

**COMPILED REPORTS TO THE GREAT LAKES
FISHERY COMMISSION OF THE ANNUAL BOTTOM
TRAWL AND ACCOUSTICS SURVEYS, 2013**



2014

**PREPARED BY
THE U.S. GEOLOGICAL SURVEY, GREAT LAKE SCIENCE CENTER**



Suggested Citation

USGS (U.S. Geological Survey). 2014. Compiled reports to the Great Lakes Fishery Commission of the annual bottom trawl and acoustics surveys for 2013 [online]. Available from http://www.glfrc.org/pubs/lake_committees/common_docs/CompiledReportsfromUSGS2014.pdf [accessed day-month-year].

Table of Contents

Fisheries Research and Monitoring Activities of the Lake Erie Biological Station, 2013...	1
R.T. Kraus, M.R. Rogers, P.M. Kocovsky, W.H. Edwards, B. Bodamer-Scarbro, K. Keretz, and S. Berkman	
Great Lakes Prey Fish Populations: A Cross-Basin Overview of Status and Trends Based on Bottom Trawl Surves, 1978-2013.....	43
O.T. Gorman, and B.C. Weidel	
Status and Trends in the Lake Superior Fish Community, 2013.....	52
M.R. Vinson, L.M. Evrard, O.T. Gorman, and D.L. Yule	
Status and Trends of Pelagic Prey Fish in Lake Huron, 2013.....	60
T.P. O'Brien, D.M. Warner, S.A. Farha, D.W. Hondorp, L. Kaulfersch, and N. Watson	
Status and Trends of Prey Fish Populations in Lake Michigan, 2013.....	74
C.P. Madenjian, D.B. Bunnell, T.J. Desorcie, M.J. Kostich, P.M. Armenio, and J.V. Adams.	
Status and Trends of the Lake Huron Offshore Demersal Fish Community, 1976-2013....	90
S.C. Riley, E.F. Roseman, M.A. Chriscinske,, T.R. Tucker, J.E. Ross, P.M. Armenio, N. Watson, and W. Woelmer	
Status of Pelagic Prey Fishes in Lake Michigan, 2013.....	103
D.M. Warner, S.A. Farha, T.P. O'Brien, L.M. Ogilvie, R.M. Claramunt, and D. Hanson	

Fisheries Research and Monitoring Activities of the Lake Erie Biological Station, 2013

Department of the Interior
U.S. Geological Survey
Great Lakes Science Center
Lake Erie Biological Station
6100 Columbus Avenue
Sandusky, Ohio 44870

Richard Kraus, Ph. D.	Station Chief and Research Fishery Biologist
Mark Rogers, Ph. D.	Research Fishery Biologist
Patrick M. Kocovsky, Ph. D.	Research Fishery Biologist
William H. Edwards, B.S.	Fishery Technician
Besty Bodamer-Scarbro, M.S.	Fishery Technician
Kevin Keretz, B.S.	Fishery Technician
Stephanie Berkman, B.S	Fishery Technician

¹Presented at: Great Lakes Fishery Commission
Lake Huron Committee Meeting
March 24, 2014

Scientific Names and Abbreviations

The following scientific names correspond to the common names of fishes in this report:

Scientific name	Common name
<i>Alosa pseudoharengus</i>	Alewife
<i>Ambloplites rupestris</i>	Rock Bass
<i>Ameiurus nebulosus</i>	Brown Bullhead
<i>Aplodinotus grunniens</i>	Freshwater drum
<i>Carpiodes cyprinus</i>	Quillback
<i>Catostomus commersonii</i>	White Sucker
<i>Cyprinus carpio</i>	Common Carp
<i>Dorosoma cepedianum</i>	Gizzard shad
<i>Ichthyomyzon unicuspis</i>	Silver Lamprey
<i>Ictalurus punctatus</i>	Channel Catfish
<i>Labidesthes sicculus</i>	Brook Silverside
<i>Macrhybopsis storeriana</i>	Silver chub
<i>Micropterus dolomieu</i>	Smallmouth bass
<i>Morone americana</i>	White perch
<i>Morone chrysops</i>	White bass
<i>Moxostoma erythrurum</i>	Golden Redhorse
<i>Moxostoma macrolepidotum</i>	Shorthead Redhorse
<i>Neogobius melanostomus</i>	Round goby
<i>Notropis atherinoides</i>	Emerald shiner
<i>Notropis hudsonius</i>	Spottail shiner
<i>Osmerus mordax</i>	Rainbow smelt
<i>Perca flavescens</i>	Yellow perch
<i>Percina caprodes</i>	Logperch
<i>Percopsis omiscomaycus</i>	Trout-perch
<i>Sander vitreus</i>	Walleye

The following abbreviations are used throughout this report:

Abbreviation	Expansion
DFO	Department of Fisheries and Oceans
FTG	Forage Task Group
LEBS	Lake Erie Biological Station
LTLA	Lower Trophic Level Assessment
MDNR	Michigan Department of Natural Resources
MSU	Michigan State University
NOAA	National Oceanic and Atmospheric Administration
ODNR	Ohio Department of Natural Resources
OMNR	Ontario Ministry of Natural Resources
OSU	The Ohio State University
USEPA	US Environmental Protection Agency
USFWS	US Fish and Wildlife Service
WTG	Walleye Task Group
YAO	Yearling and older (age 1 and older)
YOY	Young of the year (age 0)
YPTG	Yellow Perch Task Group

Executive Summary

In 2013, the U.S. Geological Survey's Lake Erie Biological Station successfully completed large vessel surveys in all three of Lake Erie's basins. Lake Erie Biological Station's primary vessel surveys included the Western Basin Forage Fish Assessment and East Harbor Forage Fish Assessment as well as contributing to the cooperative multi-agency Central Basin Hydroacoustics Assessment and the Eastern Basin Coldwater Community Assessment (see Forage Task Group and Coldwater Task Group reports, respectively). Further large vessel sampling included individual research data collection as well as assisting with University (e.g., University of Toledo) and agency (e.g., USFWS, USEPA) large vessel sampling needs. Our 2013 vessel operations began on April 4th and concluded on November 21 with a total of 77 large vessel sampling days (83 total days). During this time, crews of the R/V Muskie and R/V Bowfin deployed 174 trawls covering 147 km of lake-bottom, over 13 km of gillnet, collected hydroacoustic data that extended over 250 km of the central and eastern basins, and approximately 180 collective zooplankton, benthos, and water samples.

2013 was the first complete sampling year using the R/V Muskie. Technologies available on the new platform provided opportunities for LEBS to improve data sampling methods and results. An investment was made in mensuration gear for the trawls. This gear is attached to the trawl's headrope, footrope, and wings; thus, allowing measurement of the area swept and conversion of catches to densities. Another improvement included real-time output of water parameter sonde profiles (e.g., temperature, dissolved oxygen). The ability to view profile data on a tablet allowed quick identification of thermoclines as well as the presence (or absence) of hypoxia. Minor modifications were made to survey designs relative to last year (see 2013 report), and thus, collection of long-term data from the R/V Muskie has commenced. One minor change was that we are now indexing yellow perch maturation data during our fall trawl surveys in response to a request from the Lake Erie Yellow Perch Task Group. Within the following sections, we describe results from our 2013 sampling efforts in Lake Erie.

1.0 Western Basin Forage Fish Assessment

Abstract

Since 2004, the U.S. Geological Survey Lake Erie Biological Station has participated in a collaborative, multiagency effort to assess forage fish populations in the western basin of Lake Erie. The objectives of this evaluation were to provide estimates of densities of key forage and predator species in the western basin of Lake Erie, to assess seasonal and spatial distributions of fishes, and to assess year class strength of key forage and predator species. Under a recently revised sampling design, we sampled 41 stations during two sampling rounds that occurred in June and September. Each station was sampled with a bottom trawl, and we calculated number and biomass per hectare (CPH) swept for fish species in western Lake Erie. Our grid sampling design also permitted us to examine the distribution of water quality variables that may correlate with fish distribution; therefore, we also present interpolated maps of temperature and conductivity. Finally, this year marked the first time we were able to use acoustic net mensuration gear to measure trawl performance at each station, and here we included an analysis of trawl mensuration data that aided us in optimizing the efficiency of the trawl.

Introduction

The primary long-term objective of the Lake Erie Biological Station (LEBS) western basin bottom trawl assessments is to contribute estimates of forage fish density to the interagency database for assessing seasonal and spatial distributions of forage fishes. A second key objective is to estimate year-class strength of key forage and predator species. Indices of abundance of yellow perch are provided to the Yellow Perch Task Group of the Lake Erie Committee of the Great Lakes Fishery Commission as one of the inputs used in population modeling and stock assessments. Our data augment those collected by OMNR and ODNR, who have cooperatively sampled forage fishes throughout the western basin of Lake Erie in August since 1987. The 2013 season was the tenth consecutive year of this collaboration. Additionally, USGS was the only agency conducting bottom trawl sampling within Michigan waters of the western basin during this period. This report describes the primary results from the 2013 sampling effort.

Methods

The recently revised grid sampling design was carried out in both June and September, referred to here as spring and fall, respectively. The revised design complements the long time series of combined efforts between Ohio and Ontario and provides a foundation for addressing ongoing and emerging issues facing Lake Erie task groups. The sampling domain was defined based upon operational limits of depth ($\geq 4\text{m}$) and zoogeographic boundaries (Lorain ridge to the east, and the mouths of major rivers). The spacing of the grid was 6 minutes of longitude (E-W) and latitude (N-S) and the offset (from exact 6 minute intersections of latitude and longitude) was chosen to provide the maximum number of sampling locations that could be completed within a week ($n=41$). Due to interference from shipping lanes, the grid was shifted south by 1.85 km after the June sampling trip. Adjustment of the entire grid was preferred to subjectively moving a few sampling points, which may have biased our results in the region of major shipping lanes. The work was conducted from the R/V Muskie: a 70' LOA, purpose-built research vessel with a mono-hull and twin props. The bottom trawl net was a four-seam, three-

bridle, bottom trawl, with a fishing circle that was 200 meshes by 12 cm mesh size. The body of the net transitions from a mesh size of 12 cm to 6 cm and is constructed of polyethylene. The cod end liner is constructed of knotless nylon with a stretched mesh size of 14 mm. The head rope length is 11.2 m and the foot rope length is 14.2 m. To accommodate hard bottom habitats, the sweep was designed with 8" rubber discs interspersed between 3" rubber discs in a configuration called a "rubber cookie sweep", known to be successful for trawling for squid on glacial moraines in the north Atlantic. The bridle length is 36.6 m overall with a junction between the top and middle bridle at 18.3 m. The bridle is constructed of wire rope, with ½" diameter cable on the bottom bridle, and 3/8" diameter cable on the middle and top bridles. To fish this net we used high performance steel doors, Thyboron Type IV, outfitted with heavy duty ball bearing swivels to reduce asymmetric twisting resistance in the trawl warps. The headline height was consistently 3.0 m when measured with acoustic mensuration gear during trawling. Average wing spread varied both as a function of depth and warp scope; therefore, we analyzed wing spread to determine which warp length to depth ratio provided the most efficient wing spread. A brief synopsis of the wing spread analysis is provided in the subsequent section of this report. Prescribed trawling time was 10 minutes, and the average distance towed at a target speed of 3 knots was 934 m (s.d.=76). Area swept for each trawl sample was calculated as the product of the distance towed and the average wingspread. The average area swept (all samples pooled) was 0.5 hectares (s.d.=0.05). At each location, we also recorded water quality profiles with a YSI®6600 series multiparameter sonde, and in this report we provide a spatially interpolated summary of the distribution of temperature and

conductivity as it relates to important habitat for fishes.

For each trawl sample, fish were sorted by species and size mode (determined by eye) and each of these categories was weighed in aggregate. A subsample (maximum n=10) from each of these age-size categories was measured for individual lengths and weights (using either a triple beam balance or a motion compensating scale). When the total count exceeded the subsample, the total count was calculated by dividing the aggregate weight by the mean individual weight. Exceptions to this procedure were percids, for which each individual was measured (length and weight), and small fish with individual weights that fell below the accuracy of our scale. For the former situation with percids, on a few occasions the catch of yellow perch was so large that we used gravimetric extrapolation. For the latter situation, the subsample of fish was weighed in aggregate to obtain the average individual weight, but individual total lengths were still obtained for the subsample. Size modes determined in the field corresponded with historical inter-agency size ranges for age-groups of focal species, supporting estimation of age-group specific summaries by species. If size modes had not matched, catch summaries for conventional age-groups would have been determined from empirical size distributions (calculated by summing size frequency distributions for each size mode within species) in order to support comparisons with data from other agencies.

Results and Discussion

The 2013 western basin trawl survey season marked the first year in which the grid sampling design was employed in both June (spring) and September (fall). Overall, we captured 168,766 and 51,662 fish respectively in June and September, and for the first time in the history of the survey we were able to provide information on the distribution of both relative abundance and biomass of fishes

throughout the western basin. Further, use of the same gear throughout the entire area of interest allowed direct spatial comparisons without the need to adjust values for systematic variations in gear and vessel performance with fishing power correction factors (Tyson et al. 2006). The ability to examine both abundance and biomass distributions supports a wider range of analyses to address fish community goals and objectives for Lake Erie. For example, numeric catch values relate directly to stock assessments as indices of young-of-year abundance that predict the population size of age-classes recruiting to the fishery. By comparison, the addition of biomass data can support ecosystem level analyses that predict how nutrients and energy are transformed within the food web.

When comparing abundance versus biomass at a fundamental level, the rank order of species in the western basin looks dramatically different. The most abundant species numerically are emerald shiner and white perch, respectively in spring and fall (Figure 1.1). In terms of biomass, freshwater drum are an order of magnitude higher than the second ranked species (Figure 1.1). Changes in the numerical rank order of species between spring and fall reflect inherently more abundant young-of-year (YOY) individuals that grew to a size that is retained by our bottom trawl. This effect is primarily reflected in yellow perch, gizzard shad, and trout perch (Figure 1.1). Similar magnitude changes in rank are not necessarily reflected in biomass because individual weights of YOY are relatively small. An opposite but analogous situation is represented by emerald shiner in which a reduction in rank reflects attrition of adults between spring and fall, and YOY that are still not quite large enough to be fully retained by the gear (Figure 1.1). The picture that these data provide emphasizes strong seasonal changes in the

food web at upper trophic levels of the western basin ecosystem.

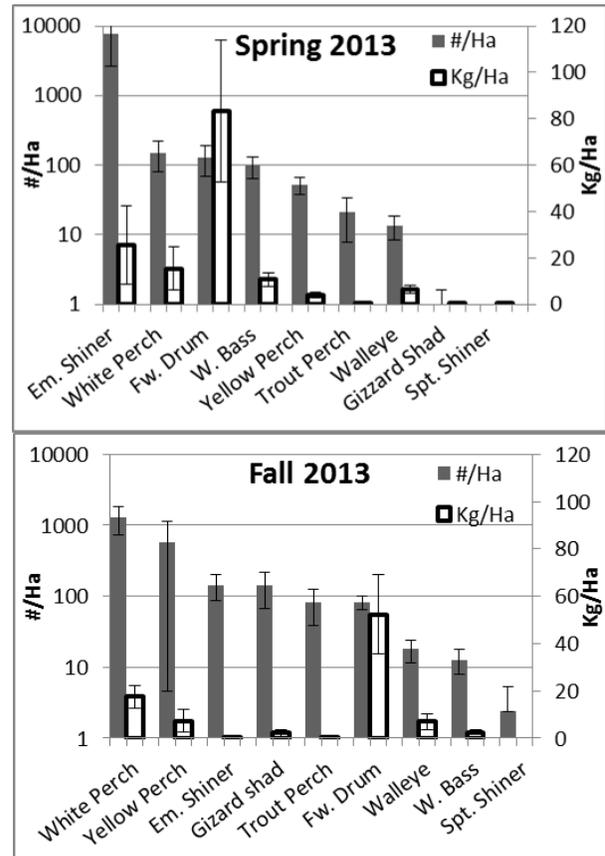


Figure 1.1 Spring and fall means of number and biomass (per hectare) of the most abundant fishes captured in bottom trawl samples from the western basin of Lake Erie.

The diversity in the catches was higher in fall than spring with a grand total of 25 unique fish species (**Table 1.1**). Some rare species contributed to the diversity including: silver lamprey, two species of redborse suckers, and brook silverside, which have only been recorded sporadically in low numbers historically on this survey. Of particular note is the high catch rate of alewife, both YOY and yearling-and-older (YAO) ages (Table 1.1) indicating successful reproduction and recruitment both in 2012 and 2013. In previous years of this survey, alewife have only been observed sporadically and in small numbers. Catch rates expressed per hectare (CPH) are reported here (Table 1.1) to provide

a reference for comparison with partner indices.

Table 1.1. June and September catch rates (number per hectare, CPH) of fishes from the western basin of Lake Erie in 2013.

Species	Spring CPH	Fall CPH
Emerald Shiner YAO	9950	26
White Perch YOY		1095
Alewife YOY		763
White Perch YAO	158	197
Yellow Perch YOY		340
Yellow Perch YAO	53	246
Freshwater Drum YAO	131	80
Gizzard Shad YOY		165
Emerald Shiner YOY		154
White Bass YAO	103	15
Trout Perch YAO	29	84
Rainbow Smelt YAO	94	2
Alewife YAO	58	26
Rainbow Smelt YOY		42
Round Goby	19	9
Channel Cat YAO	7	21
Brook Silverside		24
Quillback YAO	9	14
Trout Perch YOY		22
Silver Chub YAO	13	7
Walleye YAO	8	12
Spottail Shiner YAO	6	11
Gizzard Shad YAO	4	9
Brown Bullhead	9	2
Common Carp YAO	5	5
White Sucker YAO	6	4
Logperch YAO		9
Walleye YOY		8
Smallmouth Bass YOY		7
Rock Bass	4	2
Spottail Shiner YOY		6
Smallmouth Bass YAO	2	3
Shorthead Redhorse YAO	2	2
Golden Redhorse YAO	4	
Silver Lamprey		2
Freshwater Drum YOY		2

We also examined the spatial distribution of biomass for percids (Figure 1.2), for key forage species (Figure 1.3), and for dominant fishes that are captured as the target or as by-catch in Lake Erie recreational and commercial fisheries (Figure 1.4). The percids showed pronounced changes in distribution between spring and fall. Age-1 and age-2+ walleye were broadly distributed in the spring, but in the fall the biomass for these ages was concentrated around the reef complexes (Figure 1.2). Walleye YOY were distributed throughout the sampling domain with conspicuous absence of fish from the northwest area in Canada near the Detroit River and the southwest area along the Pelee-Lorain ridge (Figure 1.2). During spring, the highest biomass of yellow perch was in the western half of the sampling domain, primarily to the north of Pelee Island and in the Sandusky subbasin (Figure 1.2). During the fall, yellow perch biomass (both YOY and YAO) had shifted to the region northwest of the Lake Erie islands in Canadian waters (Figure 1.2). With the exception of emerald shiner in the spring, the biomass of common forage species was much lower than that of percids and generally reflected presence or absence of small catches (Figures 1.1 and 1.3). Emerald shiner were ubiquitous with concentrations of high biomass in the spring located along the northern shore west of Leamington, the southern shore in the Sandusky subbasin, and at a few stations due north of the Toussaint River (Figure 1.3). Gizzard shad occurred more frequently during fall sampling with YOY biomass concentrated near the US-Canada border in the region west of the islands. Round goby occurred mainly in Canadian waters during spring, and throughout the central portions of the sampling domain during fall (Figure 1.3). White perch, white bass and freshwater drum were ubiquitous (Figure 1.4). White perch

and white bass tended to be more concentrated in US waters (spring or fall). Freshwater drum biomass often approached 400 kg/h in most areas, with highest values at sites adjacent to islands (Figure 1.4).

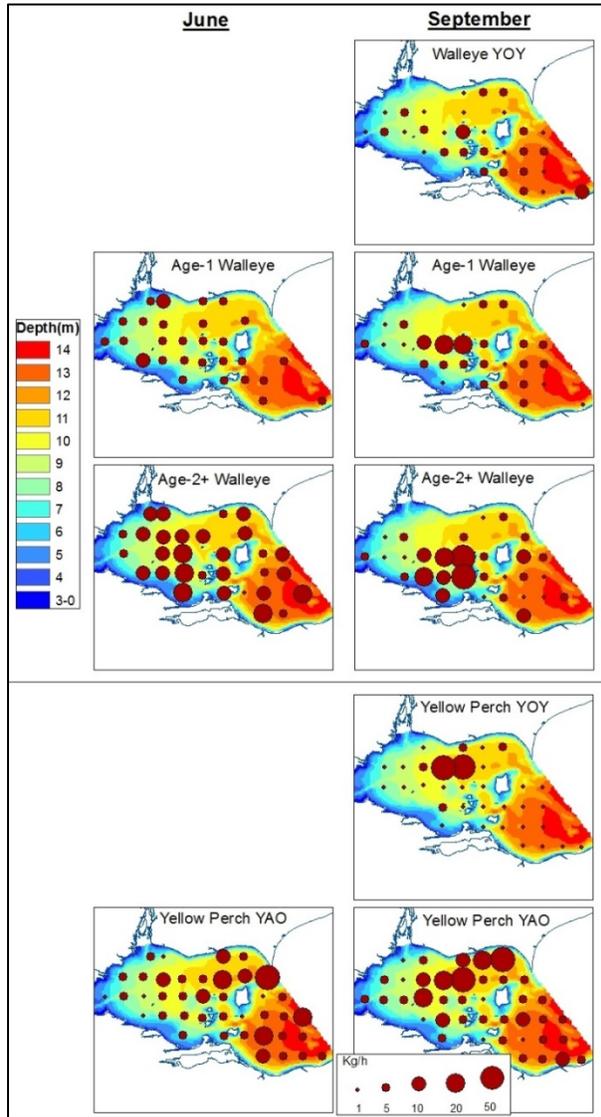


Figure 1.2 Spatial distribution of percid fish biomass (per hectare) from bottom trawl samples in the western basin of Lake Erie during 2013.

Fish are known to change spatial distribution in response to environmental gradients in temperature and mixing of water masses such as the river plumes observed in the western basin from the Detroit and Maumee Rivers. While an analysis of the correlations between

spatial distribution of fishes on our trawl survey and environmental factors is beyond the scope of this report, we developed maps of mean temperature, conductivity, and dissolved oxygen for the epilimnetic waters of the western basin (Figure 1.5).

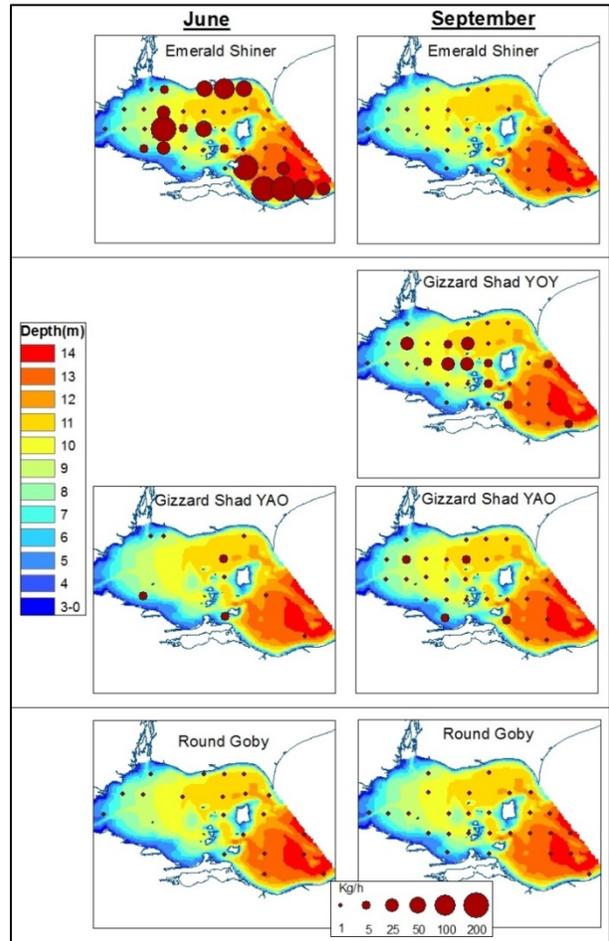


Figure 1.3 Spatial distribution of forage fish biomass (per hectare) from bottom trawl samples in the western basin of Lake Erie during 2013.

The major patterns emphasized the warmer conditions observed along the southern shore in association with the Maumee River plume and other major rivers between Toledo and Catawba Island (Figure 1.5). By comparison, waters extending from the Detroit River tended to have lower conductivity and temperature relative to the rest of the western basin. In addition, June was atypically warm in 2013, and the temperature gradient from west to east was more pronounced in June and the temperatures were warmer than in September, especially along the southern shoreline (Figure 1.5). East of the islands in the Sandusky subbasin, temperature and conductivity tended to be more homogeneous and similar to overall averages for the entire study area. These results are important for considering the role of environmental conditions on the recruitment success of percids in the western basin. For example, warm spring conditions in association with the Maumee River plume in the vicinity of the reef complexes in Ohio waters has been linked to favorable recruitment of walleye (Roseman et al. 2005).

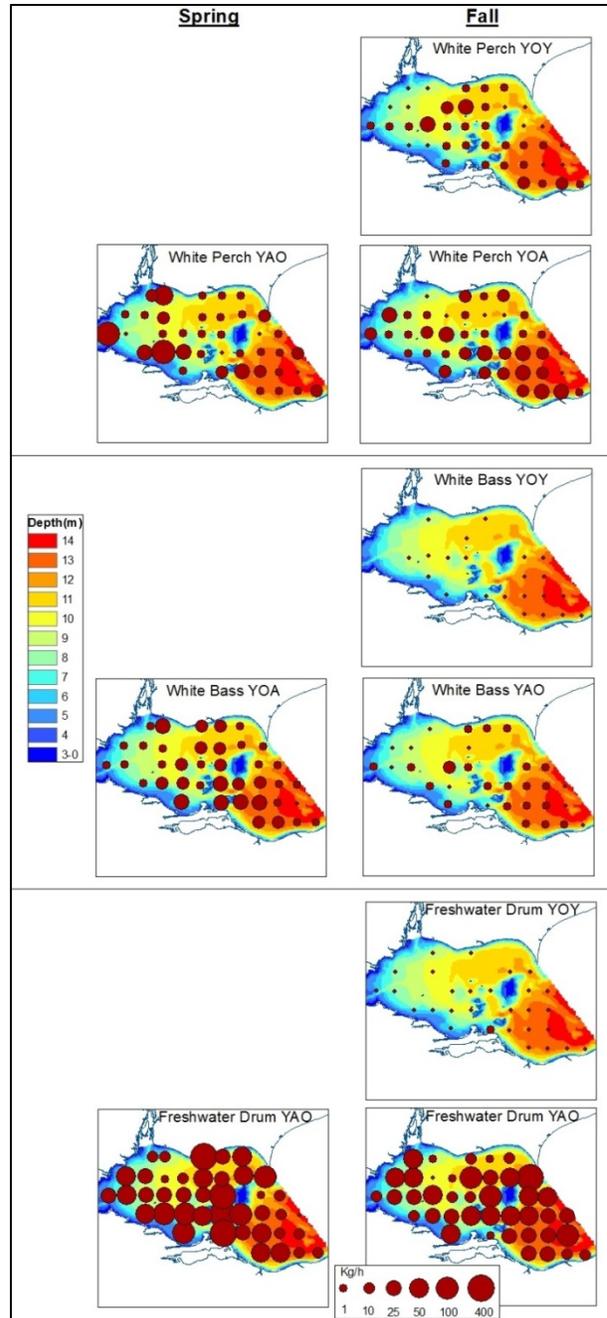


Figure 1.4 Spatial distribution of biomass (per hectare) of selected species from bottom trawl samples in the western basin of Lake Erie during 2013.

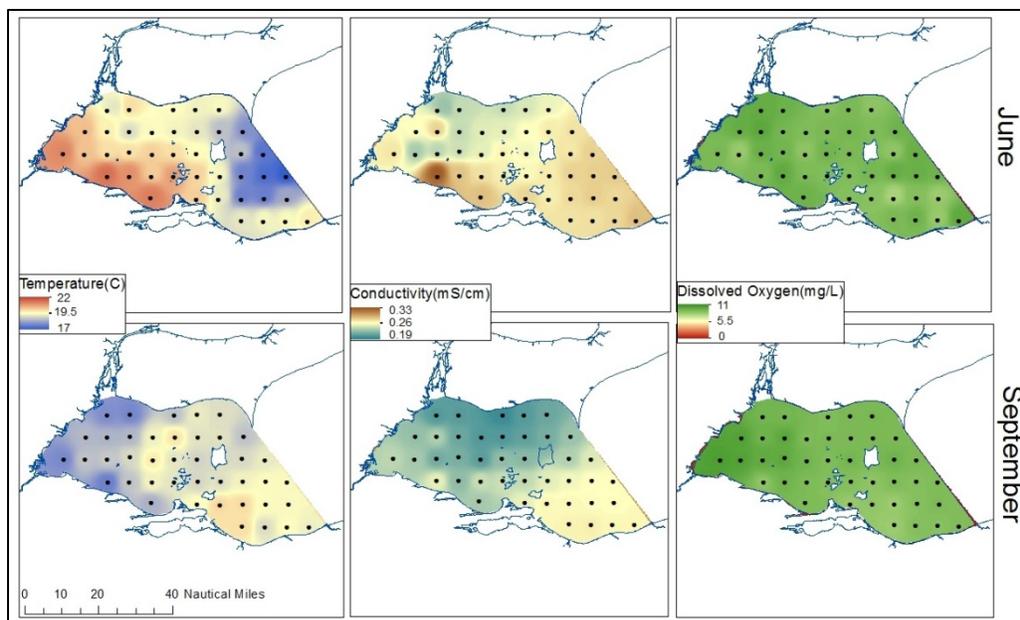


Figure 1.5 Spatial distribution of temperature (left), conductivity (middle), and dissolved oxygen at bottom trawl sampling locations in the western basin of Lake Erie during 2013.

2.0 Trawl Net Mensuration Results

The ability to evaluate trawl geometry throughout the course of a survey can greatly improve data quality and estimates of fish abundance by reducing the amount of variability that can result from gear performance. Bottom trawls are complex tools, and can be greatly affected by both operational (i.e. vessel and protocols) and environmental (i.e. bottom substrate, currents, and depth) factors (Bertrand et al. 2002; Weinberg & Kotwicki 2008). Fortunately, wireless net monitoring systems allow for the assessment of trawl performance, increasing both efficiency of field work and quality of results. The ability to identify and troubleshoot a “bad” trawl allows informed decisions to be made to either re-trawl, or to exclude unreliable data from analysis. In addition, net geometry data increases the accuracy of area swept measurements (calculated as wingspread x distance covered), which in turn increases the accuracy of fish abundance estimates.

Trawl-specific wing spread is critical to net geometry and increases the accuracy of fish density estimates. Additionally, wing spread can affect the fishing efficiency of the net, where deviations from optimal dimensions decrease the functionality of the trawl (von Szalay & Somerton 2005). As part of the research vessel replacement, LEBS acquired a NOTUS® Trawlmaster net mensuration system that was deployed on our bottom trawl during the 2013 season. We used the initial outputs from our trawl mensuration system to adjust warp length, net and door settings, and vessel speed to optimize the performance of the bottom trawl and achieve target wingspread (6.0 m) and net height (2.5 m) values based upon flume trials with a scale model of our net. We evaluated the effects of warp length and site depth on bottom trawl wing spread at 4:1, 5:1, 6:1 and 7:1 ratios (warp length to site depth), and we

evaluated wing spread across a range of depths for each ratio. Below is a short summary of the results from 2013 bottom trawls.

The four warp:depth ratios resulted in distinct logarithmic functions of site depth indicating that the length of warp deployed can have a large effect on net wingspread (Figure 2.1). The effect of warp appears to be minimal at shallower depths, and as a result, optimal wingspread may be difficult to achieve at depths less than 7 meters. As depth increases, however, the effect of warp on wing spread becomes more prominent, and the warp necessary to achieve optimal wing spread decreases. While increases in the warp:depth ratio from 4:1 to 5:1 increased the wingspread by approximate 0.5m at depths >5m, the effect of increasing the warp:depth ratio from 5:1 to 6:1 resulted in a comparatively small increase in wing spread at depths <7m. At the shallowest depths, we increased the warp:depth ratio to 7:1, but found only a very small response in wingspread, and regardless of warp:depth ratio, wingspread showed a sharp decline at depth <7m (Figure 2.1). These results suggest that warp:depth ratios of 6:1 and 5:1 are the most advantageous trawl deployment settings for our trawl/vessel at sites <7 and >7 meters, respectively, striking a balance between gear deployment time, vessel maneuverability, and achieving the maximum wing spread.

Recent harbor tests of the wingspread sensors indicated that 2013 measurements may be underestimated by as much as a meter. This underestimation is potentially due to internal software configurations that assume

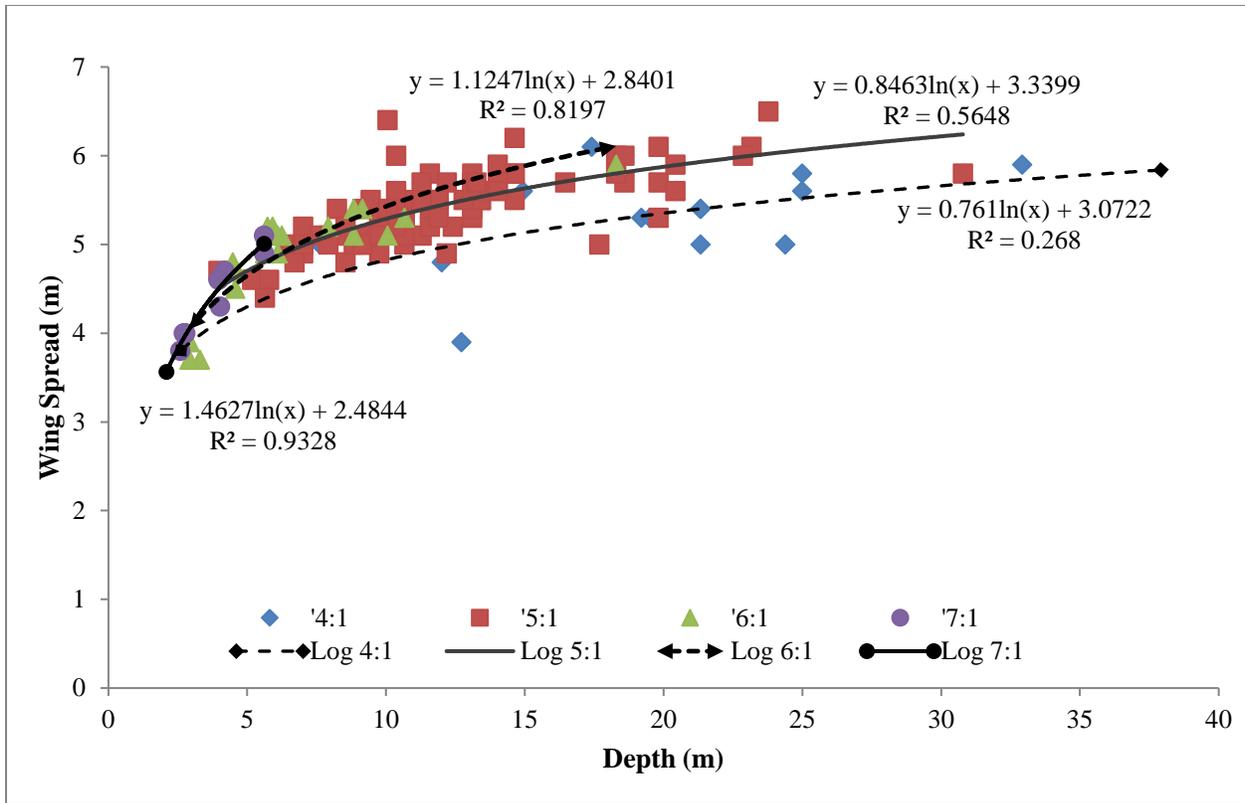


Figure 2.1 Changes in bottom trawl wingspread across depth at multiple warp length to depth ratios.

seawater conditions, rather than freshwater, resulting in the miscalculation of speed of sound through water and inaccurate distance estimations. For all future surveys, we plan to calibrate our NOTUS® sensors and develop a standard calibration protocol that is performed on a regular basis.

These data demonstrate the effect of warp and site depth on net geometry and functionality. By using the established relationships between site depth, warp, and optimal wingspread, trawls could be deployed quickly and efficiently, with minimal need for adjustment. We plan to continue to monitor net geometry in all future trawl surveys, as these variables are highly useful for maximizing trawl efficiency, determining trawl performance, and accurately estimating fish abundance.

3.0 Diet Analysis of Western Basin Age-2-and-Older Yellow and White Perch

Abstract

Native yellow perch and invasive white perch are abundant omnivores in western Lake Erie. We evaluated diets of age-2-and older yellow perch and white perch collected in Lake Erie's western basin during spring and autumn. Evaluation metrics included frequency of occurrence and contributions of prey to predator diets by weight. Benthic macroinvertebrates contributed most to yellow perch and white perch diets during spring, whereas fish prey were common in diets of both species during autumn. Compiling results from 2013 with data dating back to 2005 suggested decreased utilization of zooplankton for both yellow and white perch during spring and autumn and increased utilization of fish prey during autumn for both species.

Introduction

A fish's diet is the integrated response of multiple ecological interactions including habitat use, foraging behavior, prey community characteristics, and inter-specific interactions. Fish diet samples have quantified how the invasion of white perch into Lake Erie in the early 1950s has influenced interactions with native yellow perch which are similar in morphology and habitat use. Early research largely concluded that given the high foraging efficiency of white perch there is both high potential for inter-specific competition and that yellow perch have been negatively affected by the invasion of white perch (Parrish and Margraf 1990). More recent analyses using stable isotopes and diet contents suggest a low to moderate degree of overlap (Guzzo et al. 2013). Analysis of yellow perch diets has been proposed as a useful indicator of Lake Erie's benthic community relative to direct sampling of benthos (Tyson and Knight 2001). As part of the LEBS Western Basin Forage Fish Assessment, we annually evaluate diet composition of age-2-and-older yellow perch and white perch.

Methods

Yellow perch and white perch were collected using a bottom trawl during the USGS Western Basin Forage Assessment surveys in June (Spring) and September (Autumn), 2013 (See Section 1.0). A maximum of five age-2-and-older yellow perch and white perch that showed no signs of

regurgitation (exposed stomach or visible food content in the mouth cavity) at each bottom trawl site were retained for diet analysis. Total length, weight, sex, site location, and date were recorded for each collection. The digestive tract from each retained fish was removed, individually frozen in tap water, and returned to the laboratory for diet analysis. Otoliths were removed and processed in the laboratory to verify that our analyses were restricted to age-2-and-older fish.

In the laboratory, each fish sample was slowly thawed by immersing in cold tap water. The stomach was isolated from the digestive tract at the esophagus and pyloric caeca. The stomach was placed in a 0.25 mm sieve and cut lengthwise. Stomach contents were placed into a petri dish with soapy tap water to remove the surface tension of the water, thus allowing prey items to sink to the bottom of the dish where they were more easily identified. Once in the petri dish, stomach contents were quantified using a dissecting microscope and zooplankton, macroinvertebrates, and fish were counted and identified by taxon. A subsample was taken when ≥ 200 individuals of a particular prey item occurred in a given sample. To subsample, a petri dish was divided into eight equal sections and a count of each prey item was taken until 200 was reached. The area that contained $n=200$ was recorded and then extrapolated for the entire sample. Prey items from each stomach (when applicable) were dried at 60° C for 72 hrs to enumerate dry weights by prey taxon. For diet items that

could not be dried and weighed, length measurements were taken and later used to estimate dry weight using length-weight and wet-weight:dry-weight conversion equations (equations and sources available upon request).

Diet analyses included percent occurrence by number and percent composition by dry weight. Diet data from non-empty stomachs were used to calculate diet contribution metrics by predator type (i.e., yellow perch and white perch) and season for zooplankton, benthic macroinvertebrates, and fish prey. Percent occurrence was estimated as the number of fish examined that contained each prey item relative to the number of total fish with diet contents times 100. Percent composition by weight was calculated as the contribution of each prey type by dry weight to the total diet dry weight for each individual and then averaged across all fish for each species and season. Percent occurrence from 2013 sampling was compared to results from 2005-2012. For the historical comparison, we only used data from 2013 sampling that occurred in Michigan and Ontario waters, thus providing continuity in the time series.

Results

Frequency of occurrence

Fish that contained diet items were representative of the total range of length groups collected for both species and seasons (Figure 3.1). Lengths of fish with diet contents were also similar between species, however a few extra large yellow perch (i.e., total length exceeding 300mm) were caught during autumn sampling (Figure 3.1). The proportion of empty stomachs, relative to the number retained, was higher in the autumn than spring, and thus, we subsampled the number of sites used for diet analysis in spring. Subsampling was intended to allow diet description across the spatial extent of the

survey (Figure 3.2). The frequency of empty stomachs from autumn sampling resulted in processing of samples from all sites.

Spring sampling provided 102 age-2-and-older yellow perch stomachs from fish ranging between 160-300 mm in length. A total of 92 (90.2%) of the yellow perch stomachs contained prey. In spring 2013, benthic macroinvertebrates were present in almost all yellow perch stomachs (88.0%) and Chironomidae, *Dreissena* spp. and *Hexagenia* spp. were the most common benthic macroinvertebrates (Table 2.1). Zooplankton occurred in 19.6% of spring yellow perch diets with *Leptodora kindtii* occurring most at 14.3%. Fish prey had a 17.9% occurrence in yellow perch diets during spring sampling with emerald shiner being the most common at 8.7% (Table 2.1). During autumn sampling, 113 age-2-and-older yellow perch stomachs were collected from fish ranging from 140-320 mm in length with 43 (38%) of the stomachs containing prey. A decline in occurrence for both benthic macroinvertebrates (41.9%) and zooplankton (2.3%) was observed in autumn yellow perch diets relative to the spring. However, occurrence of fish prey increased dramatically from spring to autumn for yellow perch. Fish occurred in 62.8% of yellow perch and round goby was the most common identified fish prey occurring in 20.9% of stomachs. *Bythotrephes* sp. was only detected in autumn diets at low occurrence (2.3%).

Spring sampling provided 112 stomachs from age-2-and-older white perch with lengths between 140-290 mm. Ninety-three (83%) stomachs contained prey items. In spring, zooplankton was present in 30.4% of samples with *Daphnia retrocurva* and *Leptodora kindtii* occurring most frequently (16.1%).

Table 3.1 Percent occurrence of prey items found in the diets of age-2-and-older yellow perch and white perch collected during spring and autumn 2013 in Ontario and Michigan waters of Lake Erie's western basin.

Abbreviation: n=number of stomachs containing prey items.

Yellow Perch	White Perch
--------------	-------------

Prey Type	Prey taxa	2013 Spring n=92	2013 Autumn n=43	2013 Spring n=93	2013 Autumn n=104
Zooplanton		19.6	2.3	30.4	14.4
	<i>Bosmina</i> sp.	0.0	0.0	5.4	0.0
	<i>Bythotrephes</i> sp.	0.0	2.3	3.5	13.5
	<i>Calanoida</i> sp.	0.0	0.0	5.4	0.0
	<i>Chydorus</i> sp.	4.4	0.0	3.2	1.0
	<i>Cyclopoida</i> spp.	0.0	0.0	1.1	0.0
	<i>Daphnia retrocurva</i>	2.2	0.0	16.1	1.0
	<i>Daphnia</i> spp.	0.0	0.0	2.2	0.0
	<i>Diaphanosoma</i> sp.	1.1	0.0	1.1	0.0
	<i>Leptodora kindtii</i>	14.3	0.0	16.1	0.0
Benthic Macroinvertebrates		88.0	41.9	68.8	35.6
	Amphipoda	7.6	4.7	11.8	6.7
	Chironomidae	32.6	9.3	17.2	21.5
	<i>Dreissena</i> spp.	30.4	11.6	10.8	3.8
	Gastropoda	11.9	13.9	0.0	0.0
	<i>Hexagenia</i> spp.	27.1	0.0	40.9	2.9
	Hirudinea	11.9	2.3	5.4	2.9
	Nematoda	4.4	0.0	0.0	1.9
	Oligochaeta	2.2	0.0	1.1	0.0
	Ostracoda	1.1	0.0	3.2	1.0
	Sphaeriidae	19.6	4.7	1.1	2.9
	<i>Trichoptera</i> spp.	11.9	9.3	6.5	2.9
Crayfish		1.1	0.0	0.0	0.0
Fishes		17.9	62.8	26.9	63.5
	Emerald shiner	8.7	9.3	13.9	15.4
	Fish eggs	1.1	0.0	6.5	0.0
	Gizzard shad	0.0	6.9	0.0	1.0
	Round goby	2.2	20.9	2.2	1.9
	Rock Bass	1.1	0.0	0.0	0.0
	Trout-perch	1.1	0.0	1.1	0.0
	White bass	0.0	0.0	0.0	0.0
	White perch	1.1	2.3	0.0	1.0
	Unidentified fish	5.4	27.9	9.8	51.9

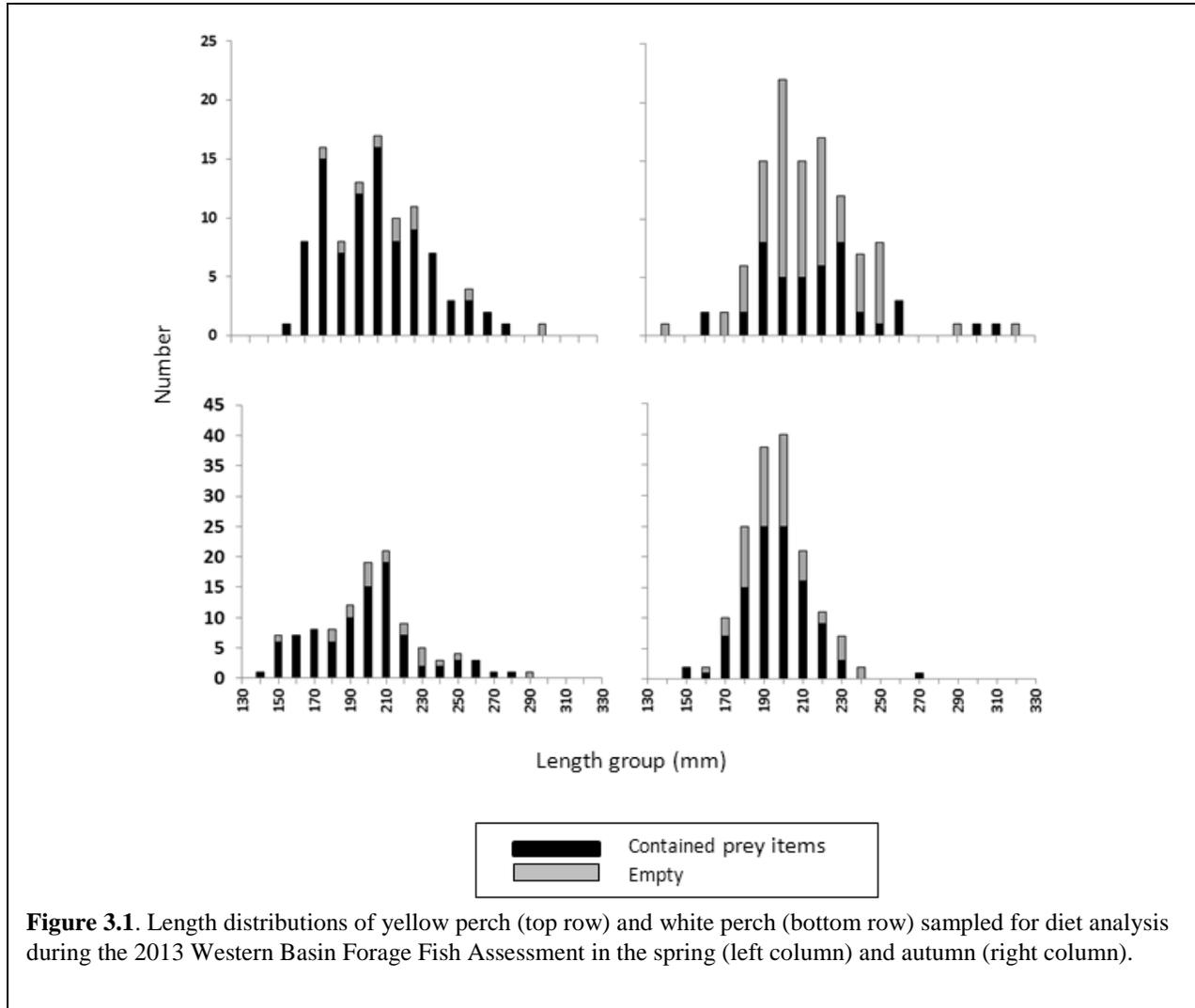
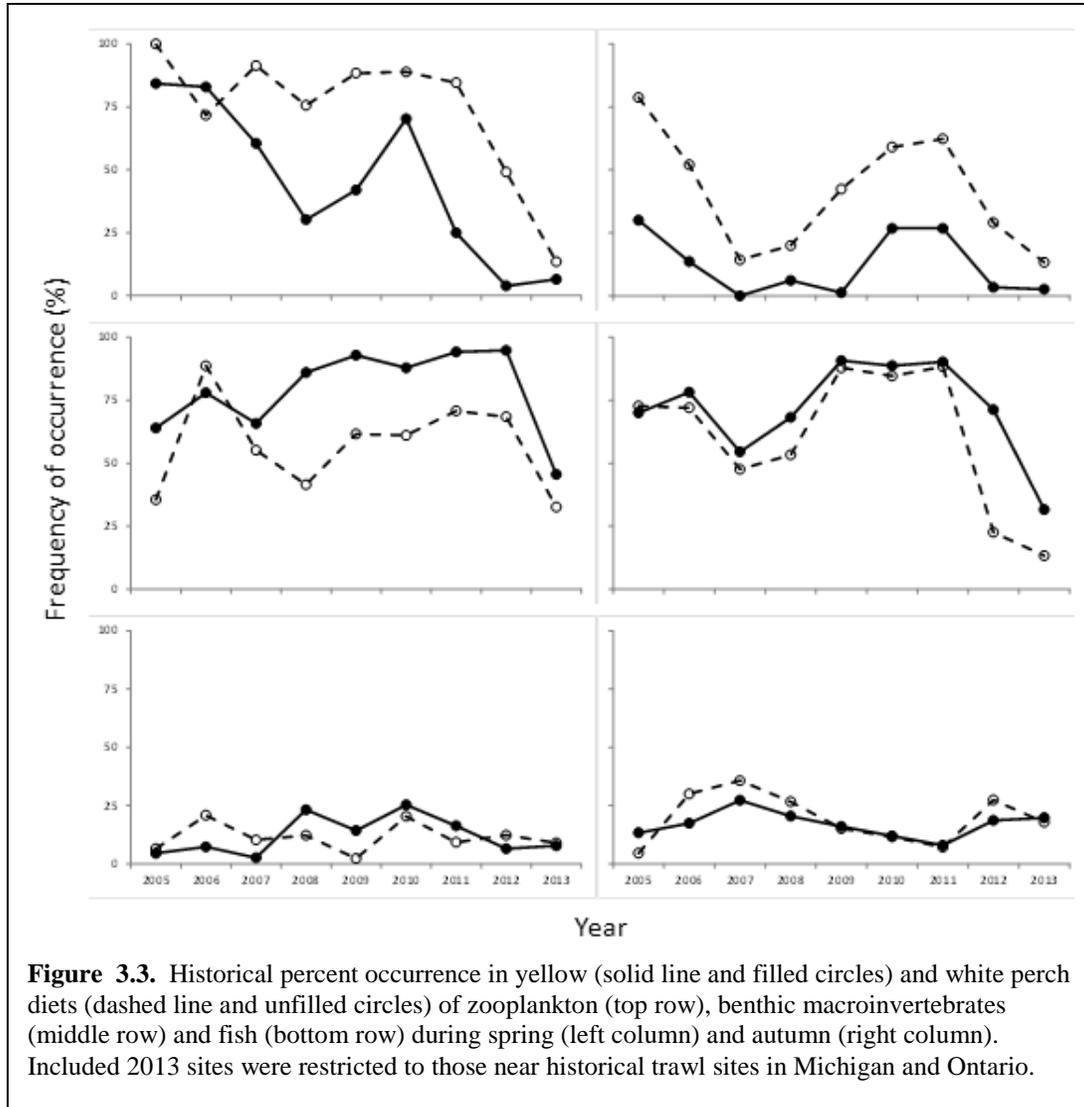


Figure 3.1. Length distributions of yellow perch (top row) and white perch (bottom row) sampled for diet analysis during the 2013 Western Basin Forage Fish Assessment in the spring (left column) and autumn (right column).



