The Qu'Appelle Long-Term Ecological Research Program: A 26-Yr Hierarchical Platform to Study Freshwater Ecosystems of the Northern Great Plains

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The Qu'Appelle Long-Term Ecological Research Program: a 26-year hierarchical platform to study freshwater ecosystems of the northern Great Plains

The Qu'Appelle Long-Term Ecological Research Program (QU-LTER) was established in 1994 as part of Dr. Peter Leavitt's research program at the University of Regina. Inspired by ecosystem research at University of Notre Dame's Environmental Research Center (UNDERC) and Canada's Experimental Lakes Area (ELA), the QU-LTER program has become a comprehensive environmental research initiative centered at the Institute of Environmental Change and Society (IECS) in Regina and with linkages to dozens of international aquatic research groups.

Program overview

The QU-LTER is a multi-tiered platform with a core program of seven lakes located along the 52,000 km^2 Qu'Appelle River catchment in southern Saskatchewan, Canada. These basins have been sampled biweekly for over 75 parameters from May to September during the past 26 years (Vogt et al. 2011), with the goal of understanding how natural and anthropogenic processes interact to regulate the structure, function and sustainability of freshwaters. In addition to monitoring, these sites have been essential for the development of mass-balance models investigating effects of land use (Hall et al. 1999), net greenhouse gas (GHG) fluxes (Finlay et al. 2010), and impacts of urban pollution (Leavitt et al. 2006), as well as whole-lake experiments on the effects of winter droughts (McGowan et al., 2005). As well, with recent advancements in sonde technology, several lake sites have been instrumented with in situ instrument systems to gain a greater understanding of lake biogeochemistry and algal bloom formation, a project led by Dr. Helen Baulch (University of Saskatchewan) in partnership with urban water treatment facilities.

The second level of the QU-LTER includes annual surveys of ~20 lakes on a seasonal basis within a larger geographical area (~150,000 km^2) to better illustrate how the LTER program represents the broader limnological landscape (Starks et al. 2014; Finlay et al. 2015). Started in 2001, this arm of the program is overseen by IECS Associate Director, Dr. Bjoern Wissel, who, in recent years, has expanded the work to include studies of winter limnology. Additionally, Drs. Kerri Finlay, Heather Haig and Britt Hall are conducting decadal-scale surveys of over 200 lakes, farm reservoirs and wetlands within the 245,000 km^2 grassland region to understand how LTER insights vary with ecosystem size and geographic location. Future projects will extend these approaches to the entire Canadian Prairies through the next generation of remote-sensing platforms.

On the tertiary level, paleolimnological analysis is conducted at many of the QU-LTER sites to extend our understanding of climate change and ecosystem dynamics over scales from decades to millennia. Uniquely, these near-annually resolved fossil records are calibrated against long-term instrumental observations and are being used by Dr. Gavin Simpson to develop new time-series modeling approaches (e.g., generalized additive models; GAMs) that quantify variation in ecosystem state (Bunting et al. 2016). By applying powerful new techniques to these sedimentary studies, such as environmental DNA (eDNA), IECS researchers seek to diversify the means and metric by which we monitor environmental variability (Plancq et al. 2019).

Together, this hierarchical approach provides a critical understanding of factors that regulate the health of aquatic ecosystems and allows development of sophisticated strategies to protect, conserve and manage lake ecosystems, particularly those in western Canada. Ultimately, our goal is to understand and anticipate how changes in climate, and anthropogenic activities interact to regulate aquatic ecosystems.

The cornerstone of the QU-LTER is rigorous, consistent and standardized monitoring of a wide variety of limnological parameters including the common physico-chemical profiles, plankton composition, and, in some lakes, fish community composition and trophic status. As well, the QU-LTER includes more rarified analyses such as measurements of optical properties (240-800 nm), surface and water-column phototrophic pigments (carotenoids and chlorophylls), algal toxin levels, DOM composition, GHG concentrations (CO_2, CH_4, N_2O), whole-lake nitrogen fixation, water balances, isotopes of water, plankton and suspended matter (δ^2H, $\delta^{18}O$, $\delta^{13}C$, $\delta^{15}N$) and, more recently, eDNA. Together, these parameters provide the foundation for studying slow-moving effects of climate, land use, urbanization and industry, as well as the reference material for evaluation of ongoing bottle assays, mesocosm studies, and whole-lake experiments.

Scientific advances

Research by IECS associates has generated over 120 papers in the past 5 years, many focusing on aquatic systems of the northern Great Plains. The principle advances by IECS researchers are summarized below.

IECS has provided international leadership to help resolve the scientific and management controversy surrounding the role of nitrogen in degrading surface waters. This work includes diverse microcosm studies (Swarbrick et al. 2019), mesocosm experiments (Donald et al. 2013; Bogard et al. 2017), estimates of N fluxes in lakes (Hayes et al. 2019, Leavitt et al. 2006), and paleolimnological assessments (Hall et al. 1999; Bunting et al. 2016). This research resulted in legislation to restrict lake pollution with nitrogen, including Manitoba's 2011 *Save Lake Winnipeg Act*. In addition, we are monitoring the limnological response of streams and lakes to a science-informed $225 million wastewater upgrade that diverted >95% of ammonia and 50% of total N from receiving water bodies, as well as studying the role of nitrogenous urea fertilizer in degrading water quality in P-rich lakes.

