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The influence of streams on nearshore water chemistry, Lake Ontario

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ABSTRACT

Large lakes have characteristics, such as a spring thermal bar; nearshore offshore gradients of nutrients, sediment, and biota; and the development of a nearshore zone often chemically, biologically, and physically different from the offshore region, that are not commonly observed in smaller lakes. The research presented here focuses on the role of rivers affecting the cross margin transport of terrigenous materials delivered during the summer on nearshore waters of Lake Ontario. On the south shore of Lake Ontario, levels of chlorophyll, total phosphorus (TP), and total coliform were higher in the Oak Orchard Creek river plume than out of it. Similarly at the Genesee River polygon, turbidity, specific conductance, temperature, TP, and chlorophyll were substantially higher in the plumes than outside of the plumes. Graphic depictions and the strong correlations ($r >= 0.70$) between specific conductance and TP, soluble reactive phosphorus , temperature, chlorophyll, total Kjeldahl nitrogen, and turbidity indicate the plumes of water are from the Genesee River and Oak Orchard Creek. The load from all creeks on the New York shore of Lake Ontario ranged from ~18 to 25% of the annual phosphorus load of the Niagara River. The cumulative impact of these small streams entering the nearshore and embayments of Lake Ontario is potentially great, as the mixing of plume and lake water appears to be limited to the nearshore areas. Terrigenous inputs likely provide the nutrient, phosphorus, which contributes to the periodic development of benthic algae blooms observed along the south shore of Lake Ontario. The conclusion that river plumes impact and sustain the nearshore of large lakes is suggested by the data.

Introduction

Research on structure and function within ecosystems has been a major effort of ecosystem science for many years. Gorham (1996) was perhaps the first to remark that "study of linkages amongst ecosystems" remains in its infancy. In freshwater systems, much of the research has focused on smaller lakes and their surrounding watersheds. Small water bodies are known to be dominated by terrigenous materials (Molot and Dillon, 1996; Wetzel, 1984, 1992). Wetzel (1984) and Cole (1999) have suggested that aquatic ecosystems, including oligotrophic large lakes, are likely to be significantly subsidized by terrigenous inputs of nutrients and organic matter, which may support approximately 10–20% of annual in-lake heterotrophy as well as autotrophy (Biddanda and Cotner, 2002). For smaller lakes, strong relationships between tributaries, the lake, and wetlands and their surrounding watersheds are well described in the literature. Land-use type and soil and nutrient losses from watersheds may have major impacts on the littoral and the pelagic regions of small lakes. For example at Conesus Lake, a small Finger Lake of New York State, the strong linkage between land use, nutrient loss, and effects on a downstream lake biota was demonstrated through a set of experimental manipulations of entire watersheds. Implementation of best management plans within the watershed to reduce nutrient and sediment loss led to significant reductions in nutrients (Makarewicz et al., 2009) from the watersheds and reductions of macrophytes (Bosch et al., 2009a), algae (Bosch et al., 2009b), and bacteria (Simon and Makarewicz, 2009) within the littoral zone of the open waters of the lake.

Large lakes, however, such as the Great Lakes, have nearshore physical and chemical characteristics that are not commonly observed in smaller lakes — a nearshore zone. Research on the linkage between these terrestrial ecosystems and the nearshore waters of large lakes has investigated the impact of spring runoff events, land use on nearshore structure, and development and extent of the nearshore zone. For example, thermal fronts may result in temporary isolation of nearshore waters (e.g., Auer and Gatzke, 2004; Makarewicz et al., 2012a). The shoreside of a thermal front in a large lake often augmented by river discharge may exhibit nutrient enrichment, as the density boundary between the offshore and nearshore water limits cross-boundary transport of sediment, nutrients, and heat (Auer and Gatzke, 2004; Blanton, 1986; Huang, 1972; Lathrop

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et al., 1990; Makarewicz et al., 2012a; Rodgers, 1966). Consequently, increased productivity may occur much earlier in the inshore regions than in the open waters during the spring (Moll et al., 1993; Wetzel, 2001).

Even in the absence of thermal barriers to mixing, nearshore–offshore gradients in chemical and biological materials (bacteria, phytoplankton, and zooplankton) may be realized in large lakes. As inputs of materials from the watershed and lake influences interact together, intense biological, chemical, and geological processing occurs (Auer and Gatzke, 2004; Henrichs et al., 2000; Klump et al., 1995) to form a highly variable chemical and biological environment — the nearshore zone (Makarewicz et al., 2012b). Nearshore–offshore gradients in biological assemblages have been observed as well and are often attributed to the trapping of nutrients in nearshore waters (Auer and Gatzke, 2004; Evans et al., 1980; Makarewicz et al., 2009; Menon et al., 1971; Moll et al., 1993; Nalewajko, 1967; Stoermer, 1968).

Makarewicz et al. (2012b) have demonstrated that the nearshore region of Lake Ontario has elevated levels of phosphorus and turbidity. For example, in the Rochester embayment both TP and turbidity were elevated out to at least 4 km from the shoreline. Compared to the offshore waters, a narrow shoreline band with a unique and highly variable water chemistry, not caused or sustained by a thermal front, extends up to 4 km into the open waters along the southern coast of Lake Ontario during the late spring and summer. Possible physical causes of the chemical and biological gradients observed were upwellings, resuspension of sediments during episodic wind events, and tributary discharge from watersheds.

