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Great Lakes nearshore–offshore: Distinct water quality regions

Peder M. Yurista *, John R. Kelly, Jill V. Scharold [1]

Mid-Continent Ecology Division, National Health and Environmental Effects Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 6201 Congdon Boulevard, Duluth, MN 55804, USA

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ABSTRACT

We compared water quality of nearshore regions in the Laurentian Great Lakes to water quality in offshore regions. Sample sites for the nearshore region were from the US EPA National Coastal Condition Assessment and based on a criteria or sample-frame of within the 30-m depth contour or 5-km distance from the shoreline, whichever occurred first. The offshore sites were composed of US EPA Great Lakes National Program Office (GLNPO) annual monitoring sites. There was a contrast in both variability and mean values of water quality values between the nearshore and the offshore regions. Lake-by-lake the nearshore was more variable and had higher average parameter values than the offshore, except for $NO_{2/3}$ which was lower in mean value. A subset of all sites was re-visited in supplemental years to explore temporal effects (57 nearshore sites in Lake Erie 2009 and for 67 nearshore sites in Lake Huron 2012). The operational sample-frame for nearshore water provided a reliable means for separating the lakes into two distinct and persistent water quality regions across years.

Introduction

The Great Lakes nearshore forms the nexus between land use activities in watersheds and the deeper offshore waters that comprise the principal volume of each lake. Impacts to the whole lake due to contaminants, nutrients, and sediments from activities within watersheds enter first through a nearshore zone-of-impact. Describing spatial characteristics and identifying key features of a nearshore or coastal zone-of-impact is a necessary step in tracking the transfer of contaminants, nutrients and sediment from the landscape to the open lake. Coastal areas can be considered as two zones; a zone-of-influence, where pressure originates from natural or anthropogenic activities, and a zone-of-impact, where problems develop or are observed as a result of the pressure. The nearshore zone-of-impact is where the cumulative effects of land-based activities and their consequences are first observed and have become of increased attention (Edsall and Charlton, 1997; GLWQA, 2012; Mackey and Goforth, 2005; Niemi et al., 2007; SOLEC, 2009). The spatial dimensions of a zone-of-impact may change depending on the issue being investigated.

The potential to organize large lakes into qualitatively different intra-lacustrine regions such as zones of influence and impact leads to increased understanding of lake-wide functioning (Pauer et al., 2006, 2011; Wang et al., 2015). Observed spatial patterns in water quality attributes provide first order guidance to identifying regional distinctions and likely transfer paths of material and pressure among lake regions. Patterns also provide insights into mechanisms or physical processes that structure or maintain the pattern or regional distinction. Models to describe the mixing of nutrients throughout the lake are more accurate when they account for structurally or functionally distinct regions (e.g. water column stratification, Wetzel, 1983). The delineation of different and persistent water quality regions in large lakes aids in appropriate and efficient distribution of sample sites (e.g. sample stratification) for research, monitoring, assessment and management of targeted resources. Finally, the impact resulting from management decisions and its spatial extent are more clearly anticipated and subsequently easier to recognize and track across distinct regions.

Identification of distinct regions in very large lakes is plagued by spatial scales of observation and multiple external stressors and internal processes that may create, maintain, or reduce regional differences. Identification of regional boundaries is limited by the extent and/or density of survey coverage of most monitoring and assessments; both spatially intensive and lake-wide extensive observations are needed (e.g. Yurista and Kelly, 2009; Yurista et al., 2012a,b). Compounding the situation, the nearshore within the Great Lakes is an open system influenced by inputs from multiple point sources, landscapes, and watersheds (Howell et al., 2012; Makarewicz et al., 2012b; Robertson and Saad, 2011; Yurista and Kelly, 2009) as well as the offshore lake. The nearshore is additionally subject to hydrodynamic processes resulting from tributary flow rates, internal currents in the lake, and mixing from stochastic weather events (Rao and Schwab, 2007; Robertson and Saad, 2011). Separations of nearshore from offshore have been based on such factors as water depth, bottom sediment characteristics shaped by different turbulent energies of their physical settings,

* Corresponding author. Tel.: +1 218 464 1521.
E-mail addresses: woollybugger@charter.net (P.M. Yurista), jackrussellkelly@gmail.com (J.R. Kelly), scharold.jill@epa.gov (J.V. Scharold).
[1] Tel.: +1 218 529 5183.

