Journal of Great Lakes Research xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/jglr

Changes in Lake Erie benthos over the last 50 years: Historical perspectives, current status, and main drivers

Lyubov E. Burlakova [a,b,*], Alexander Y. Karatayev [a,1], Christopher Pennuto [a,c,2], Christine Mayer [d,3]

[a] Great Lakes Center, SUNY Buffalo State, Buffalo, NY, USA

[b] The Research Foundation of The State University of New York, SUNY Buffalo State, Office of Sponsored Programs, Buffalo, NY, USA

[c] Biology Department, SUNY Buffalo State, Buffalo, NY, USA

[d] Department of Environmental Sciences and Lake Erie Center, University of Toledo, Toledo, OH, USA

ARTICLE INFO

Article history:
Received 6 May 2013
Accepted 20 December 2013
Available online xxxx

Communicated by Douglas Kane

Keywords:
Benthic community
Dreissena
Density
Biomass
Invasive species
Structural changes

ABSTRACT

During the last 50 years the ecosystem of Lake Erie has experienced major environmental changes, from anthropogenic eutrophication in 1930–1960s, to nutrient and pollution abatement in the 1970s, and then the introduction of exotic dreissenids in the 1980s. We used multivariate statistical techniques to examine long-term changes in the zoobenthic community, comparing contemporary collections (2009, 2011–2012) and historical data (1963–1965, 1978–1979, 1993, and 1998). The Lake Erie benthic community underwent significant changes during each decade examined, showing signs of recovery following ecosystem restoration in the 1970s, but then experiencing major structural and functional changes after dreissenid (*Dreissena polymorpha* and *D. r. bugensis*) introductions. There was a significant temporal trend in community composition changes from 1963 to 2012, and the largest difference was found between pre- and post-dreissenid invasion communities. Currently the lake-wide benthic community is dominated by dreissenids both in density (41%) and total wet biomass (97%), followed by oligochaetes and chironomids. The largest benthic density was found in the central basin, and the greatest biomass in the eastern basin. The number of exotic species found in benthic surveys increased every decade, from 1 in 1963 to 10 in 2009–2012, and the majority of the invaders were molluscs. Whereas the role of benthic invaders in community diversity is still low, their impact has had enormous consequences for the whole ecosystem.

Introduction

The story of Lake Erie is a classic example of how profoundly human activity can affect the structure and function of an ecosystem. Further, this case study illustrates the difficulty in predicting the intentional and unintentional consequences of human actions. Lake Erie experienced anthropogenic eutrophication in 1930–1960s, followed by a successful bi-national effort in nutrient and pollution abatement in the 1970s (Sweeney, 1995). The ecosystem recovery initiated by planned abatement programs was then followed by major ecosystem changes after the accidental introduction of natural "ecosystem engineers"—exotic dreissenids (Conroy and Culver, 2005; Conroy et al., 2005b; Hecky et al., 2004; Mills et al., 1993, 1998). The recovery of the benthic invertebrate community of Lake Erie has not been complete; the history of this community demonstrates how planned actions such as abatement may aide recovery, but unplanned actions such as species invasions will continue to make the trajectory of recovering systems unpredictable.

The degradation of Lake Erie started perhaps in the early 1800s with massive forest cutting, construction of sawmills and dams and the draining of wetlands (Sweeney, 1995). The first report on deterioration of water quality was issued in 1918 by the International Joint Commission on the Pollution of Boundary Waters Reference stating that the "… situation along the frontier is generally chaotic, everywhere perilous and in some cases, disgraceful" (International Joint Commission, 1918). The most dramatic growth in watershed population and economy occurred from early 1900 to 1950s; by 1930, the Great Lakes basin population increased one third in 20 years and became close to 23 million. In 1940s high demands for chemicals, rubber, steel, etc. for the Second World War Allied effort led to a major industrial expansion in the Great Lakes basin, resulting in large-scale chemical and heavy metal discharges to the lakes. The heaviest pollution appears to have occurred in the 1960s and 1970s when Lake Erie was called "America's Dead Sea" (Beeton, 1965; Sweeney, 1995).

