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Status and Trends of Benthic Populations in a Coastal Drowned River Mouth Lake of Lake Michigan

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ABSTRACT. *Muskegon Lake was designated an Area of Concern because of severe environmental impairments from direct discharge of industrial and municipal wastes. Since diversion of all municipal and industrial wastewater in 1973, few studies have assessed ecological changes associated with improved water quality. We examined distributions and long-term changes in the benthic macroinvertebrate community at 27 sites. Distributions were evaluated relative to distance from the river mouth, water depth, grain size, and known areas of sediment contamination. Temporal changes were assessed relative to wastewater diversion. Oligochaeta and Chironomidae dominated the community, and the oligochaete trophic condition index indicated that, in 1999, the lake was generally mesotrophic to eutrophic. Cluster analysis resulted in four distinct site groupings. A cluster of sites near the river mouth had the highest total density (9,375 m^{-2}) and lowest diversity (Shannon Weaver Index 1.05) suggesting an enriched habitat. A site cluster in the south central region had the lowest oligochaete density (2,782 m^{-2}), lowest oligochaete trophic condition index scores (1.00), and highest diversity (2.24), suggesting the best habitat. The chironomid community in this site cluster was dominated by predatory species, possibly resulting from high concentrations of heavy metals at some sites. Densities of all major taxonomic groups increased significantly between 1972 and 1999. Decreasing proportions of oligochaetes (0.85 to 0.68) and increasing diversity suggest improved environmental conditions over this period. Evidence suggests that changes in Muskegon Lake's benthic community were more a result of wastewater diversion than Dreissena invasion.*

INDEX WORDS: *Macroinvertebrates, multivariate statistics, historic changes, wastewater diversion, contaminants, Area of Concern.*

INTRODUCTION

Composition of the benthic macroinvertebrate community is widely considered an effective tool for evaluating environmental (trophic) conditions. Benthic macroinvertebrates are found in most habitats and are relatively easy to sample quantitatively (Canfield *et al.* 1996, Wiederholm 1980). Moreover, they form stable communities that integrate and reflect conditions of both pelagic and benthic regions over relatively long periods of time (Nalepa 1987, Wiederholm 1980). Since macroinvertebrates

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are confined to a habitat that continually receives autochthonous and allochthonous material, they integrate both autotrophic and heterotrophic processes in lakes (Wiederholm 1980).

Because benthic communities provide a "snapshot" of trophic conditions in a lake at the time samples are collected and community composition may reflect recent events, comparisons to historical data are useful in assessing long-term trends in environmental conditions and trophic state (Nalepa *et al.* 2000). Shifts in relative abundances of indicator species have been particularly effective in assessing changes in environmental conditions (Carr and Hiltunen 1965, Harman 1997, Krieger and Ross 1993, Lang 1998). For instance, prior to phosphorus abatement programs in the mid-1970s, increased densities of most benthic groups and reduced densities of pollution intolerant taxa in the Great Lakes generally reflected increased system productivity from increased nutrient loads (Carr and Hiltunen 1965, Robertson and Alley 1966). After abatement efforts were initiated, the abundance of less-tolerant species increased, and overall abundances of most benthic taxa declined in Lakes Michigan, Erie, and Ontario (Nalepa 1987, 1991; Schloesser *et al.* 1995). Given the difficulty of lake-wide experimental manipulations, comparing past and present communities may be the only practical method to assess changes resulting from human activities (Barton and Anholt 1997). In addition, these comparisons provide the only opportunity to gauge the progress of ecosystem restoration when monitoring data are limited.

In this study, we examine spatial distributions and long-term changes in the abundance and species composition of the benthic macroinvertebrate community in Muskegon Lake, a drowned river mouth lake along the southeastern coast of Lake Michigan. Prior to 1973, domestic and industrial wastes were discharged directly into the lake from various facilities located along the southern shoreline and near the mouth of the Muskegon River. The International Joint Commission (IJC) designated Muskegon Lake as an Area of Concern (AOC) because of severe environmental impairments related to these discharges. Studies of benthic communities and associated sediments in the 1950s, 1960s, and early 1970s indicated a severely degraded benthic fauna along with high levels of sediment contaminants including heavy metals and aromatic hydrocarbons (Peterson 1951, Surber 1954, Evans 1976). A tertiary wastewater treatment facility was constructed in 1973, and the discharge was diverted to a location 25 km upstream on the Muskegon River. Persistent contaminants, however, remain in sediments from some areas of the lake (Evans 1992). The response of the benthic community to the waste diversion has not been well studied. Only a few, limited surveys have been conducted since the diversion, with the last occurring in the early 1980s (Evans 1992). The objectives of our study were to evaluate benthic distributions relative to river inputs and to known areas of persistent sediment contaminants, and to assess overall changes in the benthic community since waste diversion in 1973. Since the Muskegon Lake AOC has Beneficial Use Impairments (BUIs) associated with degraded benthos and associated fisheries habitat, improvements in the benthic macroinvertebrate community can be used to assess the progress of the Remedial Action Plan (RAP) and play a critical role in future delisting assessments.

Study Area

Muskegon Lake is a large drowned river mouth lake (1,680 ha) along the southeastern shoreline of Lake Michigan. A drowned river mouth lake is formed by erosion of tributary river channels during extreme low lake levels. As water levels in the Great Lakes rose, the mouths of tributary rivers were "drowned." The formation of sand dunes at river mouths along the eastern shoreline resulted in inland lakes connected to Lake Michigan by outlet channels (Jude *et al.* 2005). Mean depth of Muskegon Lake is 7.1 m (maximum is 21 m), water volume is about 119 million m^3, and mean hydraulic retention time is about 23 days. Much of the lake's shoreline has been modified by urban and industrial development and receives 95% of its tributary inputs from the Muskegon River, which enters on the lake's east side (Fig. 1). This river is the second longest in the state (352 km) and drains a watershed of 6,819 km^2. Mean annual flow into Muskegon Lake is 55.5 $m^3 \cdot s^{-1}$. Outflow to Lake Michigan is through a navigation channel on the west side of the lake (Fig. 1).

Anthropogenic activity has affected Muskegon Lake since the early 1800s when lumber barons harvested the region's timber resources and left behind a legacy of barren riparian zones and severe erosion. Saw mills were constructed on the shoreline, and much of the littoral zone was filled with sawdust, wood chips, timber wastes, and bark. This was followed in the 1900s by an era of industrial