Updating the Planktonic Index of Biotic Integrity (P-IBI) for Lake Erie

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Douglas D. Kane

Natural Science, Applied Science, and Mathematics Division
Defiance College
701 N. Clinton St.
Defiance, OH 43512

Stuart A. Ludsin, Ruth D. Briland, and David A. Culver

Department of Evolution, Ecology, and Organismal Biology
The Ohio State University
Columbus, OH 43212

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 previous P-IBI values from previous periods of heightened eutrophy (1970) and the recovery from eutrophy (1995-2002). As expected, P-IBI scores in the range of “Fair” have predominated in both the western and central basins during 2003-2013, suggesting that the lake has indeed become more eutrophic. This decline in P-IBI scores (and hence, ecosystem health), however, has been more evident in the western basin relative to 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) and the intensity and extent of hypoxia (Michalak et al. 2013, Kane et el. 2014, 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) and other ecosystems (Science Citation Index- 29 citations since 2009, assessed on 9 October 2014). 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 post-eutrophy (1995-2002).

Methods

Phytoplankton and zooplankton data were obtained from the Ohio Department of Natural Resources-Division of Wildlife's Lake Erie Plankton Abundance Study (LEPAS) database. Annual P-IBI scores were calculated for both the western basin and central basin of Lake Erie using (Equation 1; Kane et al. 2009):

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

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;

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 lakewide P-IBI score.
Least-squares linear regressions (conducted in Minitab 7) was used to identify any trends in the data.

Results

P-IBI scores were successfully calculated for the western basin (Table 1, Figure 1) and central basin (Table 2, Figure 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” (Lake Erie Quality Index 2004) or eutrophic (Kane et al. 2008) conditions. Further, 3 years (including the last two years of the dataset, 2012 and 2013) had a value less than 2.5, which is verging on “Poor” (Lake Erie Quality Index 2004) or hypereutrophic (Munawar et al. 2012) conditions. For the central basin, 6 of 11 values were less than 3, again indicative of “Fair” (Lake Erie Quality Index 2004) or eutrophic (Kane et al. 2008) conditions, with three of the years having a value less than 2.5 (i.e., “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 (Figure 3a), with no trend ($p = 0.124$) being found in the central basin during 1996-2013 (Figure 3b).

Discussion

The re-eutrophication of Lake Erie, which began during the mid-1990s and has continued to the present, has been evidenced by several changes within the ecosystem. Such changes include increasing phytoplankton (especially cyanobacteria) biomass 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). 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 of soluble reactive phosphorus) trends in the lake basin (Michalak et al. 2013).

Recent P-IBI values from both western and central Lake Erie lend further support to the notion that the lake has become more eutrophic and that the health of this ecosystem (particularly its phytoplankton and zooplankton communities) has declined during the past decade. In fact, during 2003-2013, both the western (Figure 3a) and central (Figure 3b) basins had lower mean P-IBI values than during 1970, when Lake Erie was highly eutrophic and considered dead (Ludsin et al. 2001). Further, although the number of sites sampled has declined in the last decade, due to a variety of factors (i.e. changing projects, logistical and budgetary constraints etc.), Kane (2004) found that 5 sites could reasonably serve as a surrogate for a much larger (50+) suite of sites with respect to biomass of taxonomic groupings of phytoplankton and zooplankton. For the recent calculations, most years in both basins have 8 sites sampled (17 of 22), with very few having less than 4 sites sampled (5 of 22).

While both western and central Lake Erie had P-IBI scores that were in the range of "Fair" to "Poor", the western basin appears to be more degraded than the central basin. This notion is supported by two lines of evidence. First, a significant, negative trend in P-IBI scores was found in the western basin, but not the central basin (no trend was documented). And second, almost half of the central basin P-IBI scores were considered "Good", even verging on "Excellent" (Lake Erie Quality Index 2004). These findings were somewhat expected, as the central basin has traditionally been more oligotrophic than the western basin (Ludsin et al. 2001, Kane et al. 2009), likely owing to its greater distance from the highly agricultural Maumee River watershed, which is a known source of phosphorus that can stimulate phytoplankton (and especially cyanobacteria) growth (Baker et al. 2014, Conroy et al. 2014). However, the non-trend in central basin P-IBI scores also may reflect a lagged response, owing to its larger size than the western basin.