Figure 3.2. Percentage of stomachs with diet contents by site for yellow perch (top row) and white perch (bottom row) during spring (left column) and autumn (right column).

Benthic macroinvertebrates occurred in 68.8% of spring stomach samples with *Hexagenia* spp. being most common (40.9%). Fish were present in 26.9% of white perch stomachs with emerald shiners occurring most frequently during spring. Stomachs were collected from 158 age-2-and-older white perch that ranged from 150-270 mm during autumn sampling with 104 (65.8%) containing prey items. Fish were the most commonly occurring prey type in autumn (63.5), which was mostly composed of unidentified fish remains and emerald shiners (Table 3.1). Both zooplankton and benthic macroinvertebrates occurrence decreased from spring to autumn (Table 3.1).



Bythotrephes sp. was detected at low occurrence in spring (3.5%) and increased in autumn (13.5%).

Frequency of occurrence of zooplankton and benthic macroinvertebrates was lower for both white perch and yellow perch in 2013 than in 2012 during both seasons (Figure 3.3). Zooplankton occurrence has shown a declining trend over the past few years across both species in both seasons. Occurrence of zooplankton was up slightly in spring 2013 compared to 2012, but was still only found in 6.5% of diets. Occurrence of fish in yellow perch spring diets remained low (7.8%) and increased in the autumn (39.5% of diets). Historically, zooplankton was found in at least half of white perch sampled in spring

(maximum 100% in 2005), but they were only found in 14% of spring diets in 2013. Benthic macroinvertebrates in white perch diets were found about half as often as in 2012 across both seasons (Figure 3.2). A continuation of the recent trend in increased fish prey occurrence were observed in both predator species across seasons (Figure 3.2).

Percent composition by weight

Benthic invertebrates contributed most to age-2-and-older yellow perch diets in spring (74.6%), followed by fish prey (14.2%) and zooplankton (10.0%, Figure 3.4). *Dreissena* spp. and *Hexagenia* spp. were the predominant macroinvertebrate contributors by weight in the spring (Figure 3.5).

Leptodora kindtii & *Chydorus* spp. were the dominant zooplankton taxa, while emerald shiners were the most prominent identifiable fish prey in spring yellow perch diets (Figure 3.4). In autumn, fish prey showed a sharp increase relative to spring in contributing the most to diet weights in autumn (62.9%), followed by benthic macroinvertebrates (34.3%). The major fish prey taxa contributors in autumn were unidentified fish, round goby, and emerald shiner (21.7%, 19.5%, and 9.7%, respectively). Gastropoda and *Dreissena* spp. accounted for almost 60% of total benthic macroinvertebrates observed in diets. Zooplankton contributed very little (2.7%) to autumn yellow perch diets. Furthermore, neither *Bythotrephes* sp. contributed only 2.5% to yellow perch total diet weight in spring (Figure 3.4).

Spring white perch diets were predominantly composed of benthic macroinvertebrates (60%), followed by zooplankton (21.6%) and fish (18.6%) (Figure 3.3). *Hexagenia* spp. were the dominant benthic invertebrate taxa contributing 41% to diet weight on average in spring (Figure 3.4). *Leptodora kindtii* and emerald shiner were the dominant contributors for their prey groups, and White perch showed a shift towards increased piscivory in the autumn, while zooplankton (14.3%) and benthic macroinvertebrates (21.4%) made minor contributions to their diet weights. Unidentified fish and emerald shiners were the major fish prey taxa (47.8%, 13.8%) during autumn. Chironomids were the predominant benthic macroinvertebrate taxa and *Bythotrephes* sp. was the predominant zooplankton taxa during autumn (Figure 3.4).

In summary, yellow perch diets in spring were distributed across our western basin sampling area, whereas in fall the north shore near the Detroit River was under-represented due to a high number of empty stomachs (Figure 3.2). White perch diets were under-represented along the south shore and in the Sandusky Basin during spring, but were more evenly distributed in the fall (Figure

3.2). Yellow perch and white perch continued to exhibit lower occurrence of zooplankton and benthic invertebrates in diets in both the spring and the autumn. In contrast, both species exhibited increased occurrence of fish in diets in the autumn relative to the spring and this autumn frequency has increased in the past few years relative to historical data. *Hexagenia* spp. occurred frequently in diets in 2013 and contributed 40% to diet composition by weight in the spring. The timing of our spring sampling in 2013 coincided with a *Hexagenia* spp. hatch and we found multiple fish with full stomachs that were comprised completely of *Hexagenia* spp. We continued to detect high occurrence of *Dreissena* spp. in yellow perch diets, but importance of *Dreissena* spp. to diets may be overestimated in diet content studies due to digestion and evacuation differences relative to softer prey (Brush et al. 2012). In 2013, *Bythotrephes* sp. were infrequently observed in diets (maximum 13% of diets in white perch in autumn) and we observed no *Hemimysis* sp. or *Cercopagis* sp. in any fish diets.

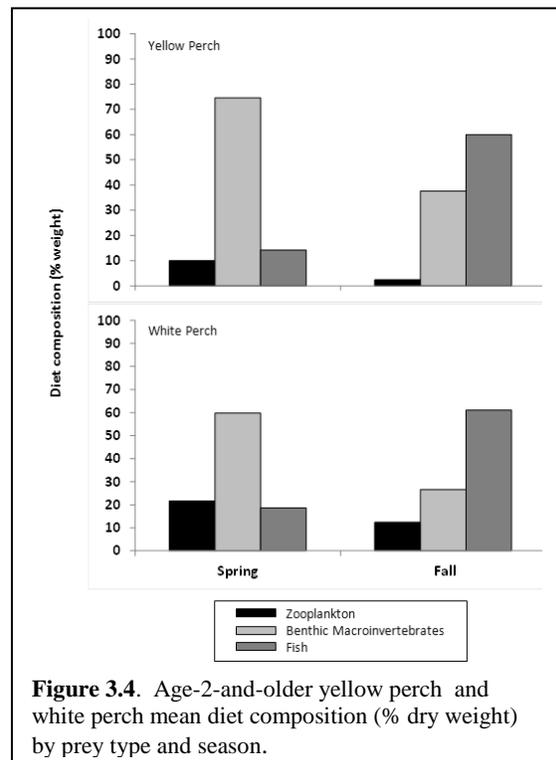


Figure 3.4. Age-2-and-older yellow perch and white perch mean diet composition (% dry weight) by prey type and season.

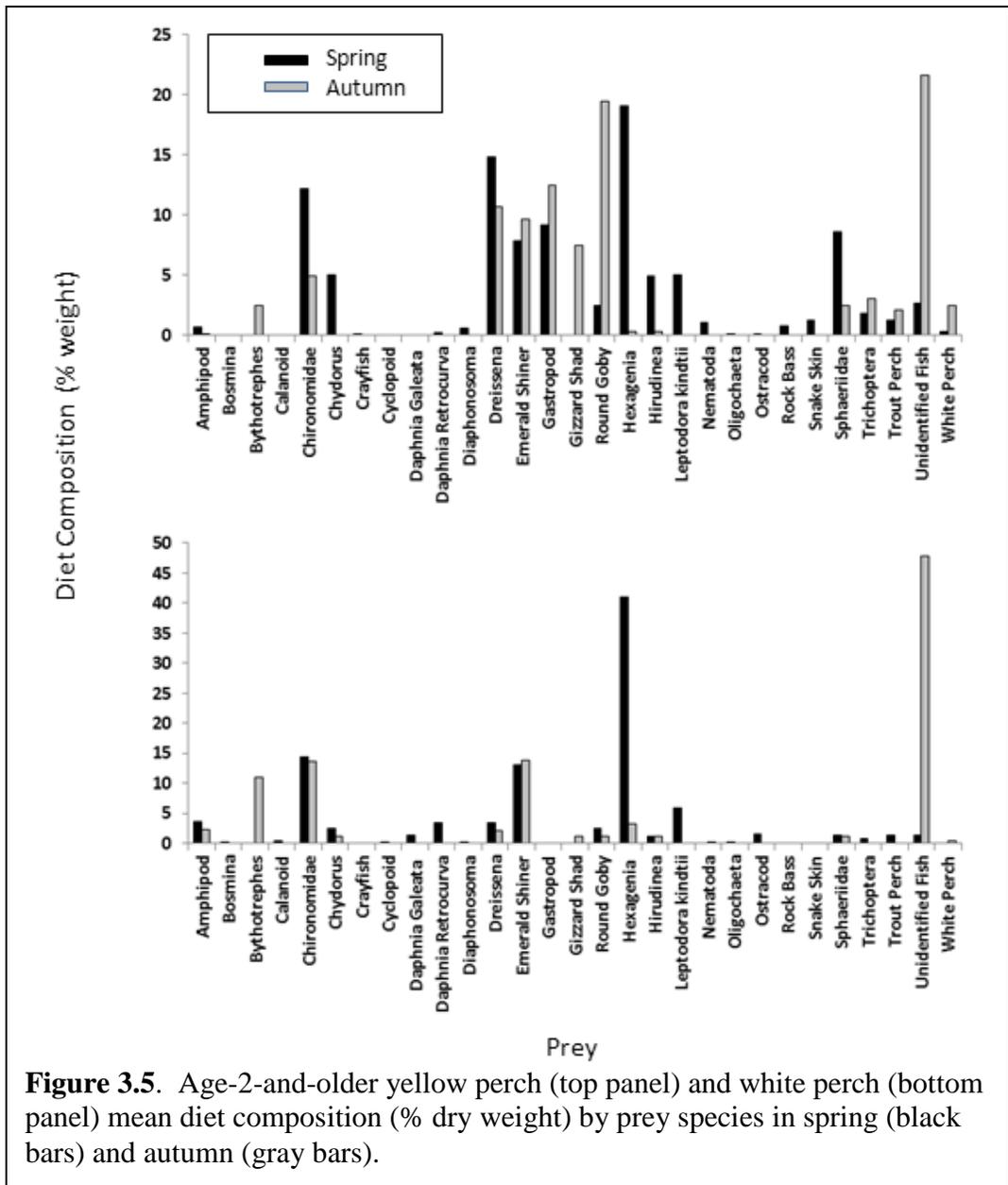


Figure 3.5. Age-2-and-older yellow perch (top panel) and white perch (bottom panel) mean diet composition (% dry weight) by prey species in spring (black bars) and autumn (gray bars).

4.0 Yellow Perch Maturity Analysis

In 2012, members of the Yellow Perch Task Group requested information on yellow perch maturity from Management Unit 1 in Lake Erie. LEBS updated sampling objectives to obtain information on yellow perch maturation following macroscopic staging categories used by Lake Erie management agencies. Below is a summary of the results.

A subsample of yellow perch was collected for a sexual maturity analysis during the LEBS East Harbor Survey (173 females, 145 males) and Western Basin Trawl Survey (26 females, 27 males). Data from both efforts were combined, and a logistic curve was fitted to predict the length at which each sex achieves maturity. Predicted lengths at both 50% and 90% mature were calculated using a bootstrap estimation routine to provide 95% confidence intervals of the length.

Male yellow perch started to mature as small as 79 mm, while the smallest mature female yellow perch was 142 mm. The logistic regression for male yellow perch portrayed a more gradual climb in maturation with size than for females (Figure 4.1). The total length at which 50% of male yellow perch were mature was significantly smaller (97 mm; 95% CI: 86-106mm) than that for females (166 mm; 95% CI: 160-174mm).

Likewise 90% of yellow perch were mature at 146 mm (95% CI: 131-162mm) and 189 mm (95% CI: 178-202mm) for males and females, respectively.

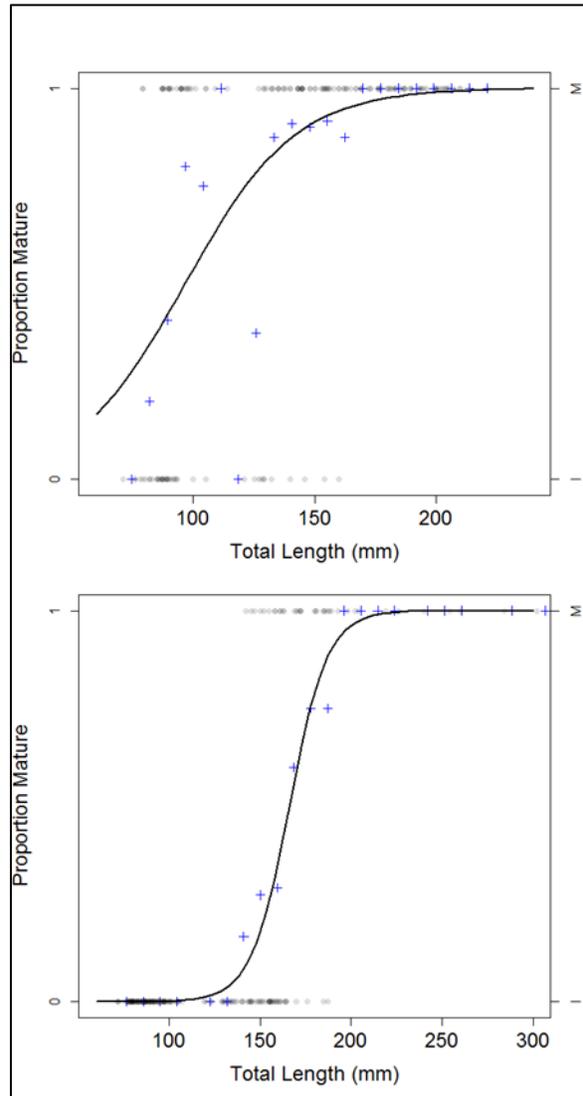


Figure 4.1 Maturity probability model based on observations of male yellow perch (top) (76-254 mm) and female yellow perch (bottom) (72-302 mm) collected during the East Harbor Forage Fish Assessment (173 females, 145 males) and Western Basin Forage Assessment (26 females, 27 males). Shaded dots signify the number of observations, while blue crosses represent the length bins within which the observations were grouped.

5.0 East Harbor

Abstract

The Lake Erie Biological Station has sampled at three depths at a site near East Harbor State Park in western Lake Erie since 1961, the longest continuous trawl data series in Lake Erie. The original purpose of this program was to index abundance of percids and other species. More recently, the program has also helped to inform how ecological changes in western Lake Erie have affected indices of abundance of managed species. In 2012 the RV Musky II was retired after 51 years of service as the only vessel used to sample the East Harbor sites. It was replaced with a larger vessel, the RV Muskie, which necessitated a change in trawl net and the gear to tow it. Herein we compare the last three years of data from the RV Musky II with the first two years of data from the RV Muskie to examine if and how the change in vessel and trawl gear affected trajectories of the time series.

Introduction

The USGS Lake Erie Biological Station's East Harbor sampling program has been ongoing since 1961, and it is the longest known continuous trawl series in Lake Erie. In addition to spanning over 50 years, the data series is unique for two prominent features: three depth strata are sampled, and replicate trawl samples are collected at each site. Of the half dozen other trawl series collected in Lake Erie, and of all trawl series collected in the Great Lakes, the East Harbor program is the only one to combine these sampling principles in a data series.

The current East Harbor sampling site was originally part of a larger set of 15-16 sites established in the late 1950s, all of which were sampled in the same manner with multiple depth strata at each site and replicate trawl samples. That program followed several years after Kinney's (Kinney, 1950, 1954) pioneering work on Trout-perch and Silver Chub in western Lake Erie. Kinney successfully used bottom trawls every month of the year to sample Trout-perch and Silver Chub for his Master's and Ph. D. degrees, respectively. In addition to capturing the target species, he also captured many others, and he opined trawls might be a useful tool for indexing abundance of young-of-year fishes. Kinney's success trawling was undoubtedly part of the impetus to use trawls in western Lake Erie to index abundance of young-of-year fishes.

The East Harbor site was one of an estimated 15-16 other sites throughout the western basin of Lake Erie when the trawling program was established (W. D. N. Busch, personal communication). The purpose of the program was to index young-of-year (YOY) abundance for projecting future year class strength of commercial species (H. van Meter and W. D. N. Busch, personal communication). The design of that original survey included not only sampling multiple depths at each site and taking replicate trawl samples, but also sampling in the morning, afternoon, and night for ensuring comprehensive sampling that would best represent relative abundances (W. D. N. Busch, personal communication).

For the years 1960-1970, indices of abundance of YOY walleyes produced by this program correlated strongly with year class contributions to the commercial walleye fishery (Busch et al. 1975). Further examination revealed an index from only 3-6 sites correlated just as strongly with year class contributions to the commercial fishery (W. D. N. Busch, personal communication), and the survey was reduced. Over time, as fiscal realities forced change, sites were eliminated until the East Harbor site was the only one that remained.

The success of the original LEBS trawling program was the impetus for basin-wide programs now used by state and provincial agencies to index abundance of Yellow Perch and Walleye for quota

allocation. Since those programs began the East Harbor data series became less important as an index of abundance, although it was one of the best predictors of Yellow Perch year class strength for several years. Because of its extraordinarily long duration, which spans multiple species invasions and other ecological shifts, it remains a valuable resource for understanding effects of these changes. Several publications have shed light on effects of Dreissenids (Stapanian et al. 2009; Kočovský and Stapanian 2011; Stapanian and Kočovský 2013), and the value of nighttime sampling to management indices (Kočovský et al. 2010).

In 2012, the original vessel used since the inception of the East Harbor program, the RV Musky II, was retired and replaced with the RV Muskie. The change in vessel necessitated change in net and all of the hardware needed to tow it (Kraus et al. 2013). Those changes essentially ended the original time series and began a new one. Here we examine data from the last three years of sampling with the RV Musky II and the first two years of sampling with the RV Muskie to assess whether and to what degree the change in vessel and net affected the historical time series.

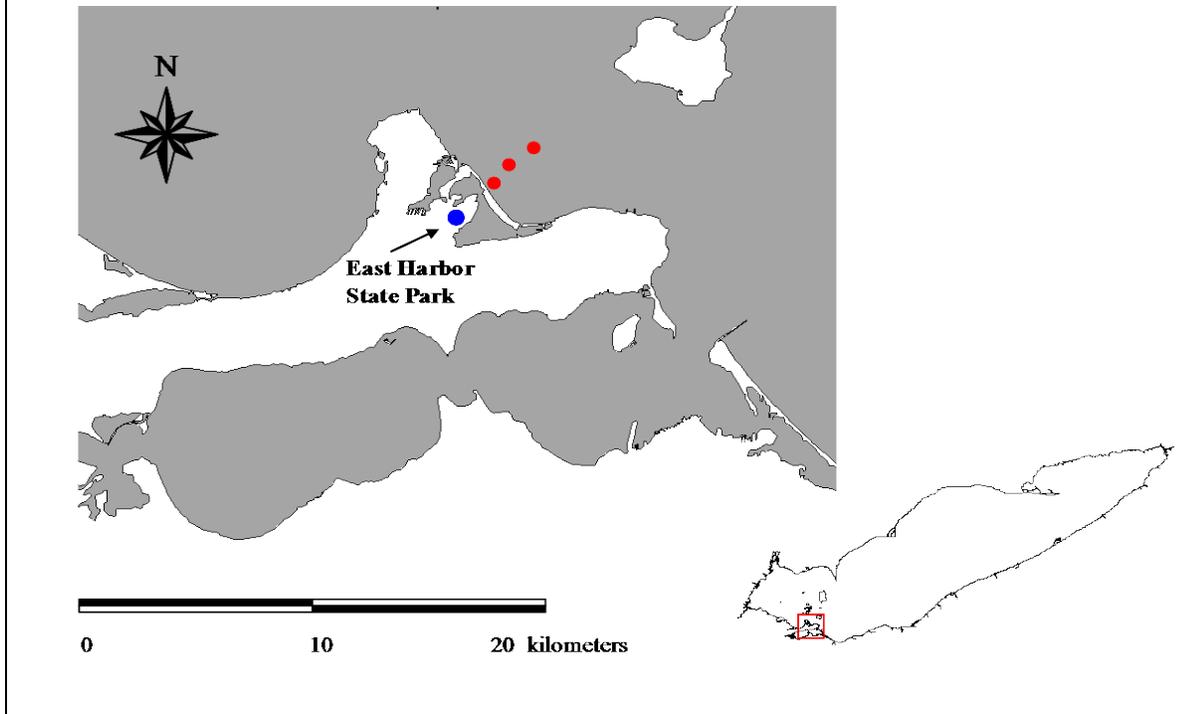
Methods

Trawl surveys were conducted in mid-October in western Lake Erie near East Harbor State Park, Ohio (Figure 5.1). On

consecutive days (weather permitting) duplicate trawls were conducted at the 3-, 4.5-, and 6-m depth contours during morning (one half hour after sunrise to 1200) and night (one half hour after sunset to approximately 2300). The trawl was towed for 10 minutes on the bottom. The trawl used on the RV Musky II through 2011 was a 7.9-m (headrope) bottom trawl with a horizontal opening of approximately 3.9 m (Kraus et al. 2013) and a vertical opening of approximately 1 m measured using SCANMAR acoustic net mensuration gear. The net used on the RV Muskie is a 11.2-m-headrope (14.2-m footrope), four-seam, three-bridle, bottom trawl, with a fishing circle of 200 meshes by 12 cm mesh size. To accommodate hard bottom habitats, the footrope has 3" rubber discs along its entire length with 8" rubber discs interspersed among the 3" discs. The 3-bridle configuration allows for the headrope to reach a targeted height of 2.5m from the bottom. Sidescan sonar analysis of the gear during operation showed that the net consistently achieved this target at a wide range of trawling speeds.

Herein we examine differences in trawling speed and acreage sampled between the vessel/trawl pairs and trends in YOY catch (number per hectare) of the most abundant benthic and pelagic species and those species of particular management concern (e.g., percids). We also examine trends for Silver Chub, which was recently upgraded from special concern to endangered in Ontario (McCulloch et al. 2013).

Figure 5.1 Location of sites sampled by the USGS Lake Erie Biological Station (red filled circles) offshore of East Harbor State Park (blue filled circle) in the western basin of Lake Erie.



Results

Trawling speed for the RV Muskie was faster than for the RV Musky II (ANOVA, $F_{2,117}=47.8$, $P<0.0001$; Table 5.1). Trawling speed for the RV Musky II did not differ among years, but the RV Muskie's speed was approximately 1 kt faster in 2013 than in 2012. With the exception of 2010, mean speed increased every year from 2009-2013, but the trend failed statistical significance ($R^2=0.69$, $P=0.11$). Because nearly all trawl samples were the prescribed 10 minutes in duration (one trawl sample in 2011 was 9 minutes), RV Muskie trawl speeds were faster than RV Musky II speeds,

Table 5.1 Mean vessel speeds by year for trawl sampling at East Harbor, 2009-2013.

Year	N	Mean speed (kts)	STDEV	Vessel	Duncan's Group ¹
2009	24	1.86	0.236	RV Musky II	C
2010	24	1.85	0.123	RV Musky II	C
2011	24	1.93	0.178	RV Musky II	C
2012	24	2.04	0.134	RV Muskie	B
2013	24	3.03	0.073	RV Muskie	A

¹ Means with different letters are significantly different at $\alpha=0.05$, corrected for family-wise error.

and the trawl fished from the RV Muskie was wider than the trawl fished from the RV Musky II, areas sampled with the RV Muskie (mean 0.391 ha, stdev 0.079 ha) was, on average 73% greater than the area sampled with the RV Musky II (mean 0.226 ha, stdev 0.024 ha).

Perception of the potential effect of change in vessel and trawl varies with species and time of day. The daytime index for Emerald Shiner increased after the transition to the new vessel, but the nighttime index decreased (Figure 5.2). Gizzard Shad density was higher in the two years of fishing with the new vessel during both daytime and nighttime sampling. Spottail Shiner density decreased slightly for the nighttime index and drastically for the daytime index the first year with the new vessel, then increased sharply for both indices the second year.

White Perch increased slightly for both daytime and nighttime indices following the transition to the new vessel, whereas Trout-perch, Yellow Perch and Round Goby densities all decreased. None of the benthic species had the large-magnitude increase between the first and second year as was observed for all three pelagic species. Silver Chub increased the first year with the new vessel/trawl and decreased slightly the second year. The daytime and nighttime indices for Walleye (Figure 5.3) decreased the first year, then increased sharply the second year. Index values for Yellow Perch moved in opposite directions the first year, but both indices decreased the second year.

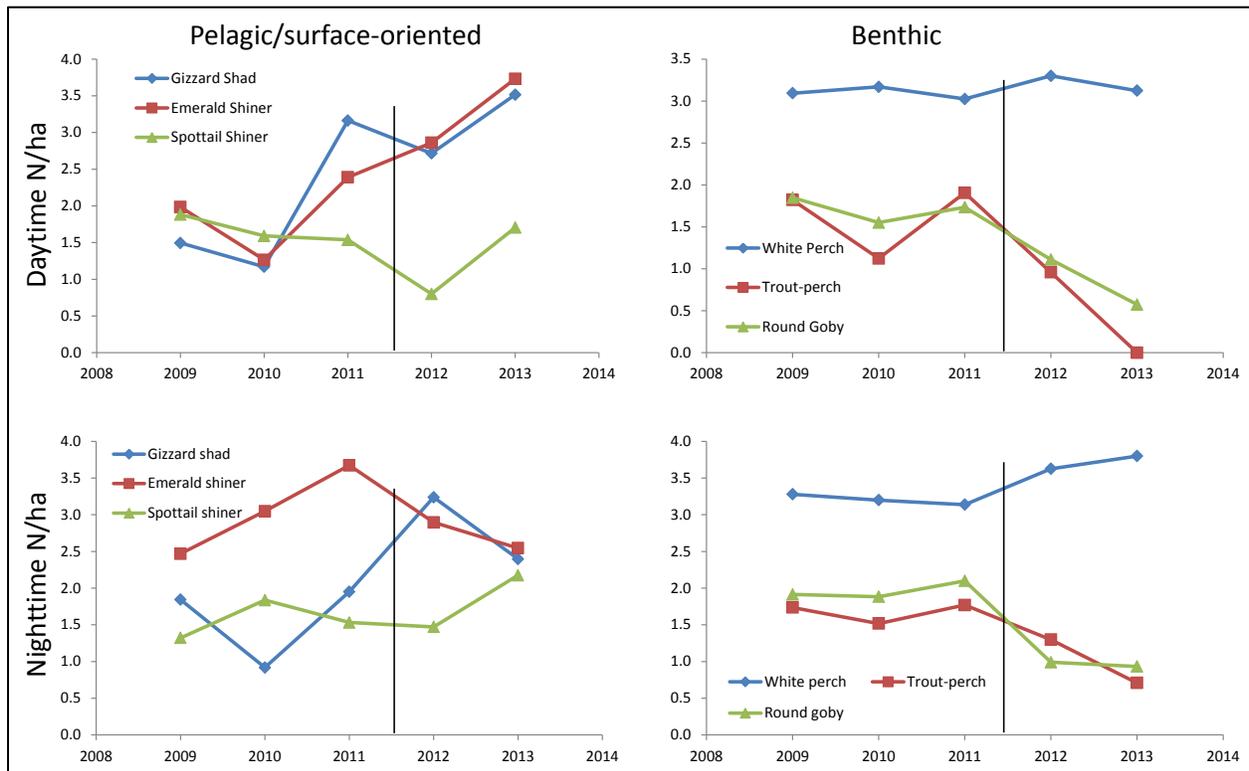


Figure 5.2 5-year trends in estimated density of the most abundant benthic and pelagic fish species at the USGS East Harbor monitoring site in western Lake Erie. The vertical lines indicate the transition from sampling with the RV Musky II and the RV Muskie.

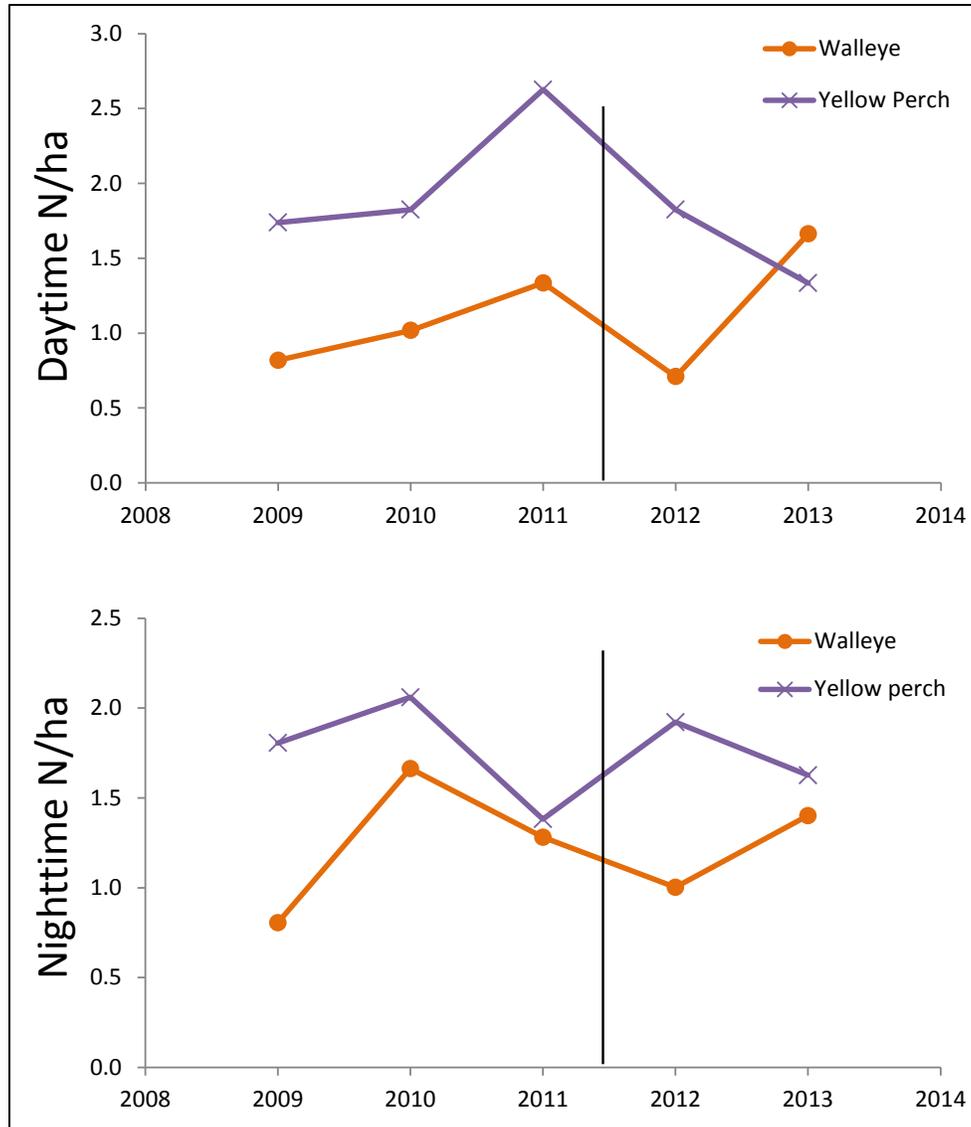


Figure 5.3 5-year trends in estimated density of Walleye and Yellow Perch at the USGS East Harbor monitoring site in western Lake Erie. The vertical lines indicate the transition from sampling with the RV Musky II and the RV Muskie.

Discussion

Trawls are among the most crude sampling devices for quantitative assessment of fish populations because of low and variable capture efficiency (e.g., Herzog et al. 2005). Because of these characteristics of trawl samples, assessing changes in absolute or relative abundance of fish species owing exclusively to changes in the trawl net itself, or how it is fished, is extremely challenging. The strongest method for assessing changes in time series when a trawl is changed would be

to conduct repeated side-by-side trawling of the gear/vessel combinations to be compared under multiple sea conditions and multiple levels of absolute and relative abundances of the species being monitored. Such comparisons would take years and are not practicable. What remains is a temporal examination of trends before and after the change to the new net and vessel to attempt to assess whether there is evidence of a change in the time series related to the new vessel/trawl combination.

In our comparison, speed varied among vessels, and because trawl time was always identical (with one exception among 120 trawl samples), and the net on the RV Muskie was larger, the area sampled was higher with the RV Muskie than the RV Musky II. For many of the species examined, there were correlations between and among year, density, speed, and area sampled. Because of this confounding we cannot say whether trends through time represent true abundance trends or artifacts of differences in sampling gears and methods. The change in speed between 2012 and 2013 was deemed necessary because net mensuration gear used in 2012 revealed the new trawl on the new vessel fished most consistently (i.e., net opening measurements were less variable) at the higher speed.

It stands to reason that increased speed was likely responsible for some portion of the high-magnitude increases in density estimates in 2013. Faster trawling speed necessarily results in greater area sampled (because time was fixed), and because area is in the denominator of the ratio N/ha , the numerator (N) has to increase more than proportionally to result in an increase in N/ha . A more-than-proportional increase would occur if either density were higher in the additional length of transect sampled (i.e., density was higher on the far end of the transect compared to the near end) or if capture probability were higher overall. Higher speed means reduced reaction time for individuals encountering the trawl to detect and evade it, which likely increases capture probability, hence total fish captured. At higher speeds fish might also tire more quickly trying to swim in front of the net, then fall back into the net. This could affect not only numbers but also relative densities if larger numbers of poorer-swimming species are encountered. Part of the increase in density estimates may also be due to higher real density. In future years we will always sample at 3 kts, which will eliminate speed as a confounding factor.

Despite the negative effects of variable speeds in interpreting temporal trends and effects of the new vessel/trawl combination on time series, there is evidence catches of some species were likely affected. Catch-per-effort of two benthic species, Trout-perch and Round Goby, decreased sharply. The rollers on the footrope of the new trawl might elevate it just enough to allow these strongly benthic-oriented species to be missed in sampling. But we still capture unionids, which reside slightly below the surface sediment, hence we know the net is fishing on bottom. Another possibility is these small benthic fish are escaping through the body mesh or a detecting a pressure wave and evading altogether. Whatever the mechanism, data for the first two years suggest the potential that we no longer index benthic species as effectively as with the former gear. LEBS is considering testing modifications to the footgear that would increase efficiency for benthic fishes. In particular, brushes between the rubber discs have been used in by commercial trawlers in the US Atlantic fleet, but NOAA outlawed this type of gear because it was too efficient at capturing benthic fishes.

Increases in daytime indices for Emerald Shiner and Spottail Shiner (YOY and YAO) and nighttime indices for Gizzard Shad and White Perch YOY seem to be a trawl/vessel effect. Large-magnitude or sustained step increases were observed for all of these species/age classes. In addition to having rollers that keep the footrope slightly off bottom, the new net also fishes ~1.5 m higher in water column compared to previous net, thus fishing a much larger area where pelagic species reside.

No obvious change in the Silver Chub index is beneficial for future monitoring. Silver Chub was once very plentiful in western Lake Erie, then the population crashed between 1954 and 1961 (a period lacking data) concurrent with the loss of *Hexagenia* spp., then rebounded slightly after gobies became established (USGS Lake Erie Biological Station, unpublished data). At the

continental scale, Silver Chub is considered stable in the United States, but at the Great Lakes-Upper St. Lawrence scale it is considered endangered in Canada, which has a recovery plan for the endangered populations (McCulloch et al. 2013). To date our East Harbor data series has been the only long-term data set for Silver Chub and the primary data source for Canada's recovery plan; thus,

maintaining this data series has real conservation benefit.

6.0 Gill Net Comparison

Abstract

Interagency stock assessments of Lake Erie walleye rely on age-distribution information from gill net surveys. Currently, ODNR and OMNR use different assessment gears, hence there is a need to quantify size-selectivity of each survey gear to reconcile spatial differences in age-structure that are confounded by the use of different gears. Furthermore, discontinuation of the manufacture of material for ODNR's existing multi-filament assessment gear necessitates developing a new monofilament gear, increasing the need for comparative data on age and size distributions. In collaboration with ODNR and OMNR, LEBS has been conducting a comparative gill net survey to develop measures of size selectivity for each gear. To date, our results have revealed different size selectivity patterns for walleye that are characteristic of the three test gears, and these patterns remained constant across four years of data collection. This work is culminating in a collaborative manuscript to be submitted for publication in 2014 in support of efforts to combine interagency data sets and transition older sampling gears from obsolete materials.

Introduction

Lake Erie's walleye fishery is one of the most important and valuable fisheries in the Great Lakes. Stock assessments are conducted on an annual basis by the Lake Erie Committee's WTG to determine harvest quotas. A key model input is the population age structure, which is estimated using fishery independent gill-net surveys that are conducted by MDNR, ODNR, and OMNR, which is also informed by commercial harvest data. Each agency uses a different type of gill net with a different configuration of mesh sizes, and this situation has highlighted uncertainties about combining datasets for use in the stock assessment. The task group has utilized various weighting approaches (e.g., proportional by variance, or expert ranking) to combine gillnet survey data, but the spatial separation of gears by jurisdiction has confounded analysis of interagency differences in age structure information for the stock assessment. To elucidate effects of gill net gear type on our understanding of spatial patterns in walleye age-structure, USGS researchers at LEBS have been conducting a cooperative gear comparison study with ODNR and OMNR. To accomplish this, we developed independent field data by fishing

all three gears simultaneously and quantified the results in terms of size-selectivity of each gear. Previously, we explored alternative scenarios of fishing power (a subjective model input), but these did not perform any better than the conventional assumption that fishing power is proportional to length of the net. Here we present selectivity curve results from the 2010, 2011, 2012, and 2013 field seasons and preliminary analyses using conventional assumptions of fishing power.

Methods

We deployed gillnets following each agency's protocol for autumn assessment of the walleye stock. These nets are hereafter referred to as the OMNR Partnership Monofilament, Multifilament (used by both MDNR and ODNR), and the ODNR New Monofilament net. All nets were suspended 6 feet below the surface. Materials, construction, and configurations for each gear are not described here, but can be found in Walleye Task Group reports (<http://www.glf.org/lakecom/lec/WTG.htm>) for the Partnership and Multifilament nets and Vandergoot et al. (2011) for the ODNR New Monofilament net. All three gears were fished simultaneously, deployed in one long strap

with each gear separated by anchors, in Ohio waters during October and November. The order was randomized on each deployment. Gear comparison sets were also conducted by the Ontario Ministry of Natural Resources in Canadian waters, but the 2013 results were not available at the time this analysis was performed; therefore, only results from Ohio are presented here. Species and size composition data were recorded for each mesh size. In this report we restricted our analysis to walleye. For a subsample of larger walleye, ages were estimated from otoliths. For the rest of the catch, age was either determined from scales or via length-based age assignment (Isermann & Knight 2005).

We analyzed the size selectivity of each gear using the SELECT method in R (Millar and Holst 1997, Millar and Fryer 1999). By simultaneously fishing all three nets, we assumed that for any particular sample the same local population of fish contacted each net. We tested this assumption, and evaluated gear differences in the estimated length distribution of fish contacting the nets. The SELECT model predicts the catch of fish, n , of length, l , captured in mesh, j , as a Poisson random variable:

$$n_{lj} \sim \text{Pois}\{p_j r_j(l) \lambda_l\}$$

which is the product of the fishing power, p , the size selectivity, r , and the length distribution of fish contacting the net, λ_l . In practice, fishing power and the selection curve are confounded; therefore, one has to specify the fishing power for each mesh. We assumed the typical convention where power is proportional to the length of net of a particular mesh size. The shape of the selectivity curve, $r_j(l)$, can take a variety of forms, and here we evaluated four of the most common: normal, binormal, lognormal, and bilognormal. For each dataset, we accepted the model with the lowest deviance given overall consistency across years. Comparisons of the overall size selectivity of each net in each year were

evaluated graphically and through comparison of parameter estimates.

Results and Discussion

Selectivity model estimation revealed that the binormal class of models performed consistently better than any of the other models that were fitted to the data (Table 6.1). The bilognormal models were problematic, and the complete set of parameters could not be estimated for all of the data sets. Although the bilognormal model fit 2013 data for the partnership net best, the sample size was low and this result was inconsistent with other years. We discarded the bilognormal model and do not consider it further in this report. With the exception of the partnership net data from 2011, the binormal selectivity models had the lowest deviance values (Table 6.1); therefore, we accepted this model and examined the selectivity curves and model parameters. This model assumes geometric similarity between walleye shape and gill net mesh size as it affects capture. In addition, the combination of two normal distributions emphasizes that walleye are commonly captured via two primary mechanisms. The first is classic wedging of fish in the mesh, which occurs when a fish tries to swim through a mesh but its body is too large to pass and it becomes wedged. The second mechanism represents fish that are entangled by their jaws, teeth, spines or other appendages and retained in this manner. The second mechanism may retain fish in larger mesh sizes that they might otherwise be able to pass through.

Table 6.1 Selectivity model deviance values (darker orange values are lower) for four common models fitted to experimental gill net catches of walleye. Total number of walleye used to estimate each model (N) varied due to local abundance each year and by vulnerability to each net type. The gray shaded cells indicate that not all of the parameters could be estimated.

model:	normal	bi-normal	lognormal	bi-lognormal	N
Multifilament					
2010	302.3	281	291.9	n/a	447
2011	379.9	321.5	381.1	n/a	749
2012	517.5	429.7	520.1	520.1	1193
2013	262.3	236.4	260.2	n/a	420
New Monofilament					
2010	168	152	179.3	n/a	309
2011	235.5	170.7	219.8	n/a	405
2012	452.1	374.6	417.3	n/a	593
2013	158	132.5	148.3	n/a	243
Partnership Monofilament					
2010	181.8	162.6	170.4	170.4	281
2011	286	288.4	299.4	n/a	512
2012	366.6	354.3	383.4	n/a	509
2013	230.7	194.9	202.7	188.8	193

Likewise, large fishes may become retained by entangling in mesh sizes that are too small to permit wedging.

Each net exhibited a unique characteristic pattern of walleye size selectivity (Figure 6.1). The binormal model is defined by two size modes and their standard deviations. The size distributions are combined by summing, and there is a multiplier with the second size mode that defines the height as either equivalent to or smaller than the first mode. The size modes could represent expected size distribution of any mesh size, but for estimation purposes, the smallest mesh size is used. The size of the smallest mesh varies by agency. Because the smallest mesh size is found on the partnership net, the size mode parameters are smallest for this net followed by the new monofilament with intermediate size modes and then the multifilament net (Figure 6.1). The multiplier (P) indicated that the second mode was typically shorter than the first by as much as

60% but usually only by 13% on average (Figure 6.1). The inter-annual variation in these size mode parameters was low with coefficients of variation that ranged between 3% and 8% for each mode estimate, with the exception of the second size mode for the partnership gill net data (CV=21%, Figure 6.1). This higher variability is in part due to low sample sizes for the partnership gear in two of the years, which correlated with lower values than other years (Table 6.1, Figure 6.1). The small sample size effect was also evident for the new monofilament in 2013, which had the lowest overall sample size (Table 6.1, Figure 6.1). When data from comparison sets in Canada are added to the analysis, we expect the performance of the selectivity model estimation to improve for the partnership net as well as the other nets, especially in 2013 when sample size was most limiting.

