Muskegon Lake Area of Concern

Evaluating Targets for Delisting Two Beneficial Use Impairments (*Loss of Fish Habitat* and *Degradation of Fish Populations*) and Response of Fish to Habitat Restoration

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Introduction

Historical Fish Habitat & Population Issues and Description of Impairments

Muskegon Lake (4,149 acres) is located on the eastern shore of Lake Michigan (Muskegon County, Michigan). The lake was formed by the combination of sand dunes constricting the flow of the Muskegon River before it enters Lake Michigan and inundation of the ancient river valley, which formed when historic Great Lakes levels were much lower. Muskegon Lake and the immediate watershed (52 square miles) were designated as an Area of Concern (AOC) in 1985 because of possible negative impacts of Muskegon Lake on Lake Michigan due to contaminated water, nutrient enrichment, and habitat degradation.

> "[P]rior to 1973, Muskegon Lake received direct discharges of industrial process wastewater, municipal wastewater treatment plant effluent, combined stormsewer overflows and urban runoff. These discharges degraded water and habitat quality of Muskegon Lake and tributaries .... [N]utrient enrichment, solids and toxicant loadings resulting in nuisance algal blooms, reduced oxygen concentrations in the water column, tainted fish and contaminated sediments. Development of petroleum, chemical and heavy industries in the ... AOC ... contaminated groundwater" [Remedial Action Plan 1987, page 1].

A wastewater treatment facility was constructed in 1973 to improve water quality in Muskegon Lake. Industrial and municipal discharges were diverted away from Muskegon Lake to the Muskegon County Wastewater Management System, which "... greatly improved water and habitat quality in Muskegon Lake by reducing the loadings of nutrients, oils, solids and toxicants" (Remedial Action Plan 1987, pages 1-2). These improvements allowed the lake, once again, to be an excellent fishery for walleye, largemouth bass, yellow perch, and northern pike (Remedial Action Plan 1987, pages 1-2).

Muskegon Lake has good-to-excellent fishing for northern pike *Esox lucius*, walleye *Sander vitreus*, smallmouth bass *Micropterus dolomieu*, largemouth bass *M. salmoides*, yellow perch *Perca flavescens*, bluegill *Lepomis macrochirus*, pumpkinseed *L. gibbosus*, black crappie *Pomoxis nigromaculatus*, channel catfish *Ictalurus punctatus*, flathead catfish *Pylodictis olivaris*, migratory rainbow trout *Oncorhynchus mykiss*, and Chinook salmon *O. tshawytscha* (O'Neal 1997). The results of a more recent creel survey conducted in 2002 suggested that the overall fishery in Muskegon Lake was "relatively good" (Hanchin *et al.* 2007). Fish effort (hours fished/acre) and harvest (fish harvested/acre) were higher in Muskegon Lake compared with Michigan's other large inland lakes (Hanchin *et al.* 2007).

Walleye is the only species currently stocked in Muskegon Lake, although brown trout *Salmo trutta* and Chinook salmon are stocked in the Muskegon Lake channel (MDNR 2007). Periodic assessments of young-of-the-year walleye in Muskegon Lake suggest very low natural reproduction in the system (MDNR 2004). The current walleye population that spawns in the Muskegon River is characterized as having average-to-high density, fast growth, low total mortality, and low angler harvest (Hanchin *et al.* 2007). Native fish species that were extirpated or are considered threatened in Muskegon Lake include lake sturgeon *Acipenser fulvescens*, white bass *Morone chrysops*, and muskellunge *Esox masquinongy* (O'Neal 1997). The Michigan Department of Natural Resources is considering reintroductions of white bass and muskellunge to Muskegon Lake. However, the presence of a large northern pike population could prove problematic for muskellunge reintroduction, and the presence of non-native white perch *Morone americana* (known competitors with white bass) could interfere with white bass reintroduction (O'Neal 1997). A small population of lake sturgeon use Muskegon Lake to gain access to the Muskegon River (Schneeberger *et al.* 2005). Nevertheless, declines of lake sturgeon, white bass, and muskellunge, along with natural walleye reproduction failure, are not unique to Muskegon Lake and are common among many drowned river mouth lakes connecting to Lake Michigan, although Muskegon River has a much larger spawning population of walleye than any of the other drowned river mouth lakes (Schneider and Leach 1979).

Restoration Targets

A multi-metric index—termed an index of biotic integrity or IBI—was used to set quantitative delisting targets for Muskegon Lake based on annual fish-sampling records collected by the Annis Water Resources Institute (AWRI) between 2004 and 2006. The IBI approach is widely used across the United States to monitor water quality. Fish that live in the water body are integrators of the overall habitat and water quality; they also reveal both episodic and cumulative human-induced disturbance in a system. Fish sampling for calculating IBI scores only was required annually because the fish themselves are integrators of time (i.e., the fish community is there continuously). A fish-based IBI can be used to address questions concerning both fish populations and habitat because the IBI is an indicator of both fish community health and the overall ecological health of the lake. Overall ecological health of a lake is linked to aquatic habitat, and aquatic habitat is linked to the overall health of the fish community.

A typical IBI includes metrics such as number and composition of species sampled, focuses on indicator species that are particularly sensitive to water quality and habitat alterations, and considers groups of organisms that have similar feeding modes. Once the sampling is completed, scientists calculate a "score" for each metric in the IBI. The final IBI score is the total of all metrics and is indicative of ecosystem health. A high score suggests a "healthier" ecosystem, whereas a low score is indicative of a "degraded" ecosystem.

The IBI used for setting delisting targets in Muskegon Lake is modified from a fish-based IBI developed for Great Lakes coastal wetlands (Uzarski *et al.* 2005). The IBI developed by Uzarski *et al.* (2005) was modified to better represent human-induced disturbance (based on land use and water quality) across a gradient of drowned river mouth lakes[1]. The disturbance gradient suggested that Pentwater Lake was indicative of a "healthier" ecosystem and Kalamazoo Lake was more indicative of a "degraded" ecosystem among the lakes sampled by AWRI during 2004-2006 (see Figure 1 for list of lakes). The modified, fish-based IBI consists of 11 metrics (Table 1) and also is being used to set delisting targets for fish populations and habitat in the Muskegon Lake AOC.

The IBI scores calculated during 2005 and 2006 suggest two clusters of lakes in the sample (Figure 1): a group with scores >33 indicative of "healthier" ecosystems, and another with scores ≤33 representing "degraded" ecosystems.[2] Moreover, Pentwater Lake has been used as a reference system when setting targets for other beneficial use impairments in the Muskegon Lake AOC (i.e., *restriction of fish and wildlife consumption* and *eutrophication or undesirable algae*). Therefore, the finding that Pentwater, Muskegon, and White lakes form a group among the lakes AWRI sampled (Figure 1) suggests that they are "healthier" than Kalamazoo and Pigeon lakes. In Great Lakes coastal wetlands, Uzarski *et al.* (2005) found anthropogenic disturbance (based on land use and water quality) was typically high for Pigeon Lake, which supports our findings in 2005 and 2006. However, among wetlands across all five Great Lakes, the drowned river mouth systems we sampled tended to be average or more impacted in terms of anthropogenic disturbance (Uzarski *et al.* 2005).

At least three pieces of evidence suggest that fish populations and, therefore, habitat are no longer severely degraded in Muskegon Lake. First, the fish-based IBI scores calculated during 2004-2006 suggest that the ecosystem health of Muskegon Lake is comparable to Pentwater Lake, a drowned river mouth lake that did not suffer the types of severe environmental degradation experienced by Muskegon Lake. Second, the 1987 Remedial Action Plan noted that Muskegon Lake experienced marked improvements in water and habitat quality, including an excellent fishery for numerous fish species, following the construction of a wastewater treatment system. Finally, more recent assessments by the Michigan Department of Natural Resources suggest that Muskegon Lake supports good fishing for several fish species with self-sustaining populations (O'Neal 1997; Hanchin *et al.* 2007).

The proposed target for delisting the *loss of fish habitat* and *degradation of fish populations* BUIs in Muskegon Lake is *to maintain or improve the lake's ecosystem health over a 3-year time span* beginning in 2009. The numerical target will be measured as an average IBI score of 38 ± 2, which is based on the mean and standard deviation[3] IBI score for Muskegon Lake during 2004-2006 (Figure 1). If after 3 years of monitoring the target is not achieved (i.e., average IBI

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[1] Note that only the 2004 fish data were used to re-calibrate the IBI proposed by Uzarski *et al.* (2005). There was a significant correlation ($r = 0.92$, $P = 0.076$, $n = 4$) between disturbance gradient and IBI score for 2004. The disturbance gradient was calculated using the approach described by Uzarski *et al.* (2005). Data collected from 2005 and 2006 provide evidence for relatively high precision of the IBI and suggest that inter-annual variation is not driving IBI scores (see Figure 1).

[2] The IBI score of 33 was arbitrarily defined based on visual interpretation of Figure 1.

[3] On average, 68% of observations should be within 1 standard deviation of the mean, assuming the population is normally distributed (Sokal and Rohlf 1995).

score $\geq$36), then fish monitoring should continue for an additional 3 years to determine whether the numerical target is achieved. This process should be repeated until the target is achieved.

