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Ten+ years gone: Continued degradation of offshore planktonic communities in U.S. waters of Lake Erie's western and central basins (2003–2013)

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ABSTRACT

Mounting evidence exists to indicate that Lake Erie is once again experiencing eutrophication. Such signs include increases in both the incidence of harmful algal blooms in the western basin and the re-emergence of large hypoxic areas in bottom waters of the central basin. Towards further assessing Lake Erie's health and the degree to which this ecosystem has become more eutrophic, we calculated a Planktonic Index of Biotic Integrity (P-IBI) for the western and central basins of Lake Erie during 2003–2013 and compared values to P-IBI values from previous periods of heightened eutrophy (1970) and the recovery from eutrophy (1995–2002). As expected, P-IBI scores in the eutrophic/hypereutrophic range (<3) have predominated in both the western and central basins during 2003–2013. This decline in P-IBI scores (and hence, ecosystem health), however, has been more evident in the western basin than in the central basin.

Introduction

Lake Erie has been becoming more eutrophic for at least a decade, as indicated by increases in both the formation of harmful algal blooms (HABs) (Michalak et al., 2013; Obenour et al., 2014; Steffen et al., 2014; Stumpf et al., 2012) and the intensity and extent of hypoxia (Scavia et al., 2014). As many of the causes and consequences of cultural eutrophication are tied to the plankton community, components of it have been used as indicators of lake ecosystem health (Conroy et al., 2008; Kane et al., 2009). With the goal of tracking changes in the Lake Erie plankton community and simultaneously assessing ecosystem health, Kane et al. (2009) developed a Planktonic Index of Biotic Integrity (P-IBI). This index was originally calculated for each of Lake Erie's basin during 1995–2002 (Kane et al., 2009), with updates for the western basin occurring for 2003 and 2004 (Kane and Culver, 2007). The P-IBI also has been successfully used as an ecosystem assessment tool in the Bay of Quinte, Lake Ontario (Munawar et al., 2012). Herein, we provide updated western basin and central basin P-IBI scores for the years 2003–2013 and compare our results to previous time periods of eutrophy (1970) and recovery from eutrophy (1995–2002).

Methods

Field and laboratory procedures and analyses followed LEPAS (Lake Erie Plankton Abundance Study) (see Kane et al., 2009 for detailed methodologies and sites), with the exception that the sites for these analyses were only from U.S. offshore waters of Lake Erie. Phytoplankton and zooplankton data were obtained from the Ohio Department of Natural Resources-Division of Wildlife's LEPAS database. Annual P-IBI scores were calculated for both the western basin and central basin of Lake Erie using Eq. (1) (Kane et al., 2009):

$$\mathbf{P-IBI} = \frac{1}{B}\sum_{k=1}^{B}\frac{1}{S}\sum_{j=1}^{S}\frac{1}{M}\left(EA_{jk} + CB_{jk} + RJ_{jk} + LM_{jk} + RA_{jk} + ZB_{jk}\right) \quad (1)$$

where

EA_{jk}	June biomass of edible algae taxa metric score;
CB_{jk}	June *Microcystis*, *Anabaena*, and *Aphanizomenon* as a percentage of total phytoplankton biomass metric score;
RJ_{jk}	June zooplankton ratio (Calanoida/(Cladocera + Cyclopoida) metric score;
LM_{jk}	July *Limnocalanus macrurus* density metric score;
RA_{jk}	August zooplankton ratio (Calanoida/(Cladocera + Cyclopoida) metric score;
ZB_{jk}	August crustacean zooplankton biomass metric score;

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Table 1
Planktonic Index of Biotic Integrity (P-IBI) values for the western basin of Lake Erie (1970, 1995–2013). Bold values indicate newly calculated P-IBI values completed for this study.

Year	Mean	Standard error	Number of sites
1970	2.76	0.13	3
1995	3.67	0.09	38
1996	2.89	0.10	51
1997	3.69	0.21	15
1998	3.00	0.21	24
1999	3.01	0.19	13
2000	2.54	0.16	7
2001	2.61	0.25	8
2002	2.51	0.25	14
2003	**2.51**	**0.20**	**8**
2004	**2.83**	**0.39**	**4**
2005	**2.36**	**0.15**	**8**
2006	**2.47**	**0.19**	**8**
2007	**2.83**	**0.06**	**8**
2008	**2.74**	**0.13**	**8**
2009	**3.09**	**0.15**	**8**
2010	**2.52**	**0.11**	**8**
2011	**2.87**	**0.14**	**8**
2012	**2.20**	**0.10**	**8**
2013	**2.30**	**0.13**	**8**

Table 2
Planktonic Index of Biotic Integrity (P-IBI) values for the central basin of Lake Erie (1970, 1996–2013). Bold values indicate newly calculated P-IBI values completed for this study.

Year	Mean	Standard error	Number of sites
1970	3.07	0.10	19
1996	3.35	0.26	7
1997	3.69	0.28	15
1998	3.22	0.34	15
1999	2.78	0.64	6
2000	2.95	0.36	6
2001	3.89	0.59	3
2002	2.64	0.25	27
2003	**3.00**	**0.22**	**2**
2004	**2.17**	**0.18**	**4**
2005	**3.25**	**0.12**	**8**
2006	**3.38**	**0.17**	**8**
2007	**3.66**	**0.08**	**8**
2008	**2.70**	**0.17**	**8**
2009	**2.46**	**0.17**	**8**
2010	**2.12**	**0.25**	**4**
2011	**3.37**	**0.12**	**8**
2012	**2.71**	**0.15**	**8**
2013	**2.80**	**NA**	**1**

M number of metrics;
S number of sites (within a basin); and
B number of basins.