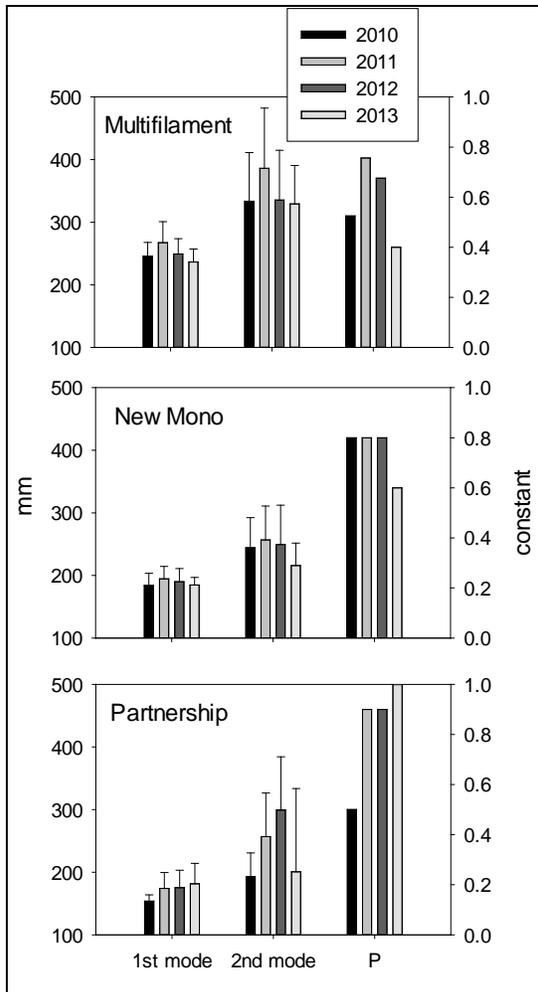


Figure 6.1 Binormal selectivity model parameters estimated with the SELECT algorithm for three different gill nets fished in comparison triplet sets during four years of testing. The modes are for the smallest mesh size in a particular gear (see text), and are plotted by year with error bars illustrating the standard deviations that define the spread of the distribution for that mode. The P parameter is plotted on the right axis and is the scaling parameter that defines the height of the second mode as a fraction of the first. The three gears are described in the text.

Each net's size selectivity was stable across years (Figure 6.2), which supports averaging selectivity curves to develop a single function for each net that can be applied to each agency's survey results. The partnership net became more variable across years for smaller sized walleye, but we expect to see more consistent results when new data from the Ontario Ministry of Natural Resources are added to the analysis.

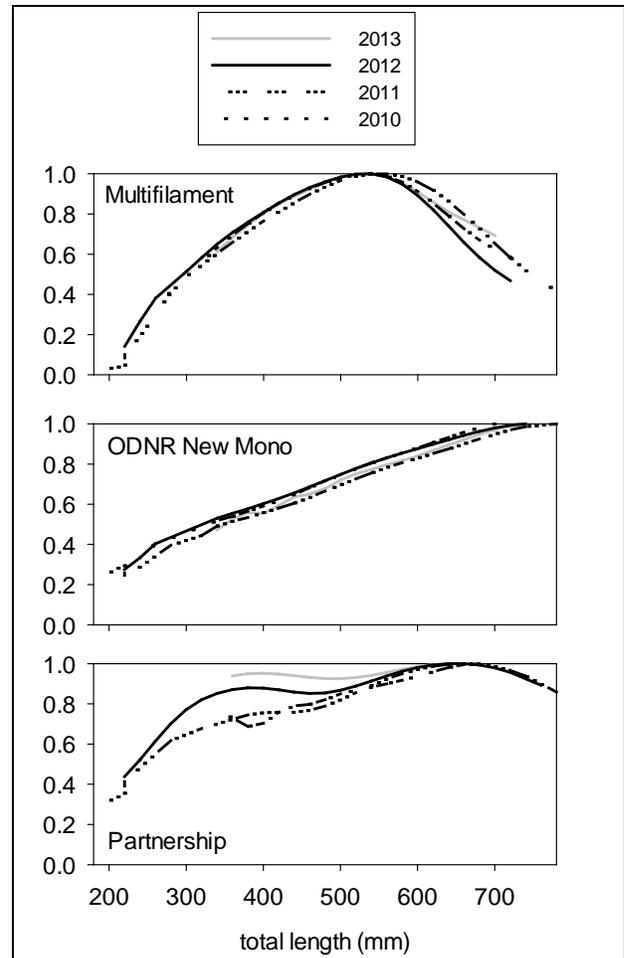


Figure 6.2 Relative size selectivity of three different gill nets for walleye in Lake Erie. Results were estimated with the SELECT algorithm for 4 years of experimental comparison gill net trials. A binormal model provided the best overall fit and is presented here.

It is not possible to pool years prior to model fitting, because this would violate the assumption that the same population of fish was available to contact the gear in each year. To varying degrees, mortality, recruitment, and environmental factors that influence distribution result in a different size distribution each fall. Walleye are highly migratory with older and larger fish migrating farther, and this can also affect the probability of encounter as a function of when and where the gill nets are deployed. This situation stresses the importance of thorough spatial coverage and adequate sample size. Additional planned analyses will provide a better understanding of spatial and sample size

effects. Further, ongoing efforts to use hydroacoustic surveys in conjunction with gill nets may provide insight on potential biases owing to shifts in spatial distributions.

Due to a number of historical contingencies and independent factors, the different fishery management agencies on Lake Erie have adopted different survey gears and developed long time-series of valuable data on the walleye population. Combining information from these data sets for a more

comprehensive view of the population has been founded on the assumption that each gear provides an equivalent view of the population age-structure. The unique experimental design of this study with simultaneous results from three different survey gill nets provides an opportunity to test this key assumption, and this is the primary topic of the manuscript that is in preparation from this work.

7.0 Lower Trophic Assessment in the Central Basin of Lake Erie

Abstract

The Lake Erie Biological Station has participated in the Lower Trophic Level Assessment (LTLA) program, which is administered by the Forage Task Group (FTG) of the Lake Erie Committee, since 2003. The purpose of the program is to monitor and report on nutrient levels and on benthic, algal, and zooplankton communities which support valuable commercial and recreational fisheries for percids in Lake Erie. We have monitored two stations near Vermilion, OH, one and, the other offshore deep (13.6 m), following standard methods established by the FTG. During our 11 years of monitoring, mean surface and bottom water temperatures, mean bottom dissolved oxygen, mean Secchi disk depths, and mean total phosphorus in summer (July-September) were mostly unchanged. Total phosphorus varied among years at the offshore site, but there is no overall trend. Secchi disk depth did not vary among years at either site, but there was an overall trend of decreasing water clarity at our nearshore site, which might be influenced by high Vermilion River discharge on sampling dates. Secchi disk depths remained within the desired range for fish community objectives most years, but total phosphorus remained higher than desired. These data suggest borderline eutrophic conditions at these sites in the central basin of Lake Erie. We will continue to monitor these sites as part of the LTLA program.

Introduction

A program to monitor nutrient levels and to assess the phytoplankton and zooplankton communities throughout Lake Erie, referred to as the Lower Trophic Sampling Program (FTG 2013), was begun by the Lake Erie Committee of the Great Lakes Fishery Commission in 1999. Conduct of the sampling program is overseen by the Forage Task Group (FTG). The Lake Erie Biological Station has participated in the program since 2003. Its purpose is to monitor nutrient levels, water clarity and quality, temperature and dissolved oxygen (DO) levels, and zooplankton and phytoplankton abundance and composition for the purpose of better understanding trophic conditions near the base of the food web and to document ecosystem change. It supports the overarching goal of the FTG to monitor and report on status and composition of the forage fish community throughout Lake Erie.

Like all other task groups under the umbrella of the Lake Erie Committee, the Forage Task Group exists largely to support the economically important commercial and recreational fisheries in Lake Erie, primarily

Yellow Perch and Walleye. Fish community objectives for Lake Erie (Ryan et al. 2003) include maintaining mesotrophic conditions that favor these percids. Mesotrophic conditions in this context are defined as total phosphorus between 9 and 18 $\mu\text{g/L}$ and Secchi disk depth of 3-6 m (FTG 2013). Hence, an important goal of the Lower Trophic Monitoring Program is to determine whether the goal of mesotrophic conditions is being met.

Here we make our initial report on the first 11 years of data collection focusing on annual trends at two sites we monitor in the central basin of Lake Erie.

Methods

Data were collected bi-weekly between May and October 2003-2013 at two sites in the central basin of Lake Erie near Vermilion, Ohio (Figure 7.1). The vessel used from 2003 through 2012 was the RV Bowfin, a 26-ft Pacific Skiff with twin outboard motors and < 1 m freeboard. In 2013 some data were collected from the 75-ft RV Musky, which is equipped with twin inboard motors and has >2 m of freeboard. Dissolved oxygen and temperature data were collected with a

hand-held YSI model Pro ODO in 2003-2012, and with either the hand-held or a 6600 V2 Sonde in 2013. Regardless of the device used, we recorded surface and bottom temperature, DO, and % DO saturation at each site. If the water column was stratified, we recorded DO at 1-m increments when using the hand-held unit, or a continuous profile when using the sonde.

Secchi disk depths were measured to the nearest quarter meter on the shade-side of the boat. Because of differences in freeboard distances of the two vessels, Secchi disk depth estimates might have been affected and thus might not be perfectly comparable between vessels.

Water samples for chlorophyll a, phytoplankton, and total phosphorus were taken from an aggregate sample of 1 liter each from four discrete depths spaced equally from 1 m below the surface to 1 m above the bottom. If the water column was stratified, then samples were taken from 1 m below the surface to 1 m above the thermocline. Samples were collected with a Van Dorn sampler. Samples for total phosphorus were collected in 125 ml bottles, which were placed immediately on ice in the field, then frozen in the lab at -20 C. Total P was analyzed at Heidelberg University's National Center for Water Quality Research..

We report mean summer (months July-September) bottom and surface temperatures, mean bottom DO, mean Secchi disk depth and mean total phosphorus for each site in this report. Chlorophyll a, total phytoplankton, zooplankton, and benthic samples are also collected in this program, but the results are not reported here. Differences among years were tested by ANOVA using PROC GLM in

SAS. Trend analysis of mean values by through time was done by least-squares linear regression (also PROC GLM).

Results

Nearshore site

Mean surface temperature, bottom temperature, total phosphorus, and Secchi disk depth did not significantly differ among years. Mean bottom DO (ANOVA, $F_{10, 54}=2.37$, $P=0.021$) was higher than all other years in 2003 (mean DO=8.41 mg/L), and lower than all other years in 2004 (mean DO=5.99 mg/L; Figure 7.2A). Secchi disk depth decreased significantly from 2003 through 2013 (Secchi=-0.0992*Year+201.46, $P=0.016$, $R^2=0.089$; Figure 7.3A). Bottom DO was always sufficiently high for fish, never falling below 2.44 mg/L (Figure 7.4A).

Mean total phosphorus values were always near or greater than the desired upper limit for mesotrophic conditions (Figure 7.2A). Secchi disk depths were statistically significantly lower than the desired range of 3-6 m in 2006, 2008, 2012, and 2013 based 95% confidence intervals not overlapping the lower limit of 3 m (not corrected for family-wise error). The only year in which the mean value was within the desired range was 2003.

Offshore site

Mean surface temperature, bottom temperature, bottom DO (Figure 7.2B), and Secchi disk depth did not significantly vary between years. Total phosphorus (ANOVA $F_{10, 63}=2.09$, $P=0.039$) was higher in 2004 (34 $\mu\text{g/L}$) than in 2009 (18.8 $\mu\text{g/L}$) and 2010 (13.6 $\mu\text{g/L}$), and in 2010 it was lower than in



Figure 7.1 Central basin lower trophic sites sampled by the Lake Erie Biological Station, 2003-2013. Red box in inset shows approximate location on Lake Erie.

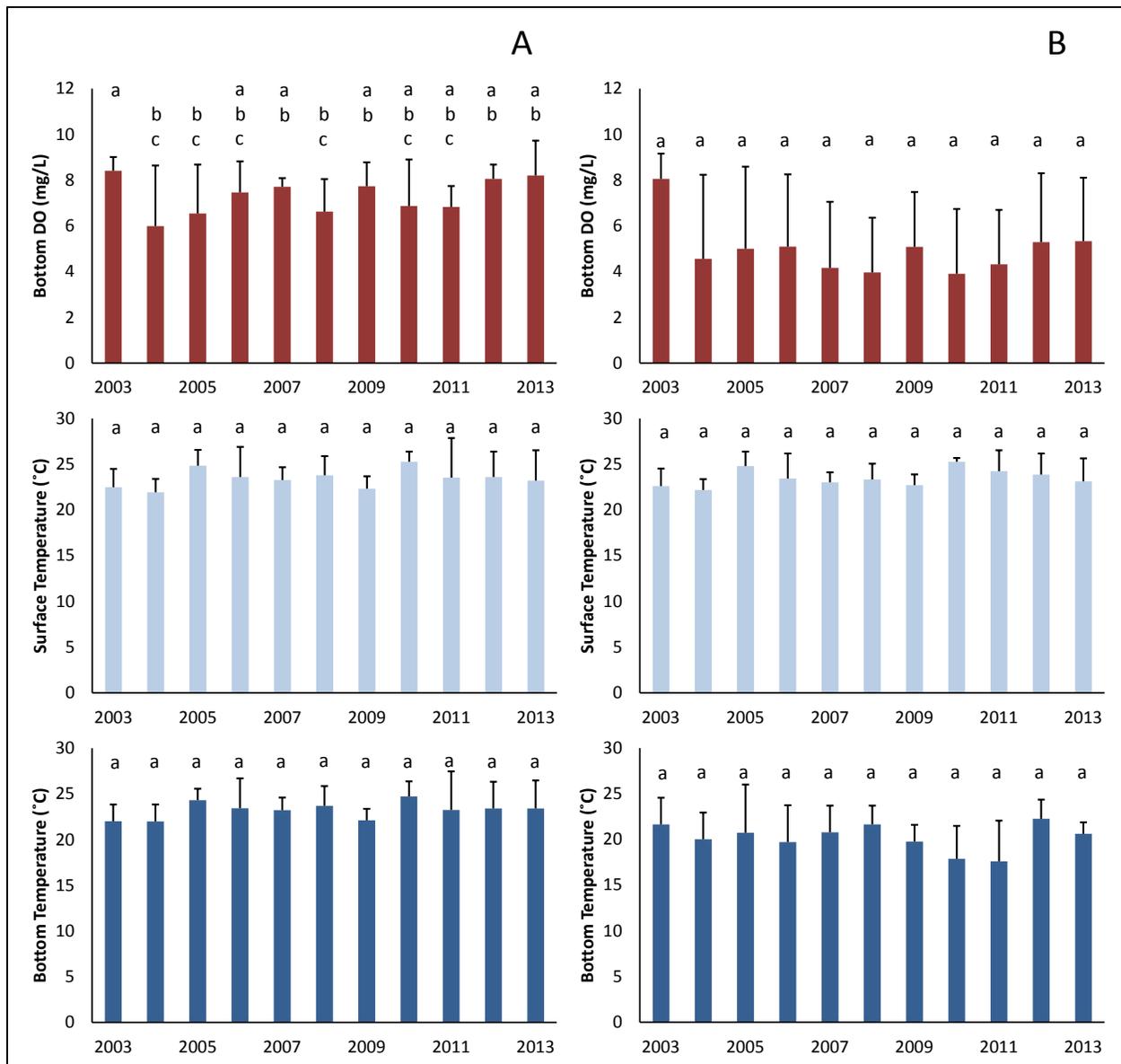


Figure 7.2 Mean bottom DO and mean surface and bottom temperatures at one nearshore site (depth 5.2 m; A) and one offshore site (depth 13.6 m, B) in the central basin of Lake Erie, 2003-2013. Years with the same letter are not significantly different.

all other years (Figure 7.3B). There were no trends through time for any of these variables. Bottom DO was frequently lower than 1 mg/L in July and August (Figure 4B).

Mean total phosphorus values exceeded the desired upper limit of 18 $\mu\text{g/L}$ in all years except 2010 (Figure 7.3B). Mean Secchi disk depths were in the preferred mesotrophic range of 3-6 m in 2003, 2005, 2007, 2008, 2010, and 2011. They were lower than the minimum desired value in all other

years, but CI's overlapped the lower range for all years except 2013.

Discussion

Lower trophic conditions at these sites generally failed to meet desired levels according to the fish community objectives (Ryan et al. 2003) for Lake Erie in nearly all years. Water clarity was typically within or not statistically distinguishable from the desired range most years at the offshore site,

but mean TP values were almost always higher. Mean total phosphorus and mean Secchi disk depths were within the desired ranges at the offshore site in 2010, but at the nearshore site mean total phosphorus was in range but Secchi disk depth was below the desired range. Variation in both values was quite high, leading to the wide CIs that prevented detecting statistical significance. For the period 2003-2013, 37-47% of total phosphorus and Secchi disk values were within the desirable range, but occasional extreme high values drove means high. Median values were slightly lower, but still higher than the upper bound of the desired range.

The lack of trends at the site scale was also affected by high variability. The only significant trend was Secchi disk depth at the nearshore site, and it was the opposite of the desired trend. Secchi disk depth decreased by approximately 10 cm annually from 2003 through 2013. With the exception of a few sampling dates in 2013, the same vessel was used to collect data throughout the time series; hence we believe the trend reflects site conditions.

Some portion of the high variability at the nearshore site might be proximity to the outlet of the Vermilion River. Plumes following high-discharge events do not extend northward into Lake Erie, rather toward the east along the shoreline. This is due in large part to the breakwall approximately 90 meters from the mouth that deflects flow either west or east. Prevailing currents typically carry water to the east directly toward our sampling site. In 2003, three of our sampling dates occurred during or no more than 2 days after 86th- to 94th-percentile discharge events (based on daily flow data from USGS gauge 1950-2011). We did not examine data from other years for timing of sampling in relation to high-flow events, but personal observation (P. Kocovsky, W. Edwards) dictates it occurred in other years as well. Hence, some portion of the variability at our nearshore site

is potentially attributable to high discharge events.

Dissolved oxygen levels below 2 mg/L, considered by the FTG to be stressful to percids (FTG 2013), were observed most years at the offshore site. Typically only one or two hypoxic events were observed in any year, although three were observed in 2007 (two on consecutive sampling periods) and 2010 (consecutive sampling periods), indicating prolonged periods of hypoxia. Thermal stratification and low DO values that accompany it in eu- and mesotrophic bodies of water are natural occurrences, but the date of onset and duration of periods of low DO can be influenced by human activities, such as nutrient (i.e., phosphorus) enhancement. If human activities change the onset or duration of hypoxia, fish populations can be negatively affected. For example, the only year we did not observe DO below 2 mg/L was 2003, which was also the last year both Yellow Perch and Walleye had high reproductive success. It is possible that one of the factors leading to high reproductive success in 2003 was because oxygen remained plentiful.

There were no significant differences or trends in surface or bottom temperatures at the site scale. Nine of the ten warmest years globally since record keeping began in 1880 (NOAA 2014) have occurred within the time period covered in this report. Deviations of mean annual global temperature from the long-term mean have been relatively constant over the past

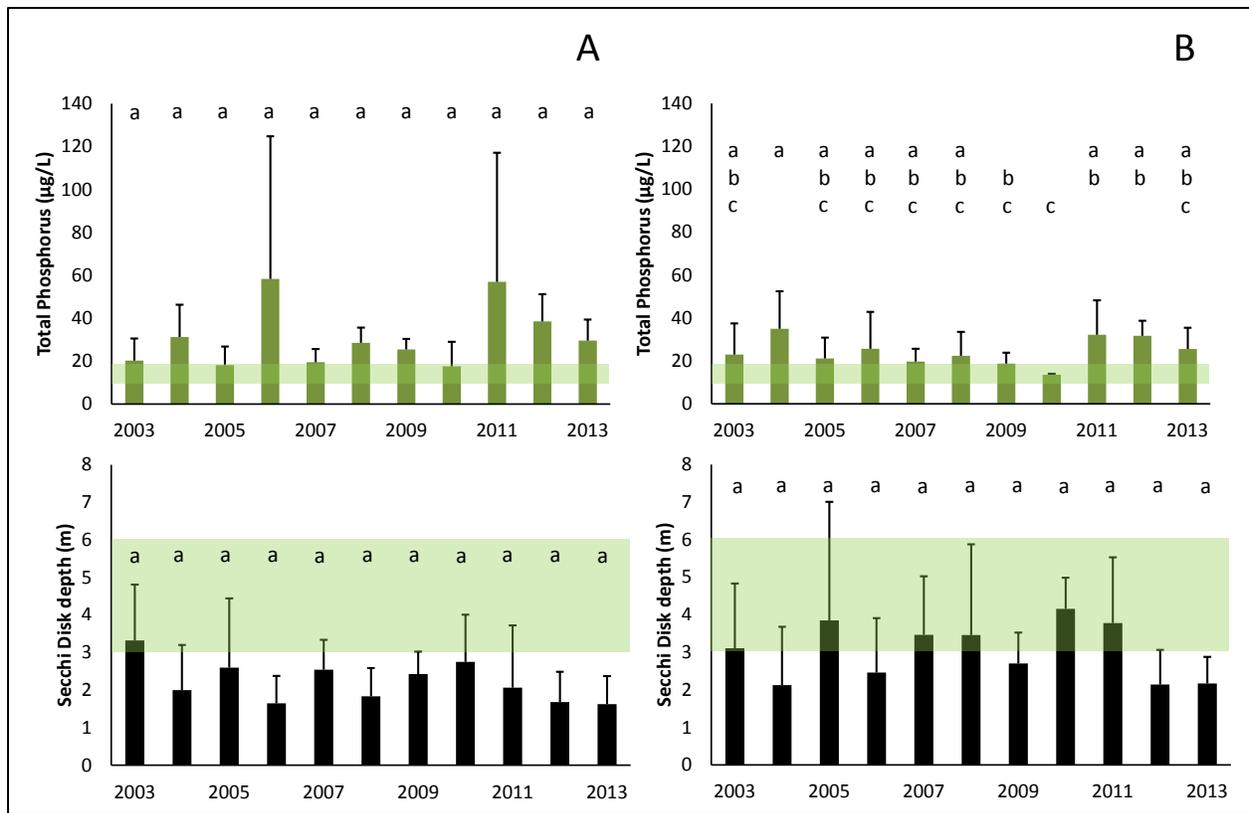


Figure 7.3 Mean total phosphorus in water samples collected at one nearshore site (depth 5.2 m; A) and one offshore site (depth 13.6 m, B) in the central basin of Lake Erie, 2003-2013. Years with the same letter are not significantly different. Green shaded bands indicate desired ranges of values to maintain mesotrophic conditions desirable for percid communities.

decade, hence no change in mean surface temperatures seems consistent with coarser scale trends. Surface water temperatures in summer remain well above preferred temperature for walleyes (Hokanson 1977) and the forage species they rely on (ODNR, unpublished data).

Based on these results, trophic conditions over the period 2003-2013 at these two sites has generally been eutrophic and contrary to goals expressed in the Fish Community Objectives for Lake Erie. Eutrophic conditions are more favorable for centrarchid species (e.g., smallmouth bass, *Micropterus dolomieu*) than the percid species that currently support commercial and recreational fisheries. These are two sites of 19 sampled by cooperating agencies in Lake Erie, and might not be representative of the lake as a whole. Results

from these sites are placed in a lake-wide context in the annual Forage Task Group Report (FRG 2014)

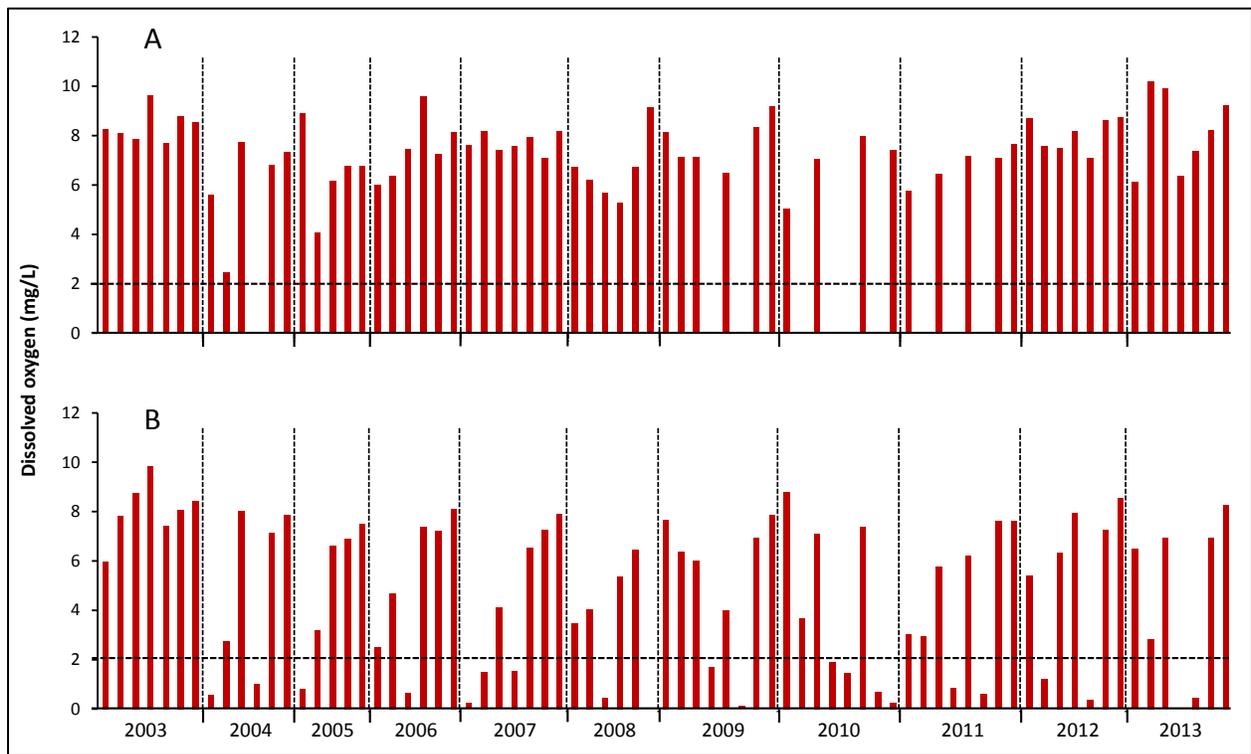


Figure 7.4 Observed dissolved oxygen levels by date between 2003 and 2013 in the central basin of Lake Erie at one nearshore sites (A) and one offshore site (B). Dashed vertical lines separate years.

8.0 Acknowledgements

We are grateful for the support and cooperation of ODNR, OMNR, MSU, and OSU on the trawl and gillnet gear comparison studies. We thank T. Cherry, D. Hall, and B. Harder for assistance in the field and L. Kolb for assistance in preparing this report. Constructive reviews were provided by C. Knight, A.M. Gorman, J. Deller, J. Markham, and B. Weidel. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

9.0 References

- Bertrand, J.A., I. Leonori, P.Y. Dremière, and G. Cosimi. 2002. Depth trajectory and performance of a trawl used for an international bottom trawl survey in the Mediterranean. *Scientia Marina*. 66(Suppl. 2): 169-182.
- Brush, J. M., A. T. Fisk, N. E. Hussey, and T. B. Johnson. 2012. Spatial and seasonal variability in the diet of round goby (*Neogobius melanostomus*): stable isotopes indicate that stomach contents overestimate the importance of dreissenids. *Canadian Journal of Fisheries and Aquatic Science*. 69: 573-586.
- Busch, W. D. N., R. L. Scholl, and W. L. Hartman. 1975. Environmental factors affecting the strength of walleye (*Stizostedion vitreum*) year-classes in Western Lake Erie, 1960-70. *J. Fish Res. Board. Can.* 32:1733-1743.
- Forage Task Group. 2013. Report of the Lake Erie Forage Task Group. Great Lakes Fishery Commission, Ann Arbor, MI, XX pp., http://glfc.org/lakecom/lec/FTG_docs/annual_reports/FTG_report_2013.pdf
- Forage Task Group. 2014. Report of the Lake Erie Forage Task Group. Great Lakes Fishery Commission, Ann Arbor, MI, XX pp., http://glfc.org/lakecom/lec/FTG_docs/annual_reports/FTG_report_2014.pdf
- Guzzo, M. M., G. D. Haffner, N. D. Legler, S. A. Rush, and A. T. Fisk. 2013. Fifty years later: trophic ecology and niche overlap of a native and non-indigenous fish species in the western basin of Lake Erie. *Biological Invasions* 15:1695-1711
- Herzog, D. P., V. A. Barko, J. S. Scheibe, R. A. Hrabik, and D. E. Ostendorf. 2005. Efficacy of a benthic trawl for sampling small-bodied fishes in large river systems. *North American Journal of Fisheries Management* 25:594–603.
- Hokanson, K. E. F. 1977. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. *Journal of the Fisheries Research Board of Canada* 34:1524-1550.
- Isermann D. A., and C. T. Knight. 2005. A Computer Program for Age–Length Keys Incorporating Age Assignment to Individual Fish. *North American Journal of Fisheries Management* 25:1153-1160
- Kinney, E.C. Jr., 1950. The life history of the trout-perch, *Percopsis omiscomaycus* (Walbaum), in western Lake Erie. Master's Thesis, The Ohio State University, Columbus.
- Kinney, E.C. Jr., 1954. A Life History Study of the Silver Chub, *Hybopsis storeriana* (Kirtland), in Western Lake Erie with Notes on Associated Species. Doctoral Dissertation, The Ohio State University, Columbus.

- Kočovský, P. M., M. A. Stapanian, and C. T. Knight. 2010. Night sampling improves indices used for management of yellow perch in Lake Erie. *Fisheries Management and Ecology* 17:10-18.
- Kočovský, P.M., Stapanian, M.A. 2011. Influence of dreissenid mussels on catchability of benthic fishes in bottom trawls. *Trans. Am. Fish. Soc.* 140, 1565-1573.
- Kraus, R., M. Rogers, P. M. Kočovský, W. H. Edwards, B. Bodamer-Scarbro, K. Keretz., and R. Wirick. 2013. Fisheries Research and Monitoring Activities of the Lake Erie Biological Station, 2012. Annual Report to the Great Lakes Fisheries Commission, Ann Arbor, MI, 41 pp.
- McCulloch, B. R., L. D. Bouvier, and N. E. Mandrak. 2013. Information in support of a Recovery Potential Assessment of Silver Chub (*Macrhybopsis storeriana*) in Ontario. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/nnn. v + 30p.
- Millar R. B., and R. Holst R. 1997 Estimation of gillnet and hook selectivity using log-linear models. *Ices J Mar Sci* 54:471-477
- Millar, R. B., and R. J. Fryer. 1999. Estimating the size-selection curves of towed gears, traps, nets and hooks. *Rev Fish Biol Fisher* 9:89-116
- NOAA National Climatic Data Center, State of the Climate: Global Analysis for Annual 2013, published online December 2013, retrieved on February 21, 2014 from <http://www.ncdc.noaa.gov/sotc/global/2013/13>.
- Parrish, D. L., and F. J. Margraf. 1990. Interactions between White Perch (*Morone americana*) and Yellow Perch (*Perca flavescens*) in Lake Erie as determined from feeding and growth. *Canadian Journal of Fisheries and Aquatic Science* 47:1779-1787.
- Roseman E. F., W. W. Taylor, D. B. Hayes, J. T. Tyson, and R. C. Haas. 2005. Spatial Patterns Emphasize the Importance of Coastal Zones as Nursery Areas for Larval Walleye in Western Lake Erie. *J Great Lakes Res* 31, Supplement 1:28-44
- Ryan, P. A., R. Knight, R. MacGregor, G. Towns, R. Hoopes, and W. Culligan. 2003. Fish-community goals and objectives for Lake Erie. *Great Lakes Fish. Comm. Spec. Publ.* 03-02. 56 p.
- Stapanian, M. A., and P. M. Kočovský. 2013. Effects of dreissenids on monitoring and management of fisheries. Pages 681-692 in: T.F. Nalepa and D. W. Schloesser, eds. *Quagga and Zebra Mussels: Biology, Impacts, and Control*, Second Edition. CRC Press, Boca Raton.
- Stapanian, M. A., P. M. Kočovský, and J. V. Adams. 2009. Change in diel catchability of young-of-year yellow perch associated with establishment of dreissenid mussels. *Freshwater Biology* 54:1593-1604.
- Tyson, J. T., T. B. Johnson, C. T. Knight, M. T. Bur. 2006. Intercalibration of research survey vessels on Lake Erie. *North American Journal of Fisheries Management* 26:559-570
- Tyson, J.T., and R. L. Knight. 2001. Response of yellow perch to changes in the benthic invertebrate community of western Lake Erie. *Transactions of the American Fisheries Society* 130:766-782.
- Vandergoot, C. S., P. M. Kocovsky, T. O. Brenden, and W. Liu. 2011. Selectivity Evaluation for Two Experimental Gill-Net Configurations Used to Sample Lake Erie

- Walleyes. North American Journal of Fisheries Management 31:832-842
- von Szalay, P.G. and D.A. Somerton. 2005. The effect of net spread on the capture efficiency of a demersal survey trawl used in the eastern Bering Sea. Fisheries Research 74:86-95.
- Weinberg, K.L. and S. Kotwicki. 2008. Factors influencing net width and sea floor contact of a survey bottom trawl. Fisheries Research 93:265-279.

**Great Lakes Prey Fish Populations:
A Cross-Basin Overview of Status and Trends
Based on Bottom Trawl Surveys, 1978-2013¹**

Owen T. Gorman and Brian C. Weidel

U.S. Geological Survey
Great Lakes Science Center
Ann Arbor, MI 48105

Introduction

The assessment of Great Lakes prey fish stocks have been conducted annually with bottom trawls since the 1970s by the Great Lakes Science Center, sometimes assisted by partner agencies. These stock assessments provide data on the status and trends of prey fish that are consumed by important commercial and recreational fishes. Although all these annual surveys are conducted using bottom trawls, they differ among the lakes in the proportion of the lake covered, seasonal timing, trawl gear used, and the manner in which the trawl is towed (across or along bottom contours). Because each assessment is unique, population indices were standardized to the highest value for a time series within each lake for the following prey species: Cisco (*Coregonus artedii*), Bloater (*C. hoyi*), Rainbow Smelt (*Osmerus mordax*), Alewife (*Alosa pseudoharengus*), and Round Goby (*Neogobius melanostomus*). In this report, standardized indices are presented in graphical form along with synopses to provide a short, informal cross-basin summary of the status and trends of principal prey fishes.

Methods

For each lake, standardized relative indices of biomass for age-1 and older fishes were calculated as the observed value divided by the maximum value observed in the times series. Similarly, standardized relative indices of year-class strengths were calculated from densities of juvenile fishes. In each lake, juvenile year-classes that best reflected the magnitude of future recruitment were used to index year-class strength. Differences in the timing of surveys across lakes and differences in methodology used to distinguish juvenile age classes resulted in adopting different age-classes (age-0, age-1, age-3) to index year-class strength for each species and lake. Year-class strengths were based on age-correlated size classes of Cisco, Bloater, and Rainbow Smelt in Lake Superior and Alewife in Lake Michigan. For other species and lakes, age-classes were assigned based on fish length cut-offs.

The Kendall coefficient of concordance (W) was calculated to determine if the time series of relative abundances for a given species was statistically “concordant” across 3 or more lakes. W can range from 0 (complete discordance or disagreement) to 1 (complete concordance or agreement). For statistical comparisons between two lakes, Spearman’s correlation r was used assess concordance of ranks, ranging from 0 (complete discordance or disagreement) to 1 (complete

¹ Prepared for: Upper and Lower Lakes Committee Meetings
Great Lakes Fishery Commission
Windsor, Ontario, March 24-28, 2014

concordance or agreement). Concordance can be expressed as either a fraction or percent. A smaller P -value for W and r indicates a greater probability of agreement in comparison of trends.

When making statistical comparisons of trends among lakes, data were restricted to years when all or a group of lakes were sampled. For all lakes, data from 1992, 1993, 1998, and 2000 were omitted from statistical comparisons because missing or atypical data were collected in one or more lakes. Comparisons with Lake Erie were restricted to 1990-2013, years when multi-agency surveys with a consistent sample design were conducted. Beginning with the 2010 report, a complete data series from Lake Huron was made available for comparison with other lakes because fishing power corrections to the Huron data were developed to account for the use of a larger bottom trawl to conduct surveys during 1992-2013. Beginning with the 2012 report, a complete lake-wide data series for Lake Erie became available after the inclusion of data from Pennsylvania waters. Assessment of cross-basin trends for Round Goby begins with 1994, the first year that these fish were detected in bottom trawl surveys in the Great Lakes.

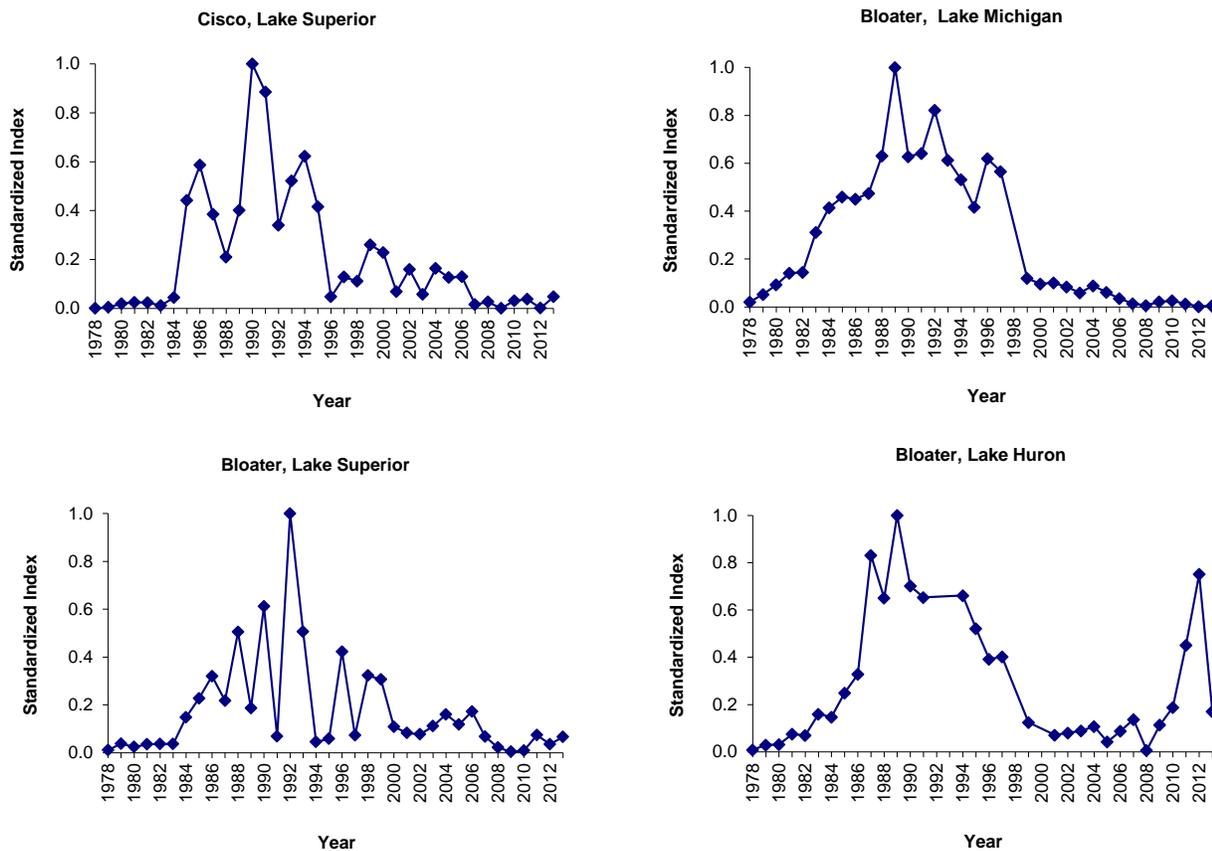


Figure 1. – Standardized indices of biomass for age-1 and older Cisco in Lake Superior and for age-1 and older Bloater in Lakes Superior, Michigan, and Huron, 1978-2013.

Results

Relative Biomass, Age-1 and Older Coregonids

Trends in relative biomass of age-1 and older coregonids (Cisco and Bloater in Lake Superior and Bloater in Lakes Michigan and Huron) among the 1978-2013 time series were significantly concordant (Fig. 1; $W = 0.68$; $P < 0.0001$). When the comparison was restricted to Bloater, the trends in relative biomass remained significantly concordant ($W = 0.66$; $P < 0.001$). In all three lakes, coregonid biomass reached peak levels in the mid-1980s through the mid-1990s. Afterwards, coregonid biomass declined, reaching historically low levels in 2007-2011 in Lakes Superior and

Michigan. In difference to trends in the other lakes, biomass of Bloater in Lake Huron rebounded following a record low in 2008 to 75% of peak biomass in 2012, due to the recruitment and growth of strong 2005 and 2007 and moderate 2008 and 2011 year classes (Figs. 1, 5). Bloater were absent from survey catches in Lakes Erie and Ontario and Cisco were rarely encountered in any Great Lake other than Superior.

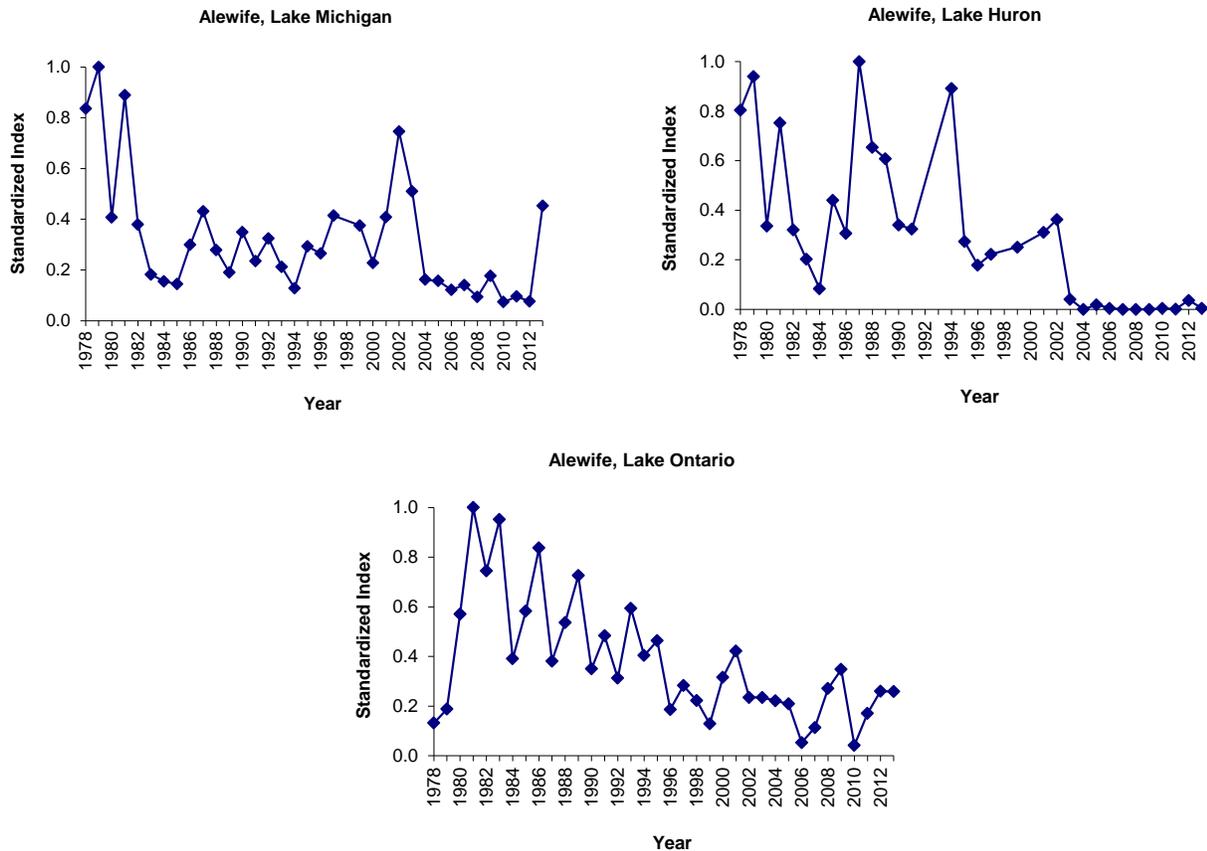


Figure 2. – Standardized indices of biomass for age-1 and older Alewife in Lakes Michigan, Huron, and Ontario, 1978-2013.

Relative Biomass, Age-1 and older Alewife

Trends in relative biomass of age-1 and older Alewife across Lakes Michigan, Huron, and Ontario were variable, though biomass was generally higher early in the time series and lower in more recent years (Fig. 2). For all three lakes, there was moderate concordance ($W = 0.60$; $P < 0.004$) among the 1978-2013 time series. In Lake Michigan, biomass of Alewife was high in the early 1980s and rapidly declined to lower levels in the mid-1980s that persisted through the 1990s. In 2002-2003 biomass rebounded strongly and then dropped to low levels in 2004-2012, reaching the lowest levels in the time series in 2010 and 2012. Then in 2013, biomass increased sharply to 45% of maximum value. In Lake Huron, biomass of Alewife was high in the beginning of the time series, declined to low levels in the mid-1980s, but unlike Lake Michigan, fluctuated widely in the late 1980s – mid 1990s with peaks in 1987 and 1994 and an intervening low in 1990-1991. After 1994, biomass declined to 18% of peak abundance in 1996, rebounded to 36% in 2002 and afterwards declined to near-zero levels in 2004-2011 and 2013, achieving record lows in 2004, 2008, and 2009. In Lake Ontario, biomass of Alewife has declined step-wise since 1980. Alewife remains a rare species in Lake Superior and survey data for Alewife in Lake Erie were not available for this comparison.

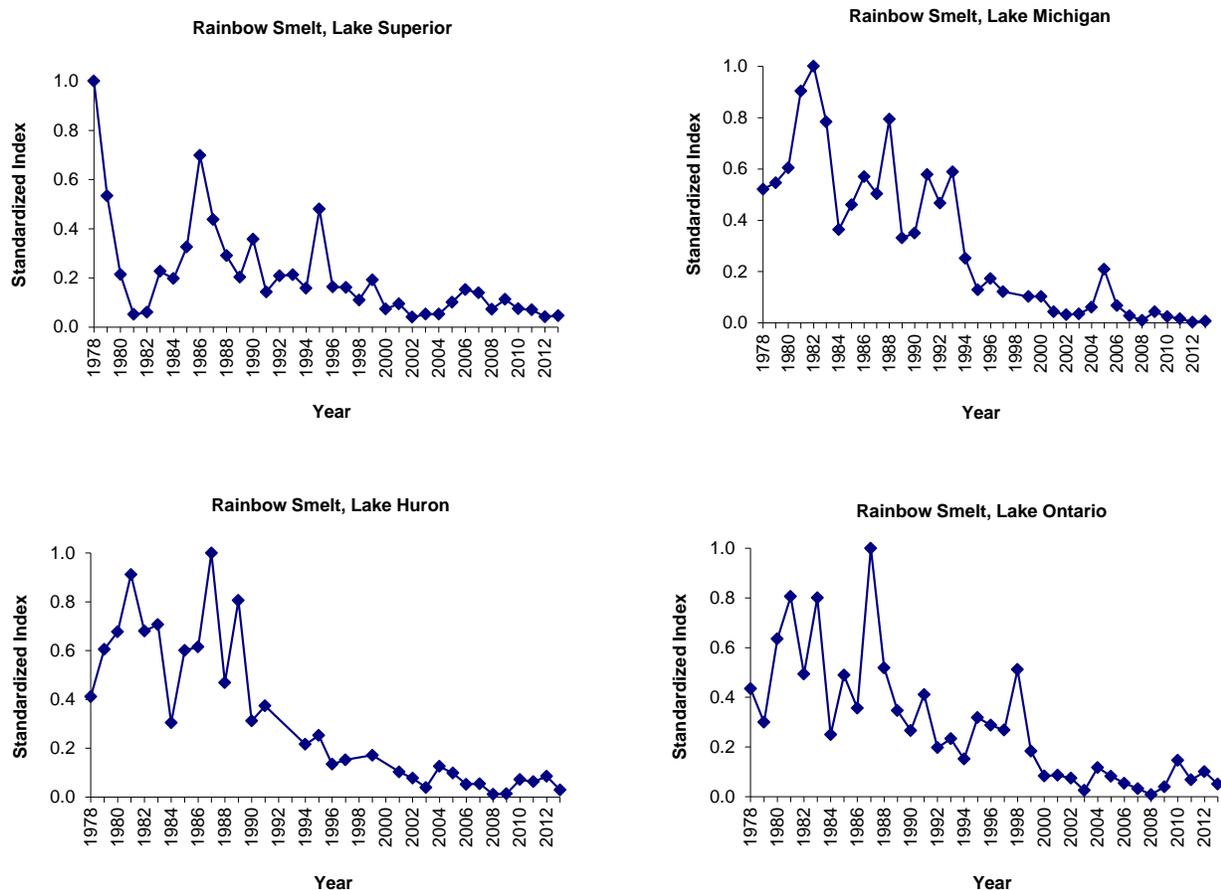


Figure 3. – Standardized indices of biomass for age-1 and older Rainbow Smelt in Lakes Superior, Michigan, Huron, and Ontario, 1978-2013.