* Corresponding author at: Great Lakes Center, SUNY Buffalo State, 1300 Elmwood Ave., Buffalo, NY 14222, USA. Tel.: +1 716 878 4504.
E-mail addresses: burlakle@buffalostate.edu (L.E. Burlakova), karataay@buffalostate.edu (A.Y. Karatayev), pennutcm@buffalostate.edu (C. Pennuto), christine.mayer@utoledo.edu (C. Mayer).
[1] Tel.: +1 716 878 5423.
[2] Tel.: +1 716 878 4105.
[3] Tel.: +1 419 530 8377.

http://dx.doi.org/10.1016/j.jglr.2014.02.008
0380-1330/

The best indicators of the deteriorating conditions, the "canaries in the coal mine", were the mayflies *Hexagenia* in western Lake Erie (Britt, 1955a, 1955b). Prior to human-driven eutrophication, mayflies where abundant: for example in the 1920s in Cleveland "the horse-drawn dump wagons [were not] adequate for the loads of Mayflies which piled up overnight under the lamp posts during a warm summer evening" (Dambach, 1969). In the 1930s, the benthic community of the western basin was dominated by *Hexagenia* and trichoptera *Oecetis* with average mayfly densities of 300–500 m^{-2}, and a maximum average to up to 1000 m^{-2} (Britt, 1955a, 1955b; Shelford and Boesel, 1942). These extensive *Hexagenia* populations were devastated in September 1953 as a result of the first recorded significant large-scale depletion of dissolved oxygen in the western basin. Densities of mayflies somewhat recovered in 1954 (Britt, 1955a, 1955b), but then were reduced again almost to extirpation in 1960s (Beeton, 1961; Carr and Hiltunen, 1965). Due to the shallow depth of the western basin (average depth 7.4 m), the discharge of the major tributaries (the Detroit and Maumee rivers that account for > 90% of the organic loading and 84% of the water volume entering the lake), and its proximity to large urban centers such as Detroit and Toledo, this basin is highly vulnerable to changes caused by human activities and was the first to suffer from anthropogenic eutrophication (Hartman, 1972; Makarewicz and Bertram, 1991). Extensive changes have occurred in other groups of benthos, including a sharp decline in the density of *Oecetis*, and a large increase in the taxa tolerant to organic enrichment (e.g., tubificids and midges) (Carr and Hiltunen, 1965). Historically, the dramatic degradation of the benthic community in the western basin has provided the strongest evidence of the magnitude of change in the Great Lakes (Brinkhurst, 1969).

Under the Great Lakes Water Quality Agreement of 1972 signed by Canada and the U.S., an extensive binational effort was undertaken to reduce and eliminate sources of pollution to Lake Erie, including bans on the sale of phosphate detergents, improvements in organic waste collection and treatment systems, and reductions in industry discharges (Sweeney, 1995). The results were dramatic and in some cases occurred more rapidly than expected (Sweeney, 1995). Water quality in the lake responded to those measures; open-lake concentrations of total phosphorus, chlorophyll *a*, phytoplankton abundance and biomass were reduced by the mid-1980s, and the pelagic ecosystem became less eutrophic (Makarewicz and Bertram, 1991). The abundance and dominance of oligochaetes in the western basin in the 1970s decreased compared to the 1960s (Dermott, 1994). Reduction in the number of oligochaetes in nearshore zones and at the mouths of the large tributaries in late 1970s–early 1980s was consistent with the reduced eutrophication (Dermott, 1994; Schloesser et al., 1995).