In general, the extent to which the offshore and nearshore habitats vary ecologically in space and time due to terrigenous inputs from watersheds is not well understood in large lakes. Few studies describe a broad, watershed-based relationship for the open coastal and nearshore waters of large lakes such as the Great Lakes (Yurista et al., 2011). The research presented here not only focuses on the role of rivers as sources of terrigenous materials delivered during the summer on nearshore waters of Lake Ontario but also describes the biological availability of nutrients. The goal of this project was to describe and establish the importance of the river plumes to transport and to determine the composition and biological availability of nutrients to the nearshore of a large lake. Transport of nutrients and sediments from watersheds via streams to lakes may be important in determining the timing and extent of nutrient availability and in structuring the biological communities, such as the benthic algae *Cladophora* and dreissenid mussels, found in the nearshore region. That is, the plume of river water into the nearshore zone of large lakes generates a constant but variable source that increases the inventory of total phosphorus, bioavailable phosphorus, and other nutrients.

Methods

Intensive sampling of the nearshore zone of Lake Ontario near the mouth of Oak Orchard Creek and the Genesee River (Fig. 1) was conducted in June and August of 2008 via two complementary approaches: fixed stations and continuous monitoring with a sensor array along a defined track transecting a 5 × 20-km sampling polygon (Figs. 2 and

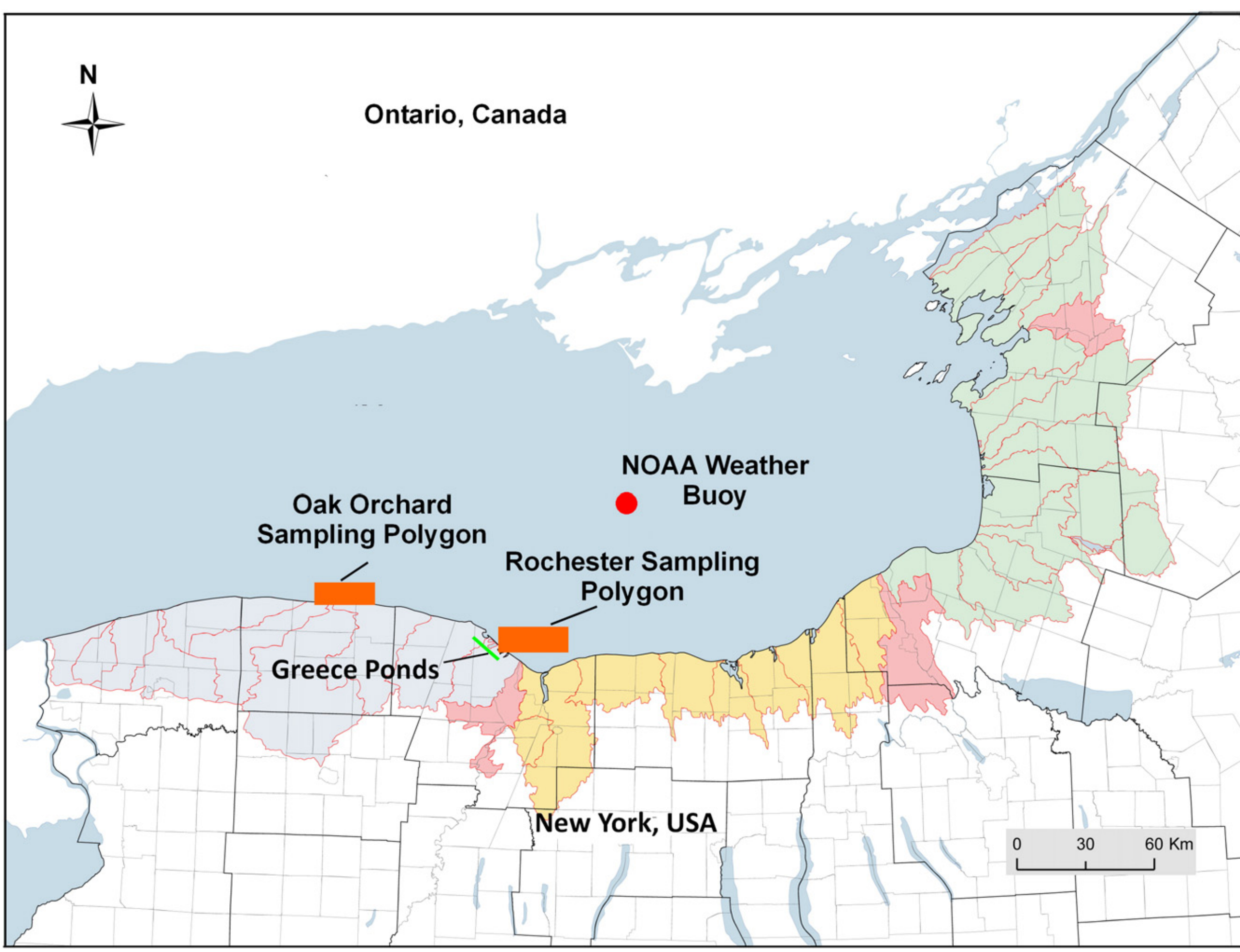

Fig. 1. The Oak Orchard and Rochester sampling sites in Lake Ontario. The Greece ponds area (Braddock Bay and Long, Buck, Cranberry and Round Ponds) are a series of small water bodies hydrologically linked to Lake Ontario. The colored coastal areas represent the HUC12 (hydrologic unit code) subwatersheds that border the lake.