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Cooperative science to inform Lake Ontario management: Research from the 2013 Lake Ontario CSMI program

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ABSTRACT

Since the mid-1970s, successful Lake Ontario management actions including nutrient load and pollution reductions, habitat restoration, and fish stocking have improved Lake Ontario. However, several new obstacles to maintenance and restoration have emerged. This special issue presents management-relevant research from multiple agency surveys in 2011 and 2012 and the 2013 Cooperative Science and Monitoring Initiative (CSMI), that span diverse lake habitats, species, and trophic levels. This research focused on themes of nutrient loading and fate; vertical dynamics of primary and secondary production; fish abundance and behavior; and food web structure. Together these papers identify the status of many of the key drivers of the Lake Ontario ecosystem and contribute to addressing lake-scale questions and management information needs in Lake Ontario and the other Great Lakes and connecting water bodies.

Introduction

Lake Ontario receives the water and associated stressors of the other four Laurentian Great Lakes as well as its own catchment and is considered the most impacted of these large aquatic ecosystems (Allan et al., 2013). Since the 1970s, successful management actions including nutrient load and pollution reductions, habitat restoration, and fishery management substantially improved conditions in Lake Ontario (Mills et al., 2003). However, several new obstacles to maintenance and restoration have emerged, including increases in water clarity (Binding et al., 2007), establishment and expansion of invasive species, including dreissenid mussels and *Cercopagis* (Holeck et al., 2015; Pennuto et al., 2012), benthic invertebrate community change (Barrett et al., 2017; Birkett et al., 2015) and the struggle for restoration of key native fishes including lake trout (*Salvelinus namaycush*), deepwater sculpin (*Myoxocephalus thompsonii*) and coregonids (Brenden et al., 2011; Lantry et al., 2007; Owens et al., 2003). While offshore nutrient concentrations have declined, near-shore habitats continue to be degraded by nutrient and sediment inputs that can limit their recreational use and influence the economic development of the region (Makarewicz and Howell, 2012). Overall, these series of events have led to a Lake Ontario that has an oligotrophic offshore and a nearshore that is challenged by tributary inputs, nuisance algae, and invasive species.

Research and annual monitoring of Lake Ontario, and the other four Great Lakes by a host of federal, state, and provincial agencies, has been crucial for maintaining these unique ecosystems and the services they provide. To supplement these efforts, each of the Great Lakes now undergoes an intensive lake-wide survey once every five years as part of the Cooperative Science and Monitoring Initiative (CSMI) (Richardson et al., 2012). This effort supplements existing annual monitoring and enables the evaluation of specific questions and hypotheses by coordinated researchers and pooling their resources. The five-year rotational cycle provides sufficient time to compile and interpret past findings and plan future sampling efforts directed at new research priorities identified by the various management groups.

The 2013 Lake Ontario CSMI effort was collaboratively planned to complement annual surveys and meet management information needs and science questions. The 2013 CSMI approach was developed through discussions in 2011 and 2012 among a broad spectrum of binational partner agencies and institutions with interest in Lake Ontario (Stewart et al., 2016). Wherever possible, 2013 surveys were coordinated to take advantage of the many long-term agency sampling efforts already in place and projects funded outside the CSMI-framework. Targeted research in 2013 focused on nutrient loading and fate; vertical dynamics of primary and secondary production, fish abundance and behavior and food web structure. This special issue presents a subset of findings from both annual and the 2013 CSMI surveys, spanning diverse lake habitats, species, and trophic levels. Together these papers identify the status of many of the key drivers of the Lake Ontario ecosystem and

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contribute to addressing lake-scale questions and management information needs in Lake Ontario as well as the other Great Lakes and connecting water bodies.

Nutrient declines and increased water clarity have changed the vertical distribution of Lake Ontario phytoplankton such that a deep chlorophyll layer (DCL) is a commonly observed and extensive feature (Barbiero and Tuchman, 2001; Watkins et al., 2015). Scofield et al. (in press), showed the DCL was a persistent feature in 2013, and at times included a diatom-rich biomass and productivity maximum. Although dynamic in time and space, the feature was closely aligned with the thermocline and depth of the photic zone and followed the typical slope of the thermocline from west to east in the lake. A decrease in water clarity in mid-August caused by calcite precipitation (whiting) coincided with the dissipation of this feature. Kelly et al. (2017) used stoichiometry and fatty acid analyses to assess the potential food quality of the DCL, finding it similar to the epilimnion. They also explored the nearshore/offshore gradient and identified a steady seasonal decrease in quality of pelagic seston from May to September.