Recently Lake Erie has become a "hot spot" for the introduction of exotic species. Both of the most well-known aquatic invaders in North America were first detected in Lake Erie: *Dreissena polymorpha*, the zebra mussel, in 1986 (Carlton, 2008), and *Dreissena rostriformis bugensis*, the quagga mussel, in 1989 (Mills et al., 1993). Both *Dreissena* species are ecosystem engineers (Karatayev et al., 1997, 2002, 2007b) that fundamentally change the flow of energy and nutrients through lake ecosystem and affect both the benthic and pelagic communities in ways that are not entirely predictable (Arnott and Vanni, 1996; Bunt et al., 1993; Conroy and Culver, 2005; Conroy et al., 2005a, 2005b; Howell et al., 1996; MacIsaac et al., 1992; Makarewicz et al., 2000; Mellina et al., 1995; Nicholls and Hopkins, 1993). Benthic freshwater systems are often detritus dominated and have little influence on planktonic systems (Hutchinson, 1993). Dreissenids are able to control pelagic processes by removing particulate matter, increasing water transparency and hence the volume of the photic zone, impacting phytoplankton standing stock, and therefore, influencing planktonic trophic interactions (Higgins and Vander Zanden, 2010; Karatayev et al., 1997, 2002, 2007b; Mills et al., 1993, 1998). As a result, the role of the benthic community in lakes populated by dreissenids increases tremendously and the benthos become capable of controlling processes and dynamics in the planktonic system and affecting the whole ecosystem. Dreissenids also have strong local impacts by physically changing benthic substrates, and providing shelter and food for other benthic invertebrates (Burlakova et al., 2005, 2012; Higgins and Vander Zanden, 2010; Karatayev and Burlakova, 1992; Karatayev et al., 1997, 2002, 2007b; Mayer et al., 2002; Ward and Ricciardi, 2007). Dreissenids have strong interactions with many species and facilitate certain functional groups (Burlakova et al., 2012; DeVanna et al., 2011b); and thus some of their effects in particular systems have run contrary to original predictions, adding further uncertainty to understanding the trajectory of the benthic community in Lake Erie.

We used historical data on benthic community composition from Lake Erie covering the last 50 years, in combination with three years of contemporary sampling to examine the long-term changes in the zoobenthic community. We used multivariate community analysis to test the temporal changes in community composition, and to assess whether invasive species played a role in altering the benthos.

Materials and methods

To determine the species composition, abundance, distribution, and year-to-year variability of the Lake Erie zoobenthos community, a total of 500 benthic samples were collected in western, central, and eastern basins in 2009, 2011, and 2012. We used transects running perpendicular to the shore with fixed sample stations at 2, 5, 10, and 20 m (Pennuto et al., in this issue). In 2009, sampling was done along six transects located near the major lake tributaries (Sandusky and Grand Rivers in central basin, and Cattaraugus Creek in eastern basin) within the Nearshore and Offshore Lake Erie Nutrient Study (NOLENS) (Fig. 1). In 2011–2012 samples were collected from eight transects spaced approximately equidistant along the southern Lake Erie shoreline (two in eastern and western basins, and four in central basin, Fig. 1) within the Lake Erie Nearshore and Offshore Nutrient Study (LENONS). Two of these transects (Grand River east (GRE) and Cattaraugus Creek west (CCW)) also were sampled as part of the 2009 NOLENS project. Samples were collected twice a year—in June and in August or September, and the data were averaged for each station. For each transect in the central and eastern basins, samples were collected from the same depths as in 2009. In the western basin, the deepest site was at 15 m depth. As the majority of 2-m samples in the central and eastern basins in 2011 yielded no animals, we excluded them from the survey in 2012. Three or more replicate samples were taken at each depth and processed separately, and then the data were pooled during analysis. All samples were collected with a petite Ponar grab (area 0.0231 m^{-2}) or Ekman grab (area 0.0225 m^{-2}), with the exception of 9 samples in 2009, which were collected by SCUBA divers from 2 and 5 m (GRE transect) and 10 m (CCW) using a an air-lift sampler (area 0.0625 m^{-2}, Pennuto et al., 2012a). In addition, 55 samples were collected with a Ponar grab (area 0.0529 m^{-2}) in June 2009 aboard of EPA R/V *Lake Guardian* at 22 routine EPA stations in all 3 basins (ER 09, 10, 15 M, 30, 31, 32, 36, 37, 38, 42, 43, 58, 59, 60, 61, 63, 73, 78, 91 M, 92, 93B, 95B, the coordinates and depths info at http://www.epa.gov/glnpo/monitoring/sop/appendix_b.pdf, accessed February 12, 2014). Samples were washed through a 500-μm mesh net. All macroinvertebrates collected were fixed with 10% neutral buffered formalin, and identified to the lowest possible taxonomic level (usually species, genus or family), counted, blotted dry on absorbent paper and weighed to the nearest 0.0001 g (total wet mass). We did not attempt to count ostracods and nematodes. The oligochaete, *Branchiura sowerbyi*, was identified to species, but all others were categorized as oligochaetes.

Historical sampling

To examine the effect of the *Dreissena* spp. invasion on the benthic community we compared pre- (prior to 1986) and post-invasion historic information with the results of recent sampling. We used the Great