Relative Biomass, Age-1 and Older Rainbow Smelt

Age-1 and older Rainbow Smelt in Lakes Superior, Michigan, Huron, and Ontario showed a concordant trend of fluctuating but declining relative biomass during 1978-2013 (Fig. 3; $W = 0.81$; $P < 0.0001$). In Lake Superior, biomass was at or near-record lows in 2002-2004, recovered to 15% of peak biomass by 2006, and then declined afterwards, reaching near-record lows in 2012 and 2013. Similarly, biomass in Lake Michigan was near record lows during 2001-2003, rose nearly 4-fold in 2005, and then dropped to record lows in 2007-2013. Mirroring the Michigan pattern, biomass in Lake Huron declined to near-record lows in 2002-2003, increased to 13% in 2004 and then declined to record lows in 2008-2009, but differing from the Michigan pattern, biomass increased to 6-8% of peak biomass in 2010-2012. In 2013, biomass dropped again, approaching a record low. A similar pattern was observed in Lake Ontario where biomass reached a near-record low in 2003 and was followed by two cycles of weak recovery and decline. Survey data for age-1 and older Rainbow Smelt in Lake Erie were not available for this comparison.

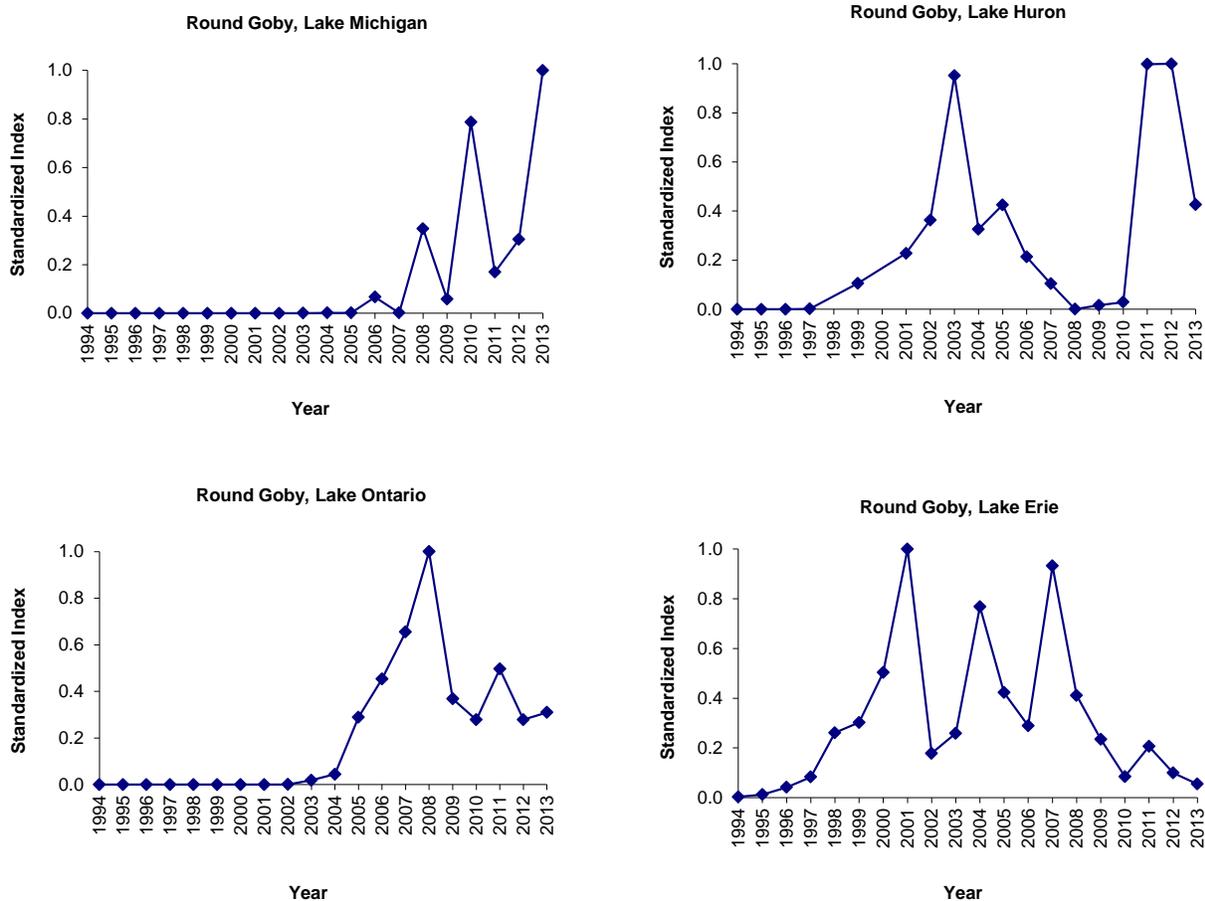


Figure 4. – Standardized indices of abundance for Round Goby in Lakes Michigan, Huron, Erie, and Ontario, 1994-2013. Indices are computed from number caught in Lake Erie and weight caught in all other lakes.

Relative Abundance, Age-0 and older Round Goby

Moderate agreement in trends in relative biomass of age-0 and older Round Goby ($W = 0.54$; $P < 0.004$) was observed among lakes where this species has become established (Lakes Michigan, Huron, Erie, and Ontario; Fig. 4). Further agreement in trends among lakes was hindered by the desynchronized expansion of Round Goby populations. The first records occurred in Lake Erie, followed by Lake Huron and then by Lakes Ontario and Michigan. Following several peaks in 2001, 2004, and 2007, biomass of Round Goby in Lake Erie appears to have waned to levels similar to that at the initial stages of expansion. After what appears to have been a similar pattern of expansion and decline in Lake Huron, biomass of Round Goby spiked to record levels in 2011 and 2013 and then declined 57% in 2013. The peak in biomass of Round Goby observed in 2013 in Lake Michigan suggests this species is still expanding in this Lake. In 2012-2013, Round Goby biomass in Ontario has remained $\leq 31\%$ of peak values and has not paralleled patterns in other lakes. These mixed results yield an unclear picture of the current state of goby populations across the Great Lakes; they may be approaching equilibrium in Lake Erie, expanding in Lakes Michigan and Huron, but the direction in Ontario remains uncertain. Round Goby have not been caught in annual bottom trawl surveys in Lake Superior.

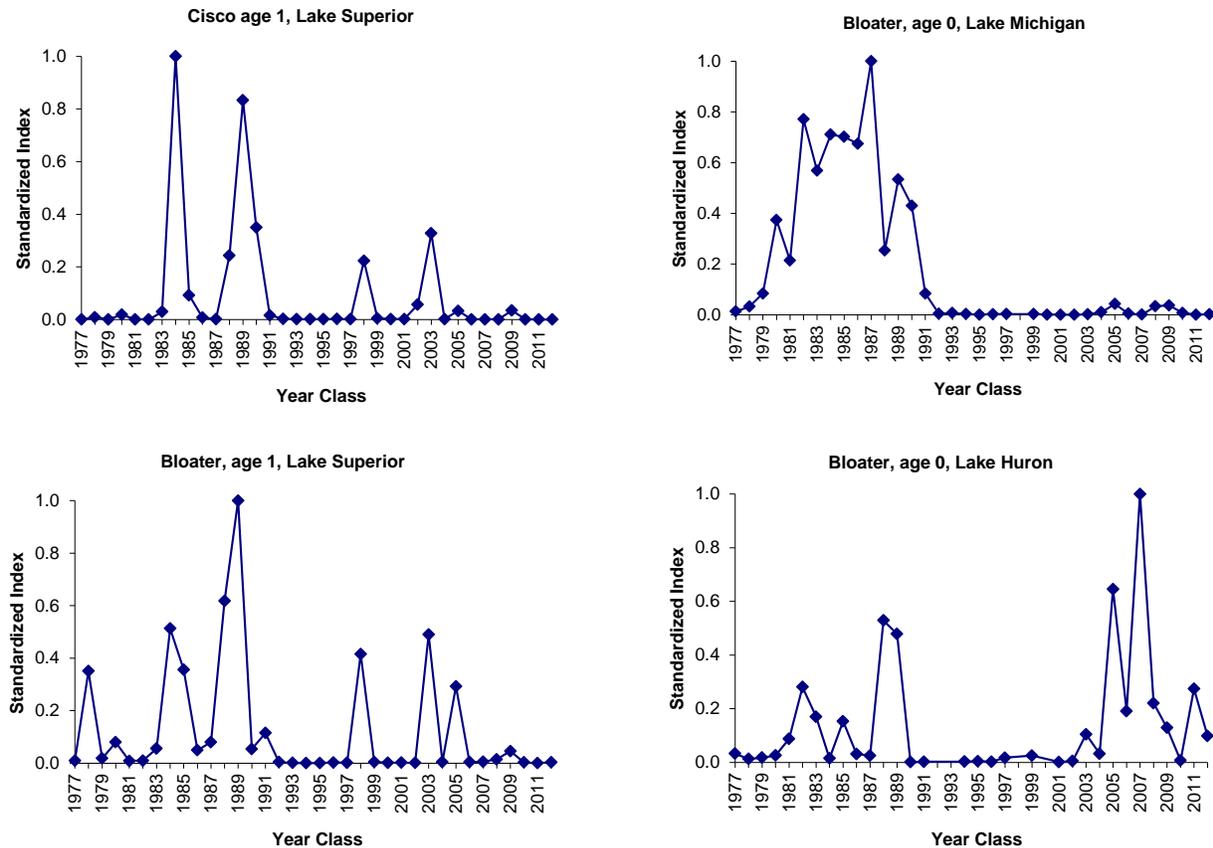


Figure 5. – Standardized indices of densities of age ≤ 1 ciscoes (Cisco and Bloater) in Lakes Superior, Michigan, and Huron, 1977-2012.

Year-Class Strengths, Coregonids

Trends in relative strengths of 1977-2012 coregonid year-classes showed moderate agreement ($W = 0.52$; $P < 0.001$) among Lakes Superior, Michigan, and Huron (Fig. 5). Restricting the comparison to Bloater improved the agreement slightly ($W = 0.61$; $P < 0.004$). All lakes shared a general pattern of stronger year-classes in the 1980s and weaker year-classes in the 1990s. Trends in relative year-class strengths of coregonids among the three upper Lakes showed higher concordance before the advent of a succession of strong and moderate year-classes in Lake Huron in 2005-2011 (1977-2004; $W = 0.57$; $P < 0.0004$). Bloater were absent from survey catches in Lakes Erie and Ontario and Cisco are rarely encountered outside of Lake Superior.

Year-Class Strengths, Alewife

Using relative abundances of Alewife at age-3 in Lake Michigan, age-0 in Lake Huron, and age-1 in Lake Ontario to assess year-class strengths, there was no agreement in trends ($W = 0.42$; $P = 0.17$) among the Lakes for 1977-2010 year-classes (Fig. 6). Agreement became significant if relative abundances of Alewife at age-0 in Lake Michigan (1978-2011 year classes) were substituted in the comparison ($W = 0.49$; $P < 0.05$). Comparison of relative abundances of age-0 Alewife (1978-2011 year classes) in Lakes Michigan and Huron was also significant ($r = 0.45$; $P < 0.05$). However, paired comparisons of relative abundances of age-1 Alewife in Lake Ontario with age-0 Alewife in Lakes Michigan and Huron showed no agreement ($r = 0.21, 0.20$; $P > 0.18, 0.19$, respectively). Similarly, comparison of 1978-2012 year classes in Lakes Huron and Ontario showed no agreement ($r = 0.040$; $P = 0.22$).

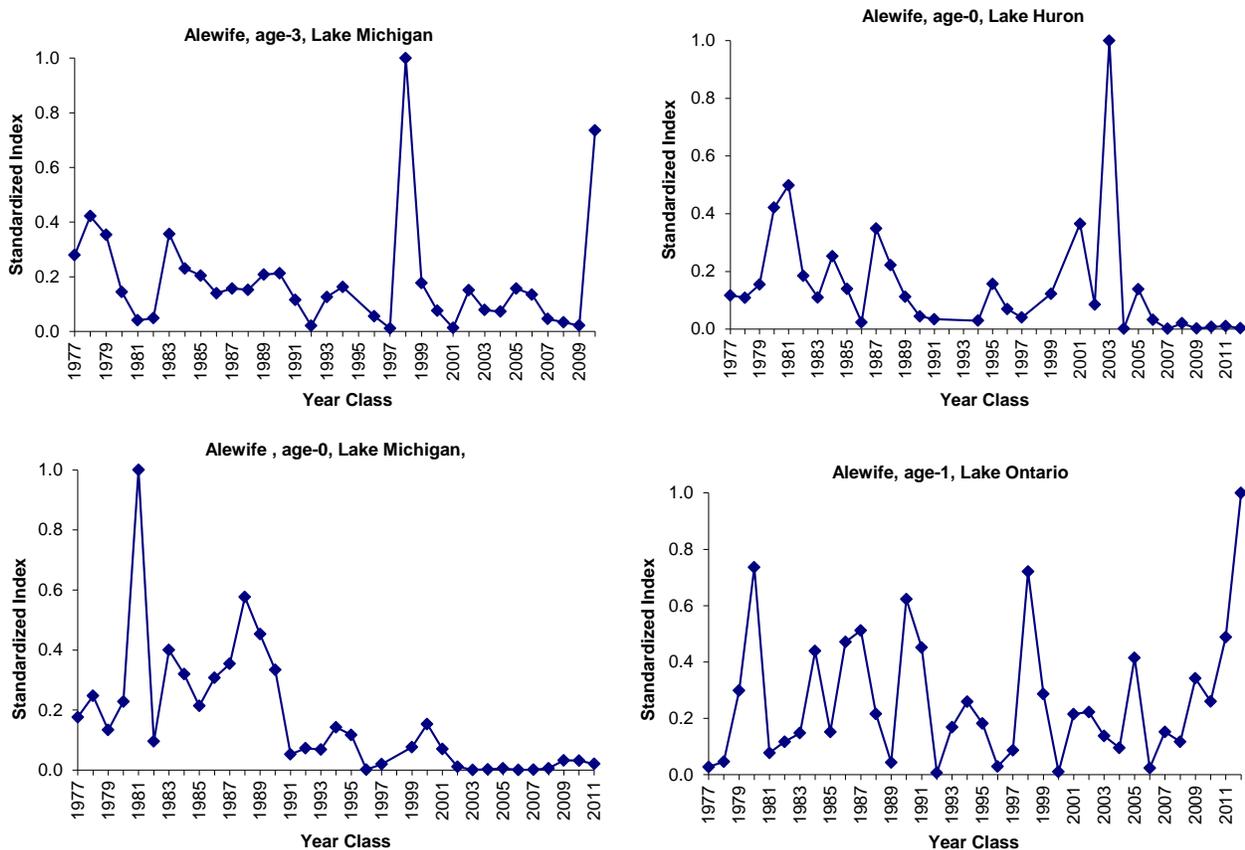


Figure 6. – Standardized indices of Alewife densities measured at age 0, 1 or 3 in Lakes Michigan, Huron, and Ontario, 1977-2012.

Comparisons of recruitment trends in Alewife at different ages are problematic because abundances at age-0, age-1, and age-3 are affected by differential survivorship. Thus it is not surprising that comparison of trends in relative year-class strengths of Alewife across the three lakes showed no agreement when these ages were considered. Paired comparisons showed moderate agreement between Lakes Michigan and Huron but no agreement with trends in Lake Ontario. Trends in year-class strengths in Ontario were highly variable with no discernible trends. However, the 2012 year class was the strongest on record. In Lakes Michigan and Huron, year-class strengths based on abundance of age-0 fish were variable but at intermediate levels through the 1980s. After 1990, year-class strengths declined in Lake Michigan, and were negligible after 2001. In Lake Huron, year-class strengths remained variable after 1990, and after producing its strongest year-class in 2003, subsequent year-classes were negligible. Alewife is a rare species in Lake Superior and survey data for Alewife in Lake Erie were not available for this comparison.

Year-Class Strengths, Rainbow Smelt

Trends in relative strengths of Rainbow Smelt year-classes across Lakes Superior, Michigan, Huron, and Ontario from 1977 to 2012 showed weak agreement ($W = 0.37$; $P < 0.05$) (Fig. 7). When the comparison was limited to Lakes Superior, Michigan, and Huron, the agreement was not significant ($W = 0.38$; $P = 0.279$). Paired comparisons among the three lakes showed that only Lakes Superior and Michigan were in agreement ($r = 0.51$; $P < 0.01$). In Lake Superior, year-class strengths varied from moderate to strong during 1977-1996, subsequently declined to weak levels in 1999-2002, and varied from weak to moderate in 2003-2009 and reached a record lows in 2010 and 2011. In Lake Michigan, year-class strengths declined steadily from 1980 to 1997 and thereafter

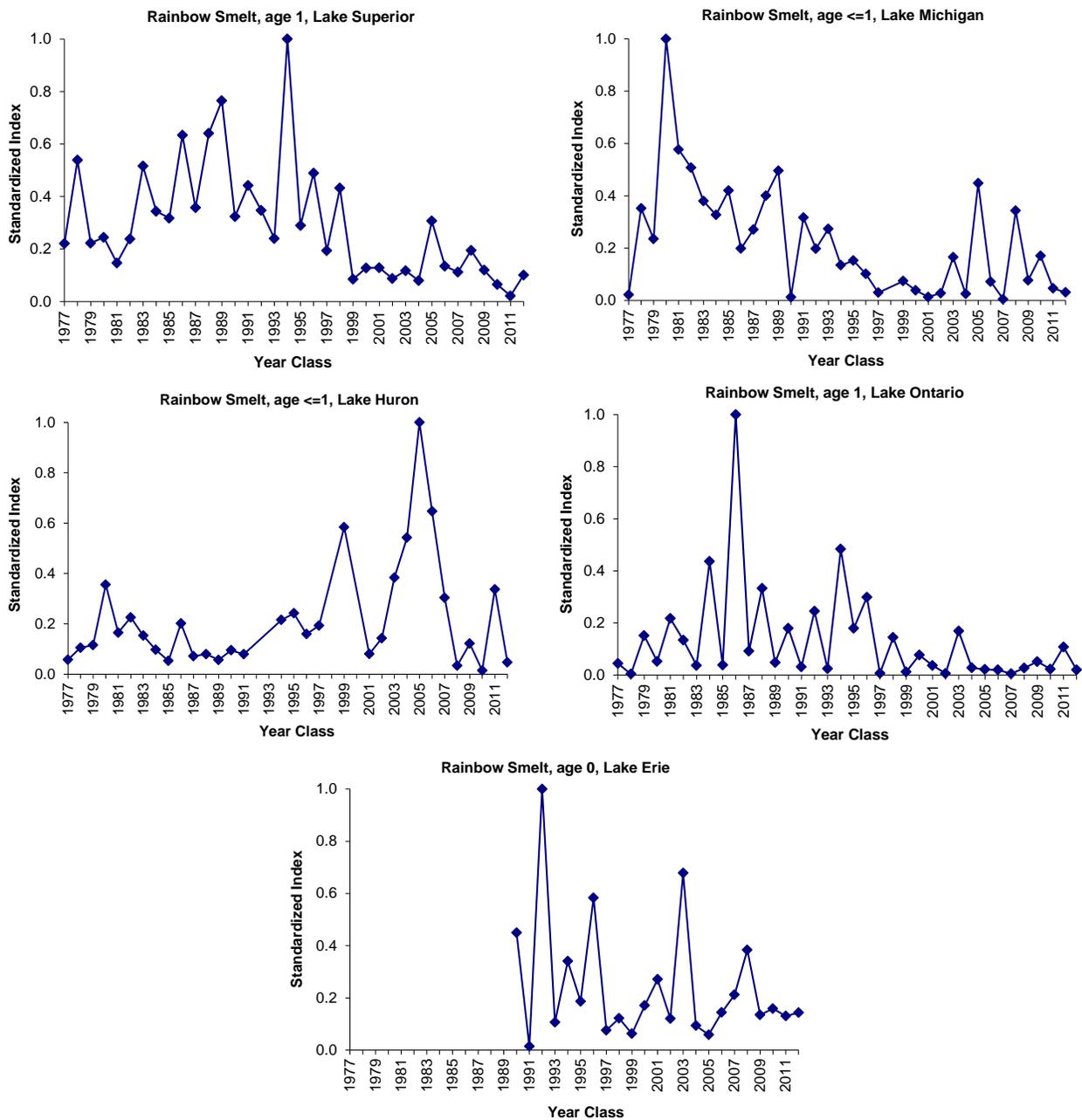


Figure 7. – Standardized indices of Rainbow Smelt densities measured at age-1 in Lakes Superior and Ontario and at age-0 in Lakes Michigan and Huron, 1977-2012.

remained weak except for the moderately strong year classes in 2005 and 2008. In contrast, year-class strengths in Lake Huron were moderate to weak over the first 26 years of the 36-year time series, and then increased rapidly to a peak in 2005 followed by a step decline to record lows in 2008 and 2010 and then rebounded to 34% of the record in 2011, only to decline sharply in 2012. In Lake Ontario, year-class strengths prior to 1999 exhibited a clear “saw-tooth” pattern caused by alternating strong and weak year-classes. This pattern was not discernible during 1999-2011 due to a succession of weak year classes. To include Lake Erie in our analysis, the comparison was restricted to the 1990-2012 year-classes. Concordance in trends in relative year-class strengths among all lakes remained not significant ($W = 0.30$; $P = 0.07$) and paired comparisons showed agreement only between Lakes Erie and Ontario ($r = 0.53$; $P < 0.05$) and Lakes Ontario and Superior ($r = 0.47$; $P < 0.05$). Agreement between Lakes Erie and Ontario was caused by concordance in up and down patterns of year-class strengths between 1990 and 2005 (Fig. 7). Agreement between Lakes Erie and

Superior appears due to concordance in higher year-class strengths between 1990 and 1997 and variable but lower year-class strengths afterwards (Fig. 7).

Summary

There was basin-wide agreement in the trends of age-1 and older biomass for all prey species, with the highest concordance occurring for coregonids and Rainbow Smelt, and weaker concordance for Alewife. For coregonids, the highest biomass occurred from the mid-1980s to the mid-1990s. Rainbow Smelt biomass declined slowly and erratically during the last quarter century. Alewife biomass was generally higher from the early 1980s through 1990s across the Great Lakes, but since the early 1990s, trends have been divergent across the lakes, though there has been a downward trend in all lakes since 2005. Recently, Lake Huron has shown resurgence in biomass of Bloater, achieving 75% of its maximum record in 2012 due to recruitment of a succession of strong and moderate year classes that appeared in 2005-2011. Also, strong recruitment of the 2010 year class of Alewife has led to a sharp increase in biomass of Alewife in Lake Michigan.

In general, trends in year-class strengths were less concordant across the basin and only coregonids showed statistical agreement across the upper Great Lakes. The appearance of strong and moderate year-classes of Bloater in Lake Huron in 2005- 2011 countered the trend of continuing weak year-classes of coregonids in Lakes Michigan and Superior. Not shown in our analysis is the appearance of the 2013 year-class of Bloater in Huron, the largest to date. There was no agreement in cross-basin trends in year-class strengths for Rainbow Smelt and Alewife, although there was agreement between pairs of lakes.

Although there was statistical agreement in trends of age-0 and older Round Goby biomass among lakes where this species has successfully invaded (Michigan, Huron, Erie and Ontario), temporal patterns of biomass in each lake were different. Round Goby may be approaching equilibrium in Lake Erie, peaking in Lake Huron, and expanding in Lake Michigan. The trend in Lake Ontario remains unclear. Declining abundance in Lake Erie has corresponded with evidence that Round Goby have become increasingly incorporated into piscivore diets, e.g., Lake Trout, Walleye, Smallmouth Bass, Yellow Perch, and Burbot in Lakes Michigan, Huron, Erie, and Ontario. Round Goby continue to be absent from spring bottom trawl assessments in Lake Superior, but their presence in the harbors and embayments of Duluth and Thunder Bay (U.S. Geological Survey and Ontario Ministry of Natural Resources, unpublished data), suggests that there is potential for future colonization.

Acknowledgements

USGS scientists and technicians Mark Vinson, Daniel Yule, Lori Evrard, Charles Madenjian, David Bunnell, Timothy DeSorcie, Mellissa Kostich, Stephen Riley, Edward Roseman, Timothy P. O'Brien, Patrick Kocovsky, Mark Rodgers, Richard Kraus, and Maureen Walsh contributed to data in this report. New York State Department of Environmental Conservation scientist Michael Connerton participated in Lake Ontario data collection. Participants collaborating in the collation of data from Lake Erie included John Deller and Eric Weimer (Ohio Department of Natural Resources), Jim Markham (New York State Department of Environmental Conservation), Chuck Murray and Mike Hosack (Pennsylvania Fish and Boat Commission), and Larry Witzel and Andy Cook (Ontario Ministry of Natural Resources).

Status and Trends in the Lake Superior Fish Community, 2013¹

Mark R. Vinson, Lori M. Evrard, Owen T. Gorman, Daniel L. Yule

U.S. Geological Survey Great Lakes Science Center Lake Superior Biological Station
2800 Lakeshore Drive East, Ashland, Wisconsin 54806 (mvinson@usgs.gov)

Abstract

In 2013, the Lake Superior fish community was sampled with daytime bottom trawls at 79 nearshore and 35 offshore locations. In the nearshore zone, a total of 23,432 individuals of 27 species or morphotypes were collected. Nearshore lakewide mean biomass was 5.5 kg ha⁻¹, which was slightly higher than that observed in the past few years, but below the long-term average of 8.8 kg ha⁻¹. In the offshore zone, a total 20,371 individuals of 13 species were collected lakewide. Offshore lakewide mean biomass was 8.9 kg ha⁻¹, which was similar to that observed in previous years.

Introduction

The U.S. Geological Survey Lake Superior Biological Station conducts annual daytime bottom trawl surveys in nearshore (~15-80 m) and offshore (100-300 m) waters of Lake Superior. These surveys provide data for assessment of long-term lakewide trends of fish species occurrences and relative abundance and biomass. Rather than absolute abundance and biomass estimates, these data have historically been considered population indices. Age and diet analyses are conducted for selected species. The nearshore survey has been conducted in spring since 1978 in U.S. waters and since 1989 in Canadian waters. The offshore survey has been conducted in summer since 2011. Herein we report on biomass estimates and recruitment of age-1 fish for selected species. Results presented are based solely on bottom trawl sampling, so fishing gear bias should be considered when interpreting the results of this survey particularly for species with reduced vulnerability to daytime bottom trawls, such as Cisco, and larger Lake Trout.

Methods

Nearshore survey

Nearshore sites are located systematically around the perimeter of the lake (Fig. 1). We used bottom trawls towed in cross-contour fashion to sample fish at depths ranging from 15-80 m. In 2013, 79 locations were sampled between 20 May and 21 June 2013 (Fig. 1). Four of the long-term survey sites were not sampled in Michigan due to commercial fishing operations, one in Big Bay and three in Whitefish Bay, and two sites along the Keweenaw Peninsula were not sampled due to mechanical problems. At each location, a single fish collection was made with a 12-m Yankee bottom trawl towed cross-contour. The median start and end depths for bottom trawl tows were 16 m (range 9-31 m) and 55 (range 31-142 m), respectively. The median trawl distance was 0.9 km (range 0.3-2.4 km). The median trawl wingspread was 8.5 m (range 6.7-10.4 m). Fish collections were sorted by species, counted, and weighed in aggregate to the nearest gram. Total length was measured on a minimum of 50 individuals per species per trawl. Length data for these individuals were then extrapolated to the entire catch. Relative density (fish/ha) and biomass (kg/ha) were estimated by dividing sample counts and aggregate weights by the area of the bottom swept by each trawl tow (ha). Biomass data are reported for all species combined and individually for Cisco, Bloater, Rainbow Smelt, Lake Whitefish, Sculpin species (Slimy Sculpin, Spoonhead Sculpin, and Deepwater Sculpin), and hatchery, lean, and Siscowet Lake Trout (scientific names are provided in Table 1). For Cisco, Bloater, Lake Whitefish, and Rainbow Smelt, age-1 year-class strength was estimated as the mean lakewide relative density for age-1 fish. Age-1 fish were estimated based on lengths; Cisco <140 mm,

¹Presented at: Great Lakes Fishery Commission, Lake Superior Committee Meeting, 25 March 2014

Bloater <130 mm, Lake Whitefish <160 mm, and Rainbow Smelt <100 mm. Lake Trout densities are presented for small, < 226 mm (ca. \leq age-3) fish.

Offshore survey

Offshore sites are randomly located around the lake using a spatially-balanced, depth-weighted probabilistic sampling design that targets depths >100 m (Fig. 1). Sample sites were selected in 2011 and the same sites were sampled since 2011. In 2013, 35 locations were sampled during daylight hours between 6 and 21 July. A single daytime bottom trawl was made at each site using a 12-m Yankee bottom trawl towed on-contour. Station sampling depths ranged from 86 to 315 m. The mean and median trawl distance was 1.7 km (range 1.5-1.9 km). The median trawl wing spread was 10.1 m (range 8.1-12.4 m). Catches were processed similarly to that described for nearshore trawls. Data are presented individually for Kiyi, Deepwater Sculpin, and Siscowet Lake Trout.

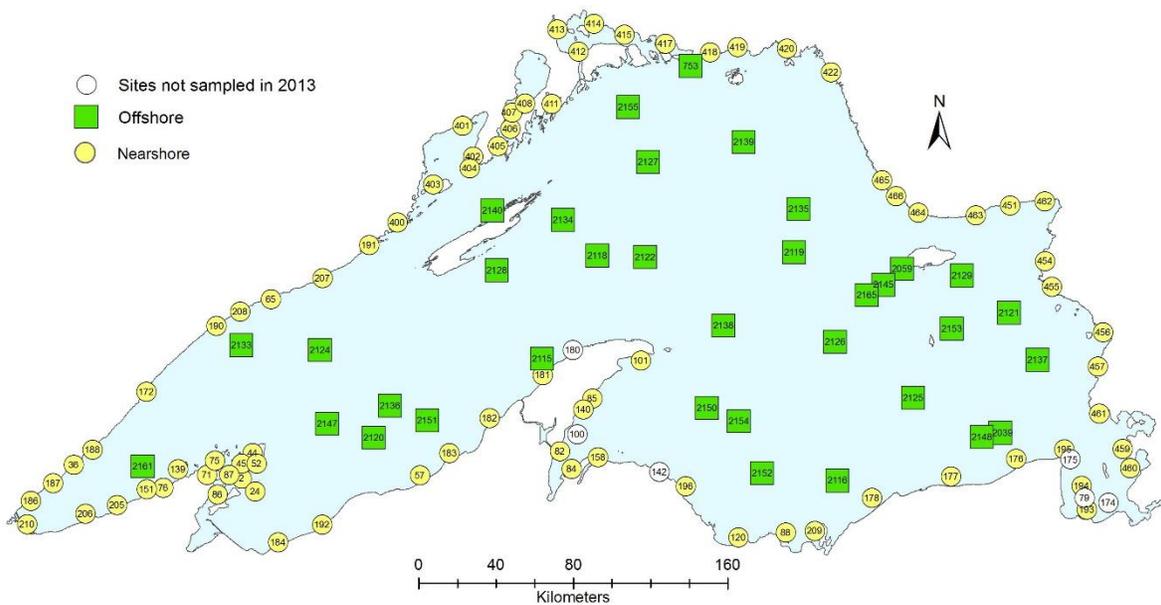


Figure 1 Location of 85 nearshore and 35 offshore bottom trawl stations established for sampling the Lake Superior fish community. In 2013, 79 nearshore and 35 offshore sites were sampled. Numbers are station numbers shown in Figure 3.

Results

Nearshore survey

Fish community biomass – In 2013, a total of 23,432 individuals of 27 species or morphotypes were collected lakewide at 79 nearshore sites (Table 1). The number of species collected at each station ranged from 0 to 15, with a mean of 6 and median of 5. Lakewide mean biomass was 5.5 kg ha⁻¹ and the median was 1.1 kg ha⁻¹ (Figure 2) in 2013. This was higher than that observed since 2008, but remained below the long-term mean of 8.8 kg ha⁻¹ and long-term average median of 1.8 kg ha⁻¹. Individual station biomass was non-normally distributed and skewed to the left (Figure 3). The skewness of the population of biomass estimates in 2013 was 4.4, which was above the long-term mean of 3.9 (Figure 3), but was not overly different from most years, suggesting that the 2013 sample population had a similar distribution to those observed in previous years. Total biomass at 20% of the sites was greater than the lakewide mean, which was near the long-term average of 22%.

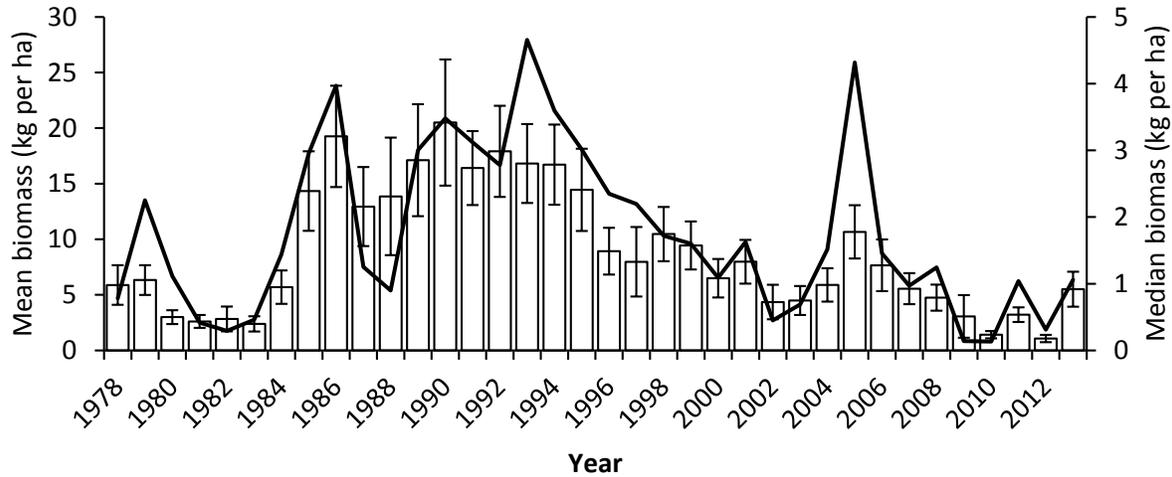


Figure 2 Bars denote the mean \pm SE (left axis) and the line is the annual median (right axis) lakewide biomass of all fish species collected in bottom trawls in nearshore stations from 1978-2013.

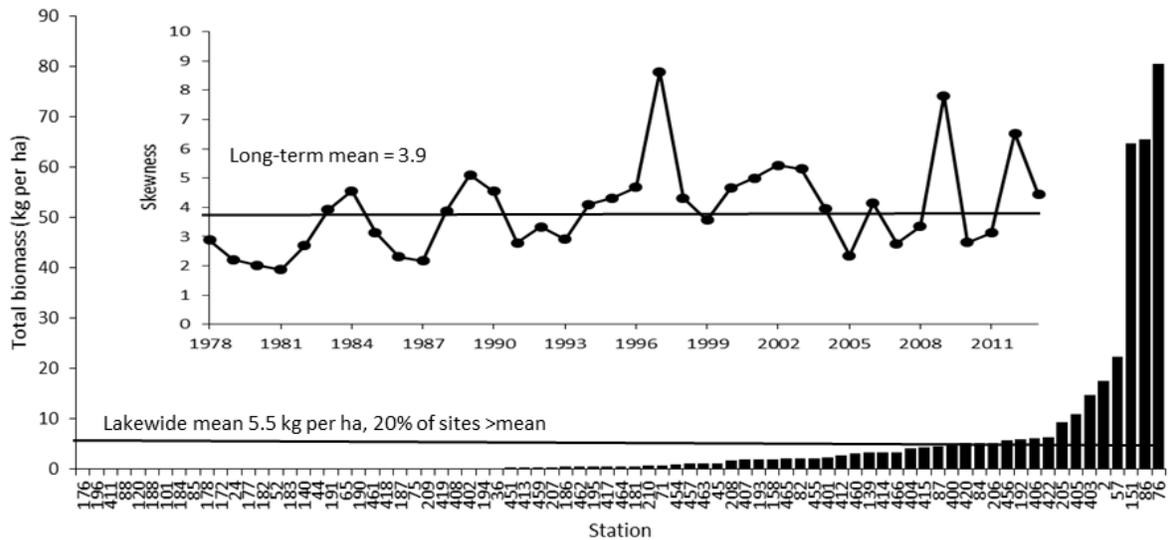


Figure 3 Bars denote the estimated biomass at individual sampling stations in 2013. Station locations are shown on Figure 1. The inset line graph shows the annual skewness in the distribution of individual station biomass estimates.

Cisco – Lakewide mean nearshore biomass for Cisco was 0.43 kg ha^{-1} in 2013. This was well below the long-term average of 2.57 kg ha^{-1} and similar to that observed since 2006 (Table 2). Density of age-1 fish was $0.17 \text{ fish ha}^{-1}$ in 2013, which was well below population estimates observed during good recruitment years when estimates typically exceed 175 fish ha^{-1} (Table 3). The last strong yearclass was produced in 2003.

Bloater – Lakewide mean nearshore biomass for bloater was 0.49 kg ha^{-1} in 2013. This was well below the long-term average of 1.76 kg ha^{-1} (Table 2). Density of age-1 fish was $0.22 \text{ fish ha}^{-1}$ in 2013, which was well below the population estimates observed during good recruitment years when estimates typically exceed 20 fish ha^{-1} (Table 3). The last strong yearclass was produced in 2003.

Lake Whitefish – Lakewide mean nearshore biomass for Lake Whitefish was 2.98 kg ha⁻¹ in 2013. This was similar to the long-term average of 2.13 kg ha⁻¹ and similar to that observed since 2006 (Table 2). Density of age-1 fish was 5.46 fish ha⁻¹ in 2013, which was below the long-term average of 7.63 fish ha⁻¹ (Table 3). The majority of Lake Whitefish (57%) were collected in management unit WI-2 in 2013.

Rainbow Smelt – Lakewide mean nearshore biomass for Rainbow Smelt was 0.53 kg ha⁻¹ in 2013. This was less than the long-term average of 1.22 kg ha⁻¹ and in the range of that observed since 2009 (Table 2). Density of age-1 fish was 142.90 fish ha⁻¹ in 2013, which was similar to the long-term average of 165.15 fish ha⁻¹ (Table 3).

Ninespine Stickleback – Lakewide mean nearshore biomass for Ninespine Stickleback was 0.02 kg ha⁻¹ in 2013. This was less than the long-term average of 0.09 kg ha⁻¹ and similar to that observed since 2002 (Table 2).

Sculpin – Lakewide mean nearshore biomass for Sculpin was 0.02 kg ha⁻¹ in 2013. This was below the long-term average of 0.07 kg ha⁻¹. Sculpin biomass has not exceeded 0.07 kg ha⁻¹ since 1996 (Table 2).

Burbot – Lakewide mean nearshore biomass for Burbot was 0.01 kg ha⁻¹ in 2013. This was below the long-term average of 0.13 kg ha⁻¹. Burbot biomass has not exceeded 0.13 kg ha⁻¹ since 2008, but Burbot biomass has been erratic throughout the long-term time series (Table 2).

Lake trout – Lakewide mean nearshore biomass for hatchery Lake Trout was 0.01 kg ha⁻¹ in 2013. Hatchery Lake Trout biomass has for the most part been near zero since 1997 (Figure 4). Lean Lake Trout biomass was 0.26 kg ha⁻¹. This is similar to that observed the past several years (Table 2). Siscowet Lake Trout nearshore biomass was 0.31 kg ha⁻¹. This was the highest biomass observed since 1996 and was the third year in a row that Siscowet Lake Trout biomass exceeded Lean Lake Trout biomass in nearshore waters (Table 2). Density of age-3 and younger Lean and Siscowet Lake Trout were 0.36 and 0.06 fish ha⁻¹ in 2013, respectively. Young Lean Lake Trout densities were less than the long-term average and siscowet densities were similar to the long-term average (Table 3).

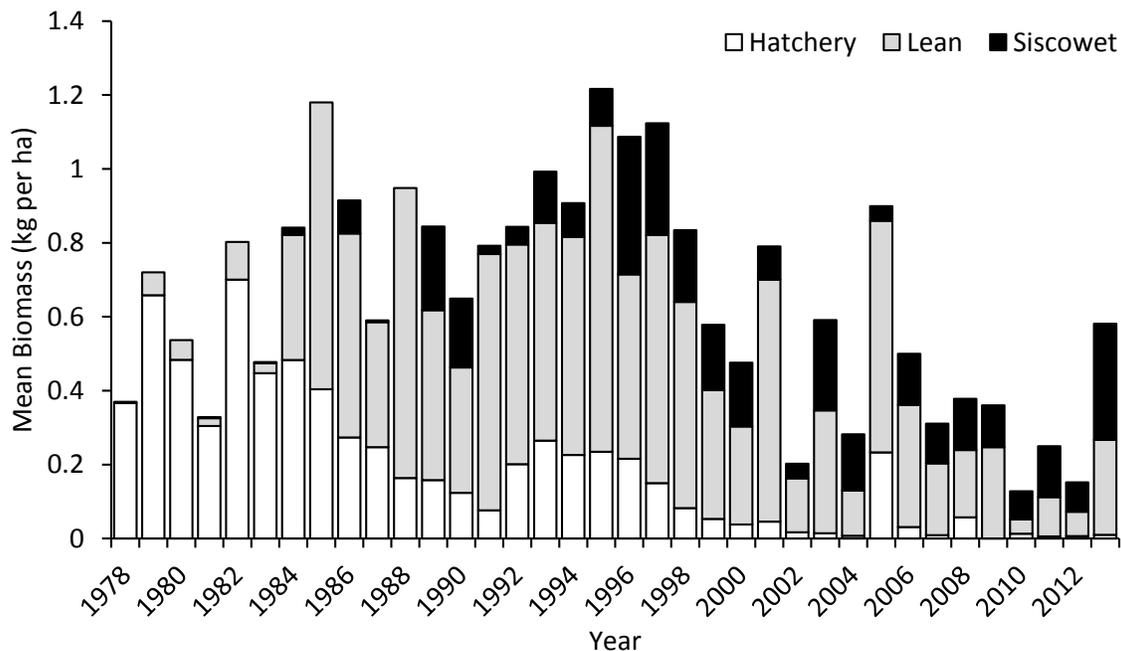


Figure 4 Mean annual lakewide biomass estimates for hatchery, lean, and siscowet lake trout estimated from bottom trawls in nearshore locations from 1978-2013.

Offshore survey

Total fish community – In 2013, a total 20,371 individuals of 13 species were collected lakewide at offshore sites (Table 1). The number of species collected at each station ranged from 1-8. The mean and median number of species collected per site was 4. Deepwater Sculpin, Kiyi, and Siscowet Lake Trout made up 98% of the total biomass collected in offshore waters (Figure 5). Mean lakewide biomass was 8.9 kg ha⁻¹, which was the same as that estimated in 2011 (8.9 kg per ha⁻¹) and more than that estimated in 2012 (6.9 kg per ha⁻¹). The median biomass was 7.2 kg ha⁻¹ in 2013.

Deepwater Sculpin – Lakewide mean offshore biomass of Deepwater Sculpin was 2.7 kg ha⁻¹. This is similar to that observed in 2011 and 2012, 2.0 and 2.9 kg ha⁻¹, respectively.

Kiyi – Lakewide mean offshore biomass of Kiyi was 2.6 kg ha⁻¹. This was a bit more than that observed in 2011 and 2012, 1.9 and 1.7 kg ha⁻¹, respectively.

Siscowet Lake Trout – Lakewide mean offshore biomass of Siscowet Lake Trout was 3.5 kg ha⁻¹. This is similar to that observed in 2011 (3.7 kg ha⁻¹) and more than observed in 2012 (2.1 kg ha⁻¹).

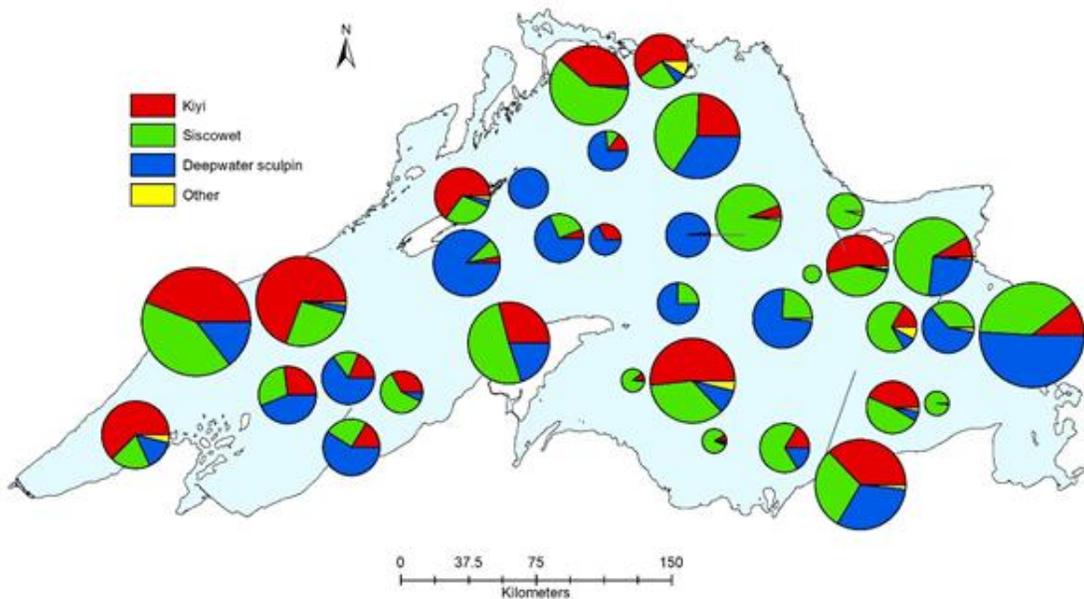


Figure 5 Mean lakewide biomass estimates for kiyi, deepwater sculpin, siscowet lake trout, and other species estimated from bottom trawls in offshore locations in 2013. Pie diameter is proportional to the biomass collected at that site and ranges from 1.0-24.7 kg ha⁻¹.

Summary

Over the 36 year history of this nearshore survey, total reported biomass has been largely dependent on recruitment of Bloater, Cisco and Lake Whitefish and survival of Rainbow Smelt to age-3 or older. These conditions have not occurred to any great degree since 2004. The lack of significant recruitment of these species, particularly Cisco, is of concern to both fishery managers and commercial fishers. The continued increase in Siscowet Lake Trout in the nearshore zone is something of interest as well. In the offshore zone, we have much less variation in biomass than the nearshore survey and it samples a different fish community. The combination of the two surveys provide a nice lakewide picture of the Lake Superior fish community that are susceptible to bottom trawls.

Table 1. Fish Species and the number of individuals collected in nearshore and offshore surveys in Lake Superior in 2013.