Unfortunately, not enough usable data were available to calculate a P-IBI score for the eastern basin of Lake Erie, which also precluded us from calculating a lake-wide P-IBI score.

Least-squares linear regressions (Minitab 7) were used to identify any trends in the data.

Results and discussion

P-IBI scores were successfully calculated for the western basin (Table 1, Fig. 1) and central basin (Table 2, Fig. 2) of Lake Erie. Recent (post-2002) mean P-IBI scores from the western basin indicate that the Lake Erie ecosystem has become more degraded; 10 of 11 years had a value less than 3, which is indicative of "fair" (Ohio Lake Erie Commission, 2004) or eutrophic (Kane et al., 2009) conditions. Further, 3 years (including the last 2 years of the dataset, 2012 and 2013) had a value less than 2.5, which is verging on "poor" (Ohio Lake Erie Commission, 2004) or hypereutrophic (Munawar et al., 2012) conditions. For the central basin, 6 of 11 values were less than 3, again indicative of "fair" (Ohio Lake Erie Commission, 2004) or eutrophic (Kane et al., 2009) conditions, with three of the years having a value less than 2.5 (i.e., verging on "poor" or hypereutrophic conditions). Finally, during the period of 1995–2013, a significant ($p = 0.006$, $R^2 = 0.36$) negative trend in mean P-IBI values was found in the western basin (Fig. 3a), with no trend ($p = 0.124$) being found in the central basin during 1996–2013 (Fig. 3b).

Since the mid-90s, there is growing evidence for the re-eutrophication of Lake Erie. Several changes within the ecosystem including increasing phytoplankton biomass (especially cyanobacteria) in both the western and central basins (Conroy et al., 2014; Kane et al., 2014), an increased extent and duration of hypoxia in the central basin (Scavia et al., 2014), and record-breaking HAB events (Michalak et al., 2013) are evident. While the causal mechanisms of these changes have not been fully resolved, they are consistent with meteorological (i.e., increasing precipitation) and agricultural (i.e., increasing loading

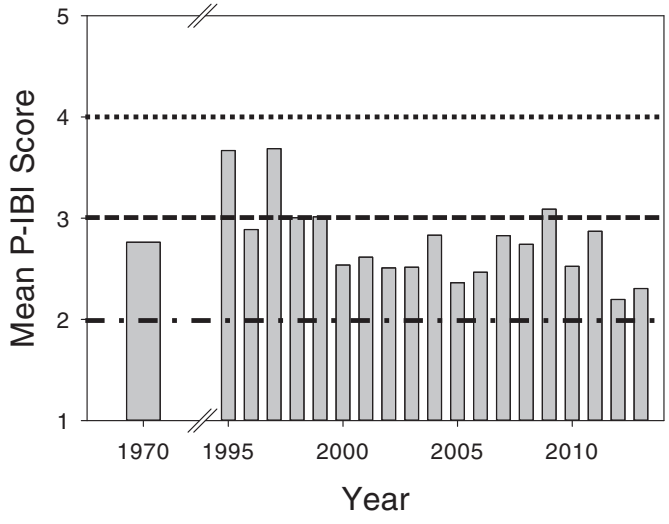

Fig. 1. Mean Planktonic Index of Biotic Integrity (P-IBI) values for the western basin of Lake Erie (1970, 1995–2013). Values >4 are considered "oligotrophic," values between 3 and 4 are considered "mesotrophic," values between 2 and 3 are considered "eutrophic," and values <2 are considered "hypereutrophic" (Kane et al., 2009; Munawar et al., 2012).

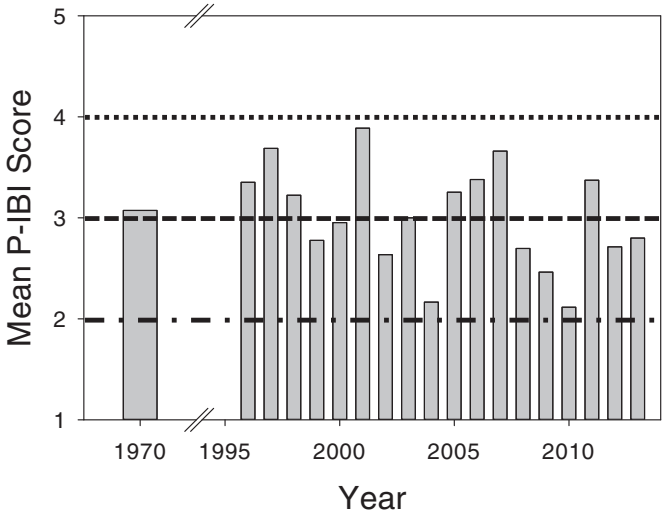

Fig. 2. Mean Planktonic Index of Biotic Integrity (P-IBI) values for the central basin of Lake Erie (1970, 1996–2013). Values >4 are considered "oligotrophic," values between 3 and 4 are considered "mesotrophic," values between 2 and 3 are considered "eutrophic," and values <2 are considered "hypereutrophic" (Kane et al., 2009; Munawar et al., 2012).