Journal of Great Lakes Research 38 (2012) 21–31

Contents lists available at SciVerse ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/jglr

Physical and chemical characteristics of the nearshore zone of Lake Ontario

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ARTICLE INFO

Article history:
Received 1 January 2011
Accepted 25 November 2011
Available online 14 January 2012

Communicated by Vi Richardson

Keywords:
Nearshore zone
Coastal zone
Phosphorus
Conductivity
Thermal bar
Lake Ontario

ABSTRACT

A long-term, 7-year lake-wide study was paired with a short-term intensive nearshore study to characterize water quality conditions of coastal Lake Ontario in New York. Mean total phosphorus (TP) concentrations in rivers (84.3 ± 7 μg P/L), embayments (129.7 ± 9.6 μg P/L), and shoreside sites (61.9 ± 7.4 μg P/L) exceeded the IJC goal of 10 μg P/L for Lake Ontario waters and were significantly higher than in offshore waters (L0-100 m, 9.5 ± 0.7 μg P/L; LO-30 m, 10.4 ± 0.08 μg P/L). In three 5 × 20-km regions of the nearshore located at Oak Orchard, Rochester, and Mexico Bay, TP levels exceeded the 10 μg P/L goal for Lake Ontario in 48% and 32% of the samples in June and August, respectively. Also, shoreside and embayment chlorophyll a were significantly higher than in offshore waters. Elevated sodium levels observed at shoreside sites of Lake Ontario are likely due to the heavy use of salt during the winter to deice roads. The elevated phosphorus concentrations observed at the shoreside sites extended into Lake Ontario. For example, at the Rochester nearshore sites in June, both TP and turbidity were elevated out to at least 4 km from the shoreline, whereas temperature and specific conductance were elevated out to 3 km from the shoreline. Shoreside sites had some chemical characteristics distinct from both the offshore (LO-30 m and LO-100 m) and river sites within the sampling polygon. A thin band of water with a unique water chemistry compared to both the offshore waters and tributaries extends up to 4 km into the open waters along the southern coast of Lake Ontario during the late spring and summer.

Introduction

Many terms exist for describing the peripheral shallows of a lake including the littoral, the coastal, and the nearshore zones. The littoral zone has been defined as the band of water from the shoreline to the depth where weeds disappear (Cole, 1994; Wetzel, 2001). Moss (1998) refines this definition further as the euphotic depth where algae can colonize the bottom sediments. In the open waters of larger lakes, such as the Laurentian Great Lakes, the littoral is often devoid of rooted macrophytes because of wave action that creates enough kinetic energy to prevent the establishment of macrophytes as in smaller lakes. From this perspective, the littoral zone as defined as the depth where benthic algae can colonize the surface of the sediments is more appropriate for large lakes. Often in larger lakes and in the ocean, the term coastal zone, a more encompassing term, is employed to include embayments, drowned river mouths, and the nearshore zone. The nearshore zone also has had various definitions ranging from simply the distance from the shore to 100 m offshore (Taylor et al., 2004), the shore to a depth of <20 m (Hall et al., 2003), or the shore to a depth of 30 m, where the depth of sand-motion initiation by the yearly median wave condition no longer exists (Hallermeier, 1981), beyond which lies the offshore zone.

Whatever terminology we may employ, in large lakes there exists a transition zone between the shoreline and the open waters that is influenced by the physical, chemical, and biological characteristics of the offshore zone and by the chemistry and accompanying flows of streams reflecting land use of watersheds. Here we will refer to

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0380-1330/$ – see front matter
doi:10.1016/j.jglr.2011.11.013

this transition area of the lake as the nearshore zone. Lake Ontario's nearshore zone encompasses 1020 km of shoreline with the Canadian and American shorelines of nearly equal length (537 km Canada; 483 km USA) (Coordinated Great Lakes Physical Data, 1977). For both Canadians and Americans, the nearshore zone is the primary zone of contact with the waters of Lake Ontario. Most importantly, the coastal waters of Lake Ontario provide valuable ecosystem services, such as drinking water and industrial usage, recreational boating, fishing and swimming, tourism, wastewater processing, and nursery areas and habitat for fish and wildlife, and are key assets in the economies of upstate New York and the Province of Ontario. Great Lakes' nearshore areas are also a valuable ecological resource providing valuable habitat for numerous species of fish, birds, and other aquatic life (Great Lakes Commission, 2010). As stated in the New York Ocean and Great Lakes Ecosystem Conservation Act (2006) "… coastal ecosystems are critical to the state's environmental and economic security and integral to the state's high quality of life and culture. Healthy coastal ecosystems are part of the state's legacy, and are necessary to support the state's human and wildlife populations…"