Interestingly, a possible legacy of the record-setting cyanobacteria bloom of 2011 (Michalak et al. 2013) exists in both the 2012 and 2013 P-IBI scores. Large declines in mean P-IBI scores occurred in both western and central Lake Erie after the relatively higher scores of 2011. Because Kane et al.'s (2009) P-IBI index is based on data from June through August and the 2011 cyanobacteria bloom event developed after this time (during September in the western basin and during October in the central basin), our 2011 P-IBI score did not capture this event.

Because of recent large *Microcystis* blooms have become more common in both western and central Lake Erie (Bridgeman et al. 2013, Michalak et al. 2013), and climate change is expected to exacerbate HABs through increased precipitation and warming temperatures, we would not be surprised to see a continued declining trends in P-IBI scores during the 21^{st} century. For this reason, we encourage continued monitoring and analysis of Lake Erie's plankton communities.

Acknowledgements

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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.

Basin	Year	Mean	Standard Error	Number of Sites
WB	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 western basin of Lake Erie (1970, 1996-2013). Bold values indicate newly calculated P-IBI values completed for this study.

Basin	Year	Mean	Standard Error	Number of Sites
CB	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**

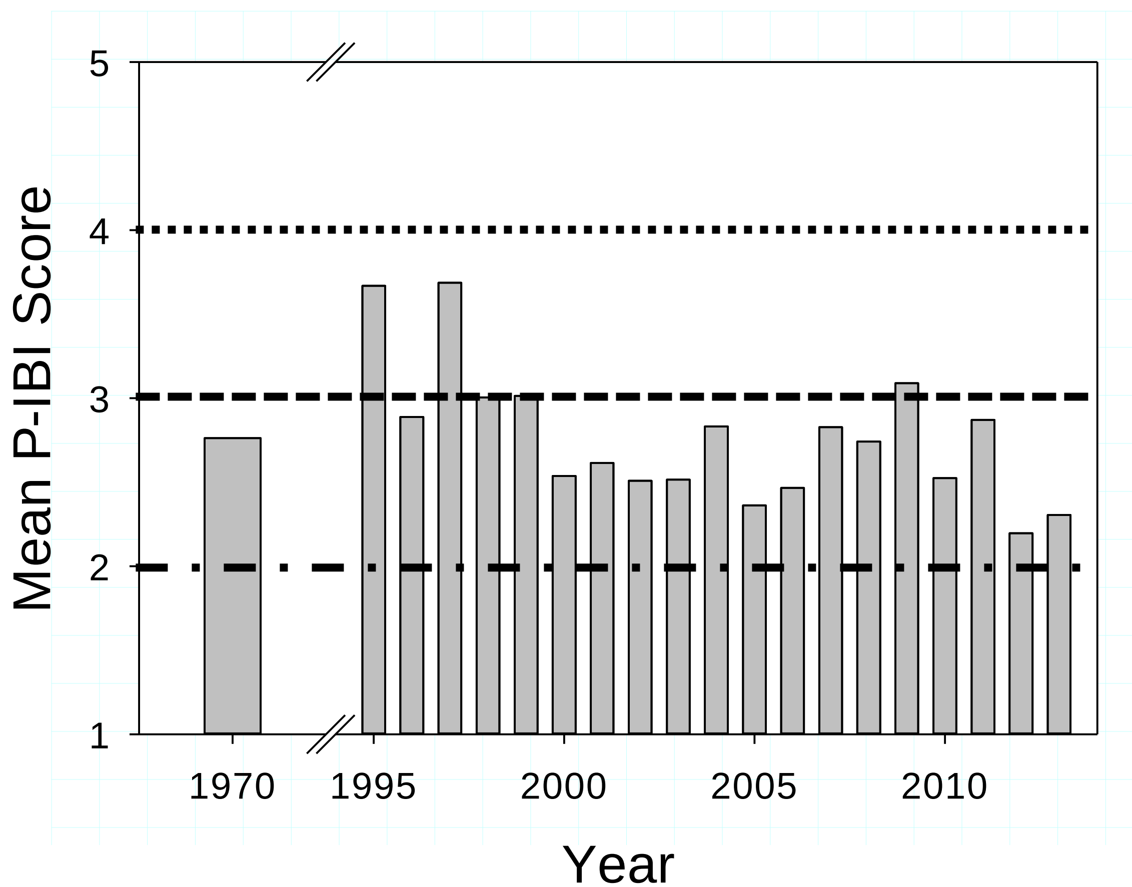

Figure 1. Mean Planktonic Index of Biotic Integrity (P-IBI) values for the western basin of Lake Erie (1970, 1995-2013). Values >4 are considered "Excellent," values between 3 and 4 are considered "Good," values between 2 and 3 are considered "Fair", and values <2 are considered "Poor" (Ohio Lake Erie Commission 2004).

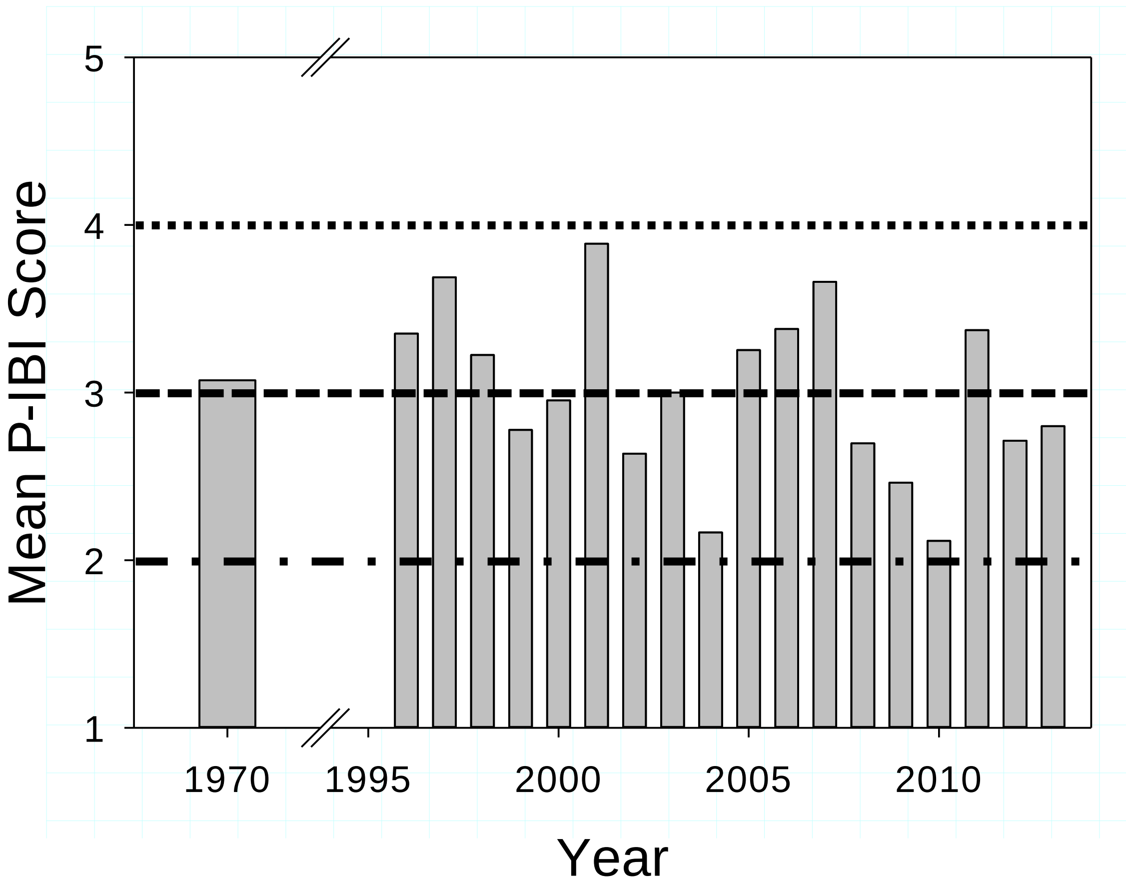

Figure 2- Mean Planktonic Index of Biotic Integrity (P-IBI) values for the central basin of Lake Erie (1970, 1996-2013). Values >4 are considered “Excellent,” values between 3 and 4 are considered “Good,” values between 2 and 3 are considered “Fair”, and values <2 are considered “Poor” (Ohio Lake Erie Commission 2004).

