists and ecotoxicologists will lead to rapid advances in our understanding of the long-term consequences of exposure to aquatic contaminants.

A useful roadmap for what an enhanced co-operation could look like can be found by examining recent investigations into the ecological effects of lake water calcium decline, a legacy of acid rain and logging in regions with calcium-poor soils. Observations of declining calcium concentrations since the 1970s in eastern North American and Scandinavian lakes have been attributed to decades of accelerated calcium leaching from catchment soils as a result of acidic deposition, and have stimulated research efforts into associated ecological implications using laboratory and field experiments, regional limnological surveys, modeling, and paleolimnology (reviewed in Jeziorski and Smol 2017). Early laboratory-based studies identified several large Cladocera (crustacean zooplankton) species as vulnerable to calcium decline, and a threshold response for *Daphnia pulex* was determined when Ca concentrations fell below 1.5-2.0 mg L⁻¹ (Ashforth and Yan 2008). A Cladocera-based paleolimnological investigation in Plastic Lake (ON, Canada) revealed a dramatic decline in *Daphnia* fossil remains consistent with declines in lakewater calcium (below critical thresholds identified in laboratory studies) recorded over the monitoring record (Jeziorski et al. 2008). A regional snapshot of cladoceran assemblage changes between present-day and pre-industrial times revealed that *Daphnia* have decreased in all lakes examined in south-central Ontario with current calcium concentrations below 2.5 mg L⁻¹ but, in contrast, *Daphnia* have increased since pre-industrial times in lakes with > 2.5 mg calcium L⁻¹ (Jeziorski et al. 2008). Collectively, this provided strong evidence that lake water calcium decline is a dominant driver of zooplankton community dynamics in soft water lakes with a legacy of acidic deposition.

Calcium decline is a recently-identified stressor on aquatic ecosystems, and the co-operation of researchers using complementary approaches resulted in a rapid accumulation of critical knowledge into the issue in a relatively short period of time (Jeziorski and Smol 2017). It provides a useful model for how paleolimnological techniques can be seamlessly integrated with other methods of inquiry to generate novel insights, with important advantages from a paleo-ecotoxicological perspective. Unlike lake water calcium decline, which often leaves no geochemical signature in the sediments to reconstruct calcium trends over time (Jeziorski and Smol 2017), the deposition histories of many contaminants of interest are routinely reconstructed using lake sediment core archives (Blais et al. 2015). Hence, the timing of important ecological shifts in key aquatic biota can be directly linked to historical fluxes of contaminants. Whilst lab and mesocosm experiments can provide a mechanistic understanding of the toxic effects of chemicals on aquatic biota, paleolimnology can provide both a historical context, as well as a means to test predictions based on laboratory/mesocosm experiments in a long-term, natural ecosystem setting. Where available, long-term limnological monitoring records can be compared against paleolimnological records to fill in any missing data in sediment core archives resulting from taphonomic processes (i.e., fossil preservation).

We are applying this approach in an ongoing multidisciplinary project to investigate the legacy impacts of arsenic contamination from historic gold mining activities in subarctic lakes near Yellowknife (NT, Canada). Our early findings showed that the onset of arsenic contamination in a naturally-fishless lake in the 1950s initially favoured *Daphnia*, known from laboratory studies to be relatively tolerant of arsenic, until extreme arsenic contamination eventually led to the functional extirpation of all Cladocera in the lake by the 1970s (Thienpont et al. 2016). No long-term monitoring records are available for Yellowknife lakes impacted by

gold mining activities, but even if records were available, they likely would not have been of sufficient duration to capture the appearance and increasing abundance of *Daphnia* following arsenic contamination, only their demise. These results suggest that *Daphnia* are not an early-warning indicator of the toxic effects of arsenic, and ecotoxicological study of arsenic toxicity in freshwaters would benefit from examinations of other important species of zooplankton that may be more sensitive.

There is a wealth of information preserved in lake sediments relevant to ecotoxicologists. This information can be harnessed to extend the short-term insights generated from laboratory and mesocosm experiments in controlled conditions to complex, natural ecosystem settings over long timescales. The value of paleolimnology to inform on the cycling of contaminants in the environment has long been recognized. What is needed now is better integration of paleolimnology with other ecotoxicological approaches to improve our understanding of the ecological consequences of long-term exposure to contaminants.