Fish	Scientific name	Nearshore	Offshore
Alewife	<i>Alosa pseudoharengus</i>	13	0
Longnose Sucker	<i>Catostomus catostomus</i>	61	0
White Sucker	<i>Catostomus commersoni</i>	1	0
Unidentified Chubs	<i>Coregonus</i>	5	0
Cisco	<i>Coregonus artedii</i>	203	2
Lake Whitefish	<i>Coregonus clupeaformis</i>	2,134	0
Bloater	<i>Coregonus hoyi</i>	566	44
Kiyi	<i>Coregonus kiyi</i>	4	2,118
Blackfin Cisco	<i>Coregonus nigripinnis</i>	1	4
Shortjaw Cisco	<i>Coregonus zenithicus</i>	89	9
Slimy Sculpin	<i>Cottus cognatus</i>	494	35
Spoonhead Sculpin	<i>Cottus ricei</i>	122	1
Johnny Darter	<i>Etheostoma nigrum</i>	2	0
Threespine Stickleback	<i>Gasterosteus aculeatus</i>	1	0
Ruffe	<i>Gymnocephalus cernuus</i>	13	0
Lake Chub	<i>Hybopsis plumbea</i>	1	0
Burbot	<i>Lota lota</i>	20	4
Deepwater Sculpin	<i>Myoxocephalus thompsonii</i>	119	17,771
Chinook Salmon	<i>Oncorhynchus tshawytscha</i>	1	0
Rainbow Smelt	<i>Osmerus mordax</i>	13,458	6
Yellow Perch	<i>Perca flavescens</i>	1	0
Trout-Perch	<i>Percopsis omiscomaycus</i>	1,251	0
Pygmy Whitefish	<i>Prosopium coulteri</i>	3,030	35
Ninespine Stickleback	<i>Pungitius pungitius</i>	1,693	2
Hatchery Lake Trout	<i>Salvelinus namaycush</i>	9	0
Lean Lake Trout	<i>Salvelinus namaycush</i>	89	0
Siscowet Lake Trout	<i>Salvelinus namaycush siscowet</i>	51	340
Total:	26 nearshore and 13 offshore species	23,432	20,371

Table 2. U.S. Geological Survey spring bottom trawl estimated nearshore mean lakewide biomass (Kg ha⁻¹) of common fishes in Lake Superior, 1978-2013. Sculpin includes slimy, spoonhead, and deepwater sculpin. All fish is the total biomass for all species.

Year	Sites	All fish	Rainbow smelt	Cisco	Bloater	Lake whitefish	Sculpin	Ninespine stickleback	Burbot	Lean lake trout	Siscowet lake trout	Hatchery lake trout
1978	43	5.88	4.07	0.01	0.13	0.70	0.14	0.27	0.17	0.00	0.00	0.37
1979	49	6.33	2.17	0.06	0.45	1.27	0.20	0.77	0.30	0.06	0.00	0.66
1980	48	3.00	0.87	0.28	0.28	0.58	0.19	0.04	0.19	0.05	0.00	0.48
1981	48	2.61	0.21	0.36	0.41	0.67	0.18	0.18	0.24	0.02	0.00	0.30
1982	32	2.83	0.25	0.35	0.43	0.85	0.03	0.05	0.06	0.10	0.00	0.70
1983	50	2.39	0.92	0.17	0.43	0.20	0.06	0.02	0.07	0.03	0.00	0.45
1984	53	5.70	0.80	0.65	1.75	1.27	0.06	0.06	0.20	0.34	0.02	0.48
1985	53	14.34	1.33	6.53	2.69	2.14	0.08	0.17	0.05	0.78	0.00	0.40
1986	53	19.26	2.84	8.65	3.79	2.65	0.07	0.06	0.18	0.55	0.09	0.27
1987	53	12.94	1.78	5.69	2.57	2.00	0.07	0.08	0.14	0.34	0.00	0.25
1988	53	13.86	1.18	3.10	5.97	2.40	0.04	0.05	0.08	0.78	0.00	0.16
1989	76	17.12	2.08	6.21	1.71	5.54	0.08	0.12	0.21	0.46	0.23	0.16
1990	81	20.50	1.95	10.12	4.85	2.36	0.08	0.18	0.11	0.34	0.19	0.12
1991	84	16.41	1.17	10.23	0.81	2.74	0.10	0.07	0.21	0.69	0.02	0.08
1992	85	17.91	1.02	3.40	8.39	3.70	0.07	0.16	0.17	0.59	0.05	0.20
1993	87	16.81	2.12	4.99	4.28	3.67	0.08	0.07	0.27	0.59	0.14	0.27
1994	87	16.72	1.89	7.24	0.42	5.42	0.08	0.08	0.11	0.59	0.09	0.23
1995	87	14.45	2.21	3.96	0.57	5.84	0.09	0.10	0.14	0.88	0.10	0.23
1996	87	8.93	1.28	1.04	3.09	1.63	0.11	0.12	0.19	0.50	0.37	0.22
1997	85	7.97	1.35	1.35	0.86	2.77	0.06	0.14	0.10	0.67	0.30	0.15
1998	87	10.47	1.47	1.09	4.37	2.26	0.07	0.08	0.07	0.56	0.19	0.08
1999	84	9.44	1.10	2.82	3.21	1.27	0.04	0.09	0.07	0.35	0.18	0.05
2000	85	6.50	0.83	2.42	0.94	1.60	0.04	0.02	0.02	0.27	0.17	0.04
2001	83	7.98	1.52	1.15	1.19	2.78	0.04	0.09	0.13	0.65	0.09	0.05
2002	84	4.35	0.18	1.48	0.57	1.69	0.02	0.03	0.10	0.15	0.04	0.02
2003	86	4.49	0.31	0.64	0.88	1.84	0.02	0.02	0.01	0.33	0.24	0.01
2004	75	5.89	0.32	1.80	1.15	1.88	0.03	0.05	0.20	0.12	0.15	0.01
2005	52	10.67	1.00	2.23	1.65	4.37	0.01	0.01	0.31	0.63	0.04	0.23
2006	55	7.66	0.95	2.25	1.79	1.70	0.02	0.04	0.08	0.33	0.14	0.03
2007	56	5.56	1.77	0.27	0.90	1.86	0.02	0.06	0.12	0.19	0.11	0.01
2008	59	4.75	0.94	0.38	0.17	2.37	0.02	0.03	0.29	0.18	0.14	0.06
2009	64	3.06	0.38	0.30	1.18	0.15	0.02	0.01	0.04	0.25	0.11	0.00
2010	76	1.41	0.22	0.31	0.23	0.27	0.05	0.01	0.03	0.04	0.08	0.01
2011	82	3.22	0.62	0.41	0.56	0.94	0.05	0.02	0.02	0.11	0.14	0.01
2012	72	1.07	0.16	0.02	0.35	0.15	0.03	0.01	0.02	0.07	0.08	0.01
2013	79	5.51	0.53	0.43	0.49	2.98	0.02	0.02	0.10	0.26	0.31	0.01
Mean	69	8.83	1.22	2.57	1.76	2.13	0.07	0.09	0.13	0.36	0.11	0.19

Table 3. U.S. Geological Survey spring bottom trawl estimated nearshore mean lakewide density (number ha⁻¹) of age-1 Cisco, Bloater, Lake Whitefish, and Rainbow Smelt and for small Lean and Siscowet lake trout. Age-1 fish were defined by lengths; Cisco <140 mm, Bloater <130 mm, Lake Whitefish <160 mm, and Rainbow Smelt <100 mm. Lean and Siscowet Lake Trout data are for fish <126 mm, < age 3.

Year	Sites	Rainbow smelt	Cisco	Bloater	Lake whitefish	Lean lake trout	Siscowet lake trout
1978	43	95.76	0.03	0.82	2.62	0.21	0.00
1979	49	234.14	6.30	30.08	3.90	0.35	0.00
1980	48	96.79	0.11	1.57	1.97	0.25	0.00
1981	48	106.26	13.48	6.85	16.43	0.57	0.07
1982	32	63.81	0.16	0.75	4.16	0.44	0.00
1983	50	103.58	0.05	0.82	0.45	0.41	0.00
1984	53	224.39	21.76	4.74	8.04	1.18	0.00
1985	53	149.51	748.02	44.00	2.47	1.30	0.00
1986	53	150.41	68.92	30.55	3.45	0.86	0.12
1987	53	275.59	5.44	4.23	11.91	0.72	0.04
1988	53	155.27	0.52	6.86	6.11	0.52	0.00
1989	76	274.78	226.80	37.69	36.08	0.26	0.13
1990	81	272.04	425.64	57.26	8.78	0.44	0.05
1991	84	162.03	236.87	11.38	17.54	0.67	0.01
1992	85	176.94	9.08	10.71	11.84	0.81	0.05
1993	87	155.24	3.34	0.22	7.68	0.84	0.20
1994	87	198.62	0.76	0.06	4.95	1.14	0.01
1995	87	401.83	1.47	0.00	13.52	1.71	0.05
1996	87	168.25	0.96	0.05	6.33	2.26	0.21
1997	85	253.04	11.09	0.18	8.80	0.77	0.07
1998	87	145.01	1.18	0.12	7.74	1.21	0.04
1999	83	216.18	90.76	0.40	9.17	0.33	0.10
2000	85	58.40	3.85	0.48	0.77	0.36	0.01
2001	83	256.32	0.83	0.12	2.37	0.52	0.03
2002	84	56.79	0.53	0.12	13.68	0.24	0.06
2003	86	77.83	33.20	0.58	7.74	0.18	0.03
2004	75	70.28	175.34	27.22	6.36	0.25	0.03
2005	52	110.39	8.19	12.07	2.97	0.60	0.07
2006	55	249.53	18.58	13.61	5.43	0.37	0.21
2007	56	360.93	0.41	0.32	19.74	0.10	0.05
2008	59	280.69	0.20	0.28	0.63	0.20	0.09
2009	64	71.64	0.27	0.59	3.00	0.07	0.07
2010	76	45.22	14.03	2.46	6.64	0.03	0.05
2011	82	73.98	0.30	0.76	3.98	0.43	0.03
2012	72	11.05	0.03	0.06	1.90	0.40	0.06
2013	79	142.90	0.17	0.22	5.46	0.36	0.06
Mean	69	165.15	59.13	8.56	7.63	0.59	0.06

Status and Trends of Pelagic Prey Fish in Lake Huron, 2013¹

Timothy P. O'Brien, David M. Warner, Steven A. Farha,
Darryl W. Hondorp, Lisa Kaulfersch, and Nicole Watson

U.S. Geological Survey
Great Lakes Science Center
1451 Green Rd.
Ann Arbor, MI 48105

Abstract

The USGS Great Lakes Science Center (GLSC) conducted acoustic and midwater trawl surveys of Lake Huron during 1997 and annually during 2004-2013. The 2013 survey was conducted during September and October and included transects in Lake Huron's main basin, Georgian Bay, and North Channel. Pelagic fish density was 1,033 fish/ha in 2013 and increased 62% over the 2012 estimate. Total biomass in 2013 (6.07 kg/ha) was similar to the 2012 estimate (6.97 kg/ha). Mean numeric density of alewife *Alosa pseudoharengus* was substantially greater in 2013 than in 2012, but the 2013 estimate has low precision. Age-0 rainbow smelt *Osmerus mordax* abundance increased from 2012, whereas age-1+ rainbow smelt decreased. Age-0 bloater *Coregonus hoyi* abundance increased over 2012 estimates. Density and biomass of large bloater in 2013 was similar to 2012 levels. Emerald shiner *Notropis atherinoides* density and biomass increased during 2013. Two adult cisco *Coregonus artedii* were captured in Georgian Bay. Based on comparable biomass estimates during 2012 and 2013, prey fish availability during 2014 will likely be similar to 2013. Lake Huron has pelagic fish biomass similar to that observed in recent lake-wide acoustic surveys of Lake Michigan and Lake Superior, but species composition differs in the three lakes. There is an increasing gradient of diversity and native species occurrence from Lake Michigan to Lake Superior, with Lake Huron being intermediate in the prevalence of native fish species like coregonines and emerald shiner.

¹Presented at: Great Lakes Fishery Commission
Lake Huron Committee Meeting
Windsor, ON, March 24, 2014

Introduction

The U.S. Geological Survey's Great Lakes Science Center has conducted bottom trawl surveys of the Lake Huron fish community since the 1970's. While those data tracked broad-scale changes in the fish community, acoustic surveys were implemented because recent research has shown this method is better at assessing pelagic species, especially over rough bottoms (Fabrizio et al. 1997, Stockwell et al. 2007, Yule et al. 2008). Acoustic surveys were first conducted during the 1970's (Argyle 1982), but the first lake-wide survey that included all of Lake Huron's distinct basins was conducted in 1997. Annual surveys have been conducted since 2004; however, only the main basin was sampled during 2006.

Survey and analytical methods

The pelagic prey fish survey in Lake Huron is based on a stratified-random design with transects in five geographic strata: eastern main basin (ME), western main basin (MW), southern main basin (SB), Georgian Bay (GB), and the North Channel (NC) (Figure 1). Within each stratum, the first transect was selected randomly based on latitude or longitude; subsequent transects were spaced evenly around the first. Effort (transects per stratum) was allocated based on stratum area and variability of total biomass in each stratum from previous surveys (Adams et al. 2006). For analysis, each transect was divided into 10 m bottom contour intervals and 5-10 m depth layers (1997), 1,000 m distance intervals and 10 m depth layers (2004-2011), or 3,000 m distance units and 10 m depth layers (2012-2013).

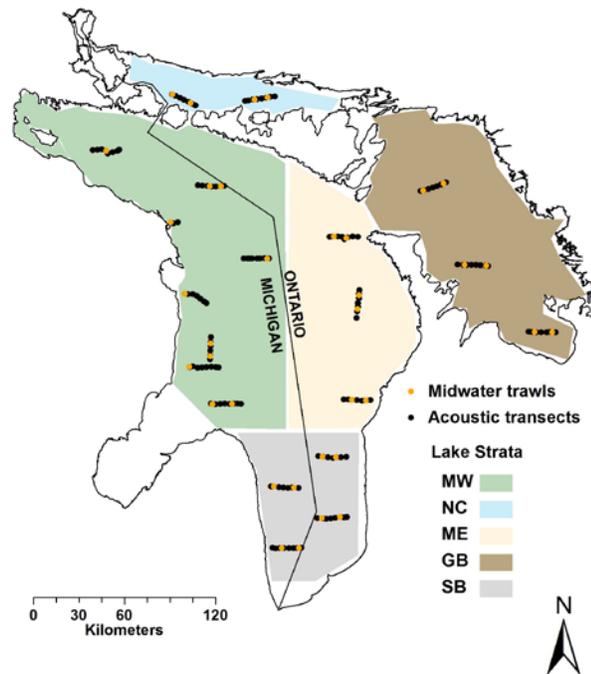


Figure 1. Hydroacoustic transects and midwater trawl locations sampled during the 2013 lake-wide pelagic fisheries survey in Lake Huron.

During 2004-2005 and 2007-2008 acoustic data were collected during September through early October with a BioSonics split-beam 120 (kHz) echosounder deployed from the Research Vessel (R/V) *Sturgeon*. In 1997, a BioSonics model 102-dual beam was used to conduct the survey. During 2006, acoustic data were collected during August with a 70 kHz echosounder and a transducer deployed via towfish from the R/V *Grayling*. During 2009, the survey was performed with a 38 kHz echosounder because the 120kHz transducer failed field calibration tests. In 2010-2013, we used both a 38 and 120 kHz echosounder to facilitate future frequency comparisons, but with the exception of 2009, only 120 kHz data are presented in this report. Fish density estimates derived from the 38 kHz echosounder were higher than expected and it was not clear how they compared to estimates from 120 kHz. Subsequent to the 2009 survey, we collected data using both transducers and have found that a) density estimates from 38 kHz are higher than from 120 kHz, b) this difference does not vary among fish species, and c) fish density estimates from the two frequencies are highly correlated ($r^2 = 0.77$). In order to provide estimates for 2009

that would have been equivalent to 120 kHz, we predicted the 2009 fish density estimates using the 38 kHz estimates and a regression model relating the two from data collected in subsequent years. Additionally, studentized residual plots indicated that the model was acceptable.

The 2013 pelagic fisheries survey was completed during 10 September – 9 October, and all sampling was conducted by the GLSC using the R/V *Sturgeon*. Twenty acoustic transects of roughly 20 km in length were sampled, resulting in approximately 430 km of acoustic data. Thirty-five midwater trawl tows were conducted in conjunction with acoustic data collection. During 2011-2012, the survey was carried out jointly between GLSC and the United States Fish and Wildlife Service (USFWS). USFWS used a 120 kHz split-beam echosounder (Simrad EK60) to sample transects located in the MW stratum. In all years, sampling was initiated one hour after sunset and ended no later than one hour before sunrise. A threshold equivalent to uncompensated target strength (TS) of -70 decibels (dB) was applied to S_v data.

Species and size composition were determined using a 15-m headrope midwater trawl (USGS) or a 21-m headrope midwater trawl (USFWS). Tow locations and depths were chosen to target fish aggregations, but we attempted to collect multiple tows per transect when fish were present so that trawl data within a stratum were available from each scattering layer formed by fish. Scattering layers were typically associated with the epilimnion, metalimnion, and hypolimnion. Trawl depth was monitored using a Netmind™ system (USGS) or a Simrad PI44 catch monitoring system (USFWS). Most midwater trawl tows were of 20 minutes duration, with tow times extended up to 25 minutes when few fish were present. Temperature profiles were obtained using a bathythermograph on each acoustic transect. All fish captured in the midwater trawl tows were identified, counted, and weighed in aggregate (g) by species. Total length in millimeters was measured on no more than 100 randomly selected individuals per species per tow. Individual fish were assigned to age categories (predominantly age-0, or predominantly age 1+) based on size using the following break points: alewife = 100 mm; rainbow smelt = 90 mm; bloater = 120 mm. Based on previous age estimates for these species, these lengths approximate the lengths of the smallest age-1 fish of these species.

Acoustic data collected in 1997 were analyzed using custom software (Argyle et al. 1998). Data collected in 2004 and later years were analyzed using Echoview™ software, which provided fish density estimates for each sampling unit. Fish density was calculated as

$$Density (fish / ha) = 10^4 \cdot \frac{ABC}{\sigma}$$

where ABC was the area backscattering coefficient (m^2 / m^2) of each 10 m high by 1000-3,000 m long cell, and σ was the mean backscattering cross section (m^2) of all targets between -60 and -30 dB in each cell. The lower threshold should have included all age-0 alewives present (Warner et al. 2002), but may have underestimated age-0 rainbow smelt density (Rudstam et al. 2003). The upper threshold excluded fish larger than our species of interest.

Density (fish/ha) of individual species was estimated as the product of acoustic fish density and the proportion of each species (by number) in the midwater trawl catches at that location. Total density per species was subdivided into age-0 and age-1+ age-classes by multiplying total density by the numeric proportions of each age group. Biomass (kg/ha) of each species was estimated as the product of density and size-specific mean mass estimated from fish lengths in

trawls, and length-weight relationships. Mean and relative standard error [RSE= (SE/mean) · 100] for density and biomass in the survey area were calculated for each species. Mean density and biomass estimates for each basin were estimated from transect data weighted for transect length.

In order to assign species and size composition to acoustic data, we used a technique described by Warner et al. (2009), with different approaches depending on the vertical position in the water column. For cells with depth < 40 m, midwater trawl and acoustic data were matched according to transect, depth layer (0-10, 10-20 m, etc., depending on headrope depth and upper depth of the acoustic cell), and by bottom depth. For acoustic cells without matching trawl data, we assigned the mean of each depth layer and bottom depth combination from the same transect. If acoustic data still had no matching trawl data, we assigned the mean of each depth layer and bottom depth combination within geographic strata. Finally, if acoustic data still had no matching trawl data, we used a lake-wide mean for each depth layer. Mean mass of species/size groups at depths < 40 m were estimated using weight-length equations from midwater trawl data. For depths ≥ 40 m, we assumed that acoustic targets were large bloater if mean TS was > -45 dB (TeWinkel and Fleischer 1999). Mean mass of bloater in these cells was estimated using the mass-TS equation of Fleischer et al. (1997). If mean TS was ≤ -45 dB, we assumed the fish were large rainbow smelt and estimated mean mass from mean length, predicted using a TS-length equation (Rudstam et al. 2003).

As recommended by the Great Lakes Acoustic SOP (Parker-Stetter et al. 2009, Rudstam et al. 2009), we used a number of techniques to assess or improve acoustic data quality. We used the N_v index of Sawada et al. (1993) to determine if conditions in each acoustic analysis cell were suitable for estimation of *in situ* TS. We defined suitability as an N_v value < 0.1 and assumed mean TS in cells at or above 0.1 were biased. We replaced mean TS in these cells with mean TS from cells that were in the same depth layer and transect having N_v < 0.1. To help reduce the influence of noise, we estimated Sv noise at 1 m on each transect using either passive data collection or echo integration of data below the bottom echoes. We then used noise at 1 m to estimate noise at all depths, which we subtracted from the echo integration data. Additionally, we estimated the detection limit (depth) for the smallest targets we include in our analyses. Acoustic equipment specifications, software versions, single target detection parameters, noise levels, and detection limits can be found in Appendices 1 and 2.

Mean, relative standard error (RSE), and confidence limits for density and biomass for the entire survey area (all three basins pooled) were estimated using stratified cluster analysis methods featured in SAS (SAS Institute Inc. 2007). Cluster sampling techniques are appropriate for acoustic data, which represent a continuous stream of autocorrelated data (Williamson 1982, Connors and Schwager 2002). Density and biomass values for each elementary sampling unit (ESU) in each stratum were weighted by dividing the stratum area by the number of ESUs in the stratum.

Numeric and biomass density by species

Alewife - The decline of alewife in Lake Huron began in 2003 (Roseman and Riley 2009) and abundance has remained low in subsequent years. Since 2004, few alewives have been captured in pelagic fish surveys, and almost all have been age-0 fish. However, during 2013 alewife density increased substantially relative to 2012, representing one of the highest values observed in the time series (Figure 2). Alewife biomass, which increased marginally during 2013 to approximately 30% of the long-term mean, remains low in Lake Huron (Figure 2). RSE for density and biomass estimates increased to 46% and 44%, respectively, in 2013. Alewife density estimated in 1997, 2005-2006, 2008, and 2013 was considerably higher than other years in the time series. However, we note that density differences, though large, did not mean that alewife have been especially abundant in any survey year. During 1997, their year of highest abundance, they were only 3.1% of total fish density. Temporal biomass differences were due in part to differences in size/age structure between 1997 and other years. In 1997 age 1+ alewife were captured, but primarily age-0 alewives were captured during 2004-2013. Age-0 alewife biomass remains low and since 2004 they have never comprised more than 2.5 % of pelagic fish biomass. Owing to their continued scarcity in Lake Huron, RSE of biomass and density estimates for alewife have continued to increase since 2007 (Figure 2). Alewife have shown no sign of returning to higher abundance. During the 2013 survey, 140 alewife were captured in the midwater trawl (approximately 4% of all fish captured). All but one of these was age-0 and most alewife came from a single trawl tow in the western main basin. These results are consistent with results from the 2013 annual bottom trawl survey (Riley et al. 2014), which indicated that alewife abundance remains very low.

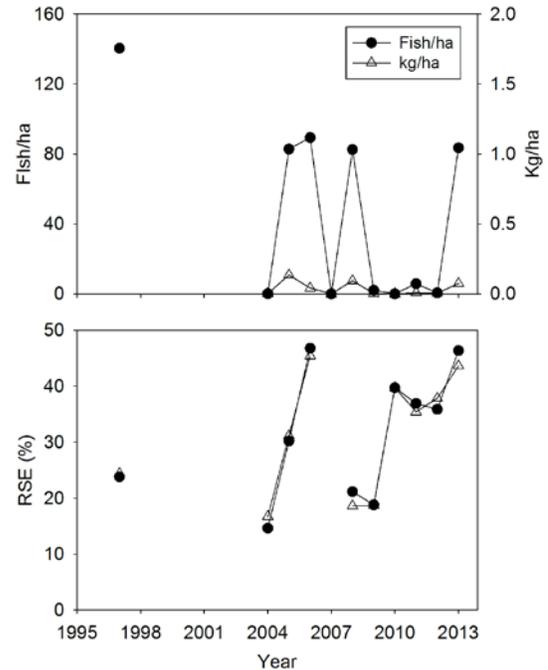


Figure 2. Acoustic estimates of alewife density and biomass in Lake Huron, 1997-2013 (upper panel), and relative standard error of estimates (lower panel).

Rainbow smelt - Abundance of age-0 rainbow smelt has been variable over the time series with the highest densities occurring during 1997, followed by 2009 and 2006 (Figure 3). During 2013, age-0 rainbow smelt density increased 2.8-fold from 2012 estimates and to 47% of the long-term mean (Figure 3). Age-0 rainbow smelt biomass showed a 1.6-fold increase from 2012 estimates and increased to 49% of the long-term mean. Age 1+ rainbow smelt biomass and density decreased in 2013 from that in 2012 (Figure 4). Density of age-1+ rainbow smelt during 2013 was 54% of 2012 estimates and 32% of the long-term mean. Age-1+ rainbow smelt biomass in 2013 was 56% of 2012 estimates and 36% of the long-term mean.

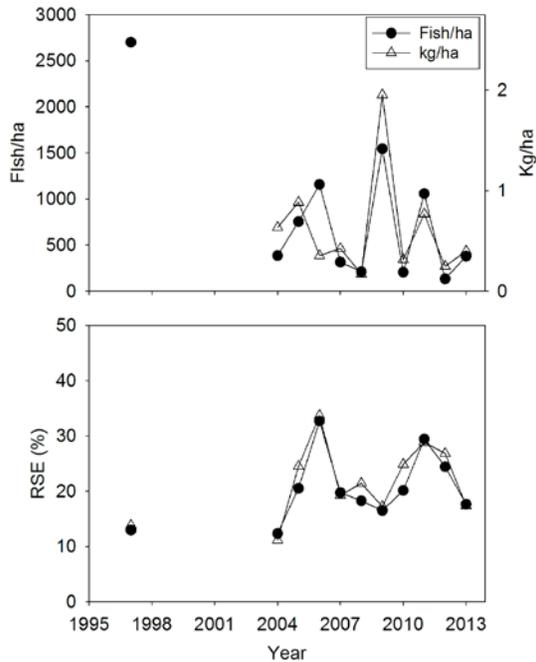


Figure 3. Acoustic estimates of age-0 (< 90 mm) rainbow smelt density and biomass in Lake Huron, 1997-2013 (upper panel), and relative standard error of estimates (lower panel).

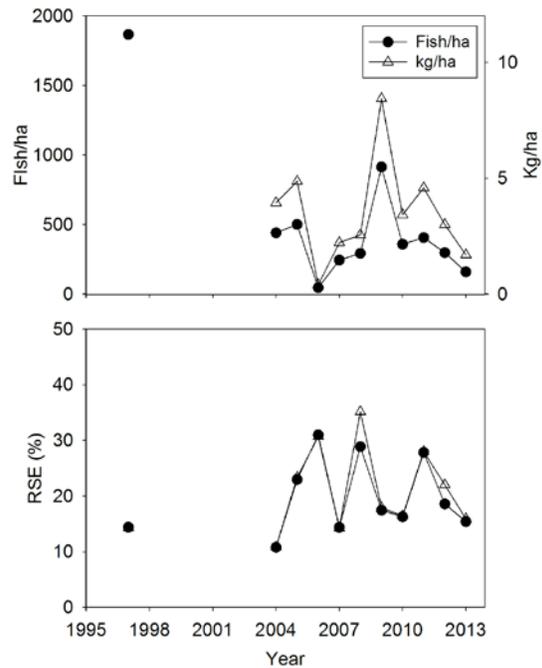


Figure 4. Acoustic estimates of age-1+ (> 90 mm) rainbow smelt density and biomass in Lake Huron, 1997-2013 (upper panel), and relative standard error of estimates (lower panel).

Lake-wide biomass and density estimates for age-1+ rainbow smelt were the second lowest for the time period. Following the highest observed age-1+ abundance in 1997, estimates of rainbow smelt density and biomass were substantially lower during 2004-2013. Although the decline has been considerable relative to 1997, during 2004-2013 acoustic survey results indicate rainbow smelt density and biomass have shown no trend for either the age-0 or age-1+ size group. RSE of density and biomass estimates for both size groups decreased in 2013. Density and biomass estimates from the 2013 bottom trawl survey in Lake Huron's main basin also indicated an increase in age-0 and a decrease in age-1+ rainbow smelt biomass and density (Riley et al. 2014).

Bloater - Estimates of age-0 bloater density in 2013 increased fivefold over the 2012 estimate and the 2013 year class was the third largest in the time series (Figure 5). Following the smallest year class observed in 1997, age-0 bloater density has increased but has been highly variable since 2004. Similarly, age-0 bloater biomass increased sixfold from 2012 estimates. RSE for age-0 density and biomass decreased from approximately 25% in 2012 to 13% in 2013. Estimates of age-1+ bloater density and biomass in 2013 were similar to 2012 and were 71% and 68%, respectively, of the long-term mean (Figure 6).

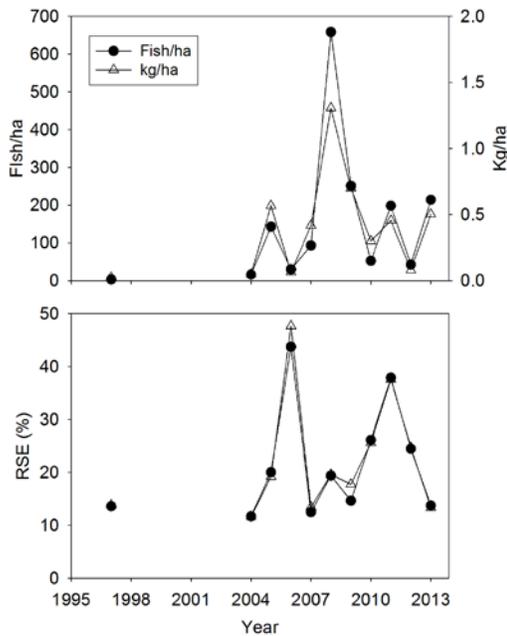


Figure 5. Acoustic estimates of age-0 (< 120 mm) bloater density and biomass in Lake Huron, 1997-2013 (upper panel), and relative standard error of estimates (lower panel).

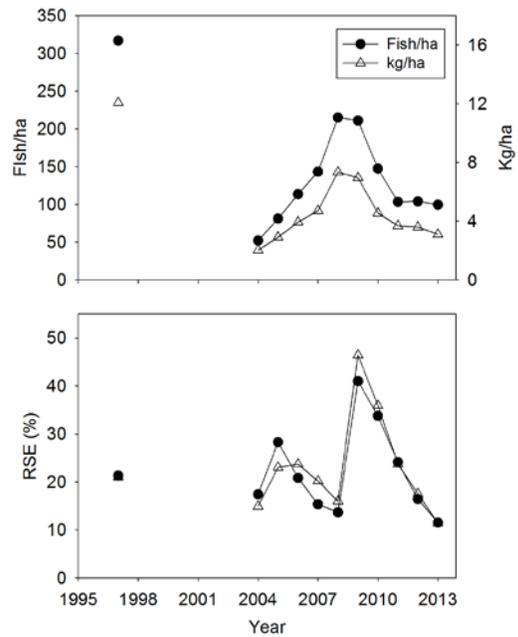


Figure 6. Acoustic estimates of age-1+ (> 120 mm) bloater density and biomass in Lake Huron, 1997-2013 (upper panel), and relative standard error of estimates (lower panel).

Density and biomass estimates of age-1+ bloater were less variable than age-0 bloater abundance during 2004-2013, but have declined from 1997 estimates (Figure 6). Both density and biomass of age-1+ bloater showed an increasing trend from 2004-2008, followed by a decrease from 2009-2010. Abundance of age-1+ bloater remained relatively unchanged during 2011-2013. Abundance of age-0 bloater estimated from the GLSC bottom trawl survey (Riley et al. 2014) were higher than acoustic/midwater trawl estimates, but both surveys detected an increase during 2013. Bottom trawl estimates of age-1+ bloater abundance were higher than acoustic/midwater trawl estimates, but estimates from both surveys were more closely aligned in 2013 than in the previous two years.

Cisco – Our acoustic and midwater trawl surveys primarily operate in deeper waters during the fall, and therefore do not sample cisco in nearshore spawning areas. During October in northern Lake Huron, cisco are primarily distributed in shallow, near shore areas (M.P. Ebener, Chippewa Ottawa Resource Authority, personal communication). Catches in midwater trawls are too sporadic to be able to use trawl proportions to apportion acoustic densities. For example, only two cisco were caught in 2013, and during 2004-2012, catches were low during acoustic surveys. GLSC sampling (all types) has captured only 110 cisco since 1980. However, because recovery of cisco is a Fish Community Objective (FCO) for Lake Huron (DesJardine et al. 1995), some

measure of progress toward their restoration to the pelagic fish community is desired. In order to measure cisco density during pelagic fish surveys we used the approach of Yule et al. (2006), who used acoustic target strength to identify targets as large cisco, with -35.6 dB as the lower limit to the target strength of large cisco (fish >250 mm). We used this method with the caveat that not all of these targets are cisco and this approach may overestimate cisco abundance. Further, we compare the density of cisco-sized targets to that measured in Lake Superior in 2011. We found that there has been no evidence of a trend in the lake-wide density of large cisco-sized targets in the period 2004-2013. Fall gill net catches of cisco in northern Lake Huron also showed no trend during 1991-2013 (M.P. Ebener, Chippewa Ottawa Resource Authority, personal communication). Mean density of targets >-36 dB in Lake Huron varied between 0.36 and 2.6 fish/ha. The 2013 estimate for density of cisco-sized targets (0.36 fish/ha) was the lowest for the time period. Furthermore, this analysis showed that density of large cisco-sized targets in Lake Huron was much lower than observed by Yule et al. (2013) during a lake-wide acoustic survey of Lake Superior in 2011 (Figure 7).

Emerald shiner - Emerald shiner density and biomass increased in 2013 from near record lows in 2012 (Figure 8). Lake-wide mean density was 93% of the long-term mean for the time series, while biomass was 84% of the long-term mean. Emerald shiner were captured in the western and southern Main Basin and were not observed in Georgian Bay or the North Channel. Emerald shiner were a small proportion (1.6%) of total pelagic fish biomass during 2013.

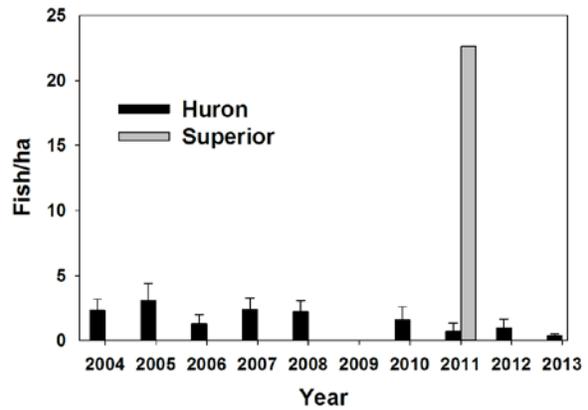


Figure 7. Density of large cisco-sized targets in Lake Huron during lake-wide acoustic surveys in the years 2004-2013. The lake-wide mean density from Lake Superior (Yule et al. 2013), estimated using similar methods, is shown for comparison.

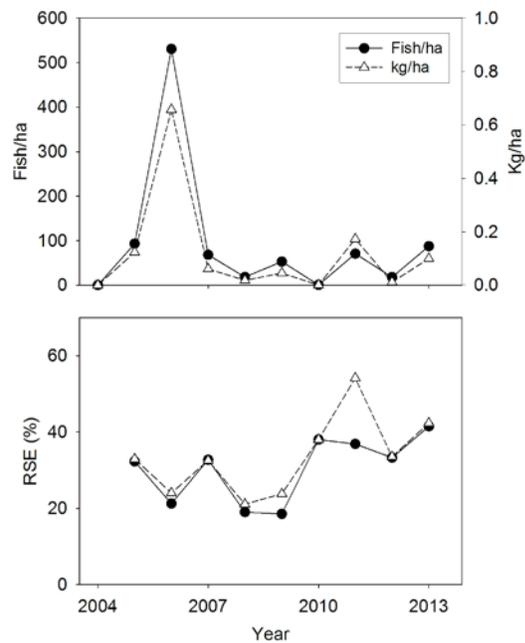


Figure 8. Acoustic estimates of emerald shiner density and biomass in Lake Huron, 1997-2013 (upper panel), and relative standard error of estimates (lower panel).

Among-basin comparisons of fish biomass

One factor that makes Lake Huron unique among the Laurentian Great Lakes is the presence of three large, hydrogeomorphically-distinct basins that make up significant portions of the total lake area. For example, Georgian Bay makes up approximately 25% of the total area of Lake Huron and is 77% of the area of Lake Ontario. These basins differ in mean depth and area, and in past years, fish biomass (Warner et al. 2009). In 2013, pelagic fish biomass was higher in the North Channel and the main basin than Georgian Bay (Figure 9), but differences in biomass among basins were not significant (Tukey's test, $P>0.05$). In addition to differences in fish biomass, the three basins have had different temporal trends in biomass and community composition. In both Georgian Bay and the main basin, fish biomass has declined since 1997 (Figure 10) and remains low, while there is no evidence of a declining trend in North Channel. Community composition differences are predominantly the result of variation in the proportion of biomass made up by rainbow smelt and bloater. Most biomass in Georgian Bay has been in the form of rainbow smelt (58%), while biomass in the main basin has consisted of similar proportions of rainbow smelt and bloater. North Channel, where rainbow smelt have made up 74% of biomass, has had even greater rainbow smelt dominance than Georgian Bay. To date, the only factor identified as having consistently influenced the biomass and community composition differences among these basins is bottom depth (Warner et al. 2009).

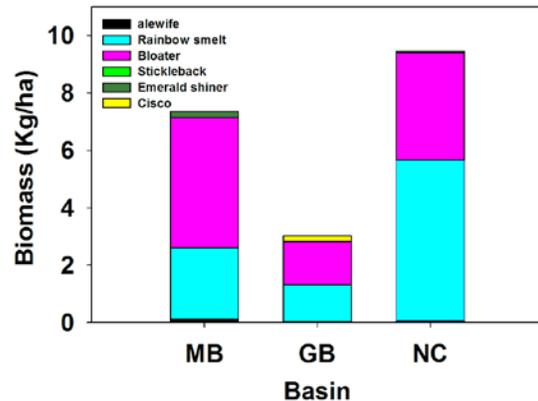


Figure 9. Acoustic estimates of total pelagic fish biomass among Lake Huron's three basins, 2013 (MB=Main Basin, GB=Georgian Bay, NC= North Channel).

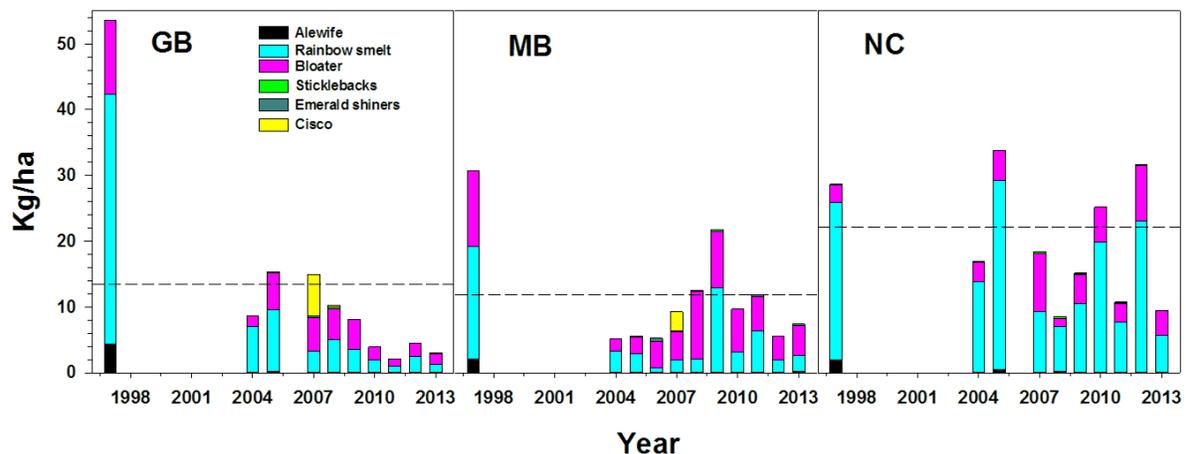


Figure 10. Pelagic fish biomass in the three basins of Lake Huron, 1997-2013. GB= Georgian Bay, MB=Main Basin, and NC = North Channel. Horizontal lines denote 1997-2012 means.

Lake-wide fish biomass

The lake-wide pelagic fish biomass estimate in Lake Huron during 2013 of 6.1 kg/ha was the second lowest for the time series. The small decrease in biomass from 2012 estimates ($\approx 13\%$), was primarily a result of decreased biomass of rainbow smelt (Figure 11). Acoustic estimates of pelagic fish biomass in Lake Huron have shown no consistent trend between 2004 and 2013. However, biomass remains much lower than in 1997. Most of this decrease in biomass is the result of decreased abundance of rainbow smelt and bloater.

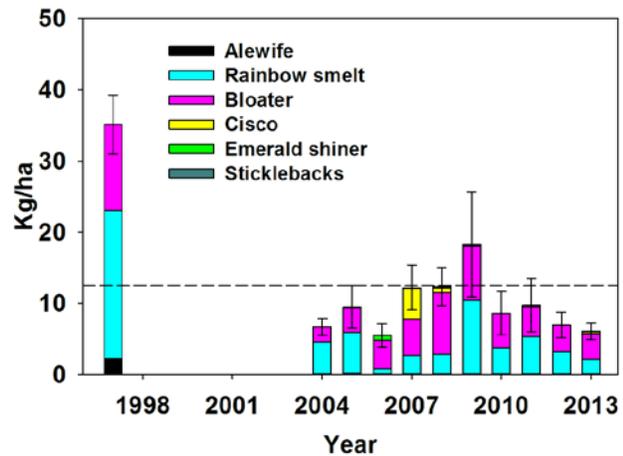


Figure 11. Lake-wide mean pelagic fish biomass in Lake Huron, 1997-2013. Error bars are 95% confidence intervals. The horizontal line denotes the 1997-2012 mean.

Discussion

This survey, as with any other type of fishery survey, includes assumptions about the sampling and data analysis techniques. For example, we assumed that the areas sampled were representative of the lake as a whole. This survey sampled areas of Lake Huron from 10 to 250 m in depth. This depth range encompassed about 85% of the total surface area of Lake Huron. However, this survey did not sample nearshore zones and large shallow embayments, especially Thunder Bay, Saginaw Bay, and Parry Sound. These areas could be responsible for high rates of pelagic fish production (Fielder and Thomas 2006, Höök et al. 2001, Klumb et al. 2003), but could not be sampled safely due to the draft of our research vessel (3 m). Given the small surface areas of these shallow-water embayments relative to the total surface area, densities would need to be considerable to influence the lake-wide mean. We conducted enough midwater tows to achieve an acceptable degree of confidence in fish community composition following guidelines in Warner et al. (2012). An additional assumption was that fish size was a reasonable proxy for fish age. We used size to assign age and assumed no overlap in age among size classes. This assumption was likely violated, especially for rainbow smelt. While this might have slight effects on our estimates of age-0 and age-1+ density and biomass, it would have no impact on our estimates of total density for a species.

Conclusions

During 2014, prey availability for piscivores will likely be similar to that seen in other recent years. Alewife biomass remains low, and there has been no trend in pelagic fish biomass since 2004. The Lake Huron forage base still remains low compared to previous decades when alewife, rainbow smelt, and bloater were more abundant. Lake-wide pelagic biomass in Lake Huron in 2013 (6.1 kg/ha) was nearly identical to biomass in Lake Michigan (6.1 kg/ha, Warner et al. 2014) and similar to Lake Superior during 2011 (6.8 kg/ha, Yule et al. 2013). There is, however, a key difference between the three lakes. In Lake Michigan, alewife are still prevalent and comprise about 77% of the pelagic biomass, while in the other two lakes, the biomass of this species is negligible. Additionally, native coregonines and other species are rare or absent in Lake Michigan. Both Huron and Superior have much greater contribution to density and biomass from native species. In the case of Lake Superior, kiyi (*Coregonus kiyi*) are numerically

dominant at depths > 100 m, while cisco make up most of the biomass (Yule et al. 2013). In Lake Huron, rainbow smelt are numerically dominant, while rainbow smelt and bloater have been alternating roles as the dominant contributor to total biomass. Additionally, there have been relatively consistent (but low) catches of emerald shiner and cisco in Lake Huron midwater trawling. In the case of emerald shiner, it is likely that their reappearance was the result of a release from predation on fry following the collapse of alewife (Madenjian et al. 2008; Schaeffer et al. 2008). Although reasonable benchmarks for cisco rehabilitation may not be clear, Fielder et al. (2007) presents options to measure success including cisco becoming a measureable component of lake trout diets and catch-per-unit-effort of large cisco (>250 mm) averaging 10 fish per tow in midwater trawl and hydroacoustic surveys. Results of this survey indicate that cisco have not been restored in Lake Huron given that cisco-sized target densities have averaged <10% of densities in Lake Superior and midwater trawl catches remain limited to few fish. Cisco also were not present in lake trout diets in Lake Huron during 2009-2011 (Roseman et al. *in review*) indicating that cisco are not prevalent in the pelagic prey fish community in U.S. waters of the main basin.

Acknowledgements: We thank the vessel crews and biologists of the R/V *Sturgeon*, R/V *Grayling*, and M/V *Spencer Baird* for their assistance with the night field surveys. Captain Joe Bergan, Lyle Grivicich, and Keith Peterson were instrumental in completion of the 2013 survey. Dan Yule and Mark Ebener provided helpful reviews of this report. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Literature Cited

- Adams J.V., R. L. Argyle, G. W. Fleischer, G. L. Curtis, and R. G. Stickel. 2006. Improving the design and efficiency of acoustic and midwater trawl surveys through stratification, with an application to Lake Michigan prey fishes. *North American Journal of Fisheries Management* 26: 612-621.
- Argyle, R. L. 1982. Alewives and rainbow smelt in Lake Huron: midwater and bottom aggregations and estimates of standing stocks. *Transactions of the American Fisheries Society* 111: 267-285.
- Argyle, R.L., G.W. Fleischer, G.L. Curtis, J.V. Adams, and R.G. Stickel. 1998. An integrated acoustic and trawl based prey fish assessment strategy for Lake Michigan. A report to the Illinois Department of Natural Resources, Indiana Department of Natural Resources, Michigan Department of Natural Resources, and Wisconsin Department of Natural Resources. U.S. Geological Survey, Biological Resource Division, Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI USA.
- Connors, M.E., and S.J. Schwager. 2002. The use of adaptive cluster sampling for hydroacoustic surveys. *ICES Journal of Marine Science* 59:1314-1325.
- Fabrizio, M. C., J. V. Adams, and G. L. Curtis. 1997. Assessing prey fish populations in Lake Michigan: comparison of simultaneous acoustic-midwater trawling with bottom trawling. *Fisheries Research* 33: 37-54.
- Fielder, D. G., M. Ebener, L. Mohr. 2007. Strategy and Options for Promoting the Rehabilitation of Cisco in Lake Huron. Great Lakes Fishery Commission, Miscellaneous publication. http://www.glfc.org/lakecom/lhc/LakeHuron_CiscoRehab.pdf. Ann Arbor.
- Fielder, D. G., and M. V. Thomas. 2006. Fish Population Dynamics of Saginaw Bay, Lake Huron 1998 – 2004. Michigan Department of Natural Resources, Fisheries Research Report. No. 2083. Ann Arbor.