Objective

My objective was to summarize the results of the fish sampling conducted in six drowned river mouth lakes during 2009-2011 and determine whether the delisting target was achieved for Muskegon Lake. Additionally, my original intent was to use the fish surveys before and after restoration in Muskegon Lake to assess the ecological benefits of the Muskegon Lake restoration project. However, delays in the restoration schedule precluded my ability to evaluate restoration effects. The surveys conducted during 2009 and 2010 represent pre-restoration conditions. Sampling in 2011 occurred only a few months after restoration was complete, thus the fish community likely did not have adequate time to respond to restoration. The 2009-2011 fish surveys provide important baseline information for future assessments of restoration success, but do not allow me to assess the effects of restoration on the fish community.

Methods

Site description

Six drowned river mouth lakes were sampled along the eastern shore of Lake Michigan: Pigeon Lake, Lincoln Lake, Kalamazoo Lake, Pentwater Lake, White Lake, and Muskegon Lake (Table 2). At each lake, with the exception of White Lake and Muskegon Lake, three sites were selected in the littoral zone that had submerged aquatic vegetation (SAV). White Lake and Muskegon Lake had four and six sites, respectively. In White Lake, site 4 was sampled in 2010 and 2011 (Table 2). In Muskegon Lake, sites 5 and 6 were reference sites, and sites 1, 2, 3 (sampled in 2009 and 2010), 4 (sampled 2009 only), and 7 (sampled 2010 and 2011) were restoration sites (Table 2).

Fish sampling

Sampling was done in July and August of 2009, 2010, and 2011. In each lake, we set three 4-mm mesh fyke nets at each site overnight (approximately 24 hours). The dimensions of the fyke nets are described by Breen and Ruetz (2006). Two of the fyke nets were set parallel to shore with mouths facing each other and connected at the lead. The third fyke net was placed about 30-50 m from the parallel nets, perpendicular to shore, with the mouth facing the shore. Wings of all nets were set at a 45° angle and leads were placed at the center of the mouth of the net.

Fish collected from fyke nets were identified to species, measured for total length (cm), and released at the point of capture (except for round gobies *Neogobius melanostomus*, which were euthanized). Any fish that could not be identified in the field was euthanized or a digital photo was taken for identification in the laboratory. For each fish species encountered, a digital photograph was taken for the reference collection. The IBI score was calculated for each site.

Environmental variables

Water temperature, conductivity, total dissolved solids (TDS), pH, oxidation-reduction potential (ORP), chlorophyll *a*, percent dissolved oxygen, dissolved oxygen concentration, and turbidity were measured using an YSI (6600 v2, 650 MDS) multiprobe sonde at each fyke net. I also collected a 500-mL sample of water at each site. Water samples were placed on ice and then returned to the laboratory for alkalinity titration and analysis of chlorine, sulfate, nitrate nitrogen, and soluble reactive phosphorus. The samples for the laboratory analysis was filtered through a .45 um filter. Chlorine and nitrate nitrogen content were determined by means of ion chromatography using a Dionex ICS-2100 while soluble reactive phosphorus was determined using a SEAL Analytical AQ2 discrete analyzer. Water depth and organic sediment depth (see Cooper *et al.* 2007b) were measured at the mouth of each net. The percent surface area of SAV was estimated visually by examining the area between the wings of the fyke net along the lead.

Results and Discussion

Summary of environmental variables

For the environmental variables measured, most exhibited minimal variation among lakes. However, an exception was Kalamazoo Lake. Mean specific conductivity of Kalamazoo Lake (579.67 μS/cm) was much higher than the other lakes, which ranged from 352.93 μS/cm to 406.22 μS/cm (Table 3). Kalamazoo Lake also had higher mean total dissolved solids (0.376 g/L) than the other lakes, which ranged from 0.229 g/L to 0.264 g/L, and higher mean chlorophyll *a* concentrations (26.82 μg/L) than the other lakes, which ranged from 6.01 μg/L to 10.48 μg/L. Mean turbidity varied the most among lakes, with Muskegon Lake lowest (2.92 NTU) and Lincoln Lake highest (18.81 NTU; Table 3).

The sites at Kalamazoo Lake had a mean water depth of 74.3 cm, organic sediment depth of 5.5 cm, SAV coverage of 20.6%, and temperature of 24.21 °C (Table 3). Kalamazoo Lake had a mean specific conductivity of 579.67 μS/cm, ranging from 565.00 μS/cm to 592.00 μS/cm. The mean value for total dissolved solids was 0.376 g/L with a range from 0.367 g/L to 0.385 g/L. The mean pH was 8.32, ranging from 8.06 to 8.75. Mean ORP was 343.56 mV, ranging from 308.90 mV to 365.00 mV. The mean percent dissolved oxygen was 108.2%, ranging from 78.90% to 161.70%. Mean dissolved oxygen concentration was 9.09 mg/L, ranging from 6.74 mg/L to 13.76 mg/L. Mean chlorophyll *a* was 26.82 μg/L, ranging from 11.50 μg/L to 54.10 μg/L. Mean turbidity was 16.08 NTU, ranging from 7.70 NTU to 27.70 NTU. There was minimal variation among years for most environmental variables expect for mean chlorophyll *a* in 2011, which was 15.77 μg/L or about half of what was measured in 2009 and 2010 (Table 3).

The sites at Lincoln Lake had a mean water depth of 77.3 cm, organic sediment depth of 4.8 cm, SAV coverage of 85.56%, and temperature of 24.67 °C (Table 3). Lincoln Lake had a mean specific conductivity of 352.93 μS/cm, ranging from 322.00 μS/cm to 384.00 μS/cm. Mean total dissolved solids was 0.229 g/L, ranging from 0.209 g/L to 0.250 g/L. Mean pH was 8.13, ranging from 7.76 and 8.76. Mean ORP was 358.48 mV, ranging from 339.00 mV to 373.00 mV. Mean percent dissolved oxygen was 90.87%, ranging from 40.30% to 147.10%. Mean dissolved oxygen concentration was 7.52 mg/L, ranging from 3.04 mg/L to 11.89 mg/L. Mean chlorophyll *a* concentration was 9.99 μg/L, ranging from 4.60 μg/L to 31.20 μg/L. Mean turbidity was 2.36 NTU, ranging from 0 NTU to 13.40 NTU. There was some variation among years for chlorophyll *a* concentration, dissolved oxygen, and pH. Specifically, mean chlorophyll *a* concentration in 2010 (16.20 μg/L) was higher than in 2009 and 2011 by about 9 μg/L. Mean percent dissolved oxygen and concentration was higher in 2010 than 2009 but was lower in 2011 than 2010. Mean pH was lowest in 2011 (7.90) relative to measurements in 2009 (8.02) and 2010 (8.47; Table 3).

The sites at Muskegon Lake had a mean water depth of 79.8 cm, organic sediment depth of 3.9 cm, SAV coverage of 28.5%, and temperature of 25.35 °C (Table 3). Muskegon Lake had a mean specific conductivity of 378.55 μS/cm, ranging from 333.00 μS/cm to 444.00 μS/cm. Mean total dissolved solids was 0.242 g/L, ranging from 0.022 g/L to 0.288 g/L. Mean pH was 8.56, ranging from 8.04 to 9.06. Mean ORP was 333.17 mV, ranging from 288.00 mV to 389.00 mV. Mean percent dissolved oxygen was 113.24%, ranging from 86.90% to 144.50%. Mean dissolved oxygen concentration was 9.28 mg/L, ranging from 7.42 mg/L to 11.82 mg/L. Mean chlorophyll *a* concentration was 10.69 μg/L, ranging from 2.2 μg/L to 113.30 μg/L. Mean turbidity was 3.03 NTU, ranging from 0 NTU to 17.20 NTU. There was some variation among years in specific conductivity, ORP, and chlorophyll *a* concentration (Table 3). Mean specific conductivity in 2011 (356.20 μS/cm) was lower than 2009 and 2010. There was a trend in decreasing ORP among years. Chlorophyll *a* concentration in 2009 (16.42, μg/L) was about twice as high as 2010 and 2011.

The sites at Pentwater Lake had a mean water depth of 82.3 cm, organic sediment depth of 2.98 cm, SAV coverage of 63.1%, and temperature of 23.93 °C (Table 3). Pentwater Lake had a mean specific conductivity of 402.93 μS/cm, ranging from 380.00 μS/cm to 417.00 μS/cm. Mean total dissolved solids was 0.262 g/L, ranging from 0.247 g/L to 0.271 g/L. Mean pH was 8.44, ranging from 7.98 to 8.99. Mean ORP was 345.73 mV, ranging from 312.00 mV to 368.00 mV. Mean percent dissolved oxygen was 110.72%, ranging from 79.80% to 154.20%. Mean dissolved oxygen concentration was 9.33 mg/L, range from 6.48 mg/L to 13.11 mg/L. Mean chlorophyll *a* concentration was 6.01 μg/L, ranging from 3.40 μg/L to 10.60 μg/L. Mean turbidity was 2.75 NTU, ranging from 0.10 NTU to 12.20 NTU. These environmental variables showed minimal variation among years during 2009-2011 in Pentwater Lake (Table 3).

