Preface to special theme, part 2

Summary of Lake Simcoe’s past, present, and future

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This special section of Inland Waters contains the final installment of a collection of papers on Lake Simcoe, Ontario, Canada. Collectively, the 4 papers in Volume 3, Issue 1 and the 13 papers in the current issue demonstrate the integrative and collaborative monitoring and research efforts underway to protect this large, multi-stressed lake. In the first preface to the special sections (Palmer et al. 2013), we detailed legislative and financial initiatives that have been implemented by the federal and provincial governments to support science in the Lake Simcoe watershed. Here, we summarize the resultant science reported in these special sections and highlight priority areas for future work.

The primary water quality concern in the Lake Simcoe watershed is excess phosphorus (P) loading that promotes the growth of algae and macrophytes, the decomposition of which depletes hypolimnetic dissolved oxygen (DO) and restricts the natural recruitment of lucrative coldwater sportfish (Evans et al. 1996). As such, P and DO are important indicators of ecosystem health in Lake Simcoe (North et al. 2013a). To meet the deepwater DO target of 7 mg L⁻¹ needed to sustain coldwater fish populations, total P (TP) loading to Lake Simcoe must be reduced to 44 tonnes yr⁻¹ (Young et al. 2011) from the most recent 5 year average of 86 tonnes yr⁻¹ (hydrologic years 2005–2009; OMOE and LSRCA 2013). TP loadings were estimated from long-term monitoring of 5 main sources (annual total for 2007–2009 ranged from 71.9 to 115.5 tonnes yr⁻¹): tributaries (47.4–80.6), atmospheric deposition (11.1–20.1), polders (drained wetlands used for agriculture; 5.3–7.2), water pollution control plants (3.7–5.0), and septic systems (4.4; Fig. 1a; OMOE and LSRCA 2013).

Despite extensive efforts to reduce anthropogenic P inputs to the lake (e.g., restrictions on P output from water pollution control plants, prohibition of new point source discharges, P reduction stewardship projects; Winter et al. 2002), TP loadings did not monotonically decrease from 1998 to 2006 (North et al. 2013a) and were relatively high in 2007–2008. However, the high loadings observed in 2007 and 2008 were more likely influenced by hydrology than anthropogenic P sources. Tributary loads, which provide the greatest contribution to TP loads, were particularly high in 2007 and 2008, coinciding with unusually high tributary flow (Fig. 1b); in fact, 2008 was the wettest year since flow records began in 1969 (O’Connor et al. 2013, OMOE and LSRCA 2013). When tributary discharges returned to typical levels in 2009, TP loading dropped to 71.9 tonnes yr⁻¹, similar to the 2002–2006 average load of 72 tonnes yr⁻¹ (OMOE et al. 2009). High flow rates in recent years have also been reported for Lake Erie (Joosse and Baker 2011) and Lake Winnipeg (Manitoba) where they were linked to increased in-lake TP concentrations (McCullogh et al. 2012). Climate change modeling in the Lake Simcoe watershed predicts greater winter precipitation and warmer air temperatures resulting in higher winter flows and earlier snowmelt, which could increase TP loading to the lake (Crossman et al. 2013). These results reaffirm the need to continue reducing TP loading to protect Lake Simcoe, particularly in a changing climate.

P reduction requires knowledge of the point and non-point P sources in the Lake Simcoe watershed and has been an on-going area of research, as demonstrated by a number of papers in this collection in Inland Waters. Two
papers investigated previously understudied P sources: groundwater and internal P loading from lake sediments. In a 2-year survey along ~2 km of the shoreline near Barrie, the largest city in the watershed, Roy and Malenica (2013) found that soluble reactive P in groundwater was elevated compared to lake water. Elevated concentrations of bioavailable nitrogen (N), metals, organic pollutants, and salts were also widespread with at least one contaminant exceeding aquatic life toxicity guidelines in ~50% of samples. These results suggest that urban groundwater may be a source of contaminants, including P, to the lake and sediment-dwelling organisms. In a comparison study of Lake Simcoe to lakes Winnipeg and Ontario (represented by the eutrophic embayment Hamilton Harbour), Loh et al. (2013) determined release rates of P and iron (Fe) during laboratory incubations to facilitate the quantification of internal P and Fe loading from sediments. This work informed a companion study by Nürnberg et al. (2013), which indicates that internal loading may be a substantial source of P to Lake Simcoe. Hiriart-Baer et al. (2013) also compared Lake Simcoe to other large lakes in their investigation of the quantity and quality of dissolved organic matter (DOM) in the lake. They found that dissolved organic carbon concentration in Lake Simcoe, which was higher than in lakes Erie and Ontario, was greater than would be expected based on lake TP and conductivity. Their results suggest the influence of an internal source of DOM in Lake Simcoe.

Non-point P loading from agriculture and construction activities was also addressed in these special issues. Using a modeling approach, Weiss et al. (2013) developed dust response units combining soil type and agricultural land use to characterize crop dust emission in the Lake Simcoe airshed. Their work identified 12 combinations of soil and crop type that account for a total of 85% of crop dust emissions. Mapping of these high priority areas will allow targeted implementation of best management practices to reduce atmospheric deposition of P-laden dust. In a jurisdictional scan, Trenouth et al. (2013) reviewed construction-phase stormwater management approaches and proposed revisions to Ontario’s current guidelines. Improved stormwater management will

Fig. 1. Annual (a) TP loading from 5 main sources and (b) flow volume for the 1998–2009 hydrological years (1 Jun–31 May) for Lake Simcoe, Canada; adapted from OMOE and LSRCA (2013).

