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Lake Michigan: Nearshore variability and a nearshore–offshore distinction in water quality

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ABSTRACT

We conducted a survey of the Lake Michigan nearshore using towed electronic instrumentation to collect data that were spatially highly resolved. The tow was 1049 km in length along the 20-m depth contour and was supplemented with grab samples at 15 sites (on average every 75 km). There was low frequency variability in the alongshore reach represented by macroscopic trends across large distance scales (over 100 s km) with local variability or high frequency changes at much smaller distances (5–10 km). We found that large scale spatial patterns in some water quality parameters were strongly correlated with adjacent landscape characterization. Landscape attributes most frequently retained in step-wise regression models for each water quality parameter were agricultural chemical factors, followed by shoreline modifications and point source attributes. Specific conductivity had the greatest amount of variability explained by landscape character (78%) with beam attenuation next (51%), and followed by chlorophyll and zooplankton (each ~30%). We combined our chemistry samples with data from the recent National Coastal Condition Assessment (2010 NCCA) and compared nearshore chemistry data with the Great Lakes National Program Office (GLNPO) offshore fixed monitoring sites. There was a significant distinction in both mean values and variability between the nearshore (<30 m depth) and offshore waters. We also used historical data and found that the distinction between near shore and offshore waters has persisted and that the same long-term trends in parameter concentrations found in the offshore were also found in the near shore.

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Introduction

Input of nutrients, toxins, and other substances to the Great Lakes primarily comes from activities in watersheds and development along the coastline. These inputs are delivered through direct landscape runoff, tributary input, and point source discharges to nearshore regions. While substances delivered to the nearshore are eventually mixed into the offshore waters, internal hydrodynamic mixing processes initially tend to entrap landscape runoff in the coastal shelf region (Csanady, 1970; Rao and Schwab, 2007) and for most of the year conditions in the near shore may be very different from those in the offshore. The condition of the nearshore water therefore may be different than observed in offshore water during the interim transport and mixing into offshore waters. Although near shore waters are the most highly used and visible parts of the lakes, regular monitoring unfortunately has concentrated on the offshore regions and the connections between the condition of the near shore waters and their adjacent shorelines remain largely unknown.

The variability of input concentrations, tributary flow volumes, and the hydrodynamics of nearshore regions has made it complicated to make assessments of the nearshore at local, regional, and whole lake scales (Mackey and Goforth, 2005; Niemi et al., 2007). Signals from external substances arising from landscape activities may be masked by their input variability, by weather events, and by transport and mixing in the alongshore direction. As a consequence of these complicating factors, a coordinated or routine monitoring program has not been developed for the nearshore region in the Great Lakes. Adequate sample numbers in the nearshore at small to large spatial scales are necessary to make assessments with acceptable confidence levels, identify trends and variation around the lake, and place in perspective effects at the local, regional, or whole lake scales.

Lake-wide monitoring of the nearshore in the Great Lakes does not currently exist, however, we have been investigating a strategy for making detailed observations in all of the Great Lakes that could form the basis for a regular monitoring program of the nearshore region (Kelly and Yurista, 2013) Definitions of a generic nearshore region have been varied and often specific to particular questions (beach, benthos, fish, etc.) and may be arbitrary, empirical, or guided by expert opinion (Kelly, 2009). Some intensive studies in Lake Michigan have been conducted periodically over the past 35 years and often cite a difference

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between nearshore and offshore conditions, although each study defined the nearshore differently (Rousar, 1973; Barton and Schelske, 1982). Site specific transects or grids may provide different conclusions of what represents the nearshore depending on where across the lake-landscape interface the study was conducted as a result of the variation in point sources, landscape activities and watershed disturbances driving the local nearshore conditions. Lake-wide synoptic information is needed to provide a spatially extensive and inclusive characterization of a nearshore region that could be used to identify lake-wide patterns or expose local anomalies.

We have previously reported on detailed surveys of nearshore regions in Lakes Superior, Huron, and Ontario (Yurista and Kelly, 2009; Yurista et al., 2012a, 2012b). This paper focuses on our work in Lake Michigan, the third largest of the Great Lakes. Our research on Lake Michigan in 2010 supported the coordinated science and monitoring initiative for the year of Lake Michigan (CSMI, Richardson et al., 2012) and the National Coastal Condition Assessment (NCCA), which for the first time formally included the Great Lakes. We used the large sample power from these surveys to observe the character of the nearshore region (<30 m depth for water quality and plankton parameters). Our goals were to observe 1) whether water quality variability along the nearshore has spatial structure, 2) whether there is a correlation in alongshore water quality to landuse characterization around the basin as a potential driver of some of the structure, and 3) whether the nearshore is measurably different from the offshore region. We also used historical data to observe the general pattern over time of nearshore condition and further assess whether it can provide an indication of impact signaling longer-term change in open offshore lake condition.

Methods

Our field methods, electronic sensors, data processing, and analyses have been consistent across a series of studies that we have reported on from 2004 to 2010 in the Great Lakes (Yurista and Kelly, 2009; Yurista et al., 2011, 2012a, 2012b; Kelly and Yurista, 2013). We have surveyed most of the US shoreline in all the Great Lakes and Canadian shorelines of Lakes Erie and Ontario, with a number of shoreline sections surveyed twice since 2004. Rather than repeat all methods we only provide a synopsis of them here, highlighting details specific to Lake Michigan. A companion paper describes a Green Bay survey track also conducted in 2010.