The sites at Pigeon Lake had a mean water depth of 67.9 cm, organic sediment depth of 3.3 cm, SAV coverage of 41.0%, and temperature of 23.39 °C (Table 3). Pigeon Lake had a mean specific conductivity of 406.22 μS/cm, ranging from 330.00 μS/cm to 479.00 μS/cm. Mean total dissolved solids was 0.264 g/L, ranging from 0.213 g/L to 0.311 g/L. Mean pH was 8.21, ranging from 7.68 to 9.18. Mean ORP was 348.10 mV, ranging from 262.00 mV to 407.00 mV. Mean percent dissolved oxygen was 92.50%, ranging from 80.40% to 105.30%. Mean dissolved oxygen concentration was 7.88 mg/L, ranging from 6.51 mg/L to 9.07 mg/L. Mean chlorophyll *a* concentration was 10.92 μg/L, ranging from 6.10 μg/L to 18.30 μg/L. Mean turbidity was 6.41 NTU, ranging from 1.50 NTU to 25.50 NTU. There was some variation among years for specific conductivity, pH, ORP, and turbidity (Table 3). Specific conductivity (426.7 μS/cm), ORP (392.67 mV), and turbidity (12.20 NTU) in 2009 were higher than 2010 and 2011, whereas pH in 2009 (7.83) was lower than 2010 and 2011 (Table 3).

The sites at White Lake had a mean water depth of 74.9 cm, organic sediment depth of 4.3 cm, SAV coverage of 49.9%, and temperature of 25.42 °C (Table 3). White Lake had a mean specific conductivity of 373.73 μS/cm, ranging from 362.00 μS/cm to 407.00 μS/cm. Mean total dissolved solids was 0.247 g/L, ranging from 0.235 g/L to 0.360 g/L. Mean pH was 8.38, ranging from 7.88 to 8.89. Mean ORP was 360.68 mV, ranging from 325.30 mV to 403.00 mV. Mean percent dissolved oxygen was 99.95%, ranging from 69.40% to 125.30%. Mean dissolved oxygen concentration was 8.17 mg/L, ranging from 5.61 mg/L to 9.77 mg/L. Mean chlorophyll *a* concentration was 10.58 μg/L, ranging from 0.90 μg/L to 67.20 μg/L. Mean turbidity was 2.92 NTU, ranging from 0 NTU to 25.00 NTU. There was some variation in pH, turbidity, ORP, and chlorophyll *a* concentration among years (Table 3). There was a trend of increasing pH among years. Turbidity (0.73 NTU) and ORP (333.45 mV) in 2011 were lower than 2009 and 2010, whereas chlorophyll *a* concentration in 2009 (4.57 μg/L) was lower than 2010 and 2011.

Mean values of chloride (Cl), sulfate (SO_4), nitrate-nitrogen (NO_3-N), soluble reactive phosphorus (SRP) and alkalinity are reported in Table 4. Overall, Kalamazoo Lake tended to have the highest Cl concentrations and alkalinity. Muskegon Lake and White Lake tended to have low NO_3-N concentrations among the lakes.

Summary of fish sampling

Over the three years of sampling, we collected 7,702 fish consisting of 48 different species (Table 5). Of the 48 species, seven species accounted for 78.78% of the total number of individuals captured. The most abundant species were bluegill *Lepomis macrochirus* (7.39%), bluntnose minnow *Pimephales notatus* (14.65%), largemouth bass *Micropterus salmoides* (18.09%), rock bass *Ambloplites rupestris* (6.74%), round goby (17.13%), pumpkinseed *Lepomis gibbosus* (9.13%), and yellow perch *Perca flavescens* (5.47%). All of these species were captured in every lake with the exception of yellow perch, which was not captured in Kalamazoo Lake.

A total of 1,938 fish consisting of 34 different species was collected from Kalamazoo Lake over the sampling period. The five species that accounted for most of the fyke-net catch were buntnose minnow (35.8%), round goby (16.9%), spotfin shiner *Cyprinella spiloptera* (8.0%), black crappie *Pomoxis nigromaculatus* (6.2%), and alewife *Alosa pseudoharengus* (5.8%). While bluntnose minnow was the most abundant fish captured over the three years, less individuals were collected each year. The catch of bluntnose minnow made up less than 5% of the catch in 2011 (Figure 2).

A total of 1,207 fish consisting of 23 different species was collected from Lincoln Lake over the sampling period. The species that accounted for most of the fyke-net catch were pumpkinseed (29.0%), largemouth bass (26.2%), bluegill (18.3%), and crappie *Pomoxis* spp. (9.4%). The catch of *Lepomis* spp. in 2009 and 2010 was much higher than in 2011 (Figure 3).

A total of 1,839 fish consisting of 28 different species was collected from Muskegon Lake over the sampling period. The five species that accounted for most of the fyke-net catch were largemouth bass (23.1%), round goby (18.2%), bluntnose minnow (14.3%), bluegill (13.0%), and rock bass (11.0%). There was little variation in the most abundant species among years, but there was variation in which species was most abundant each year (Figure 4).

A total of 1,097 fish consisting of 24 different species was collected from Pentwater Lake over the sampling period. The five species that had the highest percent of fyke-net catch were largemouth bass (30.8%), round goby (27.2%), yellow perch (14.6%) rock bass (10.2%), and banded killifish *Fundulus diaphanus* (2.5%). The percentage of largemouth bass and round goby catch varied highly among years. For instance, largemouth bass was most abundant in the catch during 2010, whereas round goby was most abundant in the catch during 2009 (Figure 5).

A total of 521 fish consisting of 28 different species was collected from Pigeon Lake over the sampling period. The five species that accounted for most of the fyke-net catch were black bullhead (25.1%), bluntnose minnow (20.1%), largemouth bass (15.0%), rock bass (10.6%), and spottail shiner *Notropis hudsonius* (7.5%). There was a relatively high number of black bullhead caught in 2009 and bluntnose minnow caught in 2010 that was not seen in other years (Figure 6).

A total of 1,100 fish consisting of 23 different species was collected from White Lake over the sampling period. The five species that accounted for most of the fyke-net catch were round goby (26.6%), largemouth bass (25.4%), pumpkinseed (14.9%), yellow perch (13.4%), and bluegill (6.2%). White Lake varied the least among years (compared to the other drowned river mouth lakes) with the same species dominating each year in similar proportions (Figure 7).

IBI scores, delisting target, and restoration

IBI scores for Pentwater, Muskegon, and White lakes were relatively consistent between the two time series (i.e., 2004-2006 compared with 2009-2011; Figure 8). However, Lincoln, Kalamazoo, and Pigeon showed relatively more annual variability. Pentwater Lake, which can be thought of as a reference, consistently had among the highest IBI scores each year among the six drowned river mouth lakes that were sampled, whereas Kalamazoo Lake typically had one of the lowest IBI scores.

In Muskegon Lake, reference sites (i.e., Musk5 and Musk6) had mean IBI scores of 38.5 (range = 37-40) in 2009, 44.5 (range = 44-45) in 2010, and 44.5 (range = 43-46) in 2011. Mean IBI scores at restoration sites were 44 (range = 40-48; $n = 4$) in 2009, 43 (range = 32-51; $n = 4$) in 2010, and 45.3 (range = 45-46; $n = 3$) in 2011. The fish surveys in Muskegon Lake during 2009-2011 should provide a baseline to evaluate responses of the fish community to restoration activities.

The mean IBI score for Muskegon Lake during 2009-2011 was 43.6 (Figure 9), which exceeded the numerical delisting target of 36 set for the *loss of fish habitat* and *degradation of fish populations* beneficial use impairments. Therefore, the numerical delisting target regarding fish IBI scores was achieved.

Delisting the *loss of fish habitat* beneficial use impairment does not mean that additional work is unnecessary to restore, protect, and improve the fishery in Muskegon Lake. Alterations to the natural shoreline of lakes—caused by human development—are a widespread problem in

Michigan lakes (O'Neal and Soulliere 2006) but not a primary reason for designation of the *loss of fish habitat* BUI on Muskegon Lake. Modifications to the lakeshore can result in loss of fish habitat and reduction in fish populations (e.g., Sass *et al.* 2006), and cumulative effects of small modifications to aquatic habitat can significantly degrade fisheries (O'Neal and Soulliere 2006).

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Table 1. Metrics for fish-based index of biotic integrity (IBI) for drowned river mouth lakes. The IBI is modified from Uzarski *et al.* (2005). Fish sampling should be conducted with fyke nets (Cooper *et al.* 2007a) at shallow (depth ≤1 m) sites with submerged aquatic vegetation. At least three fyke nets should be fished at each site. The catch of fish is then standardized across nets at a site to calculate IBI scores.

Preliminary Drowned River Mouth Lake IBI – SAV habitat only

1. Percent omnivore abundance:
   >70% score = 0 | 50 to 70% score = 3 | <50% score = 5

2. Percent piscivore richness:
   <25% score = 0 | 25 to 35% score = 3 | >35% score = 5

3. Percent carnivore (insectivore+piscivore+zooplanktivore) richness:
   <70% score = 0 | 70-80% score = 3 | >80% score = 5

4. Smallmouth bass (*Micropterus dolomieu*) mean catch per net-night:
   0 score = 0 | >0 to 5 score = 3 | >5 score = 5

5. Insectivorous Cyprinidae richness:
   >3 score = 0 | >1 to 3 score = 3 | 0 to 1 score = 5

6. Percent Centrarchidae abundance:
   0-30 score = 0 | >30 to 60 score = 3 | >60 to 80 score 5 | >80 score = 7

7. Centrarchidae richness:
   0 to 1 score = 0 | >1 to 3 score = 3 | >3 score = 5

8. Mean evenness:
   <0.2 score = 0 | 0.2 to 0.6 score = 3 | >0.6 score = 5

9. Rock Bass (*Ambloplites rupestris*) catch per net-night:
   0 to 1 score = 0 | >1 to 5 score = 3 | >5 score = 5

10. Bluegill (*Lepomis macrochirus*) abundance per net-night:
    0 to 3 score = 0 | >3 to 20 score = 3 | >20 to 30 score = 5 | >30 score = 7

11. *Lepomis* catch per net-night:
    >50 score = 0 | >20 to 50 score= 3 | >5 to 20 score = 5 | 0 to 5 score = 7

Table 2. Latitude and longitude of sampling sites in each drowned river mouth lake.

