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Review

The re-eutrophication of Lake Erie: Harmful algal blooms and hypoxia

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ABSTRACT

Lake Erie supplies drinking water to more than 11 million consumers, processes millions of gallons of wastewater, provides important species habitat and supports a substantial industrial sector, with >$50 billion annual income to tourism, recreational boating, shipping, fisheries, and other industries. These and other key ecosystem services are currently threatened by an excess supply of nutrients, manifested in particular by increases in the magnitude and extent of harmful planktonic and benthic algal blooms (HABs) and hypoxia. Widespread concern for this important international waterbody has been manifested in a strong focus of scientific and public material on the subject, and commitments for Canada-US remedial actions in recent agreements among Federal, Provincial and State agencies. This review provides a retrospective synthesis of past and current nutrient inputs, impairments by planktonic and benthic HABs and hypoxia, modelling and Best Management Practices in the Lake Erie basin. The results demonstrate that phosphorus reduction is of primary importance, but the effects of climate, nitrogen and other factors should also be considered in the context of adaptive management. Actions to reduce nutrient levels by targeted Best Management Practices will likely need to be tailored for soil types, topography, and farming practices.

Contents

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1. Introduction

Lake Erie, the southernmost, warmest, shallowest, and most biologically productive of the Great Lakes, supplies drinking water to more than 11 million consumers, processes millions of gallons of wastewater, provides habitat for economically, ecologically, and culturally important biota, and supports a substantial industrial sector, with annual income to tourism, recreational boating, shipping, fisheries, and other industries of over $50 billion (LEIA, 2012). These and other key ecosystem services are now increasingly threatened by eutrophication, manifested by increases in the magnitude, duration, and extent of harmful algal blooms (HABs; Higgins et al., 2008; Michalak et al., 2013; Steffen et al., 2014) and hypoxia (Zhou et al., 2013, 2015; Scavia et al., 2014). In recognition of these ecosystem impacts and the need to develop a sustained restoration and management programme, the International Joint Commission (IJC) commissioned the Lake Erie Ecosystem Priority (LEEP) taskforce in 2012 to evaluate current conditions, identify knowledge and monitoring gaps, provide guidance for management targets, and engage public interest and support (International Joint Commission (IJC), 2014; Watson et al., 2013). This initial IJC review, and subsequent work by binational taskforces, led to commitments for remedial action in the recently renewed Canada-USA Great Lakes Water Quality Agreement (GLWQA). Nutrients, hypoxia and algal biomass are addressed under Annex 4 of this Agreement, with specific references to setting interim total phosphorus (TP) load and basin-specific concentration targets for Lake Erie. Similarly, the 2014 renewed Canada-Ontario Agreement (COA) specifically highlights Lake Erie in the objectives to set loading and concentration targets.

Scavia et al. (2014) reviewed and evaluated recent eutrophication-related trends in Lake Erie, and developed response curves to guide hypoxia-based loading targets. Following a binational remedial effort, central basin hypoxia and west-central phytoplankton biomass showed strong declines in the late 1970s and early 1980s, followed by a general increase in these parameters since the mid-1990s which the authors attributed to increased agricultural loading of soluble reactive phosphorus (SRP). The authors also concluded that reducing central basin hypoxic area to levels observed in the early 1990s (ca. 2000 km^2) requires the reduction of TP loads by 46% from the 2003 to 2011 average or SRP loads by 78% from the 2005 to 2011 average, and that those reductions would protect fish habitat. Based on an analysis of long-term records of climate and nutrient data, however, Zhou et al. (2015) reported that a record-breaking hypoxic event in 2012 followed a period of drought and low tributary flow, while in 2011, the largest cyanobacterial bloom of the decade (as measured by remote sensing; e.g., Michalak et al., 2013) was accompanied by mild hypoxia. These and other authors have concluded that both the extent and severity of central basin hypoxia and west basin planktonic algal blooms show strong, but fundamentally different relationships with the timing and volume of spring-summer river discharge and associated nutrient inputs (Rucinski et al., 2014; Stow et al., 2015). Furthermore there is evidence that together with P, nitrogen plays an important role in planktonic bloom composition and toxicity, while light and temperature have a major effect on benthic bloom development (Auer et al., 2010; Steffen et al., 2014; Davis et al., 2015). These and other studies demonstrate that P reduction is of primary importance, but the effects of climate, nitrogen and other factors may need to be considered when developing an adaptable response which may require a tailored approach, such as the application of targeted Best Management Practices (BMPs) that account for soil types, topography, and farming practices (McElmurry et al., 2013). A proliferation of scientific and other published material has led a to global awareness of the issues challenging this lake (e.g., a Scopus database search yields >300 documents for the terms 'blooms', 'nutrients' and 'hypoxia' in Lake Erie over the past 5 years) and widespread media and website coverage (e.g., http://www.glerl.noaa.gov/res/HABs_and_Hypoxia/; http://www.cbc.ca/news/trending/algae-blooms-lake-erie-lake-st-clair-nasa-photos-show-1.3179298). This review presents a synopsis of past, present and future nutrient loading, HABs and other impairments in this lake and options for mitigation.

2. Signs of impairment: harmful blooms and hypoxia

2.1. Harmful algal blooms (HABs)

2.1.1. Planktonic HABs

In most regions of North America the majority of planktonic HABs are caused by cyanobacteria (cHABs), most often where surface waters receive high inputs of growth-limiting nutrients (phosphorus, P and nitrogen, N). Global climate and regional