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strength of seasonal thermal stratification, the structure of longitudinal currents compared to cross shelf flows, or inshore/offshore distinctions in biological communities (e.g. Auer et al., 2013; Edsall and Charlton, 1997; Gorman et al., 2012; Mackey and Goforth, 2005; Rao and Schwab, 2007; Scharold et al., 2004; US EPA, 1992; Yule et al., 2008). Defining a nearshore resource area to be surveyed for an assessment is not simple or unambiguous. Despite the difficulty of identifying a distinct nearshore region, there has been increased awareness of altered nearshore conditions (GLWQA, 2012; Mackey and Goforth, 2005; Niemi et al., 2007).

The water quality of the nearshore and offshore are often considered different (e.g. Bartone and Schelske, 1982; Neilson and Stevens, 1987). Offshore regions in the Great Lakes traditionally have been more thoroughly studied (Barbiero et al., 2002, 2012; Chapra et al., 2009, 2012; Holeck et al., 2008; Stevens and Neilson, 1987) and are considered to be spatially more uniform in character than the nearshore. Change in offshore water quality parameters occurs slowly over time (i.e. decades) due to the relatively slow turn-over times in the Great Lakes (Chapra et al., 2012). Monitoring of offshore waters has been used to track trends in Great Lakes nutrients and is effective because of low variability in the data (e.g. Stevens and Neilson, 1987). In contrast there is little comprehensive lake-wide nearshore data or a conceptual consensus within the Great Lakes research community of: 1) the defining characteristics of a nearshore zone, 2) spatial variability and trends within the nearshore, and 3) how the nearshore functions as an interface between the landscape and open lake. However, recent efforts are reducing the scarcity of comprehensive lake-wide information (e.g. Danz et al., 2007, Wang et al. 2015). Monitoring and assessing the nearshore in a thorough and representative fashion first requires definable attributes of the resource. Better understanding of spatial bounds, physical processes, and statistical characteristics of a nearshore resource will provide guidance in developing a sample-frame or target population representative of the resource within which to distribute sample sites to make efficient assessments.

Lake-wide surveys in the Great Lakes necessitate extensive spatial scope and sample numbers to allow identification of various defining features that could clearly describe spatial structuring of nearshore and offshore regions. There has been no regular lake-wide monitoring of the nearshore region of any Great Lake to provide a basic characterization of a nearshore region across the Great Lakes. However, the US EPA Office of Water provided a first spatially comprehensive bench mark survey for US Great Lakes coastal waters through a recent addition of the Great Lakes to the National Coastal Condition Assessment (NCCA) under the National Aquatic Resource Survey program (NARS). The NARS resource categories (lakes, rivers and wadeable streams, wetlands, coastal regions) are sampled on a rotating 5 year cycle. The Great Lakes were formally sampled in the coastal survey for the first time in 2010 and will continue to be sampled on a 5 year cycle.

The NCCA survey presented the opportunity to address research questions in addition to a routine assessment of condition. The NCCA survey was spatially comprehensive and targeted the understudied and less understood nearshore region across all of the Great Lakes. We have presented observations for lake-wide attributes of the nearshore in Lake Michigan with the 2010 NCCA in conjunction with a Coordinated Science and Monitoring Initiative (CSMI) effort for Lake Michigan also in 2010 (Richardson et al., 2012; Yurista et al., 2015). We are now expanding the analysis to the other four Great Lakes. We used the NCCA survey to examine characteristics of the nearshore region (<30-m for water quality) as compared to offshore conditions that are monitored annually by the US EPA Great Lakes National Program Office (GLNPO). Our two goals were to evaluate whether a reasonable and consistent description of general attributes for a nearshore region or zone-of-impact can be determined for water quality parameters across the Great Lakes and whether these attributes lead to a better concept of the nearshore region and its functional relationship to offshore regions across all the Great Lakes.