Lake	Site	Latitude	Longitude
Kalamazoo	Kzoo1	N42° 39.042'	W086° 11.820'
Kalamazoo	Kzoo2	N42° 38.911'	W086° 12.083'
Kalamazoo	Kzoo3	N42° 38.989'	W086° 12.601'
Lincoln	Linc1	N43° 58.676'	W086° 27.629'
Lincoln	Linc2	N43° 58.624'	W086° 27.165'
Lincoln	Linc3	N43° 58.766'	W086° 27.446'
Muskegon	Musk1	N43° 13.189'	W086° 17.782'
Muskegon	Musk2	N43° 14.014'	W086° 16.436'
Muskegon	Musk3	N43° 13.886'	W086° 15.813'
Muskegon	Musk5	N43° 14.778'	W086° 16.866'
Muskegon	Musk6	N43° 14.704'	W086° 18.803'
Muskegon	Musk7	N43° 13.250'	W086° 17.138'
Pentwater	Pent1	N43° 45.770'	W086° 24.636'
Pentwater	Pent2	N43° 46.255'	W086° 24.991'
Pentwater	Pent3	N43° 45.927'	W086° 24.480'
Pigeon	Pige1	N42° 54.216'	W086° 12.250'
Pigeon	Pige2	N42° 54.133'	W086° 12.107'
Pigeon	Pige3	N42° 54.095'	W086° 11.937'
White	Wht1	N43° 24.116'	W086° 21.096'
White	Wht2	N43° 24.466'	W086° 21.448'
White	Wht3	N43° 22.768'	N086° 23.781'
White	Wht4	N43° 22.296'	W086° 23.058'

Table 3. Mean water depth, organic sediment depth (OSD), coverage of submerged aquatic vegetation (SAV), water temperature (Temp), specific conductivity (Spec Cond), total dissolved solids (TDS), pH, oxidative-reduction potential (ORP), chlorophyll *a* (Chl *a*), percent dissolved oxygen (DO), DO concentration, and turbidity (Turb) for each drowned river mouth lake (Kalamazoo [Kzoo], Lincoln [Linc], Muskegon [Musk], Pentwater [Pent], Pigeon [Pige], and White [Wht] lakes) sampled from 2009 to 2011. Note that extreme values suspected to be measurement or recording errors were removed when calculating means.

	Depth (cm)	OSD (cm)	SAV %	Temp (°C)	Spec Cond (µS/cm)	TDS (g/L)	pH	ORP (mV)	Chl *a* (µg/L)	DO%	DO (mg/L)	Turb (NTU)
Kzoo	**74.34**	**5.54**	**20.63**	**24.21**	**579.67**	**0.376**	**8.32**	**343.56**	**26.82**	**108.26**	**9.09**	**16.08**
2009	74.22	5.78	26.67	22.54	584.44	0.380	8.27	358.56	31.10	128.99	11.13	22.06
2010	76.00	1.72	18.33	26.02	570.22	0.371	8.33	340.78	33.59	105.69	8.55	12.94
2011	72.80	9.11	15.00	24.08	584.33	0.379	8.36	331.36	15.77	90.09	7.59	13.23
Linc	**77.28**	**4.80**	**85.56**	**24.67**	**352.93**	**0.229**	**8.13**	**358.48**	**9.99**	**90.87**	**7.52**	**18.81**
2009	83.00	4.33	91.67	23.25	326.56	0.212	8.02	367.56	6.60	94.29	8.04	51.17
2010	77.22	3.11	82.78	26.73	365.33	0.237	8.47	349.56	16.20	120.83	9.68	2.32
2011	71.61	6.94	82.22	24.03	366.89	0.239	7.90	358.32	7.17	57.49	4.83	2.94
Musk	**79.76**	**3.94**	**28.46**	**25.35**	**378.55**	**0.242**	**8.56**	**333.17**	**10.69**	**113.24**	**9.28**	**3.03**
2009	90.83	1.19	22.11	24.64	389.33	0.253	8.40	352.22	16.42	109.53	9.08	6.14
2010	81.22	1.94	38.61	26.75	386.39	0.240	8.59	331.12	8.71	120.92	9.66	1.53
2011	67.23	8.67	23.57	24.51	356.20	0.232	8.72	312.63	6.05	108.97	9.09	1.10
Pent	**82.30**	**2.96**	**63.13**	**23.93**	**402.93**	**0.262**	**8.44**	**345.73**	**6.01**	**110.72**	**9.33**	**2.75**
2009	90.00	3.00	45.56	21.13	401.44	0.261	8.39	341.00	4.86	111.56	9.90	2.24
2010	81.30	1.67	76.67	24.36	407.89	0.265	8.41	354.00	6.82	121.44	10.14	3.04
2011	75.61	4.22	69.17	26.30	399.44	0.259	8.51	342.18	6.34	99.16	7.96	2.96
Pige	**67.85**	**3.28**	**41.04**	**23.39**	**406.22**	**0.264**	**8.21**	**348.10**	**10.92**	**92.50**	**7.88**	**6.41**
2009	76.17	1.67	54.44	22.38	426.78	0.277	7.83	392.67	9.34	87.16	7.56	12.20
2010	65.33	0.22	38.33	25.61	389.33	0.253	8.30	337.33	10.87	88.79	7.26	3.41
2011	62.06	7.94	25.00	22.17	402.56	0.260	8.48	314.29	12.56	101.57	8.82	3.62
Wht	**74.91**	**4.32**	**49.85**	**25.42**	**373.73**	**0.247**	**8.38**	**360.68**	**10.58**	**99.95**	**8.17**	**2.92**
2009	87.00	1.83	50.56	21.20	388.22	0.252	8.12	361.44	4.57	93.68	8.32	3.10
2010	67.00	1.25	49.17	26.48	370.42	0.241	8.36	387.33	14.34	94.04	7.56	4.98
2011	73.75	9.25	50.00	27.53	366.17	0.248	8.58	333.45	11.33	110.04	8.69	0.73
Overall	**76.55**	**4.12**	**46.01**	**24.63**	**409.72**	**0.266**	**8.37**	**346.85**	**12.22**	**103.26**	**8.58**	**7.50**

Table 4. Mean chloride (Cl), sulfate (SO_4), nitrate-nitrogen (NO_3-N), soluble reactive phosphorus (SRP), and alkalinity from six drowned river mouth lakes (Kalamazoo [Kzoo], Lincoln [Linc], Muskegon [Musk], Pentwater [Pent], Pigeon [Pige], and White [Wht] lakes) sampled from 2009 to 2011. The detection limit for NO_3-N was 0.01 mg/L and SRP was 0.005 mg/L. A value of one half of the detection limit was used when the measurement of a sample was below the detection limit.

	Cl (mg/L)	SO_4 (mg/L)	NO_3-N (mg/L)	SRP (mg/L)	Alkalinity (mg/L $CaCO_3$)
Kzoo	**47.89**	**30.67**	**0.7311**	**0.0034**	**215.83**
2009	74.67	31.00	0.3867	0.0025	211.50
2010	30.33	25.33	0.7567	0.0043	214.00
2011	38.67	35.67	1.0500	0.0033	222.00
Linc	**13.78**	**9.11**	**0.2283**	**0.0093**	**150.72**
2009	13.33	9.67	0.3167	0.0045	142.50
2010	12.00	9.33	0.1183	0.0042	152.67
2011	16.00	8.33	0.2500	0.0193	157.00
Musk	**23.88**	**17.06**	**0.2041**	**0.0026**	**139.71**
2009	24.83	20.50	0.2150	0.0025	142.17
2010	22.33	15.00	0.0633	0.0029	136.67
2011	24.60	15.40	0.3600	0.0025	140.40
Pent	**16.50**	**11.56**	**0.6267**	**0.0048**	**164.28**
2009	20.33	13.33	0.7467	0.0025	167.17
2010	9.83	7.67	0.2367	0.0093	162.00
2011	19.33	13.67	0.8967	0.0025	163.67
Pige	**32.00**	**28.78**	**0.6122**	**0.0046**	**128.11**
2009	41.67	31.33	0.6000	0.0043	132.83
2010	20.33	23.33	0.2267	0.0068	121.17
2011	34.00	31.67	1.0100	0.0025	130.33
Wht	**20.82**	**15.45**	**0.0873**	**0.0057**	**138.18**
2009	25.00	18.33	0.1650	0.0113	151.00
2010	15.75	11.75	0.0350	0.0041	128.50
2011	22.75	17.00	0.0813	0.0031	138.25

Table 5. The percent composition of each fish species collected during 2009-2011 sampling of all six drowned mouth lakes.