- Fleischer, G. W., R. L. Argyle, and G. L. Curtis. 1997. *In situ* relations of target strength to fish size for Great Lakes pelagic planktivores. *Transactions of the American Fisheries Society* 126: 784-796.
- Höök, T.O., N.M. Egan, and P.W. Webb. 2001. Habitat and human influences on larval fish assemblages in northern Lake Huron coastal marsh bays. *Wetlands* 21:281-291.
- Klumb, R.A., Rudstam, L.G., Mills, E.L., Schneider, C.P., and Sawko, P.M. 2003. Importance of Lake Ontario embayments and nearshore habitats as nurseries for larval fish with emphasis on alewife (*Alosa pseudoharengus*). *Journal of Great Lakes Research* 29:181-198.
- Madenjian, C.P., R. O’Gorman, D.B. Bunnell, R.L. Argyle, D.M. Warner, J.D. Stockwell, and M.A. Stapanian. 2008. Adverse effects of alewives on Laurentian Great Lakes fish communities. *North American Journal of Fish Management* 28:263 – 282.
- Parker-Stetter, S.L., Rudstam, L.G., Sullivan, P.J., and Warner, D.M. 2009. Standard operating procedures for fisheries acoustic surveys in the Great Lakes. *Great Lakes Fishery Commission Special Publication* 09-01.
- Riley, S.C. E.F. Roseman, M.A. Chriscinske, T.R. Tucker, J. Ross, P. Armenio, N. Watson, and W. Woelmer. 2014. Status and trends of the Lake Huron offshore demersal fish community, 1976-2013. A report to the Great Lakes Fishery Commission Lake Huron Committee, Windsor, Ontario, March 24, 2014.
- Roseman, E.F., J.S. Schaeffer, E. Bright, and D.G. Fielder. In review. Angler-caught Piscivore Diets Reflect Fish Community Changes in Lake Huron. *Transactions of the American Fisheries Society*. Submitted December 19, 2013.
- Roseman, E. F., and S. C. Riley. 2009. Biomass of deepwater demersal forage fishes in Lake Huron, 1994-2007: implications for offshore predators. *Aquat. Ecosyst. Health Manage.* 12: 29-36.
- Rudstam, L. G., Parker-Stetter, S. L., Sullivan, P. J., and Warner, D. M. 2009. Towards a standard operating procedure for fishery acoustic surveys in the Laurentian Great Lakes, North America. *ICES Journal of Marine Science*, 66: 1391-1397.
- Rudstam, L. G., S. L. Parker, D. W. Einhouse, L. Witzel, D. M. Warner, J. Stritzel, D. L. Parrish, and P. Sullivan. 2003. Application of *in-situ* target strength to abundance estimations in lakes- examples from rainbow smelt surveys in Lakes Erie and Champlain. *ICES Journal of Marine Science* 60: 500-507.
- SAS Institute,, Inc. 2007. OnlineDoc 9.1.2. Cary, NC, SAS Institute, Inc.
- Sawada, K., Furusawa, M., and Williamson, N. J. 1993. Conditions for the precise measurement of fish target strength in situ. *Journal of the Marine Acoustical Society of Japan*, 20: 73-79.
- Schaeffer, J.S., D.M. Warner, and T.P. O’Brien. 2008. Resurgence of emerald shiners *Notropis atherinoides* in Lake Huron’s Main Basin. *Journal of Great Lakes Research* 34:395-403.
- Schaeffer, J. S., and T. P. O’Brien. 2009. Status and Trends of Pelagic Prey Fish in Lake Huron, 2008. A report to the Great Lakes Fishery Commission, Lake Huron Committee, Ypsilanti, MI, March 2009.
- Stockwell, J. D., D. L. Yule, T. R. Hrabik, J. V. Adams, O. T. Gorman, and B. V. Holbrook. 2007. Vertical distribution of fish biomass in Lake Superior; implications for day bottom trawl surveys. *North American Journal of Fisheries Management* 27: 735-749.
- TeWinkel, L. M., and G. W. Fleischer. 1999. Vertical Migration and Nighttime Distribution of Adult Bloaters in Lake Michigan. *Transactions of the American Fisheries Society* 128: 459-474.
- Warner, D.M., L. G. Rudstam, and R. A. Klumb. 2002. In-situ target strength of alewives in freshwater. *Transactions of the American Fisheries Society* 131: 212-223.

- Warner, D.M., J.S. Schaeffer, and T.P. O'Brien. 2009. The Lake Huron pelagic fish community: persistent spatial pattern along biomass and species composition gradients. *Canadian Journal of Fisheries and Aquatic Sciences* 66:1199 - 1215.
- Warner, D.M., R.M. Claramunt, J.S. Schaeffer, D.L. Yule, T.R. Hrabik, B. Pientka, L.G. Rudstam, J.D. Holuszko, and T.P. O'Brien. 2012. Relationship between mid-water trawling effort and catch composition uncertainty in two large lakes (Huron and Michigan) dominated by alosines, osmerids, and coregonines. *Fisheries Research* 123/124:62-69.
- Warner, D.M., T.P. O'Brien, S. Farha, R.M. Claramunt, and D. Hanson. 2013. Status of pelagic prey fishes in Lake Michigan, 2012. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Duluth, MN, March, 2013.
- Williamson, N.J. 1982. Cluster sampling estimation of the variance of abundance estimates derived from quantitative echo sounder surveys. *Canadian Journal of Fisheries and Aquatic Sciences* 39:228-231.
- Yule, D.L., J.V. Adams, T.R. Hrabik, M.R. Vinson, Z. Woiak, and T.D. Ahrenstorff. 2013. Use of Classification Trees to Apportion Single Echo Detections to Species: Application to the Pelagic Fish Community of Lake Superior. *Fisheries Research* 140:123-132.
- Yule, D.L., J. V. Adams, J. D. Stockwell, and O.T. Gorman. 2008. Factors affecting bottom trawl catches; implications for monitoring the fishes in Lake Superior. *North American Journal of Fisheries Management* 28: 109-122.
- Yule, D.L., J. D. Stockwell, G.A. Cholwek, L.M. Evrard, S. Schram, M. Seider, and M. Symbol. 2006. Evaluation of methods to estimate lake herring spawner abundance in Lake Superior. *Transactions of the American Fisheries Society* 135:3 680-694.

Appendix 1. Single target detection parameters used in acoustic data analyses in 2013.

Parameter	Value
TS threshold (dB)	-77 ¹
Pulse length determination level (dB)	6
Minimum normalized pulse length	0.7
Maximum normalized pulse length	1.5
Maximum beam compensation (dB)	6
Maximum standard deviation of minor-axis angles	0.6
Maximum standard deviation of major-axis angles	0.6

¹ Only targets ≥ -60 dB were included in analysis

Appendix 2. Noise levels, detection limits, and acoustic equipment specifications in Lake Huron, 2013.

Vessel	R/V Sturgeon
Collection software	Visual Acquisition 6.0
Transducer beam angle (3dB)	8.2° split beam
Frequency (kHz)	120
Pulse length (ms)	0.4
Sv noise at 1 m (dB)	-125
TS noise at 1 m (dB)	-150
2 way equivalent beam angle	-19.34
Detection limit (m) for -60 dB target ²	61

² Assuming 3 dB signal-to-noise ratio.

Status and Trends of Prey Fish Populations in Lake Michigan, 2013¹

Charles P. Madenjian, David B. Bunnell, Timothy J. Desorcie,
Melissa J. Kostich, Patricia M. Armenio, and Jean V. Adams
U. S. Geological Survey
Great Lakes Science Center
1451 Green Road
Ann Arbor, Michigan 48105

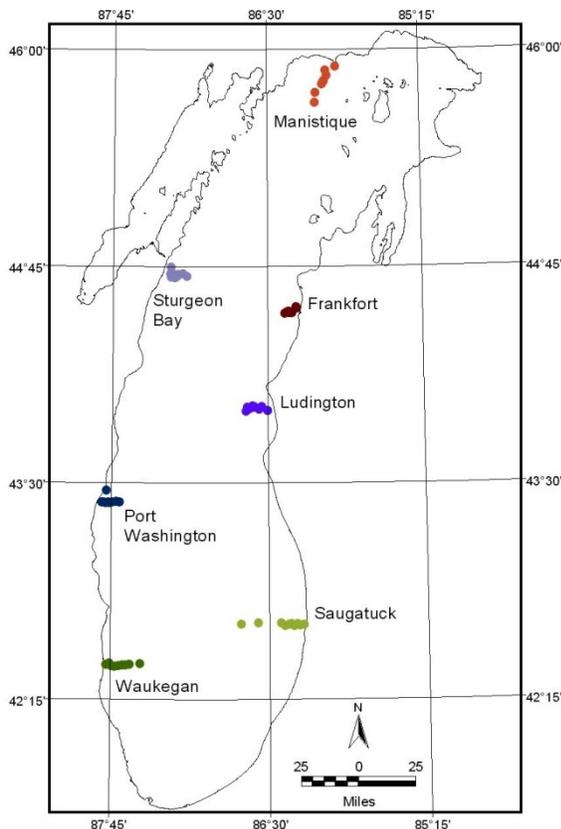
Abstract

The U.S. Geological Survey Great Lakes Science Center has conducted lake-wide surveys of the fish community in Lake Michigan each fall since 1973 using standard 12-m bottom trawls towed along contour at depths of 9 to 110 m at each of seven index transects. The resulting data on relative abundance, size and age structure, and condition of individual fishes are used to estimate various population parameters that are in turn used by state and tribal agencies in managing Lake Michigan fish stocks. All seven established index transects of the survey were completed in 2013. The survey provides relative abundance and biomass estimates between the 5-m and 114-m depth contours of the lake (herein, lake-wide) for prey fish populations, as well as burbot, yellow perch, and the introduced dreissenid mussels. Lake-wide biomass of alewives in 2013 was estimated at 29 kilotonnes (kt, 1 kt = 1000 metric tonnes), which was more than three times the 2012 estimate. However, the unusually high standard error associated with the 2013 estimate indicated no significant increase in lake-wide biomass between 2012 and 2013. Moreover, the age distribution of alewives remained truncated with no alewife exceeding an age of 5. The population of age-1 and older alewives was dominated (i.e., 88%) by the 2010 and 2012 year-classes. Record low biomass was observed for deepwater sculpin (1.3 kt) and ninespine stickleback (0.004 kt) in 2013, while bloater (1.6 kt) and rainbow smelt (0.2 kt) biomasses remained at low levels. Slimy sculpin lake-wide biomass was 0.32 kt in 2013, marking the fourth consecutive year of a decline. The 2013 biomass of round goby was estimated at 10.9 kt, which represented the peak estimate to date. Burbot lake-wide biomass (0.4 kt in 2013) has remained below 3 kt since 2001. Numeric density of age-0 yellow perch (i.e., < 100 mm) was only 1 fish per ha, which is indicative of a relatively poor year-class. Lake-wide biomass estimate of dreissenid mussels in 2013 was 23.2 kt. Overall, the total lake-wide prey fish biomass estimate (sum of alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, round goby, and ninespine stickleback) in 2013 was 43 kt, with alewives and round gobies constituting 92% of this total.

¹ Presented at: Great Lakes Fishery Commission
Lake Michigan Committee Meeting
Windsor, ON
March 25, 2014

The U.S. Geological Survey Great Lakes Science Center (GLSC) has conducted daytime bottom trawl surveys in Lake Michigan during the fall annually since 1973. Estimates from the 1998 survey are not reported, however, given the trawls were towed at non-standard speeds. From these surveys, the relative abundance of the prey fish populations are measured, and estimates of lake-wide biomass available to the bottom trawls (for the region of the main basin between the 5-m and 114-m depth contours) can be generated (Hatch et al. 1981; Brown and Stedman 1995). Such estimates are critical to fisheries managers making decisions on stocking and harvest rates of salmonines and allowable harvests of fish by commercial fishing operations.

The basic unit of sampling in our surveys is a 10-minute tow using a bottom trawl (12-m headrope) dragged on contour at 9-m (5 fathom) depth increments. At most survey locations, towing depths range from 9 or 18 m to 110 m. Age determinations were estimated for alewives (*Alosa pseudoharengus*, using otoliths) and bloaters (*Coregonus hoyi*, using scales) from our bottom trawl catches (Madenjian et al. 2003; Bunnell et al. 2006a). Although our surveys have included as many as nine index transects in any given year, we have consistently conducted the surveys at seven transects. These transects are situated off Manistique, Frankfort, Ludington, and Saugatuck, Michigan; Waukegan, Illinois; and Port Washington and Sturgeon Bay, Wisconsin (Figure 1). All seven transects were completed in 2013.



Lake-wide estimates of fish biomass require (1) accurate measures of the surface areas that represent the depths sampled and (2) reliable measures of bottom area swept by the trawl. A complete Geographical Information System (GIS) based on depth soundings at 2-km intervals in Lake Michigan was developed as part of the acoustics study performed by Argyle et al. (1998). This GIS database was used to estimate the surface area for each individual depth zone surveyed by the bottom trawls. Trawl mensuration gear that monitored net configuration during deployment revealed that fishing depth (D , in meters) influenced the bottom area swept by the trawl. We have corrected the width (W , in meters) of the area sampled according to $W = 3.232 + 7.678(1 - e^{-0.044*D})$, as well as the actual time (AT , in minutes) spent on the bottom according to $AT = \text{tow time} - 0.945 + (0.056D)$, based on trawl measurements made during June 2009 (Madenjian et al. 2010a). These relationships, along with boat speed, were used to estimate bottom area swept.

Figure 1. Established sampling locations for GLSC bottom trawls in Lake Michigan.

We estimate both numeric (fish per hectare [ha]) and biomass (kg per ha) density, although we display graphical trends mostly in biomass for brevity. A weighted mean density over the entire range of depths sampled (within the 5-m to 114-m depth contours) was estimated by first calculating mean density for each depth zone, and then weighting mean density for each depth zone by the proportion of lake surface area assigned to that depth zone. Standard error (SE) of mean density was estimated by weighting the variances of fish density in each of the depth zones by the appropriate weight (squared proportion of surface area in the depth zone), averaging the weighted variances over all depth zones, and taking the square root of the result.

NUMERIC AND BIOMASS DENSITY BY SPECIES

By convention, we classify "adult" prey fish as age 1 or older, based on total length (TL): alewives ≥ 100 mm, rainbow smelt (*Osmerus mordax*) ≥ 90 mm, bloaters ≥ 120 mm, and yellow perch (*Perca flavescens*) ≥ 100 mm. We assume all fish smaller than the above length cut-offs are age-0; length cut-offs are also aided by aging of alewife (by otoliths) and bloater (by scales). Catches of age-0 alewife are not reliable indicators of future year-class strength (Madenjian et al. 2005a), because their position in the water column makes them less vulnerable to bottom trawls. Catches of age-0 bloater, though biased low, can be used as an index of relative abundance given the positive correlation between density of age-0 bloater and density of age-3 bloater (the age at which catch curves reveal full recruitment to our gear, Bunnell et al. 2006a, 2010). Catch of age-0 yellow perch is likely a good indicator of year-class strength, given that large catches in the bottom trawl during the 1980s corresponded to the strong yellow perch fishery. At the end of this report, we report densities of age-0 yellow perch and other bottom-dwelling species such as burbot (*Lota lota*) and dreissenid mussels that are not necessarily "prey fish" but are caught in sufficient numbers to index. Unfortunately lake whitefish (*Coregonus clupeaformis*) are only rarely sampled in our trawl and the resultant trends are not meaningful.

Alewife – Since its establishment in the 1950s, the alewife has become a key member of the fish community. As a larval predator, adult alewife can depress recruitment of native fishes, including burbot, deepwater sculpin (*Myoxocephalus thompsonii*), emerald shiner (*Notropis atherinoides*), lake trout (*Salvelinus namaycush*), and yellow perch (Smith 1970; Wells and McLain 1973; Madenjian et al. 2005b, 2008; Bunnell et al. 2006b). Additionally, alewife has remained the most important constituent of salmonine diet in Lake Michigan for the last 45 years (Jude et al. 1987; Stewart and Ibarra 1991; Warner et al. 2008; Jacobs et al. 2013). Most of the alewives consumed by salmonines in Lake Michigan are eaten by Chinook salmon (*Oncorhynchus tshawytscha*, Madenjian et al. 2002). A commercial harvest was established in Wisconsin waters of Lake Michigan in the 1960s to make use of the then extremely abundant alewife that had become a nuisance and health hazard along the lakeshore. In 1986, a quota was implemented, and as a result of these restrictions, the estimated annual alewife harvest declined from about 7,600 metric tons in 1985 to an incidental harvest of only 12 metric tons after 1990 (Mike Toney, Wisconsin Department of Natural Resources, Sturgeon Bay, personnel communication). Lake Michigan currently has no commercial fishery for alewives.

According to the bottom trawl survey results, adult alewife biomass density increased from 1.4 kg per ha in 2012 to 8.2 kg/ha in 2013 (Figure 2a). However, the unusually high standard error associated with the 2013 density estimate indicated no significant increase in biomass density between the two years. Similarly, adult alewife numeric density increased from 64 fish/ha in 2012 to 417 fish/ha in 2013 (Figure 2b), but the unusually high standard error associated with the 2013 density estimate indicated no

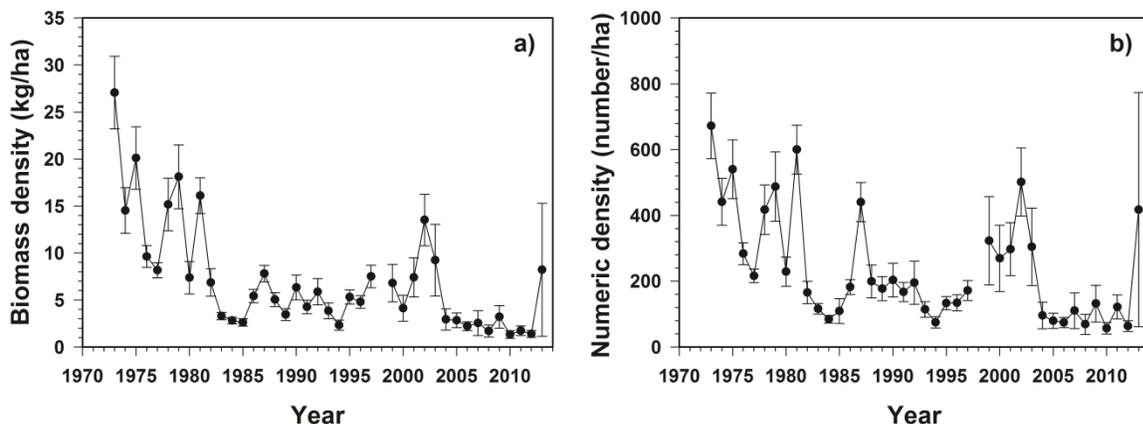


Figure 2. Density of adult alewives as biomass (a) and number (b) per ha (+/- standard error) in Lake Michigan, 1973-2013.

significant increase in numeric density between the two years. These high standard errors were primarily due to one relatively high catch of adult alewives at the 9-m depth at Saugatuck.

Given the extremely high standard errors for the 2013 estimates, adult alewife biomass density has appeared to remain at a low level during 2004-2013 (Figure 2). This continued depression of adult alewife abundance may reflect a recently intensified amount of predation exerted on the alewife population by Chinook salmon due to four factors: (1) a relatively high percentage of wild Chinook salmon in Lake Michigan (averaging 50% age-1 individuals between 2006-2010, Williams 2012), (2) increased migration of Chinook salmon from Lake Huron in search of alewives (Adlerstein et al. 2007; R. Clark, Michigan State University Quantitative Fisheries Center, personal communication), (3) increased importance of alewives in the diet of Chinook salmon in Lake Michigan between the 1990s and the 2000s (Jacobs et al. 2013), and (4) a decrease in the energy density of adult alewives during the late 1990s (Madenjian et al. 2006). The long-term temporal trends in adult alewife biomass, as well as in alewife recruitment to age 3, in Lake Michigan are attributable to consumption of alewives by salmonines (Madenjian et al. 2002, 2005a; Tsehaye et al. 2014).

We estimated that 41% and 47% of adult alewives captured in the bottom trawl during 2013 were age-1 and age-3 fish, respectively (Figure 3). Of the 314 alewives aged from the 2013 bottom trawl survey, only 8 and 6 alewives were age-4 and age-5 fish, respectively, and none of these 314 alewives were older than 5 years old. Thus, the recent trend of age truncation in alewife population age structure continued in 2013, with the oldest alewife being only 5 years old (Figure 3). Prior to 2008, age-8 alewives were routinely captured.

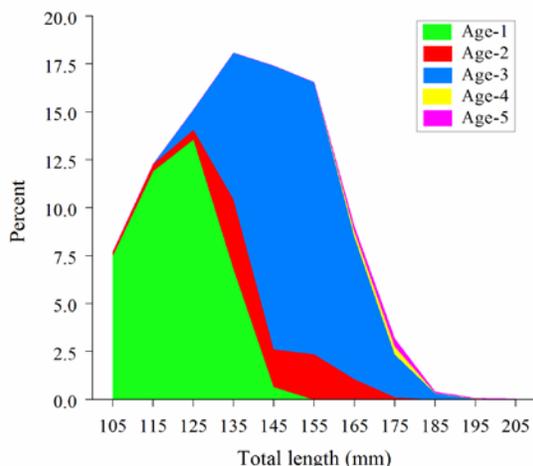


Figure 3. Age-length distribution of alewives \geq 100 mm total length caught in bottom trawls in Lake Michigan, 2013. Note that smaller alewives were captured but were not included herein.

Our results for temporal trends in adult alewife density were in general agreement with results from the lake-wide acoustic survey, which reported biomass of adult alewife during 2004-2013 to be relatively low in comparison to the biomass during 1994-1996 (Warner et al. 2014). However, Warner et al. (2014) did report a substantial increase in adult alewife biomass during 2007-2010 that was not detected by the

bottom trawl survey. On average, for adult alewife biomass density, the acoustic estimate exceeded the bottom trawl estimate by a factor of three to four. But, in 2013, the acoustic estimate (5.0 kg/ha) was not significantly different from the bottom trawl estimate (8.2 kg/ha).

Bloater - Bloaters are eaten by salmonines in Lake Michigan, but are far less prevalent in salmonine diets than alewives (Warner et al. 2008; Jacobs et al. 2010, 2013). For large (\geq 600 mm) lake trout, over 30% of the diets offshore of Saugatuck and on Sheboygan Reef were composed of adult bloaters during 1994-1995, although adult bloaters were a minor component of lake trout diet at Sturgeon Bay (Madenjian et al. 1998). For Chinook salmon, the importance of bloater (by wet weight) in the diets has declined between 1994-1995 and 2009-2010. For small ($<$ 500 mm) Chinook salmon the proportion declined from 9% to 6% and for large Chinook salmon the proportion declined from 14% to $<$ 1% (Jacobs et al. 2013). The bloater population in Lake Michigan also supports a valuable commercial fishery, although its yield has generally been declining since the late 1990s.

Although adult bloater biomass density increased from 0.11 kg per ha in 2012 to 0.41 kg per ha in 2013, adult bloater biomass density in the Lake Michigan, based on our survey results, has remained at a

relatively low level for nearly a decade (Figure 4a). These low biomass densities represent a continuation of an overall declining trend since 1989 (Figure 4a). Numeric density of age-0 bloaters (< 120 mm TL) was only 6 fish per ha in 2013 (Figure 4b), thus 2013 was the fourth consecutive year of very low densities of age-0 bloater following relatively high values in 2005, 2008, and 2009.

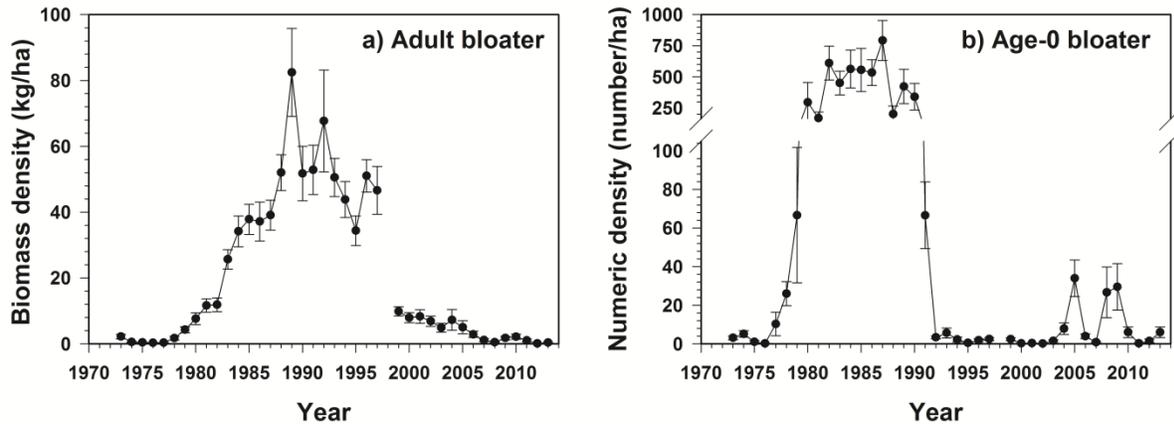


Figure 4. Panel (a) depicts biomass density (+/- standard error) of adult bloater in Lake Michigan, 1973-2013. Panel (b) depicts numeric density (+/- standard error) of age-0 bloater in Lake Michigan, 1973-2013.

The exact mechanisms underlying the relatively poor bloater recruitment since 1992, and the resultant low biomass of adult bloater, remain unknown. Of the mechanisms that have been recently evaluated, reductions in fecundity associated with poorer condition (Bunnell et al. 2009a) and egg predation by slimy and deepwater sculpins (Bunnell et al. 2014) are likely contributing to the reduced bloater recruitment, but none is the primary regulating factor. Another hypothesized mechanism, predation by adult alewife on bloater larvae, has been discounted (Madenjian et al. 2002; Bunnell et al. 2006a). Madenjian et al. (2002) proposed that the Lake Michigan bloater population may be cycling in abundance, with a period of about 30 years, although the exact mechanism by which recruitment is regulated remains unknown. Finally, a regional climate driver was hypothesized to underlie the synchrony in bloater recruitment among lakes Michigan, Huron, and Superior between 1978 and 2006 (Bunnell et al. 2010).

One additional consideration when interpreting these bottom trawl survey results is that bloater catchability may have decreased in recent years, in response to the proliferation of quagga mussels and the associated increased water clarity and decreased *Diporeia* spp. densities. Specifically, a substantial portion of the bloater population in Lake Michigan may have shifted to waters deeper than those typically surveyed by the GLSC. In support of this contention, we note that bloaters have exhibited plasticity in the bottom depths that they occupy, as the depth at which their peak densities occurred increased from 50 m in the 1930s to 85-110 m by 2004-2007 (Bunnell et al. 2012). In addition, commercial fishers have reported an increase in the depth at which they catch bloaters in Lake Michigan during the past 5 to 10 years, with the bulk of the catch from waters deeper than 130 m during recent years (M. LeClair, Susie-Q Fish Market, Two Rivers, WI, personal communication; D. McMurry, Big Stone Bay Fishery, Inc., Carp Lake, MI, personal communication). As a preliminary investigation of this movement-to-deeper-water hypothesis, we performed a bottom trawl tow at a bottom depth between 128 and 132 m at each of the Manistique, Frankfort, and Port Washington transects during 2013. No bloaters were caught in these three tows. Nevertheless, the bulk of the adult bloater population in Lake Michigan may still have been in waters deeper than 130 m during the recent bottom trawl surveys, given the reports from the commercial fishers.

In terms of comparing trends between the two surveys of Lake Michigan, for adult bloater, an order of magnitude decrease between 1992-1996 and 2001-2013 was revealed by both surveys. Similarly, low densities of age-0 bloaters in the 1990s and strong interannual variability in the 2000s were detected in both surveys. However, the years (2005, 2008, 2009) in which relatively high age-0 densities were

estimated by the bottom trawl survey were a subset of the high density years (2001, 2005, 2007-2009, 2012) estimated by the acoustic survey (Warner et al. 2014).

Rainbow smelt – Adult rainbow smelt are an important part of the diet for intermediate-sized (400 to 600 mm) lake trout in the nearshore waters of Lake Michigan (Stewart et al. 1983; Madenjian et al. 1998; Jacobs et al. 2010). For Chinook salmon, rainbow smelt comprised as much as 18% in the diets of small individuals in 1994-1996, but that dropped precipitously to 2% in 2009-2010 and rainbow smelt has been consistently rare in the diets of larger Chinook salmon since 1994 (Jacobs et al. 2013). The rainbow smelt population supports commercial fisheries in Wisconsin and Michigan waters (Belonger et al. 1998; P. Schneeberger, Michigan Department of Natural Resources, Marquette, MI, personal communication).

Despite the nominal increase in adult rainbow smelt biomass density from 0.02 kg per ha in 2012 to 0.05 kg per ha in 2013, adult rainbow smelt biomass density has remained at low levels since 2006 (Figure 5a). Adult rainbow smelt biomass density was highest from 1981 to 1993, but then declined between 1993 and 2001, and has remained at a relatively low density, except in 2005, since 2001. Age-0 rainbow smelt numeric density has been highly variable since 2002 (Figure 5b). Age-0 numeric density in 2013 was 11 fish per ha, which was only 6% of the long-term average. Causes for the general decline in rainbow smelt biomass and production remain unclear. Consumption of rainbow smelt by salmonines was higher in the mid 1980s than during the 1990s (Madenjian et al. 2002), yet adult and age-0 (< 90 mm TL) rainbow smelt abundance remained high during the 1980s (Figure 5b). Results from a recent population modeling exercise suggested that predation by salmonines was not the primary driver of long-term temporal trends in Lake Michigan rainbow smelt abundance (Tsehaye et al. 2014).

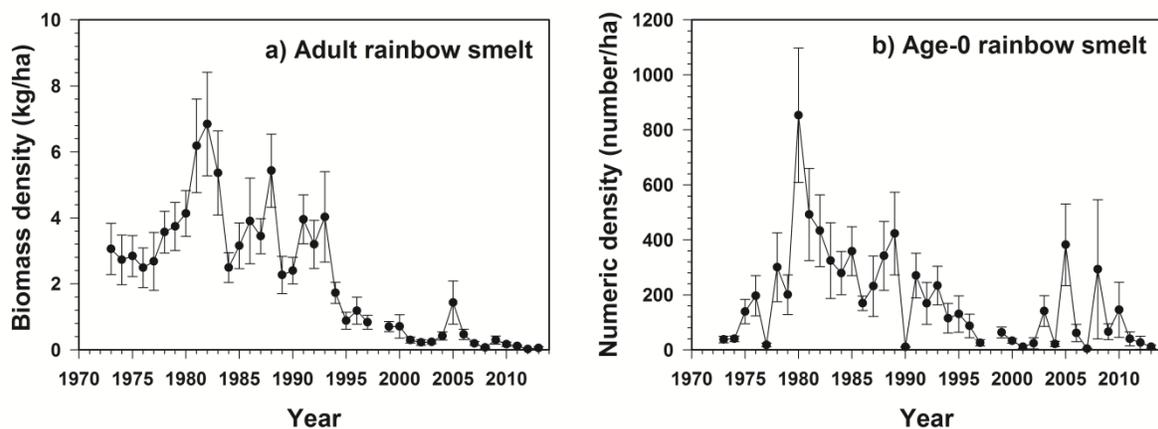


Figure 5. Biomass density (+/- standard error) of adult (a) and age-0 (b) rainbow smelt in Lake Michigan, 1973-2013.

Temporal trends in rainbow smelt biomass from the acoustic and bottom trawl surveys in Lake Michigan have been similar since 2001. The bottom trawl survey has documented relatively low rainbow smelt biomass during 2001-2013, with a minor peak in 2005 (Figure 5a). Similarly, biomass of rainbow smelt in the acoustic survey was relatively low during 2001-2013, with minor peaks occurring during 2005-2006 and 2008-2009 (Warner et al. 2014). Results from both the acoustic and bottom trawl surveys indicated that rainbow smelt biomass in Lake Michigan during 1992-1996 was roughly four times higher than rainbow smelt biomass during 2001-2013.

Sculpins – From a biomass perspective, the cottid populations in Lake Michigan have been dominated by deepwater sculpins, and to a lesser degree, slimy sculpins (*Cottus cognatus*). Spoonhead sculpins (*Cottus ricei*), once fairly common, suffered declines to become rare to absent by the mid 1970s (Eck and Wells 1987). Spoonhead sculpins were encountered in small numbers in our survey between 1990 and 1999 (e.g., Potter and Fleischer 1992), but have not been sampled since 1999.

Slimy sculpin is a favored prey of juvenile lake trout in nearshore regions of the lake (Stewart et al. 1983; Madenjian et al. 1998), but is only a minor part of adult lake trout diets. When abundant, deepwater sculpin can be an important diet constituent for burbot in Lake Michigan, especially in deeper waters (Van Oosten and Deason 1938; Brown and Stedman 1995; Fratt et al. 1997).

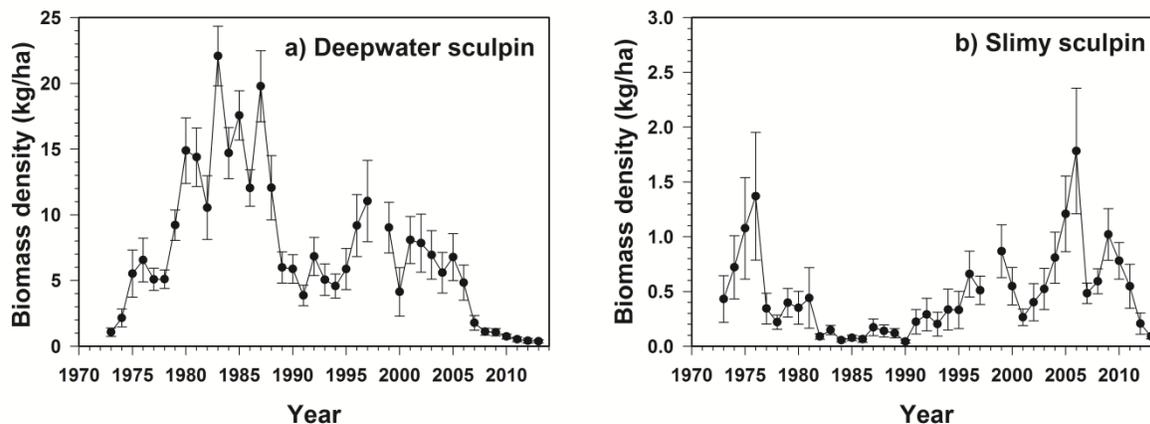


Figure 6. Biomass density (+/- standard error) for deepwater (a) and slimy sculpin (b) in Lake Michigan, 1973-2013.

Deepwater sculpin biomass density was 0.38 kg per ha in 2013 (Figure 6a), which was only 5% of the long-term average biomass and the lowest estimate of the time series. For every year since 2009, this biomass estimate has reached a record low. During 1990-2005, both deepwater sculpin biomass density and numeric density trended neither downward nor upward. However, biomass of deepwater sculpin sampled in the bottom trawl has declined precipitously since 2005. Madenjian and Bunnell (2008) demonstrated that deepwater sculpins have been captured at increasingly greater depths since the 1980s. Therefore, one potential explanation for the recent declines in deepwater sculpin densities is that an increasing proportion of the population is now occupying depths deeper than those sampled by our survey (i.e., 110 m). Furthermore, because the deepwater sculpin has historically occupied deeper depths than any of the other prey fishes of Lake Michigan, a shift to waters deeper than 110 m would seem to be a reasonable explanation for the recent declines in deepwater sculpin densities. Moreover, this explanation was supported by data from the additional trawl tows at bottom depths between 128 and 132 m during 2013. At each of these three transects (Manistique, Frankfort, Port Washington), the maximum deepwater sculpin biomass density occurred at the bottom depths between 128 and 132 m. Previous analysis of the time series indicated deepwater sculpin density is negatively influenced by alewife (predation on sculpin larvae) and burbot (predation on juvenile and adult sculpin, Madenjian et al. 2005b). Based on bottom trawl survey results, neither alewife nor burbot significantly increased in abundance during 2007-2013 to account for this decline in deepwater sculpins. Which factor or factors could have driven the bulk of the deepwater sculpin population to move to waters deeper than 110 m during 2007-2011? This shift to deeper water by deepwater sculpins coincided with the population explosion of the profundal form of the quagga mussel (*Dreissena rostriformis*) in depths between 60 and 90 m (Bunnell et al. 2009b; T. Nalepa, NOAA Great Lakes Environmental Research Laboratory, personal communication). Perhaps some consequences of the colonization of deeper waters by quagga mussels prompted a move of deepwater sculpins to deeper water. If this hypothesis were correct, then a substantial decline in quagga mussel abundance in the 60-m to 90-m deep waters could lead to a shift of deepwater sculpins back to shallower waters.

Slimy sculpin biomass density was 0.09 kg per ha in 2013, marking the fourth consecutive year of a decline (Figure 6b). Biomass density of slimy sculpins in 2013 approached the minimal levels observed during 1984-1986 and 1990. Slimy sculpin abundance in Lake Michigan appeared to be regulated, at least in part, by predation from juvenile lake trout (Madenjian et al. 2005b). We attribute the slimy sculpin recovery that occurred during the 1990s to, in part, the 1986 decision to emphasize stocking lake trout on offshore reefs (as opposed to the nearshore areas where our survey samples, Madenjian et al.

2002). Likewise, the slimy sculpin decline since 2009 coincided with a substantial increase in the rate of stocking juvenile lake trout into Lake Michigan (FWS/GLFC 2010).

Round goby – The round goby (*Neogobius melanostomus*) is an invader from the Black and Caspian Seas. Round gobies have been observed in bays and harbors of Lake Michigan since 1993, and were captured in the southern main basin of the lake as early as 1997 (Clapp et al. 2001). Round gobies were not captured in the GLSC bottom trawl survey until 2003, however. By 2002, round gobies had become an integral component of yellow perch diet at nearshore sites (i.e., < 15 m depth) in southern Lake Michigan (Truemper et al. 2006). Round gobies also had become an important constituent of the diet of burbot in northern Lake Michigan by 2005 (Hensler et al. 2008; Jacobs et al. 2010). Round gobies are also fed upon by smallmouth bass (*Micropterus dolomieu*) and lake trout, and more recently by lake whitefish, in Lake Michigan (T. Galarowicz, Central Michigan University, personal communication; McKenna 2014; S. Hansen, Wisconsin DNR, personal communication).

Round goby biomass density exhibited a peak value of 3.1 kg per ha in 2013; however, there was an unusually high degree of uncertainty, arising from the bulk of the round gobies being caught in a single trawl tow at the 18-m depth at Waukegan, associated with this estimate (Figure 7a). In general, standard errors associated with the reported mean biomass densities for round goby were relatively high. Given this high degree of uncertainty, round goby abundance in Lake Michigan may already be leveling off in response to control by piscivores. This hypothesis was supported by the round goby mortality estimates by Huo et al (2014), who estimated that round gobies in the main basin of Lake Michigan are experiencing annual mortality rates of between 75 and 85%, which are comparable to the mortality rates currently experienced by Lake Michigan adult alewives (Tsehaye et al. 2014).

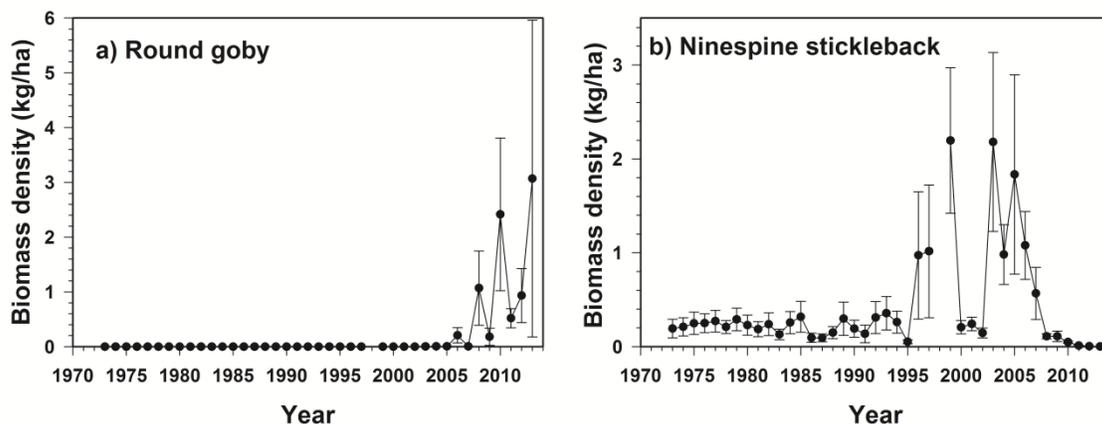


Figure 7. Biomass density (+/- standard error) of round goby (a) and ninespine stickleback (b) in Lake Michigan, 1973-2013.

Ninespine stickleback – Two stickleback species occur in Lake Michigan. Ninespine stickleback (*Pungitius pungitius*) is native, whereas threespine stickleback (*Gasterosteus aculeatus*) is non-native and was first collected in the GLSC bottom trawl survey during 1984 (Stedman and Bowen 1985). Ninespine stickleback is generally captured in far greater densities than the threespine. Relative to other prey fishes, ninespine sticklebacks are of minor importance to lake trout and other salmonines. In northern Lake Michigan, for example, sticklebacks occur infrequently in the diet of lake trout (Elliott et al. 1996; Jacobs et al. 2010). Biomass density was only 1 g per ha in 2013 (Figure 7b), the lowest value of the time series and only 0.3% of the long-term average. Biomass of ninespine stickleback remained fairly low from 1973-1995, increased dramatically in 1996-1997, and exhibited larger interannual variability between 1999 and 2007. Since 2008, however, biomass has been maintained at near record-low levels. The relatively high mean level of ninespine stickleback abundance during 1996-2007 has been attributed to dreissenid mussels somehow enhancing ninespine stickleback spawning and nursery habitat, perhaps through proliferation of *Cladophora* (Madenjian et al. 2010b). One plausible explanation for the low ninespine stickleback abundance during 2008-2013 is that piscivores have begun to incorporate ninespine

sticklebacks into their diets as the abundance of alewives has remained at a low level. Jacobs et al. (2013) found ninespine sticklebacks to be a rare diet item (i.e., 2% occurrence) among large Chinook salmon in 2009-2010 after a 0% occurrence in 1994-1996.

LAKE-WIDE BIOMASS

We estimated a total lake-wide biomass of prey fish available to the bottom trawl in 2013 of 43 kilotonnes (kt) (1 kt = 1000 metric tonnes) (Figure 8a, Appendix 1). Total prey fish biomass was the sum of the population biomass estimates for alewife, bloater, rainbow smelt, deepwater sculpin, slimy sculpin, ninespine stickleback, and round goby. Total prey fish biomass in Lake Michigan has trended downward since 1989, primarily due to a dramatic decrease in bloater biomass (Figure 8a). During 2002-2012, decreases in alewife and deepwater sculpin biomasses also contributed to the continued decrease in total prey fish biomass. Total biomass first dropped below 30 kt in 2007, and remained below 30 kt during 2007-2012, but then increased to 43 kt in 2013. This increase must be interpreted with caution, however, due to the high degree of uncertainty in the 2013 biomass estimates for alewife and round goby.

As Figure 8b depicts, the 2013 prey fish biomass was apportioned as: alewife 67.0% (29.0 kt), round goby 25.0% (10.8 kt), bloater 3.7% (1.6 kt), deepwater sculpin 3.1% (1.3 kt), slimy sculpin 0.7% (0.3 kt), rainbow smelt 0.5% (0.2 kt), and ninespine stickleback < 0.1% (0.004 kt).

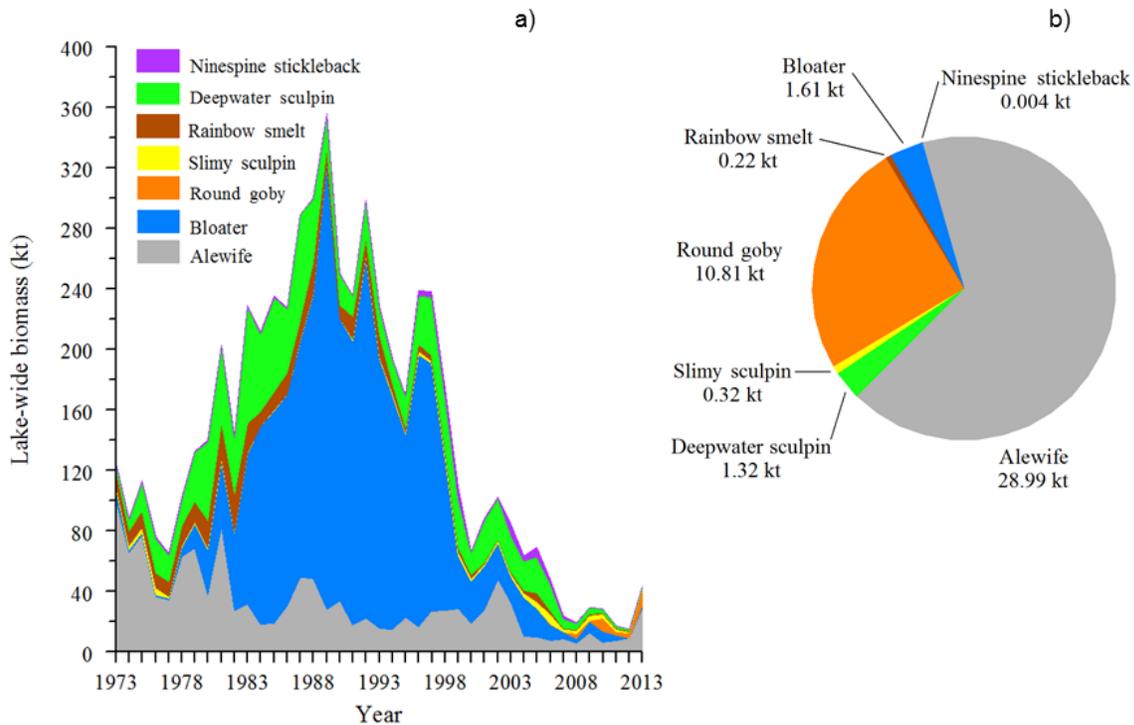


Figure 8. Estimated lake-wide (i.e., 5-114 m depth region) biomass of prey fishes in Lake Michigan, 1973-2013 (a) and species composition in 2013 (b).

OTHER SPECIES OF INTEREST

Burbot – Burbot and lake trout represent the native top predators in Lake Michigan. The decline in burbot abundance in Lake Michigan during the 1950s has been attributed to sea lamprey predation (Wells and McLain 1973). Sea lamprey control was a necessary condition for recovery of the burbot population in Lake Michigan, however Eshenroder and Burnham-Curtis (1999) proposed that a reduction in alewife abundance was an additional prerequisite for burbot recovery.

Burbot collected in the bottom trawls are typically large individuals (>350 mm TL); juvenile burbot apparently inhabit areas not usually covered by the bottom trawl survey.

Burbot biomass density was 0.1 kg per ha in 2013, which was 13% of the long-term average. After a period of low numeric density in the 1970s, burbot showed a strong recovery in the 1980s (Figure 9a). Densities increased through 1997, but declined thereafter. Perhaps the apparent decrease in burbot abundance during 2007-2013 was due to a portion of the burbot population moving to waters deeper than 110 m in response to a movement of deepwater sculpins, favored prey of burbot (Van Oosten and Deason 1938; Gamble et al. 2011), to deeper waters.

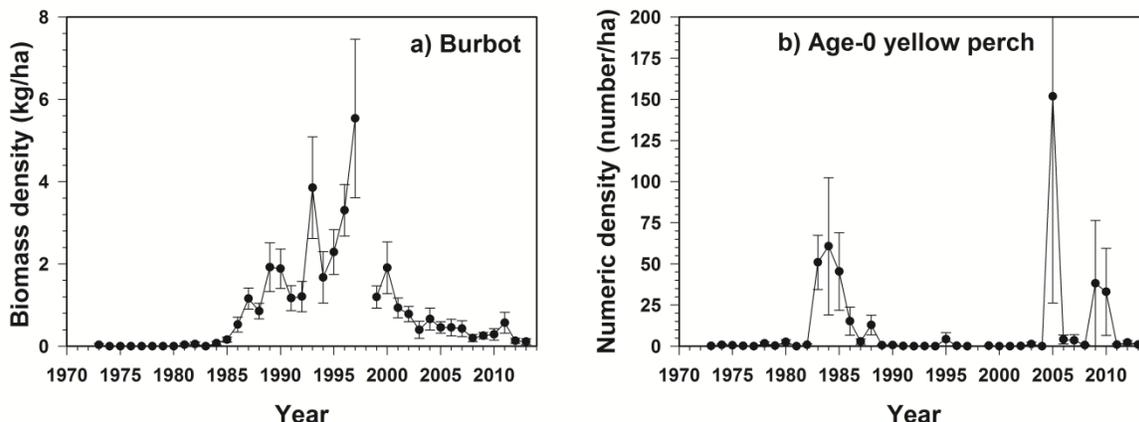


Figure 9. Biomass density (+/- standard error) of burbot (a) and numeric density (+/- standard error) of age-0 yellow perch (b) in Lake Michigan, 1973-2013.