Methods

The frame boundaries for the nearshore were delineated from existing standard GIS coverage of the Great Lakes (Kelly et al., 2015). Summarized features and brief notes are described here. The shoreline was readily identified as the inner boundary. The outer boundary between the nearshore to the offshore for water quality parameters is more difficult to establish (e.g. Kelly et al., 2015; SOLEC, 2009; US EPA, 1992; Yurista et al., 2015) but was designed to include the shallow, warm and well-mixed waters that are fully open to landscape drainage and coastal current flows. Empirical data from research has suggested this outer limit for a zone-of-impact can be approximated by a 25–30 m water depth contour, within which the influence of tributary loadings can be detected (Yurista et al. 2009, Makarewicz et al., 2012a,b; Howell et al., 2012). As another factor, the summer hypolimnion generally encroaches along the bottom near a 30-m depth contour (e.g. Edsall and Charlton, 1997). Nearshore bathymetry varies greatly across the five lakes; 30-m can be very close to the shoreline in Lake Superior, but only a small highly distant portion of Lake Erie exceeds 30-m depth. We defined a shoreline-related region using criteria that the outer limit was determined either by reaching a 30-m depth contour or a distance of 5-km from shore, whichever occurred first, to constrain the sample-frame to the expected region of direct land-based influence. The 30-m 5-km criteria were also influenced by studies of physical processes (Csanady, 1970; Murthy and Dunbar, 1981; Rao and Schwab, 2007). These analyses of hydrodynamics and alongshore currents in coastal waters suggest a physical mechanism for separating the offshore from the nearshore region, which receives direct watershed input. Alongshore currents create a coastal-boundary region within the 3–5 km range from shore, but may extend out to 10-km and retard mixing from watershed input to the offshore waters. We developed a GIS procedure to exclude isolated areas of shoals and islands within 5-km that were separated by deep water from the main shoreline and its watershed influences.

Water quality samples for this study were collected under two separate monitoring programs during the summer of 2010. One monitoring program was the annual GLNPO Open Lake Water Quality summer survey of the Great Lakes. A total of 77 sample sites across the Great Lakes were visited in 2010 and 65 are used here (Erie, Huron, Ontario, and Superior) with Lake Michigan sites reported previously (Yurista et al., 2015). The routine GLNPO offshore monitoring (Aug 1–25, 2010) and sample analyses followed standardized procedures (GLNPO, 2010). Minimum detection for water quality parameters was NCCA: 0.001 mg P/L, 0.002 mg N/L, −GLNPO: 1 μg P/L, 0.03 mg N/L, 0.03 mgCl/L. We restricted water quality parameters to averages of routine samples by site from the approximate epilimnetic volume of the water column (<20-m) to contrast with comparable and generally unstratified surface waters of nearshore regions.

The other survey was the NCCA conducted by the EPA Office of Water in US waters of the Great Lakes. The sample design for the NCCA coastal region of the Great Lakes is described fully elsewhere (USEPA, 2009a, Kelly et al., 2015). Samples for the 2010 NCCA were collected in the Great Lakes through an EPA–State partnership using methods (USEPA, 2009a, b) consistent with those used by GLNPO. The sample site selection for the 2010 Great Lakes NCCA was probability based (Stevens and Olsen, 2004) to provide 45 target coastal sites with 5 revisits per lake (0–30 m, and less than 5-km from shore). An additional 151 sites in smaller bays were targeted with an embayment enhancement survey that extended across the Great Lakes. The embayment enhancement focused exclusively on selecting sites in smaller bays (>1 and <100 km^2) that were within the NCCA nearshore sample frame, to aid in understanding the relationship of embayments to the broader more open nearshore coastal areas. The total number of sites actually sampled was 405. We restricted data to a summer peak season where biological systems are well developed, strong thermal stratification is prevalent, and nutrients levels stable in comparison to the