Common Name	Scientific Name	%
Alewife	*Alosa pseudoharengus*	1.67
Banded Killifish	*Fundulus diaphanus*	1.80
Black Bullhead	*Ameiurus melas*	1.74
Black Crappie	*Pomoxis nigromaculatus*	2.29
Blackchin Shiner	*Notropis heterodon*	0.44
Blacknose Shiner	*Notropis heterolepis*	0.65
Blackside Darter	*Percina maculata*	0.01
Bluegill	*Lepomis macrochirus*	7.39
Bluntnose Minnow	*Pimephales notatus*	14.65
Bowfin	*Amia calva*	0.62
Brook Silverside	*Labidesthes sicculus*	0.96
Brown Bullhead	*Ameiurus nebulosus*	0.56
Channel Catfish	*Ictalurus punctatus*	0.21
Common Carp	*Cyprinus carpio*	0.08
Emerald Shiner	*Notropis atherinoides*	0.49
Fathead Minnow	*Pimephales promelas*	0.04
Flathead Catfish	*Pylodictis olivaris*	0.05
Freshwater Drum	*Aplodinotus grunniens*	0.04
Gizzard Shad	*Dorosoma cepedianum*	0.71
Golden Redhorse	*Moxostoma erythrurum*	0.05
Golden Shiner	*Notemigonus crysoleucas*	0.01
Green Sunfish	*Lepomis cyanellus*	0.04
Iowa Darter	*Etheostoma exile*	0.01
Johnny Darter	*Etheostoma nigrum*	0.21
Largemouth Bass	*Micropterus salmoides*	18.09
Logperch	*Percina caprodes*	0.18
Longnose Gar	*Lepisosteus osseus*	0.06
Mimic Shiner	*Notropis volucellus*	0.57
Northern Pike	*Esox lucius*	0.18
Pumpkinseed	*Lepomis gibbosus*	9.13
Quillback	*Carpiodes cyprinus*	0.03
Rock bass	*Ambloplites rupestris*	6.74
Round Goby	*Neogobius melanostomus*	17.13
Sand Shiner	*Notropis stramineus*	0.26
Shorthead Redhorse	*Moxostoma macrolepidotum*	0.04
Silver Redhorse	*Moxostoma anisurum*	0.05
Smallmouth Bass	*Micropterus dolomieu*	1.40
Spotfin Shiner	*Cyprinella spiloptera*	2.05
Spottail Shiner	*Notropis hudsonius*	2.19
Tadpole Madtom	*Noturus gyrinus*	0.05
Walleye	*Sander vitreus*	0.01
Warmouth	*Lepomis gulosus*	0.06
White Bass	*Morone chrysops*	0.09
White Crappie	*Pomoxis annularis*	0.87
White Perch	*Morone americana*	0.08
White Sucker	*Catostomus commersonii*	0.34
Yellow Bullhead	*Ameiurus natalis*	0.19
Yellow Perch	*Perca flavescens*	5.47

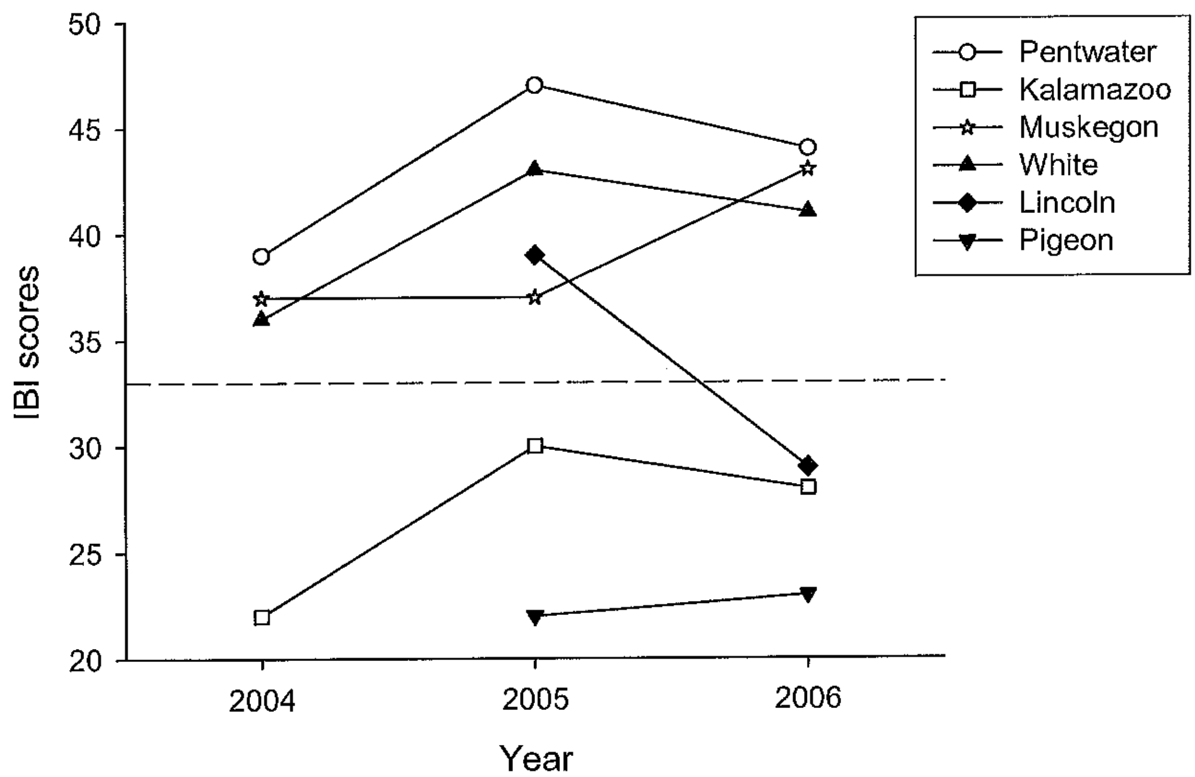

Figure 1. Scores from fish-based index of biotic integrity (IBI) for six drowned river mouth lakes. Data from 2004 were used to build the IBI. The dashed line represents the break (at an IBI score of 33) between relatively "healthy" and "degraded" ecosystems among the six lakes studied. Metrics used in the IBI are described in Table 1. One site with submerged aquatic vegetation was sampled in each lake (see Cooper *et al.* [2007a] for a description of sampling methods and locations).

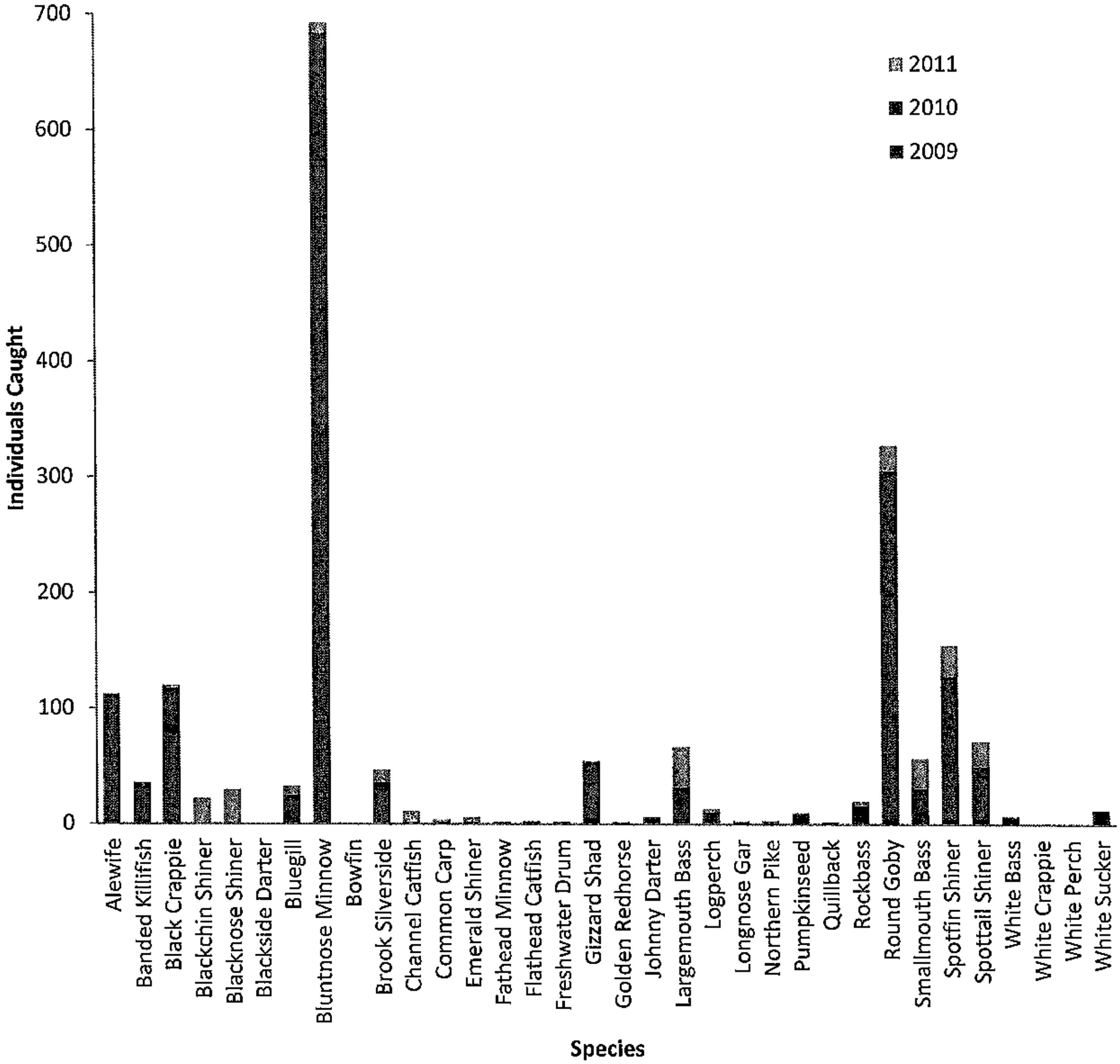

Figure 2. Number of individuals captures caught in Kalamazoo Lake during 2009-2011 sampling.