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REFERENCES

Ashforth D, Yan ND. 2008. The interactive effects of calcium concentration and temperature on the survival and reproduction of *Daphnia pulex* at high and low food concentrations. *Limnol Oceanogr* 53:420-432.

Blais JM, Rosen M, Smol JP, editors. 2015. Environmental Contaminants: Using Natural Archives to Track Sources and Long-term Trends of Pollution. Dordrecht, Netherlands: Springer, 509 pp.

Jeziorski A, Smol JP. 2017. The ecological impacts of lakewater calcium decline on softwater boreal ecosystems. *Environ Rev* doi: 10.1139/er-2016-0054.

Jeziorski A, Yan ND, Paterson AM, DeSellas AM, Turner MA, Jeffries DS, Keller B, Weeber RC, McNicol DK, Palmer ME, McIver K, Arseneau K, Ginn BK, Cumming BF, Smol JP. 2008. The widespread threat of calcium decline in fresh waters. *Science* 322: 1374-1377.

Smol JP. 2008. Pollution of Lakes and Rivers: A Paleoenvironmental Perspective – 2nd Edition. Oxford, UK: Blackwell Publishing, 383 pp.

Thienpont JR, Korosi JB, Hargan KE, Williams T, Eickmeyer DC, Kimpe LE, Palmer MJ, Smol JP, Blais JM. 2016. Multi-trophic level response to extreme metal contamination from gold mining in a subarctic lake. *Proc Roy Soc Biol* 283: 20161125.

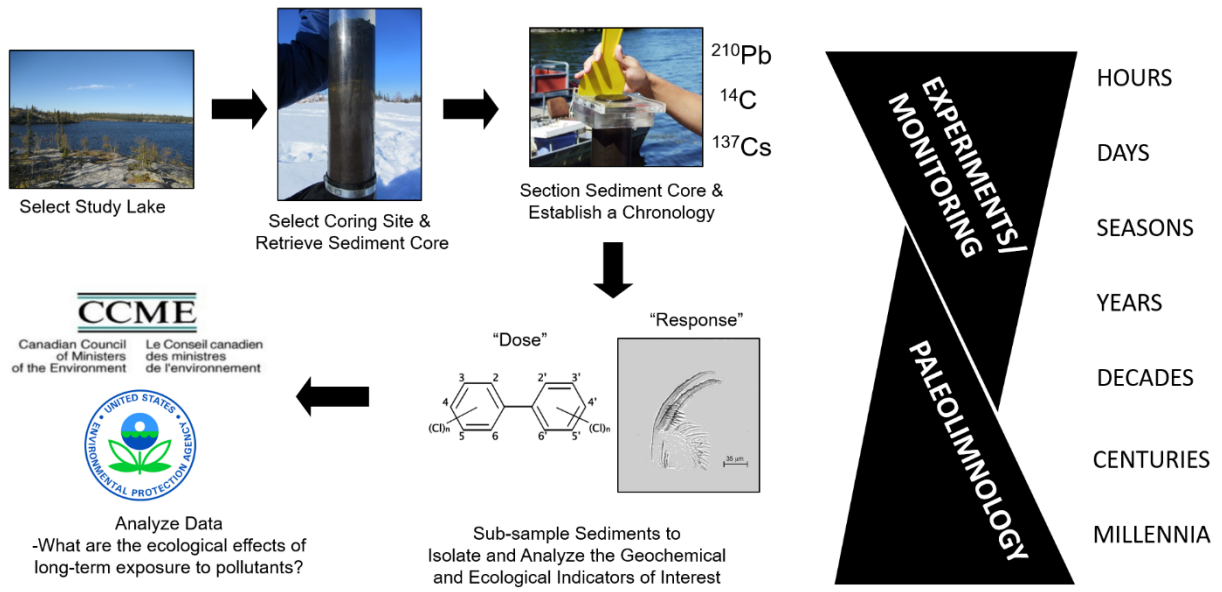


Figure 1 – The “paleo-ecotoxicological” approach, a modification of the paleolimnological approach that takes advantage of the geochemical record for reconstructing contaminant deposition histories (the “dose” of a contaminant), and the biological proxy record (e.g., fossil remains of *Daphnia* post-abdominal claws, as shown) for assessing ecological changes in key groups of aquatic biota in response to long-term contaminant exposure. The information preserved in lake sediments can provide an unique long-term perspective from which to assess ecosystem risk, for example by testing predictions from laboratory and mesocosm experiments in a natural ecosystem setting, helping to inform decision-making in establishing water quality benchmarks.