Age-0 yellow perch – The yellow perch population in Lake Michigan has supported valuable recreational and commercial fisheries (Wells 1977). GLSC bottom trawl surveys provide an index of age-0 yellow perch numeric density, which serves as an indication of yellow perch recruitment success. The 2005 year-class of yellow perch was the largest ever recorded (Figure 9b) and the 2009 and 2010 year-classes also were higher than average. Strong yellow perch recruitment in these recent years was likely attributable to a sufficient abundance of female spawners and favorable weather (e.g., Makauskas and Clapp 2000). Numeric density of the 2013 year-class was only 1 fish per ha, indicative of a relatively weak year-class.

Dreissenid mussels – The first zebra mussel (*Dreissena polymorpha*) noted in Lake Michigan was found in May 1988 in Indiana Harbor at Gary, Indiana. By 1990, adult mussels had been found at multiple sites in the Chicago area, and by 1992 were reported to range along the eastern and western shoreline in the southern two-thirds of the lake, as well as in Green Bay and Grand Traverse Bay (Marsden 1992). In 1999, catches of dreissenid mussels in our bottom trawls became significant and we began recording biomass for each tow. Lake Michigan dreissenid mussels include two species: the zebra mussel and the quagga mussel. The quagga mussel is a more recent invader to Lake Michigan than the zebra mussel (Nalepa et al. 2001). According to the GLSC bottom trawl survey, biomass density of dreissenid mussels was highest in 2007 (Figure 10a), which followed an exponential like increase between 2004 and 2006 (Bunnell et al. 2009b). The biomass density of dreissenid mussels in 2013 was 6.6 kg per ha (Figure 10a). Interannual variability in dreissenid mussel density following 2007 is difficult to explain. The exceptionally high densities in 2006 and 2007 were attributable to the expansion of quagga mussels into deeper (> 60 m) waters of Lake Michigan. However, there was no clear explanation for the drastic drop in dreissenid mussel biomass density between 2007 and 2008. According to the results of the benthic macroinvertebrate survey led by Tom Nalepa at NOAA-GLERL, quagga mussel biomass density in Lake Michigan appears to have peaked sometime between 2008 and 2010. This peaking may be in response to the exceeding of the carrying capacity, and a decline in quagga mussel biomass density may be expected in upcoming years.

Over this same period of dreissenid mussel increases, prey fish biomass was declining, which led to a dramatic increase in the percentage of dreissenids in the total bottom trawl catch (Figure 10b). Some authors have attributed the recent decline in prey fish to food-web changes induced by the expansion of dreissenids (Nalepa et al. 2009). However, Bunnell et al. (2009b) proposed that the bulk of the decline in total prey fish biomass may be better explained by factors other than food-web-induced effects by dreissenids, including poor fish recruitment (that preceded the mussel expansion), shifts in fish habitat, and increased fish predation by Chinook salmon and lake trout.

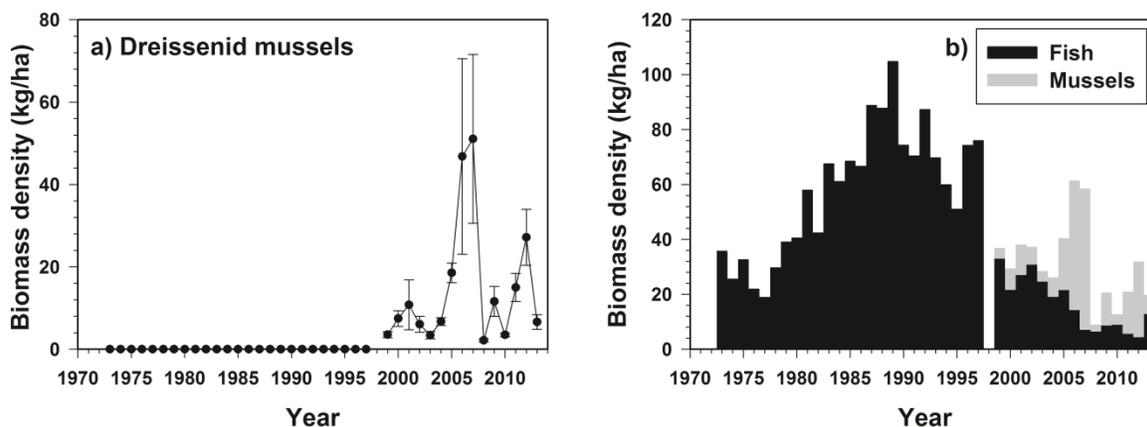


Figure 10. Panel (a) depicts biomass density (+/- standard error) of dreissenid mussels in the bottom trawl in Lake Michigan between 1999 (first year mussels were weighed) and 2013. Panel (b) depicts biomass of dreissenids and total fish biomass estimated by the bottom trawl between 1973 and 2013.

A comparison of the biomass density of dreissenid mussels (6.6 kg per ha) with biomass density of all species of fish (13 kg per ha) caught in the bottom trawl in 2013 indicated that 34% of the daytime benthic biomass available to the bottom trawl was dreissenid mussels (Figure 10b).

CONCLUSIONS

Although total prey fish biomass in 2013 was higher than that estimated for years 2007-2012, total prey fish biomass was still relatively low during 2013. Further, uncertainty in the 2013 total prey fish biomass estimate was extremely high. Prudently, we conclude that, based on the bottom trawl survey results, total prey fish biomass in Lake Michigan has remained at a low level during 2007-2013. This low level of prey fish biomass was attributable to a suite of factors, two of which can be clearly identify as: (1) a prolonged period of poor bloater recruitment since 1992 and (2) intensified predation on alewives by Chinook salmon during the 2000s. Adult alewife density has been maintained at a relatively low level over the last 10 years and the age distribution of the adult alewife population has become especially truncated in recent years. As recent as 2007, alewives as old as age 9 were sampled in this survey whereas the oldest alewife sampled in 2013 was age 5. Whether or not the alewife population in Lake Michigan will undergo a collapse in coming years (similar to what occurred in Lake Huron) will depend on several factors. Primarily, the extent to which predation by salmonines influences the survival of the large 2010 alewife year-class is critical. Salmonine predation on the 2012 alewife year-class will also be important. In addition, alewife sustainability will depend on the ability of alewife spawning stock to produce another strong year-class in the next few years, which will at least partially depend on appropriate environmental factors being met (Madenjian et al. 2005b).

According to the bottom trawl survey estimates, native fishes represented only 7.5% of the total prey fish biomass in Lake Michigan in 2013. Native deepwater sculpin and ninespine stickleback were at record-low levels in 2013, biomass of native slimy sculpin continued a 4-year downward trend in 2013, and biomass of native bloater remained low in 2013. When interpreting the bottom trawl survey results, the

possibility that two of these native species, deepwater sculpin and bloater, shifted their habitat use to deeper waters during recent years should be considered. If this shift did indeed occur, then the bottom trawl estimates for these two fishes may represent extreme underestimates of their biomass in Lake Michigan.

Scientists and managers continue to ask critical questions regarding the importance of “bottom-up” effects on prey fish biomass in Lake Michigan. For example, to what extent do (1) ongoing declines in total phosphorus (Evans et al. 2011), (2) the proliferation in dreissenid mussels, and (3) the resultant diminishment of the spring phytoplankton bloom (Fahnenstiel et al. 2010) reduce the capacity of Lake Michigan to produce the biomass of prey fish that was observed only two decades ago? We point out that the Lake Michigan ecosystem has already demonstrated its capacity to produce a strong year-class of alewives in 2010 despite the changes described above. Nonetheless, having a complete understanding of the answers to these questions will require additional years of surveillance, across-lakes comparisons, and food-web analyses.

ACKNOWLEDGMENTS

We thank Capt. Shawn Parsons and Engineer Jim Page for their seamanship on our 2013 survey. Reviews provided by Brian Breidert and Brad Eggold improved this report.

REFERENCES

- Adlerstein, S. A., E. S. Rutherford, D. Clapp, J. A. Clevenger, and J. E. Johnson. 2007. Estimating seasonal movements of Chinook salmon in Lake Huron from efficiency analysis of coded wire tag recoveries in recreational fisheries. *N. Am. J. Fish. Manage.* 27:792-803.
- Argyle, R. L., G. W. Fleischer, G. L. Curtis, J. V. Adams, and R. G. Stickel. 1998. An Integrated Acoustic and Trawl Based Prey Fish Assessment Strategy for Lake Michigan. A report to the Illinois Department of Natural Resources, Indiana Department of Natural Resources, Michigan Department of Natural Resources, and Wisconsin Department of Natural Resources. U. S. Geological Survey, Biological Resources Division, Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI USA.
- Belonger, B. B. T. Eggold, P. Hirethota, S. Hogler, B. Horns, T. Kroeff, T. Lychwick, S. Marcquenski, P. Peters, S. Surendonk, and M. Toney. 1998. Lake Michigan Management Reports, Wisconsin Department of Natural Resources. Lake Michigan Committee Meetings, Great Lakes Fishery Commission, Thunder Bay, Ontario, March 16-17, 1998.
- Brown, E. H., Jr., and R. M. Stedman. 1995. Status of forage fish stocks in Lake Michigan, 1994. Pages 81-88 in Minutes of Great Lakes Fishery Commission, Lake Michigan Committee Meeting, Milwaukee, Wisconsin, March 29-30, 1995.
- Bunnell, D. B., C. P. Madenjian, and T. E. Croley II. 2006a. Long-term trends of bloater recruitment in Lake Michigan: evidence for the effect of sex ratio. *Can. J. Fish. Aquat. Sci.* 63:832-844.
- Bunnell, D. B., C. P. Madenjian, and R. M. Claramunt. 2006b. Long-term changes of the Lake Michigan fish community following the reduction of exotic alewife (*Alosa pseudoharengus*). *Can. J. Fish. Aquat. Sci.* 63:2434-2446.
- Bunnell, D. B., S. R. David, and C. P. Madenjian. 2009a. Decline in bloater fecundity in southern Lake Michigan after decline of *Diporeia*. *J. Great Lakes Res.* 35:45-49.
- Bunnell, D. B., C. P. Madenjian, J. D. Holuszko, J. V. Adams, and J. R. P. French III. 2009b. Expansion of *Dreissena* into offshore waters of Lake Michigan and potential impacts on fish populations. *J. Great Lakes Res.* 35:74-80.
- Bunnell, D. B., J. V. Adams, O. T. Gorman, C. P. Madenjian, S. C. Riley, E. F. Roseman, and J. S. Schaeffer. 2010. Population synchrony of a native fish across three Laurentian Great Lakes: evaluating the effects of dispersal and climate. *Oecologia* 162:641-651.
- Bunnell, D. B., R. L. Eshenroder, A. E. Krause, and J. V. Adams. 2012. Depth segregation of deepwater ciscoes (*Coregonus* spp.) in Lake Michigan during 1930-1932 and range expansion of *Coregonus hoyi* into deeper waters after the 1990s. *Advances in Limnology Series (Biology and Management of Coregonid Fishes – 2008)*. 63:3-24.
- Bunnell, D. B., J. G. Mychek-Londer, and C. P. Madenjian. 2014. Population-level effects of egg predation on a native planktivore in a large freshwater lake. *Ecol. Freshw. Fish* 23: in press.

- Clapp, D. F., P. J. Schneeberger, D. J. Jude, G. Madison, and C. Pistis. 2001. Monitoring round goby (*Neogobius melanostomus*) population expansion in eastern and northern Lake Michigan. *J. Great Lakes Res.* 27:335-341.
- Eck, G. W., and L. Wells. 1987. Recent changes in Lake Michigan's fish community and their probable causes, with emphasis on the role of the alewife *Alosa pseudoharengus*. *Can. J. Fish. Aquat. Sci.* 44(Suppl. 2):53-50.
- Elliott, R. F., and eight coauthors. 1996. Conducting diet studies of Lake Michigan piscivores- a protocol. U.S. Fish and Wildlife Service, Fishery Resources Office, Report 96-2, Green Bay, Wisconsin.
- Eshenroder, R. L. and M. K. Burnham-Curtis. 1999. Species succession and sustainability of the Great Lakes fish community. Pages 145-184 in W. W. Taylor and C. P. Ferreri (ed) *Great Lakes Fisheries Policy and Management: A Binational Perspective*. Michigan State University Press, East Lansing, MI.
- Evans, M. A., G. Fahnenstiel, and D. Scavia. 2011. Incidental oligotrophication of North American Great Lakes. *Environ. Sci. Technol.* 45: 3297–3303.
- Fahnenstiel, G., S. Pothoven, H. Vanderploeg, D. Klarer, T. Nalepa, and D. Scavia. 2010. Recent changes in primary production and phytoplankton in the offshore region of southern Lake Michigan. *J. Great Lakes Res.* 36(Suppl. 3):20-29.
- Fratt, T. W., D. W. Coble, F. Copes, and R. E. Bruswitz. 1997. Diet of burbot in Green Bay and western Lake Michigan with comparison to other waters. *J. Great Lakes Res.* 23:1-10.
- FWS/GLFC. 2010. Great Lakes Fish Stocking database. U. S. Fish and Wildlife Service, Region 3 Fisheries Program, and Great Lakes Fishery Commission.
- Gamble, A. E., T. R. Hrabik, J. D. Stockwell, and D. L. Yule. 2011. Trophic connections in Lake Superior Part 1: The offshore fish community. *J. Great Lakes Res.* 37:541-549.
- Hatch, R. W., P. M. Haack, and E. H. Brown, Jr. 1981. Estimation of alewife biomass in Lake Michigan, 1967-1978. *Trans. Am. Fish. Soc.* 110:575-584.
- Hensler, S. R., D. J. Jude, and J. He. 2008. Burbot growth and diet in Lakes Michigan and Huron: an ongoing shift from native species to round gobies. Pages 91-107 in V. L. Paragamian and D. H. Bennett (ed) *Burbot: Ecology, Management, and Culture*. American Fisheries Society, Symposium 59, Bethesda, MD.
- Huo, B., C. P. Madenjian, C. Xie, Y. Zhao, T. P. O'Brien, and S. J. Czesny. 2014. Age and growth of round gobies in Lake Michigan, with preliminary mortality estimation. *Biol. Invasions*, in review.
- Jacobs, G. R., C. P. Madenjian, D. B. Bunnell, and J. D. Holuszko. 2010. Diet of lake trout and burbot in northern Lake Michigan during spring: evidence of ecological interaction. *J. Great Lakes Res.* 36:312-317.
- Jacobs, G. R., C. P. Madenjian, D. B. Bunnell, D. M. Warner, and R. M. Claramunt. 2013. Chinook salmon foraging patterns in a changing Lake Michigan. *Trans. Am. Fish. Soc.* 142:362-372.
- Jude, D. J., F. J. Tesar, S. F. DeBoe, and T. J. Miller. 1987. Diet and selection of major prey species by Lake Michigan salmonines, 1973-1982. *Trans. Am. Fish. Soc.* 116:677-691.
- Madenjian, C. P., and D. B. Bunnell. 2008. Depth distribution dynamics of the sculpin community in Lake Michigan. *Trans. Am. Fish. Soc.* 137:1346-1357.
- Madenjian, C. P., T. J. DeSorcie, and R. M. Stedman. 1998. Ontogenic and spatial patterns in diet and growth of lake trout from Lake Michigan. *Trans. Am. Fish. Soc.* 127: 236-252.
- Madenjian, C. P., G. L. Fahnenstiel, T. H. Johengen, T. F. Nalepa, H. A. Vanderploeg, G. W. Fleischer, P. J. Schneeberger, D. M. Benjamin, E. B. Smith, J. R. Bence, E. S. Rutherford, D. S. Lavis, D. M. Robertson, D. J. Jude, and M. P. Ebener. 2002. Dynamics of the Lake Michigan food web, 1970-2000. *Can. J. Fish. Aquat. Sci.* 60:736-753.
- Madenjian, C. P., J. D. Holuszko, and T. J. Desorcie. 2003. Growth and condition of alewives in Lake Michigan, 1998-2001. *Trans. Am. Fish. Soc.* 132:1104-1116.
- Madenjian, C. P., T. O. Höök, E. S. Rutherford, D. M. Mason, T. E. Croley II, E. B. Szalai, and J. R. Bence. 2005a. Recruitment variability of alewives in Lake Michigan. *Trans. Am. Fish. Soc.* 134:218-230.
- Madenjian, C. P., D. W. Hondorp, T. J. Desorcie, and J. D. Holuszko. 2005b. Sculpin community dynamics in Lake Michigan. *J. Great Lakes Res.* 31:267-276.

- Madenjian, C. P., S. A. Pothoven, J. M. Dettmers, and J. D. Holuszko. 2006. Changes in seasonal energy dynamics of alewife (*Alosa pseudoharengus*) in Lake Michigan after invasion of dreissenid mussels. *Can. J. Fish. Aquat. Sci.* 63:891-902.
- Madenjian, C. P., R. O'Gorman, D. B. Bunnell, R. L. Argyle, E. F. Roseman, D. M. Warner, J. D. Stockwell, and M. A. Stapanian. 2008. Adverse effects of alewives on Laurentian Great Lakes fish communities. *N. Am. J. Fish. Manage.* 28:263-282.
- Madenjian, C. P., D. B. Bunnell, J. D. Holuszko, T. J. Desorcie, and J. V. Adams. 2010a. *Status and Trends of Prey Fish Populations in Lake Michigan, 2009*. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Windsor, Ontario, March 23, 2010.
- Madenjian, C. P., D. B. Bunnell, and O. T. Gorman. 2010b. Ninespine stickleback abundance in Lake Michigan increases after invasion of dreissenid mussels. *Trans. Am. Fish. Soc.* 139:11-20.
- Makauskas, D., and D. Clapp. 2000. Status of yellow perch in Lake Michigan and Yellow Perch Task Group progress report. In Minutes of 2000 Annual Meeting of the Lake Michigan Committee. Great Lakes Fishery Commission, Ann Arbor, Michigan.
- Marsden, J. E. 1992. The zebra mussel invasion. *Aquaticus* 23:19-27.
- McKenna, P. R. 2014. Use of stomach contents, fatty acids, and stable isotopes to detect spatial variability in lake trout diets throughout the Laurentian Great Lakes. M.S. Thesis, University of Illinois, Urbana-Champaign, Illinois.
- Nalepa, T. F., D. W. Schloesser, S. A. Pothoven, D. W. Hondorp, D. L. Fanslow, M. L. Tuchman, and G. W. Fleischer. 2001. First finding of the amphipod *Echinogammarus ischmus* and the mussel *Dreissena bugensis* in Lake Michigan. *J. Great Lakes Res.* 27:384-391.
- Nalepa, T. F., D. L. Fanslow, G. A. Lang. 2009. Transformation of the offshore benthic community in Lake Michigan: recent shift from the native amphipod *Diporeia* spp. to the invasive mussel *Dreissena rostriformis bugensis*. *Freshwater Biol.* 54:466-479.
- Potter, R. L. and G. W. Fleischer. 1992. Reappearance of spoonhead sculpins (*Cottus ricei*) in Lake Michigan. *J. Great Lakes Res.* 18:755-758.
- Smith, S. H. 1970. Species interactions of the alewife in the Great Lakes. *Trans. Am. Fish. Soc.* 99:754-765.
- Stedman, R. M., and Bowen, C. A. 1985. Introduction and spread of the threespine stickleback (*Gasterosteus aculeatus*) in lakes Huron and Michigan. *J. Great Lakes Res.* 11:508-511.
- Stewart, D. J., and M. Ibarra. 1991. Predation and production by salmonine fishes in Lake Michigan, 1978-88. *Can. J. Fish. Aquat. Sci.* 48:909-922.
- Stewart, D. J., D. Weininger, D. V. Rottiers, and T. A. Edsall. 1983. An energetics model for lake trout, *Salvelinus namaycush*: application to the Lake Michigan population. *Can. J. Fish. Aquat. Sci.* 40:681-698.
- Truemper, H. A., T. E. Lauer, T. S. McComish, and R. A. Edgell. 2006. Response of yellow perch diet to a changing forage base in southern Lake Michigan, 1984-2002. *J. Great Lakes Res.* 32:806-816.
- Tsehaye, I., M. L. Jones, J. R. Bence, T. O. Brenden, C. P. Madenjian, and D. M. Warner. 2014. A multispecies statistical age-structured model to assess predator-prey balance: application to an intensively managed Lake Michigan pelagic fish community. *Can. J. Fish. Aquat. Sci.* 71: in press.
- Van Oosten, J., and H. J. Deason. 1938. The food of the lake trout (*Cristivomer namaycush*) and of the lawyer (*Lota maculosa*) of Lake Michigan. *Trans. Am. Fish. Soc.* 67:155-177.
- Warner, D. M., C. S. Kiley, R. M. Claramunt, and D. F. Clapp. 2008. The influence of alewife year-class strength on prey selection and abundance of age-1 Chinook salmon in Lake Michigan. *Trans. Am. Fish. Soc.* 137:1683-1700.
- Warner, D. M., T. P. O'Brien, S. H. Farha, R. M. Claramunt, and D. Hanson. 2014. *Status of Pelagic Prey Fishes in Lake Michigan, 1992-2013*. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Windsor, Ontario, March 25, 2014.
- Wells, L. 1977. Changes in yellow perch (*Perca flavescens*) populations of Lake Michigan, 1954-75. *J. Fish. Res. Board Can.* 34:1821-1829.
- Wells, L., and A. L. McLain. 1973. Lake Michigan: man's effects on native fish stocks and other biota. Great Lakes Fishery Commission. Technical Report 20. 56 p.

Williams, M. C. 2012. Spatial, temporal, and cohort-related patterns in the contribution of wild Chinook salmon (*Oncorhynchus tshawytscha*) to total Chinook harvest in Lake Michigan. M.S. Thesis. Michigan State University, East Lansing, Michigan.

Appendix 1. Mean numeric and biomass density, as well as lake-wide biomass (defined as biomass available to the bottom trawls for the region of the main basin between the 5-m and 114-m depth contours) estimates for various fishes and dreissenid mussels in Lake Michigan during 2013. Estimates are based on the bottom trawl survey. Standard error enclosed in parentheses. NA denotes that estimate is not available.

Taxon	Numeric density (fish per ha)	Biomass density (kg per ha)	Lake-wide biomass (kt)
age-0 alewife	3.01 (2.20)	0.016 (0.012)	0.056 (0.042)
adult alewife	417.42 (355.80)	8.216 (7.083)	28.933 (24.943)
age-0 bloater	6.01 (2.79)	0.048 (0.023)	0.169 (0.080)
adult bloater	9.89 (3.32)	0.408 (0.206)	1.438 (0.724)
age-0 rainbow smelt	10.75 (6.73)	0.011 (0.009)	0.039 (0.030)
adult rainbow smelt	8.73 (7.66)	0.052 (0.046)	0.183 (0.161)
deepwater sculpin	38.86 (11.79)	0.375 (0.124)	1.321 (0.436)
slimy sculpin	17.47 (4.76)	0.090 (0.024)	0.318 (0.084)
ninespine stickleback	0.80 (0.39)	0.001 (0.001)	0.004 (0.002)
Burbot	0.07 (0.04)	0.112 (0.070)	0.395 (0.247)
age-0 yellow perch	0.91 (0.91)	0.002 (0.002)	0.008 (0.008)
round goby	230.64 (201.60)	3.069 (2.890)	10.807 (10.179)
dreissenid mussels	NA	6.588 (1.798)	23.201 (6.331)

Status and Trends of the Lake Huron Offshore Demersal Fish Community, 1976-2013¹

**Stephen C. Riley, Edward F. Roseman, Margret A. Chriscinske,
Taaja R. Tucker, Jason E. Ross, Patricia M. Armenio,
Nicole Watson, and Whitney Woelmer**

*U. S. Geological Survey
Great Lakes Science Center
1451 Green Rd.
Ann Arbor, MI 48105*

Abstract

The USGS Great Lakes Science Center has conducted trawl surveys to assess annual changes in the offshore demersal fish community of Lake Huron since 1973. Sample sites include five ports in U.S. waters with less frequent sampling near Goderich, Ontario. The 2013 fall bottom trawl survey was carried out between 25 October – 21 November 2013 and included all U.S. ports as well as Goderich, ON. The 2013 main basin prey fish biomass estimate for Lake Huron was 47 kilotonnes, less than half of the estimate in 2012 (97 Kt), and approximately 13 percent of the maximum estimate in the time series. The biomass estimate for YAO alewife in 2013 was lower than in 2012, remained much lower than levels observed before the crash in 2004, and populations were dominated by small fish. Estimated biomass of rainbow smelt also decreased and was the second lowest observed in the time series. Estimated YAO bloater biomass in Lake Huron was also reduced compared to 2012. YOY alewife, rainbow smelt, and bloater abundance and biomass increased over 2012. Biomass estimates for deepwater and slimy sculpins, trout-perch, ninespine stickleback, and round goby in 2013 were lower than in 2012 and remained low compared to historic estimates. Wild juvenile lake trout were captured again in 2013, suggesting that natural reproduction by lake trout continues to occur.

¹Presented at: Great Lakes Fishery Commission
Lake Huron Committee Meeting
March 24, 2014, Windsor, Ontario

Introduction

Lake Huron supports valuable recreational and commercial fisheries that may be at risk due to recent widespread ecological changes in the lake (Bence and Mohr 2008; Riley et al. 2013). Recent major ecosystem changes in Lake Huron include the invasion of dreissenid mussels and drastic declines in the abundance of the native amphipod *Diporeia* sp. (McNickle et al. 2006; Nalepa et al. 2003, 2005, 2007), decreases in lake whitefish *Coregonus clupeaformis* and Chinook salmon *Oncorhynchus tshawytscha* catches (Mohr and Ebener 2005; Bence and Mohr 2008; Johnson and Gonder 2012), significant changes in the abundance and species composition of the zooplankton community (Barbiero et al. 2009), the invasion of the round goby *Neogobius melanostomus*, and the collapse of the offshore demersal fish community (Riley et al. 2008).

The USGS Great Lakes Science Center (GLSC) began annual bottom trawl surveys on Lake Huron in 1973, and the first full survey with ports covering the Michigan waters of the lake was conducted in 1976. These surveys are used to examine relative abundance, size and age structure, and species composition of the offshore demersal fish community. The primary purpose of this report is to present estimates of the abundance and biomass of offshore demersal fish species that are important as prey to common predators in the lake (i.e., lake trout *Salvelinus namaycush* and Chinook salmon).

Methods

The GLSC has monitored fish abundance annually from 1973-2013 using 12 m headrope (1973-1991) and 21 m headrope (1992-2013) bottom trawls at fixed transects at up to eleven depths (9, 18, 27, 36, 46, 55, 64, 73, 82, 92, and 110 m) at five ports (De Tour, Hammond Bay, Alpena, Au Sable Point, and Harbor Beach) in the Michigan waters of Lake Huron (Fig. 1). Both trawls used a 4.76 mm square mesh cod end. The same fixed transects were sampled each year from the USGS R/V *Kaho* during 1973-1977 and from the USGS R/V *Grayling* during 1978-2013; some transects were fished from the USGS R/V *Cisco* in 1990. The first year that all of the Michigan ports were sampled was 1976. Sampling has been intermittently conducted at Goderich (Ontario) from the R/V *Grayling* since 1998 using the same trawling protocols as U.S. ports; this port was sampled in 2013.

Single 10-min trawl tows were conducted during daylight at each transect each year. Tow duration was occasionally less than 10 min due to large catches or obstacles in the tow path; catches for these tows were corrected to be comparable to 10-min tows (see formula below). Trawl catches were sorted by species, and each species was counted and weighed in aggregate. Large catches (> ca. 20 kg) were subsampled; a random sample was sorted, counted, and weighed, and the remainder of the catch was weighed for extrapolation of the sample.

We applied correction factors to standardize trawl data among depths, as the actual time on bottom for each trawl increased with depth (Fabrizio et al. 1997). Relative abundance was standardized to CPE (catch per 10 min on bottom) as

$$C_t = \frac{10N}{K_t T},$$

where C_t is the catch per 10 min (CPE) on bottom for trawl type t , N is the catch, T is tow time, and K_t is a correction factor that varies with fishing depth (D in m) and trawl type such that $K_{12} = 0.00400D + 0.8861$ for the 12-m trawl and $K_{21} = 0.00385D + 0.9149$ for the 21-m trawl. Catches were expressed in terms of density and biomass (number/ha and g/ha) by dividing the CPE by the area swept by the trawl. The area swept was estimated as the product of the distance towed (speed multiplied by tow time) and the trawl width. Trawl width estimates were depth-specific and were based on trawl mensuration data collected

from the R/V *Grayling* in 1991, 1998, and 2005 (USGS unpublished data). Catches were weighted by the area of the main basin of Lake Huron that occurred in each depth range. Lakewide biomass was estimated as the sum of the biomass of the common species sampled in the survey, and is not a true “lakewide” estimate, as sampling is conducted only to a depth of 110 m.

We partitioned the catches of alewife *Alosa pseudoharengus*, rainbow smelt *Osmerus mordax*, and bloater *Coregonus hoyi* into size-based age classes based on length-frequency data. Year-specific length cutoffs were determined from length-frequency data and used to apportion the catch into age-0 fish (young-of-the-year, or YOY) and those age-1 or older (yearling and older, or YAO). In earlier reports, a constant length cutoff was used in all years.

To make density estimates from the two trawls comparable, we multiplied density estimates from the 12-m trawl (1976-1991) by species-specific fishing power corrections (FPCs) developed from a comparative trawl experiment (Adams et al. 2009). We applied FPCs greater than 1.0 to the density and biomass of alewife, rainbow smelt (YAO only), bloater, and FPCs less than 1.0 to the density and biomass of slimy sculpin *Cottus cognatus* and deepwater sculpin *Myoxocephalus thompsonii*. Catches of trout-perch *Percopsis omiscomaycus* were not significantly different between the two trawls. Insufficient data were available to estimate FPCs for ninespine stickleback *Pungitius pungitius* and YOY rainbow smelt; density estimates were not corrected for these species.

Trawl surveys on Lake Huron are typically conducted between 3 October and 15 November. In 1992 and 1993, however, trawl surveys occurred in early- to mid-September, and these data were not used in this report because the distribution of many offshore species in the Great Lakes is highly seasonally variable (Dryer 1966; Wells 1968) and data collected in September may not be comparable to the rest of the time series. In 1998, sampling was conducted in a non-standard manner, and these data were also excluded. The fall survey was not conducted in 2000 and was not completed in 2008. We did not use data prior to 1976 because all ports and depths in Lake Huron were not consistently sampled until 1976.

Fish abundance estimates reported here are likely to be negatively biased, primarily due to variability in the catchability of fish by the trawl, which may reflect the vulnerability of fish to the gear or the distribution of fish off the bottom. Many individuals of some demersal species may be pelagic at some times and not available to our trawls, particularly young-of-the-year alewife, rainbow smelt and bloater. Results reported here should therefore not be interpreted as absolute abundance estimates for any species.

Some of the fluctuations in abundance of individual species that we observed may be a result of changes in catchability caused by altered fish distributions. For example, catchability of a given species might differ from year to year due to changes in temperature or food distribution, and observed changes in abundance might result from fish becoming less catchable by bottom trawls in recent years. The invasion of Lake Huron by dreissenid mussels may also have affected the efficiency of the trawl, as has been observed in Lake Ontario (O’Gorman et al. 2005). Data reported here were collected at a restricted range of depths in areas that were free of obstructions and were characterized by sandy or gravel substrates, and it is therefore possible that USGS trawl data do not fully characterize the offshore demersal fish community. There are no other published long-term data on offshore demersal fish abundance in Lake Huron that would allow us to investigate the representativeness of the trawl data. Despite the foregoing constraints, however, these data are currently the best available to assess trends in the Lake Huron offshore demersal fish community.

Results

The 2013 Lake Huron fall bottom trawl survey was carried out during 25 October – 21 November. A total of 43 trawl tows were completed and all standard ports were sampled, including Goderich, Ontario. Twenty fish species were captured in the 2013 survey: rainbow smelt, alewife, bloater, deepwater sculpin, slimy sculpin, trout-perch, lake whitefish, round whitefish *Prosopium cylindraceum*, ninespine stickleback, threespine stickleback *Gasterosteus aculeatus*, lake trout, spottail shiner *Notropis hudsonius*, burbot *Lota lota*, round goby, yellow perch *Perca flavescens*, gizzard shad *Dorosoma cepedianum*, longnose sucker *Catostomus catostomus*, white sucker *Catostomus commersonii*, emerald shiner *Notropis atherinoides*, and white bass *Morone chrysops*.

Alewife abundance in Lake Huron remained low in 2013. YAO alewife density and biomass estimates decreased from 2012, and remained much below levels observed before the population crashed (Fig. 2). YOY alewife density and biomass showed a slight increase in 2013, but remained relatively low (Fig. 2). YAO rainbow smelt density in Lake Huron in 2013 decreased compared to 2012 and remained relatively low (Fig. 3). YOY rainbow smelt abundance and biomass increased dramatically compared to 2012 and were the highest observed since 2006. YAO bloater density and biomass in Lake Huron have been increasing in recent years, but the 2013 estimates were much lower than observed in 2012 (Fig. 4). YOY bloater abundance and biomass in 2013 showed a marked increase over 2012 and were the highest estimates observed in the survey (Fig. 4).

Slimy sculpins have rarely been captured in the Lake Huron bottom trawl survey since 2006, and very few were captured in 2013 despite high catches in 2012 (Fig. 5). Abundance and biomass estimates for deepwater sculpins in Lake Huron in 2013 were also lower than in 2012 and were relatively low compared to historic estimates (Fig. 5). The 2013 abundance and biomass estimates for ninespine stickleback and trout perch were also lower than in 2012 and were among the lowest in the time series (Fig. 6). Round goby abundance and biomass estimates for 2013 were lower than those observed in 2012 (Fig. 7).

The total main basin prey biomass estimate (5 - 114 m) in 2013 was 47 kilotonnes, about half of the estimate in 2012 (Fig. 8). This estimate is higher than the extreme low estimates in 2006-2010, and represents approximately 13 percent of the maximum lakewide biomass estimate observed in 1987. Approximately 37 percent of the 2013 biomass estimate was made up of YAO bloater.

The density of wild juvenile lake trout observed in 2013 was lower than the 2012 estimate, which was the highest density observed since juvenile lake trout began to appear in the catches in large numbers in 2004 (Fig. 9). Juvenile lake trout were apparently at low density in Lake Huron in 2013.

Discussion

The abundance of prey fish in Lake Huron has remained at very low levels since the collapse of the offshore demersal fish community (Riley et al. 2008), although survey catches in 2012 suggested that several species were beginning to increase in abundance. The estimated lakewide biomass of prey fish in 2012 was the highest reported since 2001, but the 2013 estimate is approximately half as high as 2012. The estimated biomass of YAO rainbow smelt and alewife in 2013 were lower than in 2012 and remained low compared to earlier data, and these populations were dominated by small fish. The reduction in the abundance of these exotic species is consistent with fish community objectives for Lake Huron (DesJardine et al. 1995), but does not bode well for Chinook salmon populations in the lake (Roseman and Riley 2009), which rely on these species as prey.

YAO bloater showed a consistent positive trend in biomass for 2009-2012, but the 2013 estimate was much reduced from 2012. The abundance of this native species is currently at a moderate level, higher than the extreme low estimates observed in 2001-2006. YAO bloater are one of the only species that has increased in abundance in recent years, and continued monitoring of this species will determine whether conditions in the lake are conducive to the survival and recruitment of native coregonids. YOY bloater abundance and biomass in 2013 were the highest ever observed, which may be a result of successful reproduction by the large YOA population in 2012.

Deepwater and slimy sculpins, ninespine sticklebacks, and trout-perch are currently minor components of lake trout diets in the Great Lakes, but were probably more important before the invasion of the lakes by alewife and rainbow smelt (e.g., Van Oosten and Deason 1938). In 2013, biomass estimates for deepwater and slimy sculpins, sticklebacks, and trout-perch were lower than in 2012, and remained relatively low compared to historical high estimates. Assessments of deepwater and slimy sculpin diets are currently underway at the GLSC to assess the composition of their diets as invertebrate communities continue to change.

Round gobies have recently become a significant part of the diet of lake trout in some areas of the Great Lakes (Dietrich et al. 2006), including Lake Huron (Ji He, MDNR Alpena, pers. comm., E. F. Roseman, USGS, unpublished data). Round gobies were first captured in the Lake Huron trawl survey in 1997, reached peak abundance in 2003, and declined in abundance until 2011. Our results suggest that round goby are currently at a moderate level of abundance in the offshore waters of Lake Huron, although sharp fluctuations in the time series suggest that abundance estimates for this species may be particularly sensitive to the effects of factors such as fish movement due to temperature or other factors.

The estimated lakewide biomass of common offshore prey species in Lake Huron has increased each year since 2009, but decreased in 2013. The peak estimated biomass of prey fish in Lake Huron occurred in the late 1980s, and has declined steadily since then; a similar decline has occurred in Lake Michigan (Bunnell et al. 2009). It is possible that these declines are associated with the invasion of the lakes by several exotic species including the spiny water flea (*Bythotrephes longimanus*), zebra mussels, quagga mussels, and round gobies, all of which have been introduced since the mid-1980s. Similar declines in some species (particularly coregonines) have occurred in Lake Superior (Gorman and Bunnell 2009; Gorman et al. 2009), however, where these exotic species have not invaded.

Naturally-produced juvenile lake trout were first captured in relatively large numbers by the Lake Huron fall survey in 2004, the year after the alewife population collapsed (Riley et al. 2007). Catches generally declined after 2004, but rebounded to high levels in 2011 and 2012 before declining in 2013. This suggests that the conditions that are conducive to natural reproduction of lake trout in Lake Huron may be sporadic. These wild juvenile lake trout are now recruiting to gill net surveys as adults (He et al. 2012), which is the first lakewide evidence of natural recruitment of wild adult lake trout outside of Lake Superior since the 1950s, and is an important step towards lake trout rehabilitation in Lake Huron.

The results of this survey show that there has been great variability in the abundance or biomass of a number of fish species (YOY benthopelagic planktivores, round goby, wild juvenile lake trout) over the last decade. Low levels of prey fish abundance have persisted since approximately 2006, although the 2012 survey provides evidence that the abundance of some species may be starting to rebound. These results, along with other analyses (Riley and Adams 2010), may indicate that the offshore demersal fish community in Lake Huron is currently in an unstable state.

Acknowledgements

We thank Shawn Parsons, Joe Bergan, and Jim Page for their seamanship and dedication to completing the survey. S. Nelson, L. Zhang, and D. Benes provided database and computer support. Kurt Newman provided helpful insights and suggestions that improved this report.

Literature Cited

- Adams, J. V., S. C. Riley, and S. A. Adlerstein. 2009. Development of fishing power corrections for 12-m Yankee and 21-m wing trawls used in the USGS Lake Huron fall bottom trawl survey. Great Lakes Fish. Comm. Tech. Rep. 68.
- Barbiero, R. P., M. Balcer, D. C. Rockwell, and M. L. Tuchman. 2009. Recent shifts in the crustacean zooplankton community of Lake Huron. Can. J. Fish. Aquat. Sci. 66: 816-828.
- Bence, J. R., and Mohr L. C. [eds.]. 2008. The state of Lake Huron in 2004. Great Lakes Fish. Comm. Spec. Pub. 08-01.
- Bunnell, D. B., C. P. Madenjian, J. D. Holuszko, T. J. Desorcie, and J. B. Adams. 2009. Status and trends of prey fish populations in Lake Michigan, 2008. U.S.G.S Annual Report to the Great Lakes Fishery Commission, Lake Huron Committee Meeting, Ypsilanti, MI, March 2009.
- DesJardine, R. L., T. K. Gorenflo, R. N. Payne, and J. D. Schrouder. 1995. Fish-community objectives for Lake Huron. Great Lakes Fish. Comm. Spec. Pub. 95-1. 38 pages.
- Dietrich, J. P., B. J. Morrison, and J. A. Hoyle. 2006. Alternative ecological pathways in the eastern Lake Ontario food web: round goby in the diet of lake trout. J. Great Lakes Res. 32: 395-400.
- Dryer, W. R. 1966. Bathymetric distribution of fish in the Apostle Islands Region, Lake Superior. Trans. Am. Fish. Soc. 95: 248-259.
- Fabrizio, M. C., J. V. Adams, and G. L. Curtis. 1997. Assessing prey fish populations in Lake Michigan: comparison of simultaneous acoustic-midwater trawling with bottom trawling. Fish. Res. 33: 37-54.
- Gorman, O. T., and D. B. Bunnell. 2009. Great Lakes prey fish populations: a cross-basin overview of status and trends in 2008. U.S.G.S Annual Report to the Great Lakes Fishery Commission, Lake Huron Committee Meeting, Ypsilanti, MI, March 2009.
- Gorman, O. T., L. M. Evrard, G. A. Cholwek, J. M. Falck, and D. L. Yule. 2009. Status and trends of prey fish populations in Lake Superior, 2008. U.S.G.S Annual Report to the Great Lakes Fishery Commission, Lake Huron Committee Meeting, Ypsilanti, MI, March 2009.
- He, J. X., M. P. Ebener, S. C. Riley, A. Cottrill, A. Kowalski, S. Koproski, L. Mohr, and J. E. Johnson. 2012. Lake trout status in the main basin of Lake Huron, 1973-2010. N. Am. J. Fish. Manag. 32: 402-412.
- McNickle, G. G., M. D. Rennie, and W. G. Sprules. 2006. Changes in benthic invertebrate communities of south Lake Huron following invasion by zebra mussels (*Dreissena polymorpha*), and potential effects on lake whitefish (*Coregonus clupeaformis*) diet and growth. J. Great Lakes Res. 32:180-193.
- Johnson, J.E. and D. Gonder. 2012. Status of introduced salmonines. In The state of Lake Huron in 2010. Edited by S.C. Riley. Great Lakes Fish. Comm. Spec. Pub. 13-01, pp. 50-59.
- Mohr, L. C., and M. P. Ebener. 2005. Status of lake whitefish (*Coregonus clupeaformis*) in Lake Huron. In Proceedings of a workshop on the dynamics of lake whitefish (*Coregonus clupeaformis*) and the amphipod *Diporeia* spp. in the Great lakes. Edited by L. C. Mohr and T. F. Nalepa. Great Lakes Fish. Comm. Tech. Rep. 66, p. 105-125.
- Nalepa, T. F., D. L. Fanslow, M. B. Lansing, and G. A. Lang. 2003. Trends in the benthic macroinvertebrate community of Saginaw Bay, Lake Huron, 1987 to 1996: Responses to phosphorus abatement and the zebra mussel, *Dreissena polymorpha*. J. Great Lakes Res. 29(1):14-33.

- Nalepa, T. F., D. L. Fanslow, and G. Messick. 2005. Characteristics and potential causes of declining *Diporeia* spp. populations in southern Lake Michigan and Saginaw Bay, Lake Huron. *In* Proceedings of a workshop on the dynamics of lake whitefish (*Coregonus clupeaformis*) and the amphipod *Diporeia* spp. in the Great lakes. Edited by L. C. Mohr and T. F. Nalepa. Great Lakes Fish. Comm. Tech. Rep. 66, p. 157-188.
- Nalepa, T. F., D. L. Fanslow, S. A. Pothoven, A. J. Foley III, and G. A. Lang. 2007. Long-term trends in benthic macroinvertebrate populations in Lake Huron over the past four decades. *J. Great Lakes Res.* 33: 421-436.
- O’Gorman, R., R. W. Owens, S. E. Prindle, J. V. Adams, and T. Schaner. 2005. Status of major prey fish stocks in the U.S. waters of Lake Ontario, 2004. Great Lakes Fishery Commission, Lake Ontario Committee Meeting, Niagara Falls, Ontario, 29-30 March 2005.
- Riley, S. C., J. X. He, J. E. Johnson, T. P. O’Brien, and J. S. Schaeffer. 2007. Evidence of widespread natural reproduction by lake trout *Salvelinus namaycush* in the Michigan waters of Lake Huron. *J. Great Lakes Res.* 33: 917-921.
- Riley, S. C., E. F. Roseman, S. J. Nichols, T. P. O’Brien, C. S. Kiley, and J. S. Schaeffer. 2008. Deepwater demersal fish community collapse in Lake Huron. *Trans. Am. Fish. Soc.* 137: 1879-1890.
- Riley, S. C., and J. V. Adams. 2010. Long-term trends in habitat use of offshore demersal fishes in western Lake Huron suggest large-scale ecosystem change. *Trans. Am. Fish. Soc.* 139: 1322-1334.
- Riley, S. C., L. Mohr, and M. P. Ebener. 2013. Lake Huron in 2010 and beyond. *In* The state of Lake Huron in 2010. Edited by S.C. Riley. Great Lakes Fish. Comm. Spec. Pub 13-01.
- Roseman, E. F., and S. C. Riley. 2009. Biomass of deepwater demersal forage fishes in Lake Huron, 1994-2007: implications for offshore predators. *Aquat. Ecosyst. Health Manage.* 12: 29-36.
- Van Oosten, J., and H. J. Deason. 1938. The food of the lake trout (*Cristovomer namaycush*) and of the lawyer (*Lota maculosa*) of Lake Michigan. *Trans. Am. Fish. Soc.* 67: 155-177.
- Wells, L. 1968. Seasonal depth distribution of fish in southeastern Lake Michigan. *U. S. Fish and Wildlife Ser. Fish. Bull.* 67: 1-15.

Figures



Figure 1. Bottom trawl sampling locations in Lake Huron, 2013

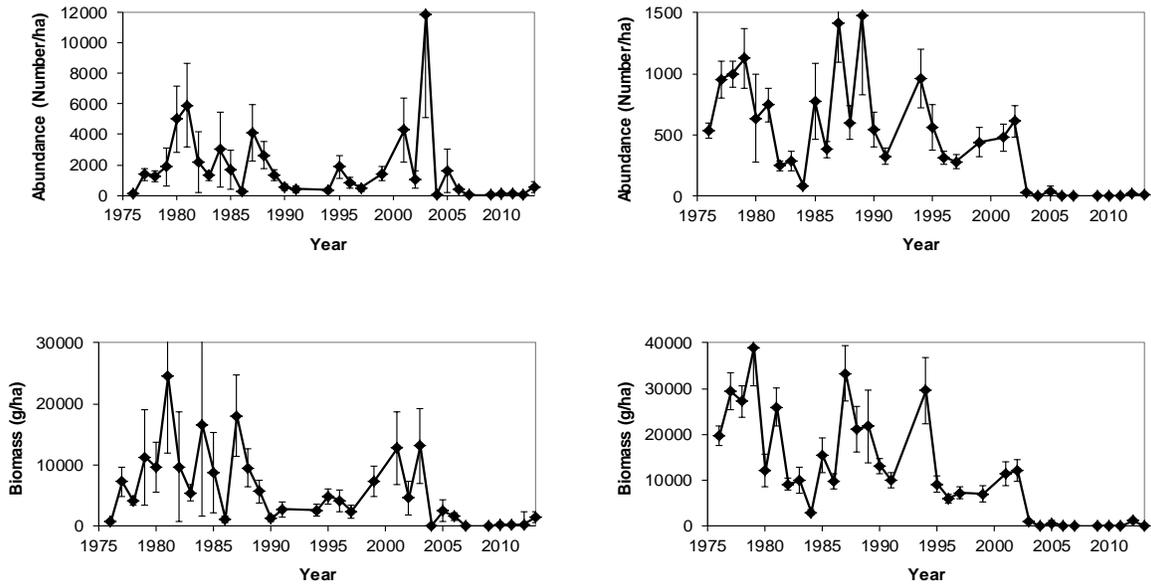


Figure 2. Density of young-of-the-year (YOY: left panels) and adult (YAO: right panels) alewives as number (top panels) and biomass (bottom panels) of fish per hectare in Lake Huron, 1976-2013. 1976-1991 estimates were corrected using fishing power corrections developed by Adams et al. (2009). Error bars are 95% confidence intervals.