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reduce sediment-bound P export from construction in high urban growth areas like the Lake Simcoe watershed.

Three additional papers in this collection characterized P export from tributaries and modeled the effectiveness of different management strategies in achieving mandated TP reductions. Miles et al. (2013) examined the relationships between land use and the export of different forms of P over an entire hydrological year in the Beaver River catchment, a major inflow to Lake Simcoe. They found that P concentrations varied greatly over time and tended to be positively correlated with agricultural land use but negatively correlated with woodlands and wetlands. However, even at a small spatial scale, relationships were complex and varied depending on the form of P and time period of analysis. P dynamics in the Beaver River were further assessed by Baulch et al. (2013) using the Branched-INCA-P process-based biogeochemical model on data from multiple monitoring stations throughout the catchment. While model performance was moderate, simulations adequately represented spatial differences in P and identified several P export ‘hotspots’. The authors also found that P concentrations in ~23% of samples collected in 2010–2011 exceeded provisional water quality thresholds. Jin et al. (2013) extended the application of the INCA-P model to the entire Lake Simcoe watershed and simulated P concentrations in the lake. The modeled effectiveness of various management scenarios on tributary (Baulch et al. 2013) and lake (Jin et al. 2013) P concentrations indicate that extensive, multifaceted point and non-point source control measures are needed to meet TP reduction targets.

While TP loading reductions are critical for the protection of Lake Simcoe, the quality of P inputs is also important (Joosse and Baker 2011). P bioavailability was investigated by North et al. (2013b) who showed that agricultural (specifically, cropland) land use can have a significant effect on the availability of P to algae in tributaries of Lake Simcoe. This work linking nutrient management in the watershed with downstream water quality and impacts on aquatic biota is widely applicable to other systems and improves our understanding of P export from the land to the lake. This integrative approach was exemplified by North et al. (2013a) who compiled numerous datasets to assess long-term trends in parameters from every trophic level in the lake to examine their interaction with P and DO dynamics. As well, a previously untested mechanism for DO depletion in Lake Simcoe was explored by Quinn et al. (2013) who showed that annual production by heterotrophic bacteria was low, suggesting DO demand at lower trophic levels is unlikely to be a major contributor to low hypolimnetic DO. The authors also discussed the influence of water quality and temperature on spatial and seasonal patterns in bacterial activity. Potentially pathogenic bacteria in Lake Simcoe were also examined in this collection of papers. Khan et al. (2013) reported on the prevalence of Campylobacter species, which have been linked to human gastrointestinal infections in other areas, at Lake Simcoe beaches over a 2-year period. They found that Campylobacter was present infrequently and at concentrations well below infective doses. Study results suggest that fecal contamination in sand and rivers, as well as bird droppings along shorelines, are potential bacterial sources.

Six of the papers in this collection also tackled the pressing issue of aquatic invasive species, specifically the spiny water flea Bythotrephes longimanus and dreissenid mussels. Kelly et al. (2013) examined the dynamics of Bythotrephes, an invasive zooplankton that may have significant ecosystem-level impacts, in Lake Simcoe. They reported significant bottom-up (prey abundance) and top-down (predation) controls on mean annual Bythotrephes abundance. Warm epilimnetic temperatures and increased water clarity were also found to positively influence Bythotrephes abundance. Reduced cladoceran abundance coincident with peak Bythotrephes abundance suggests this predator has a strong top-down impact on favoured prey. Ongoing monitoring will provide additional insight on the effects of this invasive predator.

Dreissenid mussels were established in the lake by 1996 (Evans et al. 2011), and have caused dramatic changes in other invaded ecosystems (Higgins and Vander Zanden 2010), including increased transparency and reduced nutrient and algal concentrations. Similar patterns following dreissenid establishment in Lake Simcoe (reviewed in North et al. 2013a) warranted investigations for similar potential effects. The nearshore in particular may be affected by dreissenids (Higgins and Vander Zanden 2010), which are most concentrated within the 5–15 m isopleths of the lake (North et al. 2013a). Reviewing existing data, North et al. (2013a) reported a decline in benthic invertebrate density in offshore regions, but an increase in nearshore regions following dreissenid establishment, consistent with recently reported patterns for benthic biomass (Rennie and Evans 2012). An estimated 14-fold increase in the secondary production of nearshore littoral benthos following dreissenid establishment may result from both an increase in benthic-derived production and sestonic production diverted towards littoral zones via dreissenid filtering (Ozersky et al. 2012).

Two papers used spatially-explicit contemporary data to examine dreissenid impacts on algal concentrations at nearshore versus offshore sites. Guildford et al. (2013) demonstrated significantly lower indicators of phytoplankton biomass at nearshore sites (those where
The Lake Simcoe ecosystem, particularly in the nearshore areas of the lake. Eutrophication and invasive species are not the only stressors impacting the Lake Simcoe watershed and future work needs to focus on how multiple stressors, including contaminants and climate change, are affecting water quality, biota, and ecosystem services and functions in Lake Simcoe. Given the tremendous degree of interest and a renewed source of funding (LSCUF; Palmer et al. 2013), these areas of research will hopefully be addressed in the next round of projects and through enhanced monitoring programs. Lake Simcoe is well on its way to becoming the most research-intensive lake in Canada.

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