Changes in water clarity and phytoplankton depths have also influenced the vertical behavior of Lake Ontario invertebrates. Watkins et al. (2017 used a variety of sampling techniques to demonstrate zooplankton exhibited classic diel vertical migration (DVM), inhabiting lake habitats near the thermocline in the day and the epilimnion at night. This behavior persisted beyond times when a DCL was present, suggesting that these organisms may use the DCL as a food source, however it is likely not the only driver of migration behavior. O'Malley et al. (2017-this issue) demonstrated that diets of vertically-migrating *Mysis diluviana*, a critical prey for fish, shifted seasonally from greater proportions of algae in spring to increased zooplanktivory in summer and fall. In contrast to *Mysis* diets from 1995, current Lake Ontario mysid diets include the invasive predatory cladoceran, *Cercopagis pengoi* (O'Malley et al., 2017-this issue). Quantifying the behavior and feeding dynamics of Lake Ontario pelagic invertebrates is critical for developing food web relationships and effective lake management.

Species invasions and trophic changes have also influenced the Lake Ontario fish community. Riha et al. (2017) demonstrated Lake Ontario's dominant forage fish species, alewife, dispersed throughout the epilimnion at night in the summer, but formed schools near the thermocline during the day. As with the zooplankton, this behavior occurred with and without a DCL present. Cyclopoid copepods and cladocerans were the primary diet items for this species, although deepwater calanoid *Limnocalanus* were also eaten. Happel et al. (2017), used fatty acids to demonstrate that round goby, an abundant benthic invader, were an important diet item for brown and lake trout. Although their relative importance was lower in more pelagic predators such as Chinook and coho salmon. Similarly, Hoyle et al. (2017-this issue) showed that round goby were important in immature walleye diets in the Bay of Quinte; however, mature walleye migrated from Bay of Quinte spawning grounds to main-lake habitats to consume alewife. Despite the continued dominance of nonnative prey fish such as alewife and round goby, Lake Ontario's native deepwater sculpin population have increased (Weidel et al., 2017-this issue). Historic observations suggest this species may have been extirpated from Lake Ontario by the mid-1900s; however since 2008, bottom trawl catches suggest the population is increasing rapidly (Weidel et al., 2017-this issue). Genetic analyses compared samples from the rebounding Lake Ontario deepwater sculpin to historic Lake Ontario deepwater sculpin samples and contemporary samples from the upper Great Lakes and found the current population is more similar to the Upper Lakes populations (Welsh et al., 2017-this issue). The current Lake Ontario population also has reduced allelic diversity relative to upper Great Lakes populations, indicating a possible founder effect (Welsh et al., 2017-this issue).

The offshore Lake Ontario benthic invertebrate community underwent significant change in the 1990s when the native and abundant amphipod *Diporeia* disappeared as quagga mussels invaded all Lake Ontario benthic habitats (Birkett et al., 2015). McKenna et al. (2017) developed a spatially-explicit ecosystem model to simulate this Lake Ontario benthic invertebrate community change. Model results suggest the observed declines in Lake Ontario *Diporeia* are best explained by a disease-like mortality mechanism rather than a competition for food mechanism. Model simulations also forecast a plateauing mussel population and a potential recovery of *Diporeia* although there are few signs this recovery is occurring.

Lake Ontario's near shore benthic habitat was a research focus because of previous lake-wide effort (Makarewicz and Howell, 2012), and efforts to understand this important habitat continued in 2013. Makarewicz and Lewis (2015) found water quality and biological parameters identified six distinct regions that characterized Lake Ontario nearshore habitats. This work identified specific lake regions, stressed by nutrients, that may be candidates for watershed remediation. Duffy et al. (2017) assessed the status of the lake bottom within the Rochester Area of Concern (AOC) and found that the sediment toxicity and benthic invertebrate community within the Rochester AOC were similar to or better than adjacent embayment and lake habitats. Howell and Dove (2017), demonstrate that input of nutrients and turbidity from Lake Erie and surrounding watershed continues to have strong impacts on western Lake Ontario near shore habitats. Interestingly, the increased turbidity may have caused beds of *Cladophora*, a nuisance algae, to grow in shallower water in the St. Catherines area relative to other locations in Lake Ontario.

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