Despite significant improvement in the water quality of the open offshore waters in the last three decades (Holeck et al., 2009; Mills et al., 2003), the Lake Ontario nearshore and embayments—bays and drowned river mouths—are suffering from many impairments that severely limit their recreational use and ultimately affect the economic development of the region (Makarewicz, 2000). These impairments include invasive species; habitat destruction; algae blooms; harmful algal blooms; erosion, sedimentation, and associated nutrient enrichment; turbidity; beach closings; and fish consumption advisories due to toxicants. For example, cultural eutrophication of embayments is evident as chlorophyll and TP concentrations are often elevated in Lake Ontario embayments compared to the nearshore and offshore zones (Hall et al., 2003). In addition, seven Areas of Concern (Eighteenmile Creek, Niagara River, Hamilton Harbor, Port Hope Rochester embayment, Toronto Metro Region, and the Bay of Quinte) are in the Lake Ontario nearshore zone. Although some beneficial use impairments have been delisted (Oswego River and Harbor) in the areas of concerns, impairments still remain along the entire southern coastline. As of 2010, portions of the south shore coastal zone of Lake Ontario have been placed on the 303 d list of impaired waters of the Clean Water Act. The most objectionable of these are odiferous floating pods of algae (mostly *Cladophora*) washing up on the shoreline and the presence of fecal indicators that impact aesthetics and use of the lakeshore for shoreline residents, the general public, and tourists walking the shoreline. These impairments often lead to beach postings/closures (Makarewicz, 2000). For example, Ontario Beach in Rochester, NY, was closed 39% (31 days) and 31% (25 days) of the time in the 2004 and 2005 summer swimming season, respectively (C. Knauf, Personal Communication, Monroe County Health Department). Within the Great Lakes in general, the 17,000-km nearshore zone is stressed by human population growth, heavy industry, and point and nonpoint source pollution.

Despite the economic and ecological importance of the nearshore zone, development of policies to mitigate nearshore problems and restore this region is generally limited by a lack of understanding of structure and function within the nearshore zone and of the stressors and driving forces in this region of the lake. As Hall et al. (2003) note, most studies of nutrients and plankton have focused on the offshore zone. The extent to which the embayment, offshore, and nearshore habitats vary ecologically in space and time is not well understood. The overall goal of this study was to identify and describe characteristics of the nearshore zone of Lake Ontario. This was achieved by a 7-year study that compared and contrasted the water quality of the offshore, nearshore, river, and embayment habitats spatially along the 483-km Lake Ontario shoreline of New York. This was coupled to a short-term intensive study that focused on three 5×20-km regions (referred to as sampling polygons) to identify the degree and causes of nutrient variability within the nearshore zone. The smaller scale intensive monitoring of the sampling polygons provided insight into the factors that affect and define the nearshore zone in a large lake system. The results presented here have relevance to the ongoing discussion on the resurgence of *Cladophora* in the Great Lakes and the phosphorus shunt hypothesis (Hecky et al., 2004). Lastly, we documented the occurrence and the spatial extent of phosphorus concentrations in the nearshore zone that exceeded the 10 μg P/L target concentration for ambient waters of the Great Lakes.

Methods

The "Long-Term Coastal Zone Spatial Study" (LTCZSS) refers to a sampling program undertaken from 2003 to 2009 where water samples were collected from June through September in every year with occasional samples from May and October from 38 sites along the southern shore of Lake Ontario from the Niagara River in the west to Chaumont Bay (Fig. 1). Sites were selected to cover a wide variety of habitat types that included rivers, embayments, coastal shoreside waters (wadeable depth), and offshore waters (LO-30 m and LO-100 m depths) along the southern shore of Lake Ontario (Fig. 1). Sites east of Port Bay were sampled from 2005 to 2009 only, but remaining sites were sampled from 2003 to 2009. Embayments (Braddock Bay, Chaumont Bay, Henderson Harbor, Little Sodus Bay, Irondequoit Bay, Long Pond, Port Bay, Sackets Harbor, Sandy Pond, Sodus Bay) and rivers (Niagara River, Twelvemile Creek, Eighteenmile Creek, Oak Orchard Creek, Salmon River, Sandy Creek, Genesee River, Salmon Creek at Pultneyville, Oswego River) (Fig. 1) were sampled at a depth of 1 m (Van Dorn-type water bottle) at either the mouth of the river or, if an embayment, near the outlet to Lake Ontario. Shoreside samples were taken in the open waters at wadeable depth (~0.5 to 1 m) and from locations generally to the west (west of Oswego, NY) and south (east of Oswego, NY) of the outlet of the embayment or river to reduce the influence of river or embayment on water quality. Two open water sites north of Sandy Creek [LO-30 m (30-m water depth, 2.4 km from shoreline) and LO-100 m (100-m water depth, 7.8 km from the shoreline)] were sampled biweekly at a 1-m depth from June through September (occasionally May and October). Wind data for the open lake was obtained from the NOAA Lake Ontario Buoy (Station 45012) located 37 km north northeast of Rochester, New York (Fig. 1).

The goal of the "Short-Term Intensive Polygon Study" (STIPS) was to describe the nearshore Lake Ontario shoreside to offshore nutrient gradient within 5×20-km sampling polygons. Three locations (referred to as polygons) were selected for intensive monitoring of the nearshore zone via two complementary approaches: fixed stations and continuous monitoring along a defined track transecting each polygon (Fig. 2). The three locations, Rochester (ROC), Oak Orchard (OOC), and Mexico Bay (MEX) (Fig. 1), drain watersheds of different land use characteristics (urban and agriculture, agriculture, rural forested, respectively) and were sampled in the late spring (May/June) and summer (August, Fig. 2) in 2008.

The major river entering the Oak Orchard polygon is Oak Orchard Creek (length = 99.3 km). Land use patterns in the Oak Orchard Creek watershed are predominantly rural and agriculture, with secondary residential and commercial uses. Sixty-five percent of the watershed (70,405 ha) is in agriculture which contains a unique muckland soil area noted for high value vegetable production area (Zollweg et al., 2005) and recognized as an area of high nutrient losses to downstream systems (Makarewicz and Lewis, 1998).

The Mexico Bay polygon is located at the eastern end of Lake Ontario (Fig.1). On the land side of the Mexico polygon are several embayments, the largest being North Sandy Pond, formed by the eastern Lake Ontario sand dunes that form a ridge on the landward