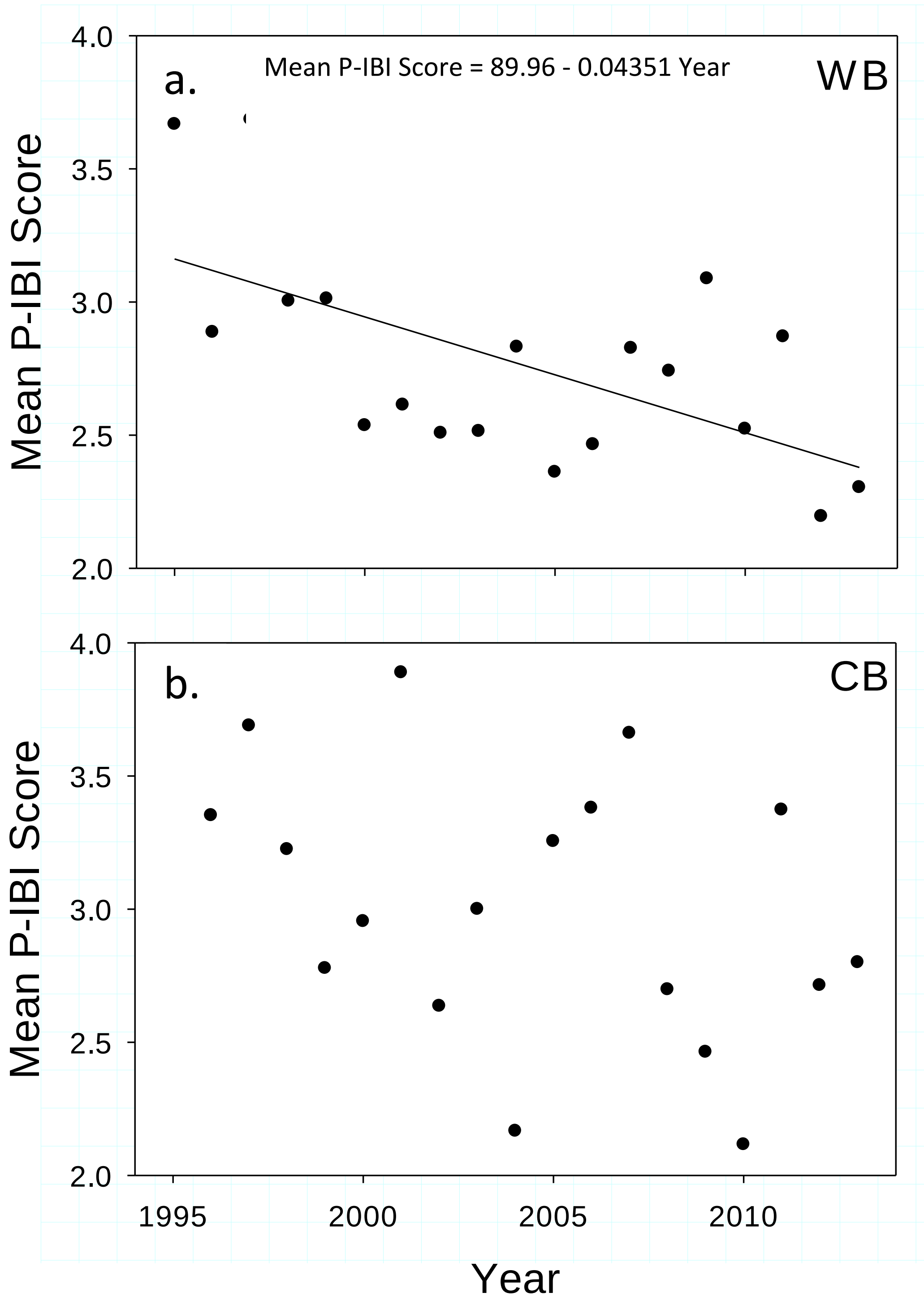

Figure 3. Mean P-IBI Score versus year for the a) western basin and b) central basin. A significant, negative linear relationship exists for the western basin (p=0.006) but not the central basin (p=0.124).