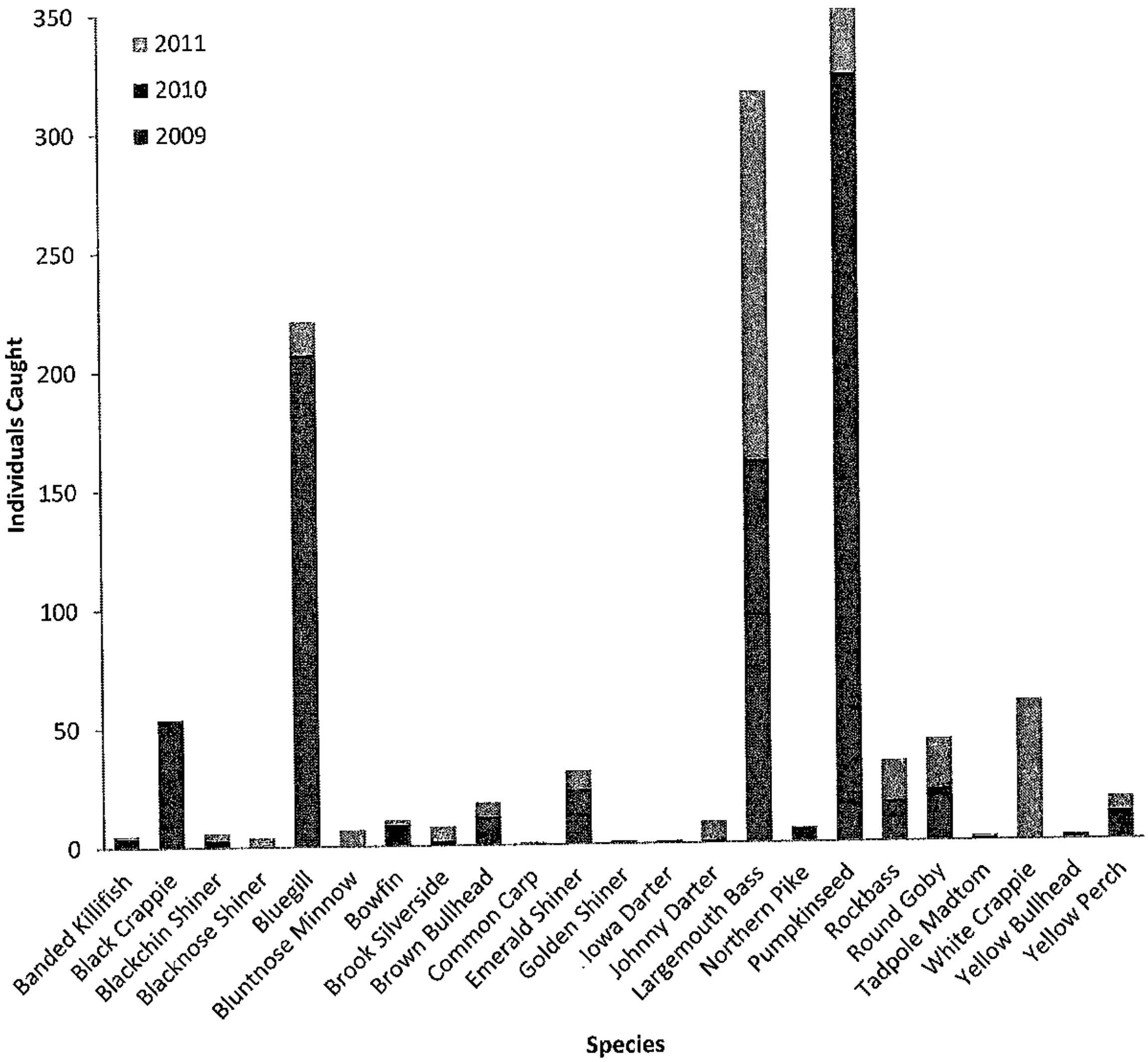

Figure 3. Number of individuals captures caught in Lincoln Lake during 2009-2011 sampling.

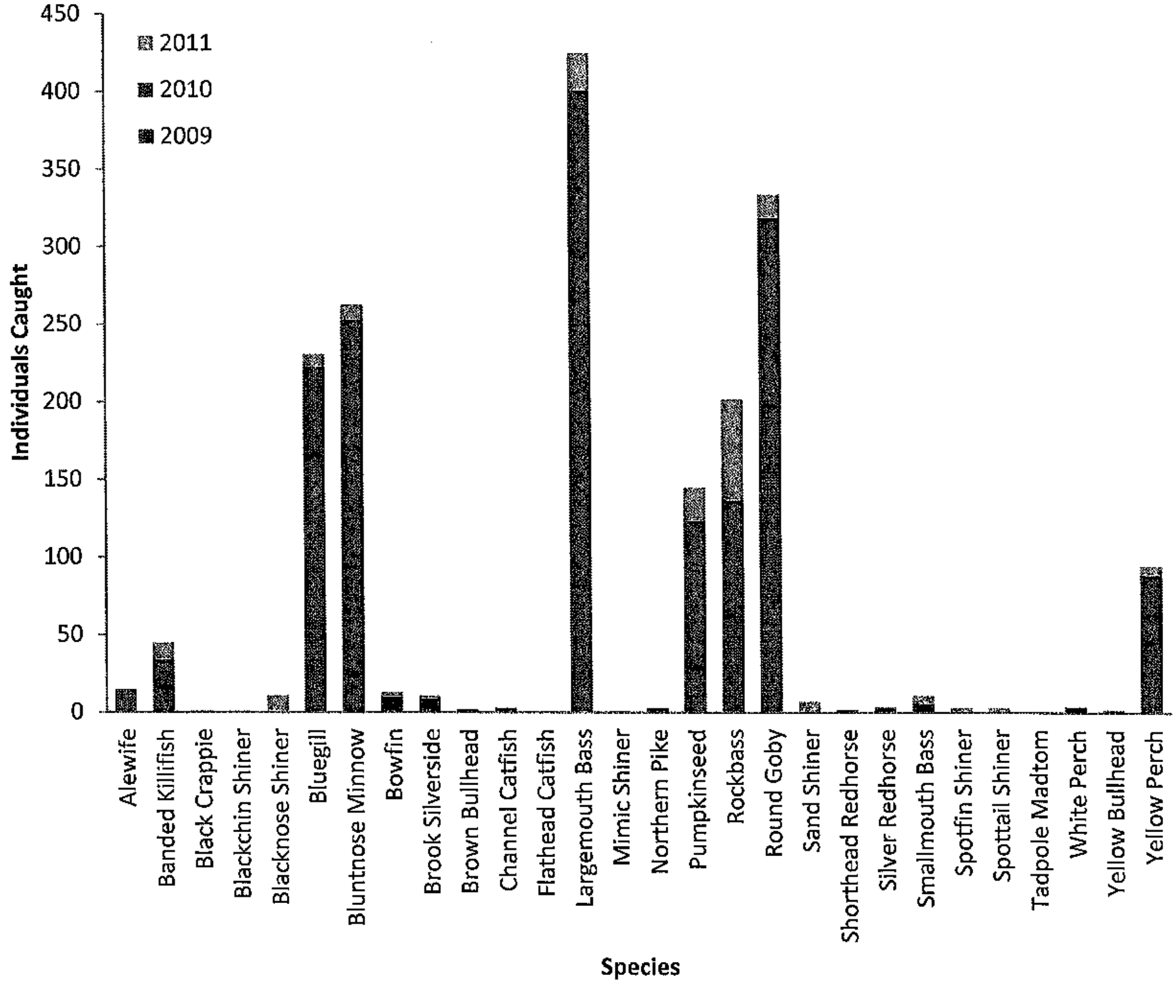

Figure 4. Number of individuals captures caught in Muskegon Lake during 2009-2011 sampling.