IECS Director, Dr. Peter Leavitt, has developed the Energy –*mass* flux framework to quantify the pathways by which climate and humans impact aquatic ecosystems (Leavitt et al. 2009). In this model influx of energy (e.g., irradiance, heat, wind) increases spatial synchrony and predictability of lake properties, whereas the influx of *mass* (e.g., water, solutes) reduces coherence among sites, making management more difficult (Vogt et al. 2011). Using a combination of whole-lake experiments, landscape surveys, and climate reconstructions, Leavitt and collaborators have revealed that variation in jet-stream position, and consequently winter precipitation, is a key mechanism regulating water availability in the Prairies (Michels et al. 2007). In collaboration with regional crop insurance agencies, this work has been used to demonstrate that the risk of severe prairie droughts is as high as 45% by 2030 AD, with losses up to $650 billion. New paleolimnological investigations are using isotopes and lipids to track changes in temperature and water source across the Canadian Prairies (Plancq et al. 2018).

As director of the regional lake surveys, Dr. Bjoern Wissel uses stable isotopes to track food web dynamics in lakes over a range in salinity. Due to the variable regional climate, this long-term study has developed a hierarchical model of the interactive effects of land use and climate on lentic ecosystems (Cooper and Wissel 2012; Starks et al. 2014). Stakeholder surveys with custom questionnaires have addressed how the lack of knowledge of prairie lake ecosystems affects management priorities and effectiveness (Nanayakkara and Wissel 2017; Nanayakkara et al. 2018). This work has lain the foundation for current studies that look at the susceptibility of grassland lakes to the eventual invasion by exotic mussels.

GHG studies led by Dr. Kerri Finlay have demonstrated that prairie inland waters capture atmospheric CO_2 on scales equivalent to one-third of all agricultural CO_2 emissions (Finlay et al. 2015, 2019). Recently, Dr. Finlay has expanded her research to include fluxes of CH_4 and N_2O to demonstrate the potential of inland agricultural reservoirs ('farm dugouts') to sequester GHG (Webb et al. 2019). Ongoing studies are looking at GHG fluxes across multiple seasons, physical scales (pond to lake), and climatic cycles (drought, pluvial) to quantify the interaction between climate and land use on GHG fluxes.

Dr. Britt Hall examines geochemical and biological controls on the methylmercury and organic carbon cycling in lakes, prairie wetlands and soils. Using mass balance budgets (Hall et al. 2019), stable Hg isotope incubations (Hoggarth et al. 2015) and 16S rRNA gene amplicon work, Dr. Hall works to understand the role of dissolved organic carbon (DOC) complexity, Hg bioavailability, and microbial community composition on Hg methylation and C sequestration in the context of a changing climate.

The impact of water availability and inflow on aquatic ecosystem function is a central theme that is infused the above research. Lead by Dr. Heather Haig, IECS has developed the use of water isotopes (δ^2H, $\delta^{18}O$) to quantify the relative importance of water sources (winter vs. summer precipitation), lake water balance (evaporation-precipitation), residence time, and overland inflow, even in unguaged watersheds (Haig, 2019). This research uses lake surveys, agricultural reservoirs, streams, and QU-LTER data to track hydrological variability of a wide variety of surface waters across the Canadian Prairies. Ongoing work will integrate these isotope models with QU-LTER monitoring data to look at hydrological drivers of water quality and ecosystem structure.

Rigorous statistical modeling underpins all work completed at IECS, and is facilitated by the research of Dr. Gavin Simpson, Director of the Numerical Analysis Faculty within IECS. Dr. Simpson's research focuses on developing techniques to work with the non-linear relationships within limnological and paleolimnological data. His publications have advanced our understanding of time series modeling, particularly with the application of GAMs (Simpson 2018) and hierarchical GAMs (Pedersen et al. 2019). Ongoing research in this area is focused on identification of abrupt change in climatically-sensitive inland waters using paleolimnological records.

IECS maintains several advanced analytical facilities, including the Cellular Impacts Facility (Dr. Tzu-Chiao Chao) and the Stressor Quantification Facility (Dr. Zoraida Quiñones-Rivera). In both units the collaborative nature of IECS is emphasized wherein researchers and students are encouraged to make use of the equipment and local expertise for a small subsidized fee. Visiting collaborators are welcomed to IECS with affordable on-campus housing, office and laboratory space, field equipment, and such resources as are required to complete their research. In addition, the University of Regina sponsors a $25,000 Fulbright Canada Visiting Research Chair (Award 10416-CA).

Collaborations and consultation outside academia are a cornerstone of operations at IECS, including projects and consultations with many Indigenous communities, as well as municipal, provincial, and federal governments. Institute members also have a long history of scientific leadership including executive and board membership within ASLO, the Ecological Society of America, the Society of Canadian Limnologists, and the Canadian Institute of Ecology and Evolution. In each case, our goal is to provide the highest quality of science, service and outreach while seeking new opportunities and partnerships.

By providing the infrastructure, data and expertise, IECS attracts top calibre researchers to expand their programs to include prairie ecosystems. In particular, IECS is actively seeking ambitious and curious students and researchers interesting in deepening their understanding of aquatic systems. Current projects include; whole-lake N diversion, a wetland fertilization-experiment, high resolution paleolimnology, ecosystem state change studies in modern and paleo-environmental records, greenhouse gas fluxes in diverse waterbodies, winter limnology, and investigations of the importance of connectivity between waterbodies.

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