Field surveys

We towed electronic instrumentation along the nearshore of Lake Michigan at a targeted bottom contour depth of 20 m. We chose to tow along the 20-m contour because this depth is representative of a broader 10- to 30-m region (Yurista et al., 2012a, 2012b). The 10-to-30-m region surveyed represented 91% by volume of 0- to 30-m in Lake Michigan. The tow was conducted during a more biologically stable and a less dynamic period of late summer, to reduce high variability from rapidly changing temperature following thermal bar dissipation and phytoplankton blooms of spring and early summer with accompanying rapid changes in water quality. A total of 1049 km was surveyed in Lake Michigan during 9–15 September 2010 from the RV *Lake Guardian* (Fig. 1). The tow encircled most of the lake with the exception of a portion of the northeastern region of the lake. We also conducted 6 cross-contour tows in the lake from a water depth of 10 out to 30 m. The cross-contour tows varied in length from 4 to 10 km.

Our instrument array consisted of a SeaBird 19plus CTD, augmented with a fluorometer (Wetstar, Wet Labs), and a transmissometer (C-star-660 nm, 25-cm path, Wet Labs). The CTD was multiplexed with a laser-optical plankton counter (LOPC, Brooke Ocean Technology, 2004; Herman et al., 2004), GPS data, and bottom depth sonar. The in situ sensors were attached to a VFin-493 tow platform. Data from the sensors were combined with ship position and bathymetric data and written to a computer file every 0.5 s. A sinusoid tow pattern (tow-yo) added a vertical dimension to sensor readings and was generally restricted in travel to a range of 2 m above the bottom to about 2 m below the surface. We towed at a target speed of 2.5 m s^{-1} (~9.5 km h^{-1}).

We stopped along the tow track at 15 sites (with one site repeated at start and end of cruise) in Lake Michigan to collect fixed-point water samples, zooplankton net tows, CTD profiles using a CTD system independent from that of the tow instrumentation, and to perform routine inter-calibration and QA of the towed instrumentation with the shipboard instrumentation (Fig. 1). Water samples were collected at 2 m and at either 10 or 15 m in conjunction with the inter-calibrations. We analyzed water samples for total phosphorous, total nitrogen, $NO_{2/3}$, chlorophyll a, chloride, and other anions and cations.

Unfiltered water was digested for total nitrogen and phosphorous with an autoclave using an alkaline persulfate method. Digested samples were analyzed for nitrate plus nitrite by passing digested samples through a copperized cadmium column, quantitatively reducing nitrate species to nitrite, diazotization, and coupling to produce a magenta dye read at 540 nm. Phosphorous in the digested samples was quantified by forming an antimony-phosphomolybdate complex, ascorbic acid reduction forming a blue color, and read at 880 nm. Inorganic dissolved nitrate from filtered water (0.45-μm hydrophilic membrane filter) followed the above nitrate procedure without digestion. Analyses were performed on a Lachat Chem 8000 automated flow injection system (Nitrate/Nitrite, QuickChem Method 10-107-04-1-K Low Flow, 1995 and Orthophosphate, QuickChem Method 10-115-01-1-Q Low Flow, 1995, Lachat Instruments, Hach Company, Loveland, CO). Chlorophyll was determined by filtering 1 to 2 l sample water through a GF/F filter, extracting the filter using a saturated magnesium carbonate acetone solvent, and reading the fluorescence with a Turner Designs TD-700 Fluorometer. Chloride was determined by ion chromatography using a Dionex DX 600 (Thermo Scientific) at nearshore sites (Mid-Continent Ecology Division [MED]) and by Lachat for offshore sites (GLNPO, 2010).

Water quality samples for the 2010 NCCA were collected in Lake Michigan through an EPA/State partnership using methods consistent with ours (USEPA, 2009a). The sample design for the Great Lakes NCCA was probability-based to provide 45 coastal sites per lake (0–30 m, and less than 5 km from shore). Samples were collected from 44 of the 45 design locations, 34 sites within Lake Michigan proper and 10 sites located in Green Bay. An additional 28 sites in smaller bays of Lake Michigan were targeted with an embayment enhancement survey that extended across the Great Lakes. The embayment enhancement focused exclusively on smaller bays (>1 to 100 km^2) to understand their relationship to the broader more open nearshore coastal areas. We used chemistry data from the NCAA that were collected during the summer peak season to match conditions during our observation period. We used sample sites where data were collected during mid-July to mid-September (7/13–9/15 n = 22) with an average date of August 5. The restricted time period is also more consistent with GLNPO and our sampling dates. All sampling and analysis procedures are described in the NCCA field and laboratory manuals (USEPA, 2009a, 2009b).

Zooplankton tows were taken from 2 m above bottom to the surface with a 0.5-m diameter net having 153-μm screen size and monitored with a flow meter. The zooplankton samples were preserved in buffered formalin. Taxonomy, size, and abundance were determined by counting a minimum of 400 organisms from each sample following procedures from GLNPO (2010). Chlorophyll a and zooplankton biomass from net tows were used for instrument field correlations (fluorometer, LOPC).

Field instrument correlations

The LOPC was calibrated in the field following the procedure in Yurista et al. (2009) and based on Sprules et al. (1998). The field

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