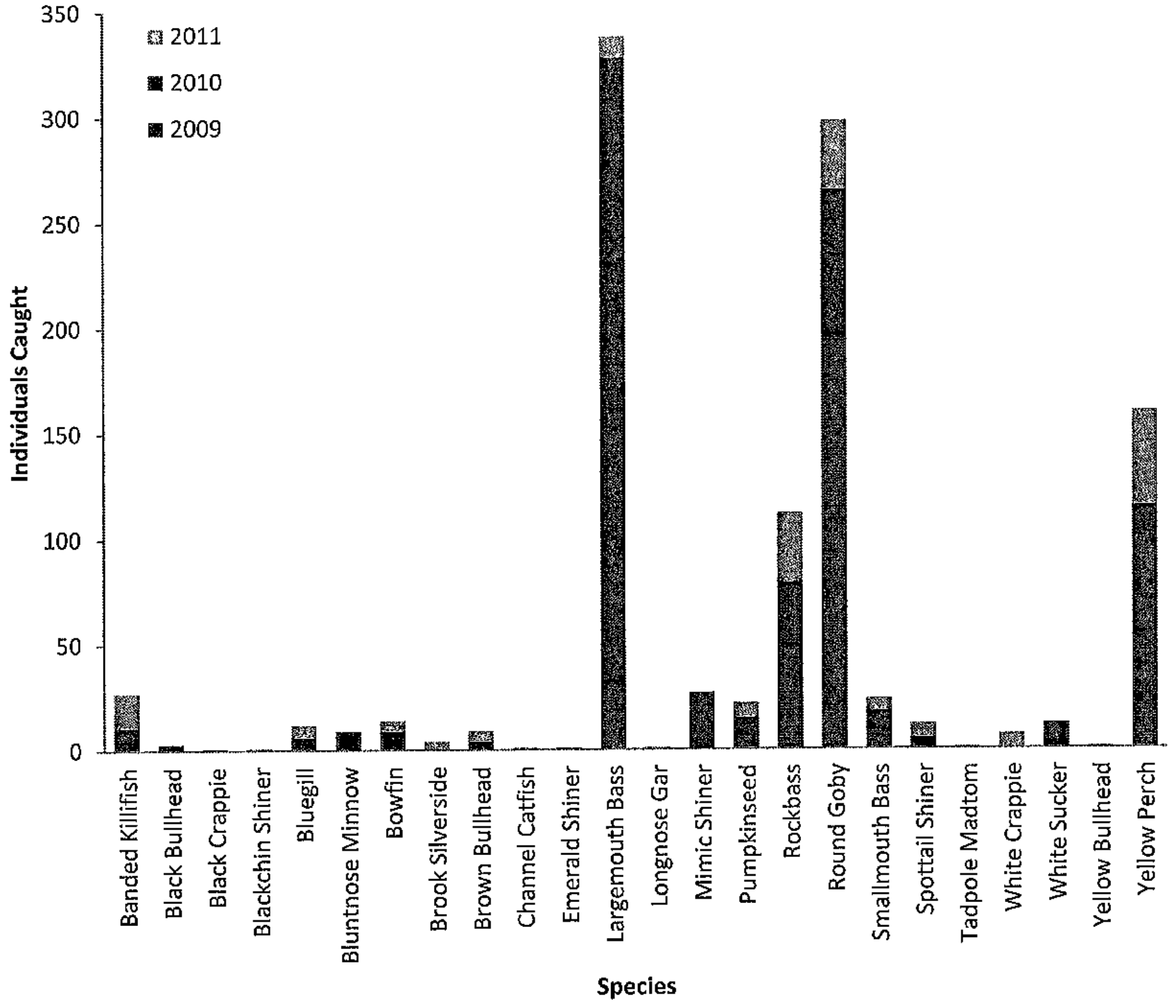

Figure 5. Number of individuals captures caught in Pentwater Lake during 2009-2011 sampling.

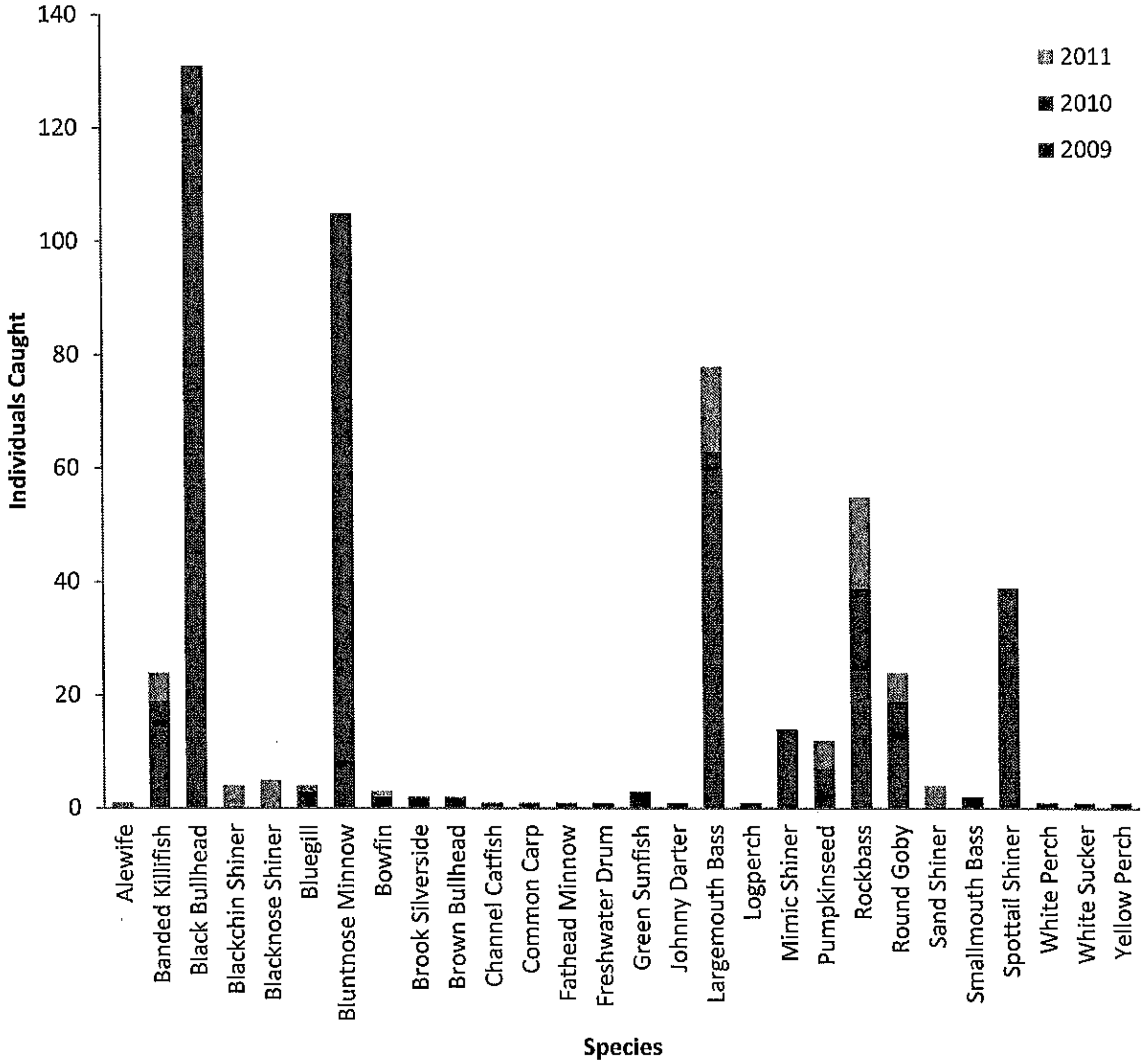

Figure 6. Number of individuals captures caught in Pigeon Lake during 2009-2011 sampling.

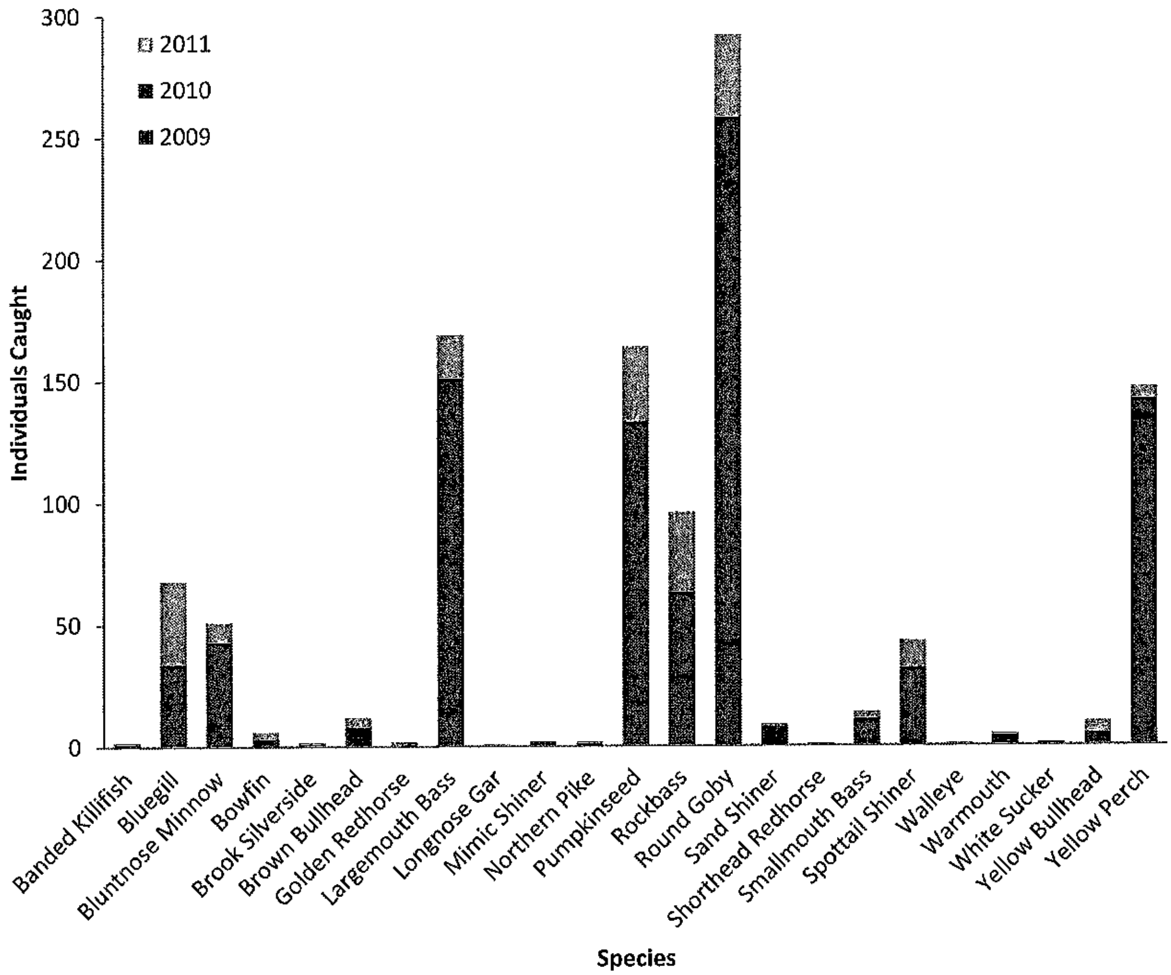

Figure 7. Number of individuals captures caught in White Lake during 2009-2011 sampling.

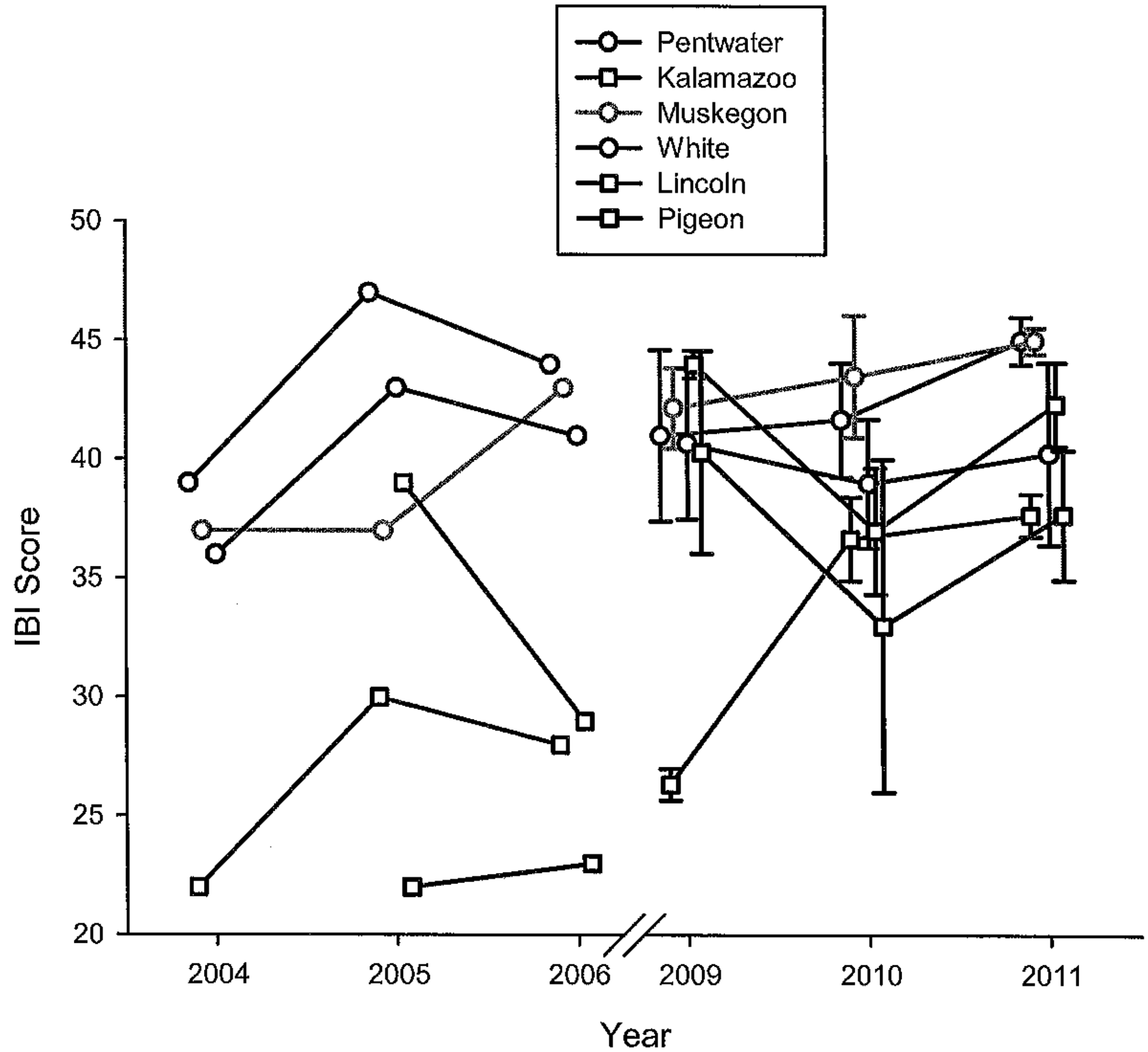

Figure 8. Scores from fish-based index of biotic integrity (IBI) for six drowned river mouth lakes. One site with submerged aquatic vegetation (SAV) was sampled in each lake during 2004-2006 and at least three sites with SAV were sampled in each lake during 2009-2011. Observations during 2004-2006 were used to set numerical delisting target, and observations during 2009-2011 were used to evaluate numerical delisting target. Error bars represent ± 1 standard error.

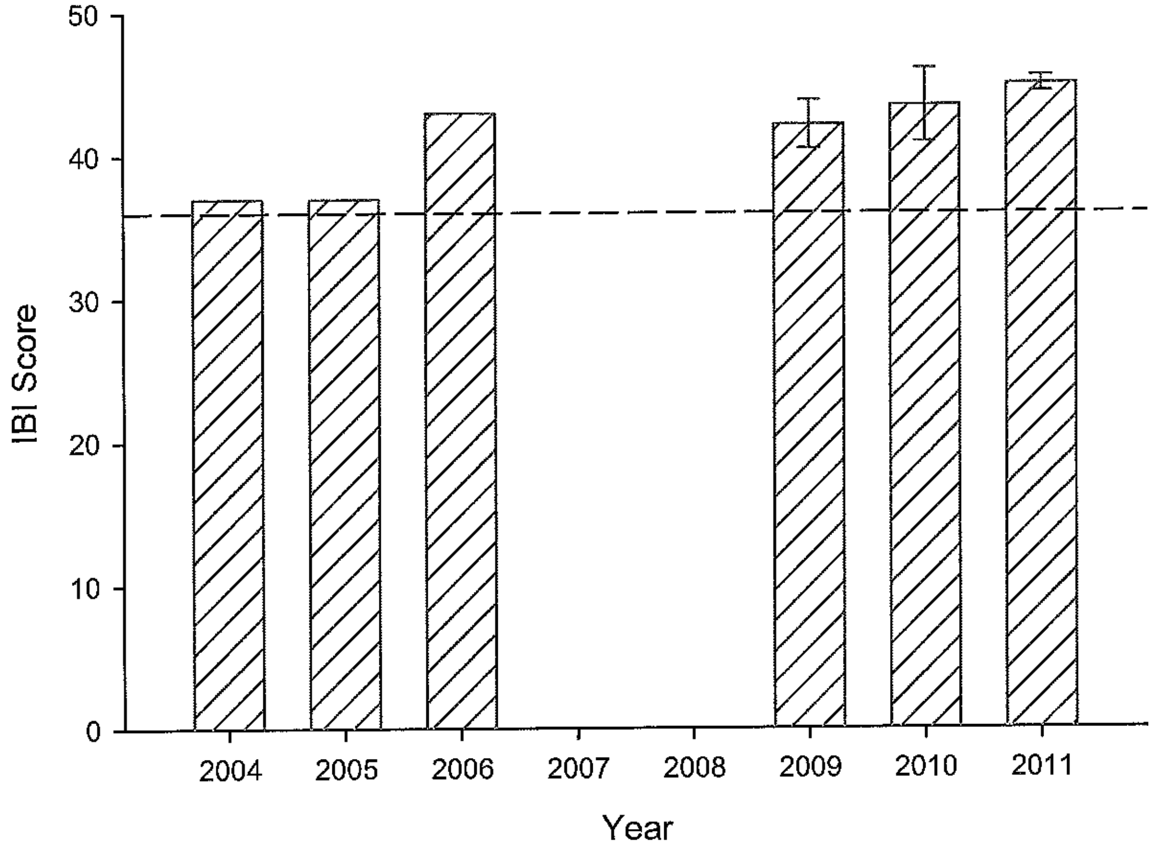

Figure 9. Scores from fish-based index of biotic integrity (IBI) for Muskegon Lake. The dashed line represents the numerical delisting target of 36. Error bars represent ± 1 standard error.