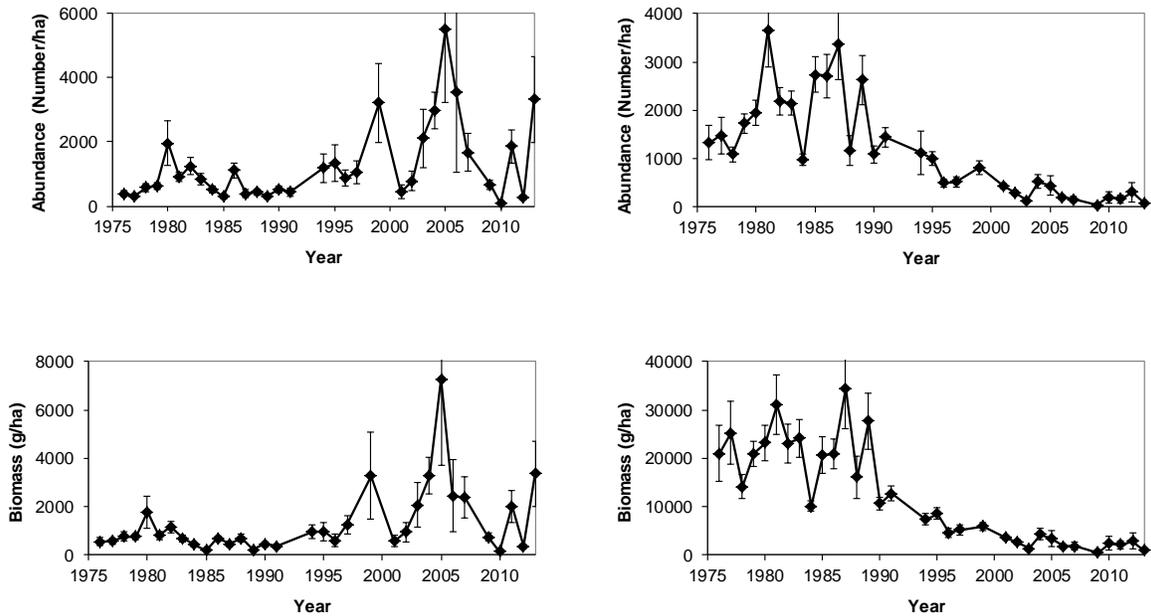


Figure 3. Density of young-of-the-year (YOY: left panels) and adult (YAO: right panels) rainbow smelt as number (top panels) and biomass (bottom panels) of fish per hectare in Lake Huron, 1976-2013. 1976-1991 estimates for YAO were corrected using fishing power corrections developed by Adams et al. (2009); YOY data are uncorrected. Error bars are 95% confidence intervals.

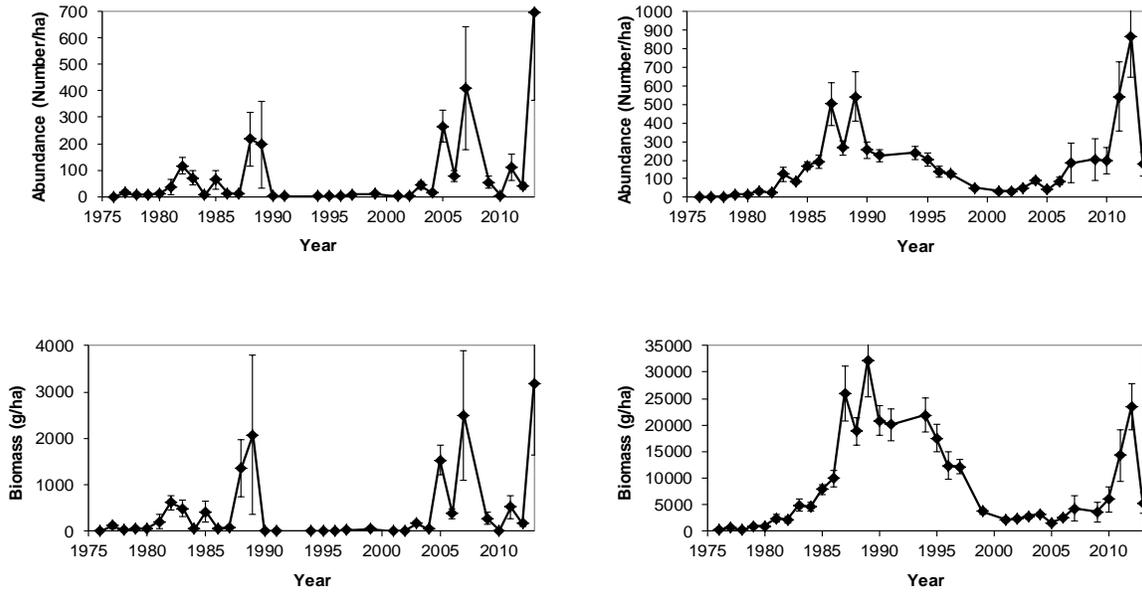


Figure 4. Density of young-of-the-year (YOY: left panels) and adult (YAO: right panels) bloater as number (top panels) and biomass (bottom panels) of fish per hectare in Lake Huron, 1976-2013. 1976-1991 estimates were corrected using fishing power corrections developed by Adams et al. (2009). Error bars are 95% confidence intervals.

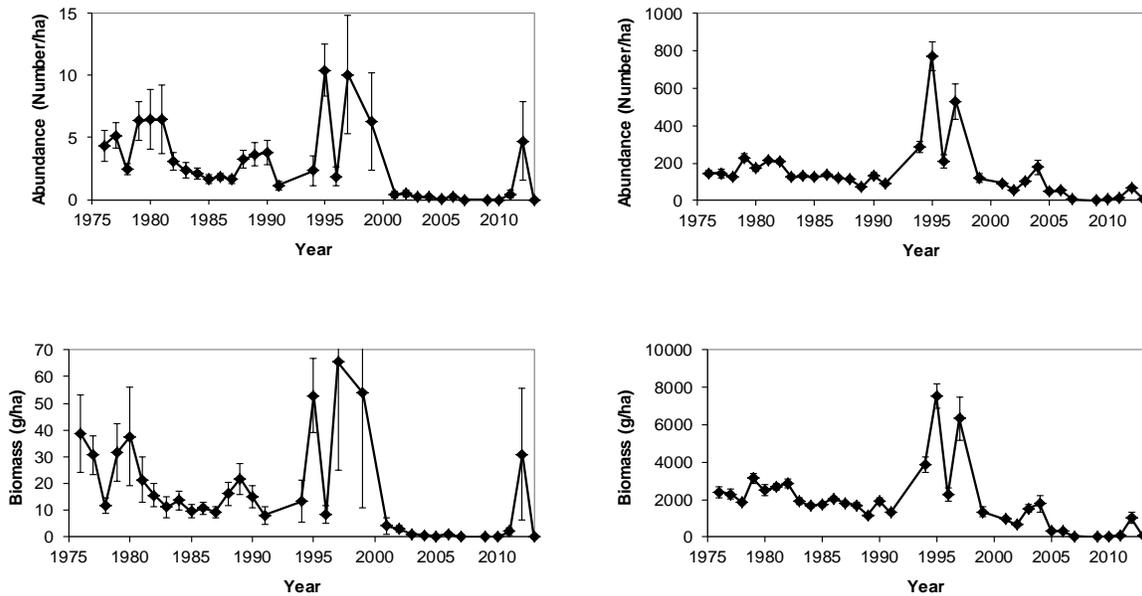


Figure 5. Density of slimy (left panels) and deepwater (right panels) sculpins as number (top panels) and biomass (bottom panels) of fish per hectare in Lake Huron, 1976-2013. 1976-1991 estimates were corrected using fishing power corrections developed by Adams et al. (2009). Error bars are 95% confidence intervals.

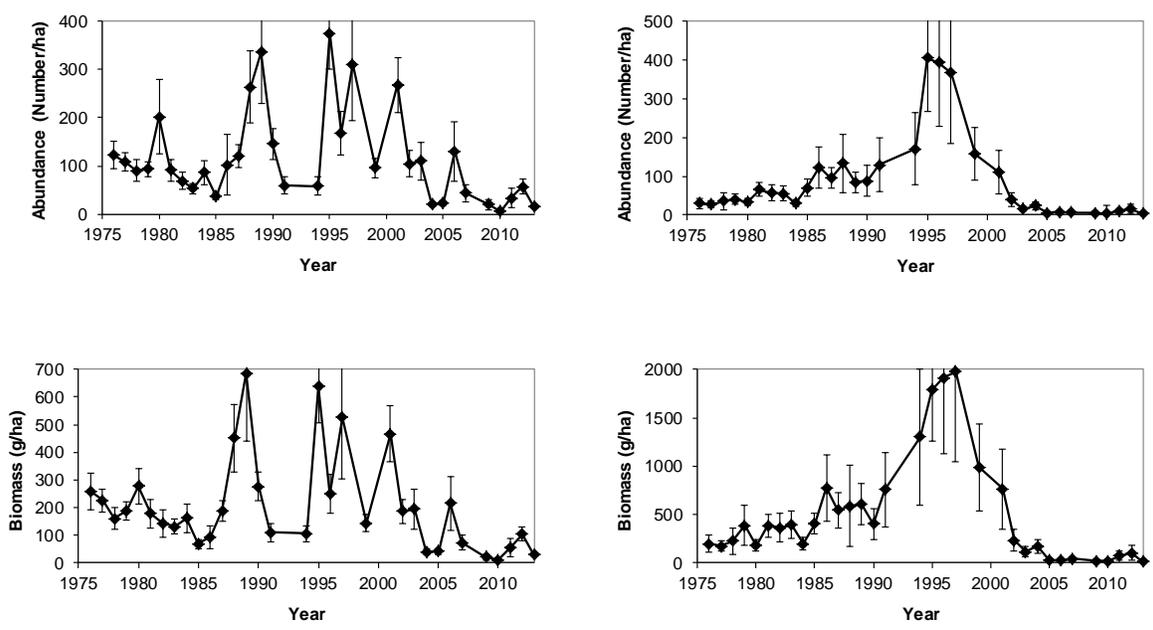


Figure 6. Density of ninespine stickleback (left panels) and trout-perch (right panels) as number (top panels) and biomass (bottom panels) of fish per hectare in Lake Huron, 1976-2013. Error bars are 95% confidence intervals.

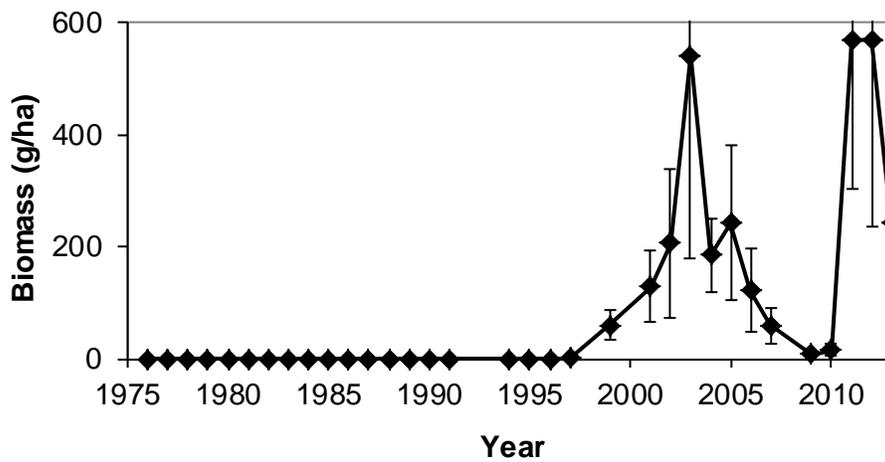
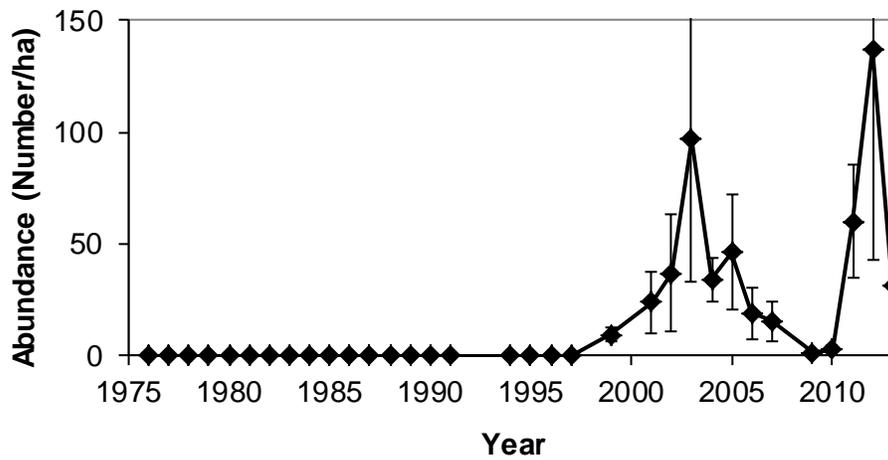


Figure 7. Density of round goby as number (top panel) and biomass (bottom panel) of fish per hectare in Lake Huron, 1976-2013.

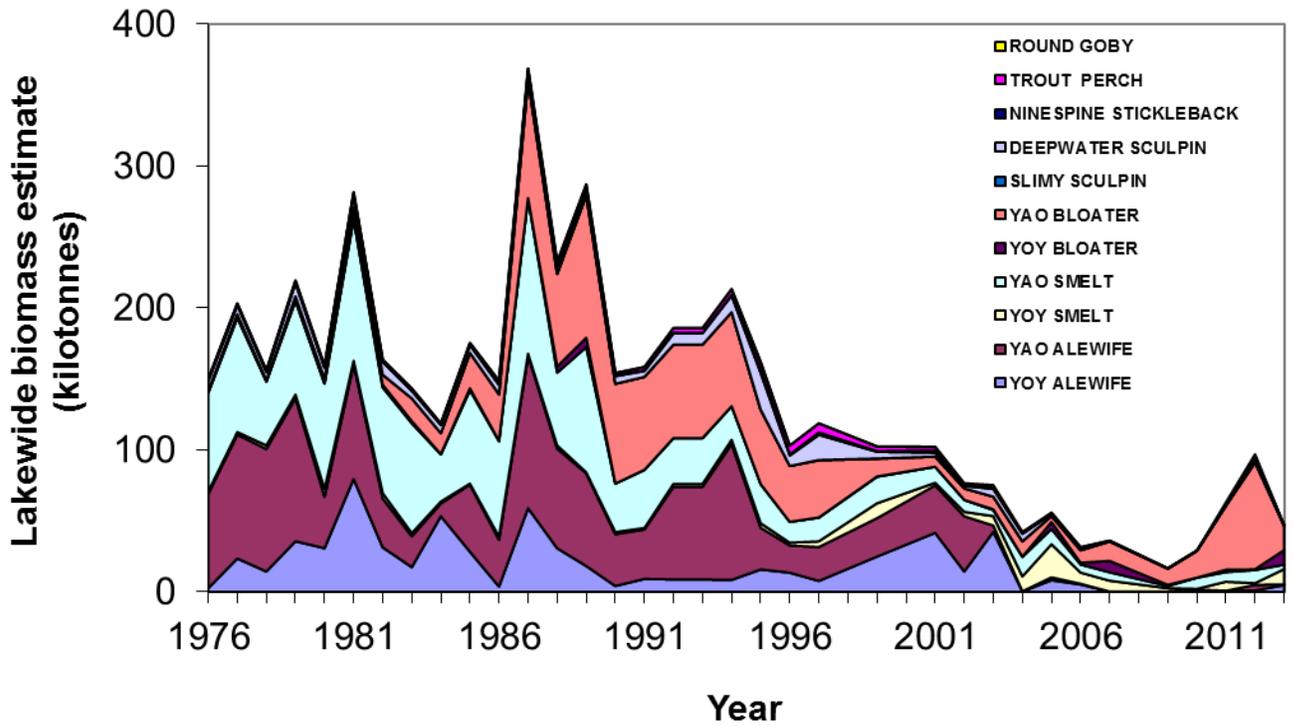


Figure 8. Offshore demersal fish community biomass in the main basin of Lake Huron, 1976-2013. Valid data were not collected in 1992, 1993, 1998, 2000, and 2008; biomass estimates for those years represent interpolated values.

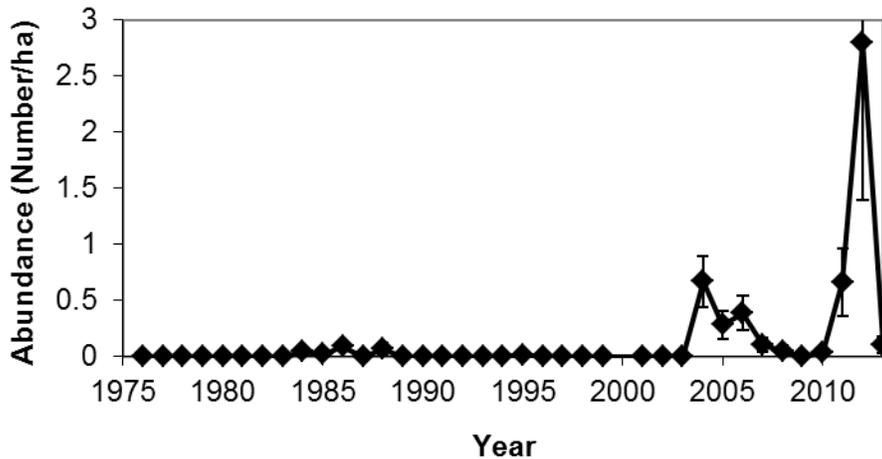


Figure 9. Density of wild juvenile (YOY, < 125 mm) lake trout collected in fall bottom trawls from Lake Huron 1976-2013. Error bars are 95% confidence intervals.

Status of Pelagic Prey Fishes in Lake Michigan, 2013¹

David M. Warner², Steven A. Farha², Timothy P. O'Brien², Lynn Ogilvie², Randall M. Claramunt³, and Dale Hanson⁴

²U.S. Geological Survey
Great Lakes Science Center
1451 Green Road
Ann Arbor, Michigan 48105

³Michigan Department of Natural Resources
Charlevoix Fisheries Research Station
96 Grant Street
Charlevoix, MI 49720

⁴U.S. Fish and Wildlife Service
Green Bay National Fish & Wildlife Conservation Office
2661 Scott Tower Drive
New Franken, Wisconsin 54229

ABSTRACT

Acoustic surveys were conducted in late summer/early fall during the years 1992-1996 and 2001-2013 to estimate pelagic prey fish biomass in Lake Michigan. Midwater trawling during the surveys as well as target strength provided a measure of species and size composition of the fish community for use in scaling acoustic data and providing species-specific abundance estimates. The 2013 survey consisted of 27 acoustic transects (546 km total) and 31 midwater trawl tows. Mean prey fish biomass was 6.1 kg/ha (relative standard error, RSE = 11%) or 29.6 kilotonnes (kt = 1,000 metric tons), which was similar to the estimate in 2012 (31.1 kt) and 23.5% of the long-term (18 years) mean. The numeric density of the 2013 alewife year class was 6% of the time series average and this year-class contributed 4% of total alewife biomass (5.2 kg/ha, RSE = 12%). Alewife \geq age-1 comprised 96% of alewife biomass. In 2013, alewife comprised 86% of total prey fish biomass, while rainbow smelt and bloater were 4 and 10% of total biomass, respectively. Rainbow smelt biomass in 2013 (0.24 kg/ha, RSE = 17%) was essentially identical to the rainbow smelt biomass in 2012 and was 6% of the long term mean. Bloater biomass in 2013 was 0.6 kg/ha, only half the 2012 biomass, and 6% of the long term mean. Mean density of small bloater in 2013 (29 fish/ha, RSE = 29%) was lower than peak values observed in 2007-2009 and was 23% of the time series mean. In 2013, pelagic prey fish biomass in Lake Michigan was similar to Lake Huron, but pelagic community composition differs in the two lakes, with Lake Huron dominated by bloater.

¹Presented at: Great Lakes Fishery Commission
Lake Michigan Committee Meeting
Windsor, ON, March 25-26, 2014

INTRODUCTION

Annual evaluation of long-term data on prey fish dynamics is critical in light of changes to the Lake Michigan food web during the last 40 years (Madenjian et al. 2002) and continued restructuring due to exotic species, pollution, fishing, and fish stocking. Alewives are the primary prey in Lake Michigan and of especial importance to introduced salmonines in the Great Lakes (Elliott 1993; Rybicki and Clapp 1996; Warner et al. 2008; Jacobs et al. 2013), and, as such, constitute an important food web component. The traditional Great Lakes Science Center (GLSC) prey fish monitoring method (bottom trawl) is inadequate for fish located off bottom (Fabrizio et al. 1997). In particular, bottom trawls provide particularly biased estimates for age-0 alewives (*Alosa pseudoharengus*) based on catchability estimates from stock assessment modeling (Tsehaye et al. 2014). Much of the alewife biomass will not be recruited to bottom trawls until age-3 (Madenjian et al. 2005), but significant predation by salmonines may occur on alewives \leq age-2 (Warner et al. 2008). Alewife abundance patterns tend to be highly variable because recruitment of alewife is variable and total alewife density is highly correlated with the density of alewife \leq age-2 (Warner et al. 2008). Because of the ability of acoustic equipment to count organisms far above bottom, this type of sampling is ideal for highly pelagic fish like age-0 alewives, rainbow smelt (*Osmerus mordax*), and bloater (*Coregonus hoyi*) and is a valuable complement to bottom trawl sampling.

METHODS

Sampling Design

The initial Lake Michigan survey adopted by the Lake Michigan Technical Committee (Fleischer et al. 2001) was a stratified quasi-random design with three strata (north, south-central, and west) and unequal effort allocated among strata. The location of strata and number of transects within each stratum was determined from a study of geographic distribution of species and the variability of fish abundance within strata (Argyle et al. 1998). A modified design (Figure 1) was developed in 2004 (Warner et al. 2005), which included two additional strata (north and south offshore). The initial three strata were retained, but their size was modified based on data collected in 2003 as well as NOAA Coast Watch Great Lakes node maps of sea surface temperature from 2001-2003. In 2007-2013, the number of transects in each stratum was optimized based on stratum area and standard deviation of biomass using methods in Adams et al. (2006). In 2013, the acoustic survey consisted of 27 transects with a total sampled distance of 546 km accompanied by 31 midwater trawl tows.

Fish Data Collection and Processing

The lakewide pelagic prey fish survey has been typically conducted as a cooperative effort. In 2013, United States Geological Survey (U.S.G.S.), Michigan Department of Natural Resources (M.D.N.R.), and United States Fish and Wildlife Service (U.S.F.W.S.) contributed to the completion of the survey. Annual sampling has been conducted between

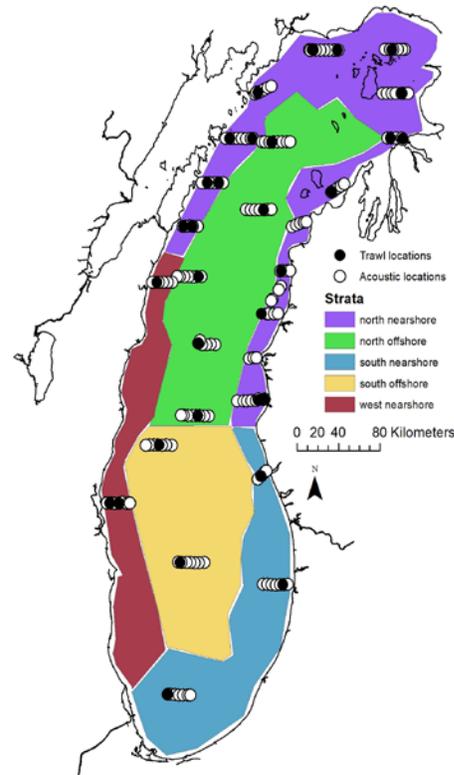


Figure 1. Map of Lake Michigan showing strata used in design and analysis of the lakewide acoustic assessment. Symbols represent acoustic and midwater trawl locations for 2013.

August and November, with acoustic data collection initiated \approx 1 hour after sunset and ending \approx 1 hour before sunrise. Several different vessels, 10-32 m in length and with sampling speeds ranging from 5-11 km/hour, have been used. Different echosounders also have been used through the years (Biosonics 102 dual beam, DE5000 dual beam, DT split beam, DT-X split beam and Simrad EK60 split beam). Acoustic data however have always been collected using echosounders with a nominal frequency of 120 kilohertz. With the exception of one unit used in 2001, echosounders have been calibrated during the survey using methods described in Foote et al. (1987) and MacLennan and Simmonds (1992). Transducer deployment techniques have included a towfish, sea chests (Fleischer et al. 2002), hull mounting, and sonar tubes. While the towfish samples more of the water column than other methods, all methods lead to a portion of the upper water column (top 3-4 m) being unsampled. Fish density estimates in the area of the water column sampled by all of these deployment techniques, however, are comparable.

Midwater trawls were employed to identify species in fish aggregations observed with echosounders and to provide size composition data. Trawl tows targeted aggregations of fish observed in echograms while sampling, and typically trawling locations were chosen when there was uncertainty about the composition of fish aggregations observed acoustically. Cod end mesh on all trawls was 6.35 mm. A trawl with a 5-m headrope was fished from the S/V Steelhead in 1992-2009 and a 12 m headrope trawl was used in 2010-2013. On the U.S.G.S. vessel R/V Grayling, a variety of trawls were used (Argyle et al. 1998). On the U.S.G.S. vessels R/V Siscowet, R/V Kiyi and R/V Sturgeon (2001 to present), a trawl with \approx 15 m headrope was used. On the U.S.F.W.S. vessel M/V Spencer F. Baird, a 21-m trawl was used. In the 1990s, trawl depth was monitored using net sensors. Similar sensors were used in 2001-2005 (except 2002 on U.S.G.S. vessel, 2001-2004 on M.D.N.R. vessel). In cases without trawl sensors, warp length and angle were used to estimate fishing depth. Since 2005, trawl sensors have been used on all trawls. Given the small size (<200 mm) and relatively limited swimming speed of fish present, we expect little influence of trawl size on species and size composition data.

Group weight, by species, of trawl catches was measured in the field (nearest 2 g) or fish were weighed individually in the laboratory (nearest 0.1 g). Total catch weight was recorded as the sum of weights of individual species. Fish were measured as total length (mm) either in the field or frozen in water and measured upon return to the laboratory. Lengths of fish in large catches of a given species (> 100 fish) were taken from a random subsample (typically 50-100 fish). Rainbow smelt were assigned to two size categories (< 90 mm, \geq 90 mm), while the size cutoff for bloater was < or \geq 120 mm. Alewives in each midwater tow were assigned to age classes using year-specific age-length keys with age estimated from sagittal otoliths for a subsample of alewife each year. Age-length keys were available for each year except 1992. The key for 1992 was constructed by averaging the 1991 and 1993 keys. In 2001, trawl data were only available for the north nearshore and north offshore strata. To provide an estimate of species composition and size for other strata, the mean of catch proportions and sizes from 2002-2003 were used.

Estimates of Fish Abundance and Biomass

Transect data were subdivided into elementary distance sampling units (EDSU) consisting either of horizontal intervals between adjacent 10 m bottom contours that were 5 or 10 m deep (1990s) or of 1,000-3,000 m intervals that consisted of 10 m layers (2000s). Data collected at bottom depths > 100 m were defined as offshore strata. Data from the 1990s were analyzed using custom software (Argyle et al. 1998). Data collected from 2001-2013 were analyzed with Echoview 4.8 and 5.0 software.

An estimate of total fish density for data from 2001-2013 was made using the formula

$$(1) \text{ Total density (fish / ha)} = 10^4 \times \frac{ABC}{\sigma}$$

where 10^4 = conversion factor ($\text{m}^2 \cdot \text{ha}^{-1}$), ABC = area backscattering coefficient ($\text{m}^2 \cdot \text{m}^{-2}$) and σ = the mean backscattering cross section (m^2) of all targets between -60 and -30 dB. An echo integration threshold equivalent to target strength of -70 dB was applied to ABC data. Based on a target strength (TS) – length relationship for alewives (Warner et al. 2002), the applied lower threshold should have allowed detection of our smallest targets of interest ($\approx 20 - 30$ mm age-0 alewife). This threshold may have resulted in underestimation of rainbow smelt density because TS of age-0 rainbow smelt in August is as low as -74 dB (Rudstam et al. 2003).

In order to assign species and size composition to acoustic data, we used a technique described by Warner et al. (2009), with different approaches depending on the vertical position in the water column. For cells with depth < 40 m, midwater trawl and acoustic data were matched according to transect, depth layer (0-10, 10-20 m, etc., depending on headrope depth and upper depth of the acoustic cell), and by bottom depth. For acoustic cells without matching trawl data, we assigned the mean of each depth layer and bottom depth combination from the same transect. If acoustic data still had no matching trawl data, we assigned the mean of each depth layer and bottom depth combination within geographic strata. If acoustic data still had no matching trawl data, we used a lakewide mean for each depth layer. Mean mass of species/size groups at depths < 40 m were estimated using weight-length equations from midwater trawl data. For depths ≥ 40 m, we assumed that acoustic targets were large bloater if mean TS was > -45 dB (TeWinkel and Fleischer 1999). Mean mass of bloater in these cells was estimated using the mass-TS equation of Fleischer et al. (1997). If mean TS was ≤ -45 dB, we assumed the fish were large rainbow smelt and estimated mean mass from mean length, predicted using a TS-length equation (Rudstam et al. 2003).

As recommended by the Great Lakes acoustic SOP (Parker-Stetter et al. 2009; Rudstam et al. 2009), we used a number of techniques to assess or improve acoustic data quality. We used the N_v index of Sawada et al. (1993) to determine if conditions in each acoustic analysis cell were suitable for estimation of *in situ* TS. We defined suitability as an N_v value < 0.1 and assumed that mean TS in cells at or above 0.1 was biased. We replaced mean TS in these cells with mean TS from cells that were in the same depth layer and transect with $N_v < 0.1$. We also estimated noise at 1 m using ambient noise from each transect using either passive data collection or echo integration of data below the bottom echo. To help reduce the influence of noise, we subtracted an estimate of noise which was estimated from ambient noise measurements for each transect. Additionally, we estimated the detection limit (depth) for the smallest targets we include in our analyses. Acoustic equipment specifications, software versions, single target detection parameters, noise levels, and detection limits are in Appendices 1 and 2.

Densities (fish/ha) of the different species were estimated as the product of total fish density and the proportion by number in the catch at that location. Total alewife, rainbow smelt, and bloater density was subdivided into size- or age class-specific density by multiplying total density for these species by the numeric proportions in each age or size group. Biomass (kg/ha) for the different groups was then estimated as the product of density in each size or group and size or age-specific mean mass as determined from fish lengths in trawls (except as described for depths ≥ 40 m).

Mean and relative standard error ($\text{RSE} = (\text{SE}/\text{mean}) \times 100$) for density and biomass in the survey area were estimated using stratified cluster analysis methods featured in the statistical routine SAS PROC SURVEYMEANS (SAS Institute Inc. 2004). Cluster sampling techniques are appropriate for acoustic data, which represent a continuous stream of autocorrelated data (Williamson 1982; Connors and Schwager 2002). Density and biomass values for each ESDU in each stratum were weighted by dividing the stratum area (measured using GIS) by the number of ESDUs in the stratum.

RESULTS

Alewife – Alewife density in 2013 (385 fish/ha, RSE = 12%) was 25% of density observed in 2012 and was 23% of the long-term (1992-2013) mean of 1,674 fish/ha. The primary difference between 2012 and 2013 was the very low density of age-0 alewife in 2013. Age-0 alewife density (72 fish/ha, RSE = 22%, Figure 2), was 6% of the long-term mean of 1,212 fish/ha. Total alewife biomass (5.2 kg/ha, RSE = 12%) in 2013 was similar to 2012 and 40% of the long-term mean of 13.2 kg/ha. Biomass of age-1 or older (YAO) alewife was relatively constant from 2001-2007 (Figure 3), increased in 2008-2010, and then declined by 72% from 2010 to 2012. In 2013 biomass of the YAO group was 5.0 kg/ha (RSE = 12%), which consisted of fish from the 2008-2012 year-classes. Biomass estimates of YAO alewife in 2013 from both the acoustic and bottom trawl surveys were similar to those in 2012.

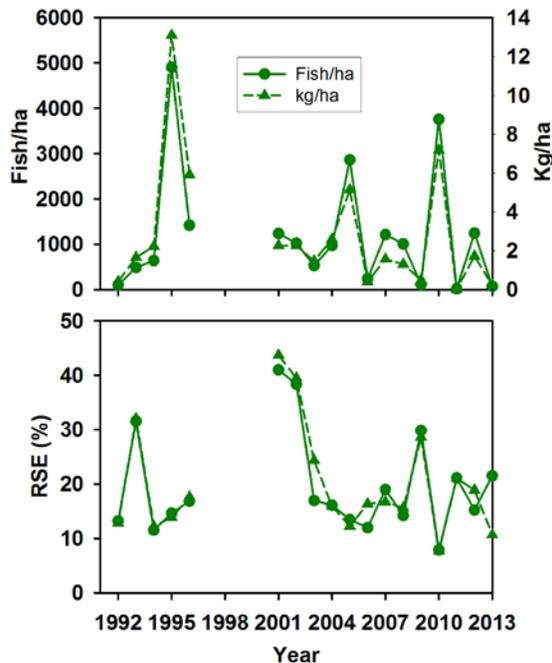


Figure 2. Acoustic estimates of age-0 alewife density and biomass in Lake Michigan, 1992-2013 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

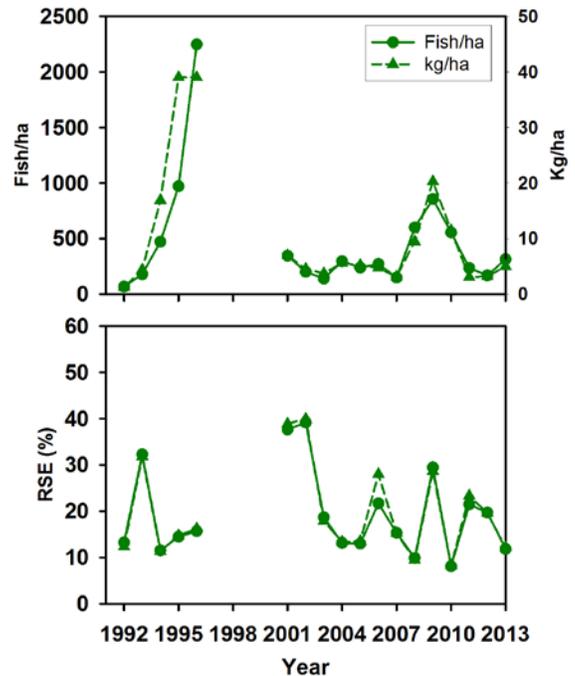


Figure 3. Acoustic estimates of age-1 or older alewife density in Lake Michigan, 1992-2013 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

Rainbow smelt – Density of rainbow smelt generally increased from 2002-2008 (Figure 4), before declining to much lower levels in 2009-2013. However, biomass has been consistently low since 2007. Rainbow smelt density in 2013 (89 fish/ha, RSE = 18%) was the second lowest in the time series. Biomass of rainbow smelt in 2013 (0.24 kg/ha, RSE = 53%) was similar to the 2012 biomass (0.25 kg/ha) and was only 6% of the long term mean. Rainbow smelt > 90 mm in length constituted roughly 50% of the population and 90% of biomass. Both acoustic and bottom trawl survey results showed biomass in 2013 was similar to 2012, but the acoustic biomass estimate was nearly four times the bottom trawl estimate (Madenjian et al. 2014). Both acoustic and bottom trawl survey results indicate that rainbow smelt are far less abundant than in the early 1990s.

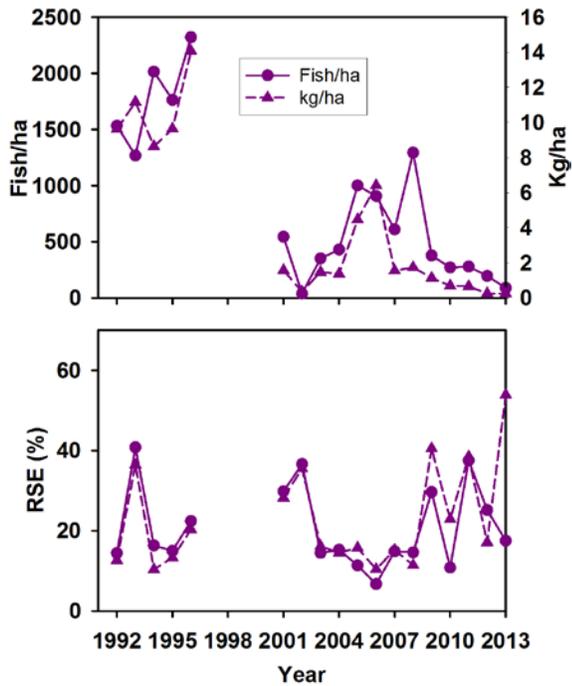


Figure 4. Acoustic estimates of rainbow smelt density and biomass in Lake Michigan, 1992-2013 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

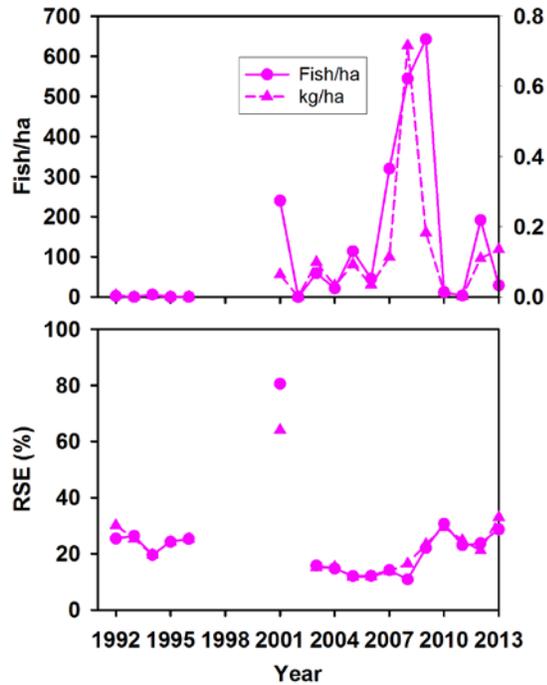


Figure 5. Acoustic estimates of small bloater density and biomass in Lake Michigan, 1992-2013 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

Bloater – Much like rainbow smelt, bloater continue to be present at low densities relative to the 1990s. Mean density of bloater in 2013 (39 fish/ha, RSE = 20%) was the second lowest in the time series. Small bloater have been highly variable from 2001-2013 (Figure 5), while large bloater showed a weak decreasing trend in this time period, with the lowest density and biomass in the time series observed in 2013 (Figure 6).

DISCUSSION

The results of the 2013 Lake Michigan acoustic survey indicate continued variability in alewife biomass, persistently low biomass of rainbow smelt and bloater, and continued low abundance of native species. Peak alewife biomass occurred in 1995 and 1996 (≈ 40 kg/ha), and the two highest values during 2001-2013 (2009-2010) were only half as much as in 1995-1996. Total prey fish biomass in 2013 was the second lowest ever observed in the acoustic survey (Figure 7). Total pelagic fish biomass in Lake Michigan

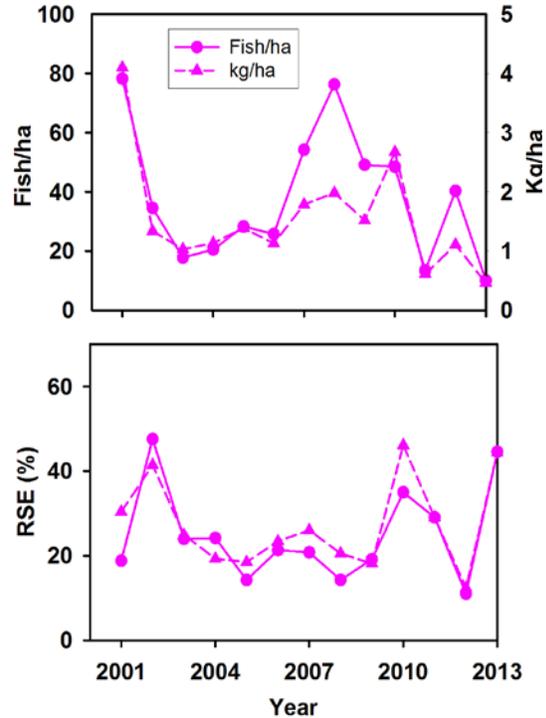


Figure 6. Acoustic estimates of large bloater density and biomass in Lake Michigan, 2001-2013 (upper panel) shown with relative standard error of the estimates (RSE, lower panel).

(6.1 kg/ha) was similar to that in Lake Huron in 2013 (6.1 kg/ha, O'Brien et al. 2014) as well as Lake Superior in 2011 (6.8 kg/ha, Yule et al. 2013).

As with any survey, it is important to note that trawl or acoustic estimates of fish density are potentially biased and, when possible, we should describe the effects of any bias when interpreting results. With acoustic sampling, areas at the surface (0-4 m) or near the bottom (bottom 0.3-1 m) are not sampled well or at all. The density of fish in these areas therefore is unknown. Air-water interface problems, technology limitations, as well as time limitations preclude the use of upward or side-looking transducers to effectively sample the surface. Alewife and rainbow smelt (primarily age-0) may occupy the upper 3 m of the water column and any density calculation in this area results in underestimation of water column and mean lakewide density. Depending on season, in inland New York lakes and Lake Ontario, 37-64% of total night-time alewife catch in gill nets can occur in the upper-most 3 m (D.M. Warner, unpublished data). However, highest alewife and rainbow smelt catches and catch-per-unit-effort with midwater tows generally occur near the thermocline in Lake Michigan (Warner et al. 2008; Warner et al. 2012). We are less concerned with bias in alewife and rainbow smelt densities attributable to ineffective acoustic sampling of the bottom because of their pelagic distribution at night, when our sampling occurs. In Lake Michigan, day-night bottom trawling was conducted at numerous locations and depths in 1987 (Argyle 1992), with day and night tows occurring on the same day. After examining these data we found that night bottom trawl estimates of alewife density in August/September 1987 were only 6% of day estimates (D.M. Warner, unpublished data). Similarly, night bottom trawl estimates of rainbow smelt density were \approx 6% of day estimates. Evidence suggests however that bloater tend to be more demersal; in Lake Superior, night acoustic/midwater trawl sampling may detect only 60% of bloater present (Yule et al. 2007). Day-night bottom trawl data from Lake Michigan in 1987 suggested that the availability of bloater to acoustic sampling at night was somewhat higher (mean = 76%, D. M. Warner, unpublished data). Slimy sculpins (*Cottus cognatus*) and deepwater sculpins (*Myoxocephalus thompsonii*) are poorly sampled acoustically and we must rely on bottom trawl estimates for these species (Yule et al. 2008). We also assumed that our midwater trawling provided accurate estimates of species and size composition. Based on the relationship between trawling effort and uncertainty in species proportions observed by Warner et al. (2012), this assumption was likely reasonable.

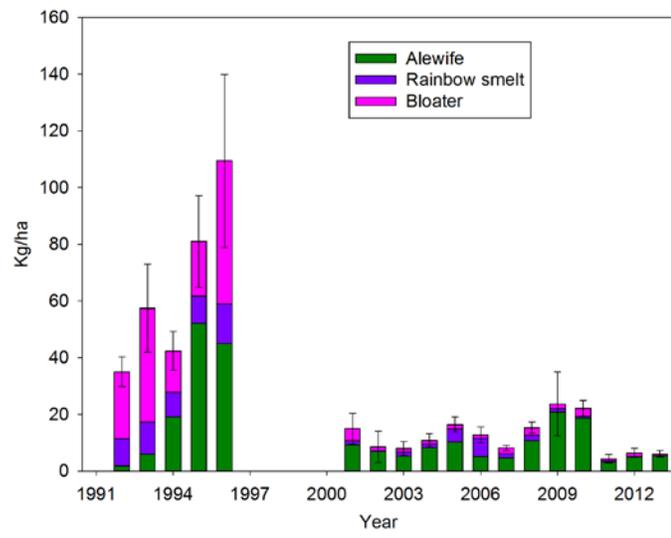


Figure 7. Acoustic estimates of total prey fish biomass in Lake Michigan, 1992-2013.

We made additional assumptions about acoustic data not described above. For example, we assumed that all targets below 40 m with mean TS > -45 dB were bloater. It is possible that this resulted in a slight underestimation of rainbow smelt density. We also assumed that conditions were suitable for use of *in situ* TS to estimate fish density, which could also lead to biased results if conditions are not suitable for measuring TS (Rudstam et al. 2009) and biased TS estimates are used. However, we searched for areas where TS was biased using Nv and found that no cells had Nv > 0.1, indicating bias in the TS estimates was unlikely. We assumed that noise levels did not contribute significantly to echo integration data and

did not preclude detection of key organisms. This assumption was supported by our estimates of noise and detection limits for targets of interest (Appendix 2). Detection limits were such that the smallest fish were detectable well below the depths they typically occupy. Finally, we have assumed that the estimates of abundance and biomass are relative. In other words, they are not absolute measures. This assumption is supported by recent estimates of catchability derived from a multispecies age structured stock assessment model (Tsehaye et al. 2014).

Prey fish biomass in Lake Michigan remains at levels much lower than in the 1990s, and the estimate of total lakewide biomass (29.6 kt) from acoustic sampling was the second lowest in the time series. This is in contrast to 2008-2010, when biomass was relatively high (but still lower than in the 1990s). This recent decline, resulting primarily from decreased alewife biomass, demonstrates the dynamic nature of the pelagic fish community in Lake Michigan. Because of predation and a weak 2013 alewife year class, it seems likely that biomass of alewife will be lower in 2014 than in 2013. However, a strong 2014 year class could offset mortality of older fish. The large difference between prey fish biomass in the 1990s and the 2000s resulted primarily from a decrease in large bloater abundance, but alewife and rainbow smelt declined as well. Bloater densities showed an increasing trend 2001-2009, driven primarily by increases in small bloater. A similar pattern was observed in Lake Huron (Schaeffer et al. 2012), but only in Lake Huron has there been any evidence of increased abundance resulting from recruitment to larger sizes, as bottom trawl estimates of large bloater density have increased in recent years in Lake Huron but not in Lake Michigan (Madenjian et al. 2012; Schaeffer et al. 2012). Alewife were the dominant component of pelagic prey fish biomass in 2013 (Table 1), and numerically constituted 75% of fish density. Limited recruitment of small bloater, numerical dominance of alewife, along with the continued absence of other native species, suggests that little progress is being made toward meeting the Fish Community Objective (FCO, Eshenroder et al. 1995) of maintaining a diverse planktivore community, particularly relative to historical diversity. Bloater and emerald shiner (*Notropis atherinoides*) were historically important species, but bloater currently exist at low biomass levels and emerald shiner have not been captured in Lake Michigan by GLSC surveys since 1962 (D.M. Warner, unpublished data). Similarly, kiyi (*Coregonus kiyi*) are absent from offshore regions of Lake Michigan, which is in stark contrast to Lake Superior, where Yule et al. (2013) found kiyi to be the most numerous species in 2011. As a result, large areas of Lake Michigan which were formerly occupied by fish are now devoid of fish, and movement of energy and nutrients through diel vertical migration has essentially disappeared. In Lake Huron, collapse of the alewife population in 2003-2004 was followed by resurgence in emerald shiner abundance in 2005-2006 (Schaeffer et al. 2008) and by increased abundance of cisco [*Coregonus artedii*, (Warner et al. 2009)]. Given evidence from acoustic surveys from lakes Michigan and Huron as well as the evidence provided by Madenjian et al. (2008), it appears that emerald shiners are suppressed by all but the lowest levels of alewife abundance.

While it is clear that abundance patterns for alewife have been driven in large part by continued high predation pressure (Tsehaye et al. 2014), it is not clear what led to the drastic decline in bloater abundance from the 1980s to present. Madenjian et al. (2002) proposed that bloater recruitment and abundance are regulated by internal cycling. Recent stock-recruit modeling for bloater in Lakes Michigan and Huron indicated that sex ratio had an important impact on recruitment (Collingsworth et al. 2014). Based on ages of bloater captured in the bottom trawl survey, relatively high levels of age-0 bloater in 2007-2009 acoustic surveys (Figure 5) are reflected in age composition of YAO bloaters in recent years, as most of the larger bloater aged in 2009-2011 were hatched in 2007-2009, adding support to the belief that bloater become fully recruited to the bottom trawl by age-3 (Bunnell et al. 2006). Data from both acoustic and bottom trawl surveys suggest that recruitment has not been sufficient to offset mortality. We hypothesize that predation on small bloater by salmonines could be an important limit to recruitment at times (see Warner et al. 2008) as these small fish are found in the same location as alewife and at times can be important to some predators (Elliott 1993; Rybicki and Clapp 1996; Warner et al. 2008). Both Lake Michigan surveys suggest that recruitment in Lake Michigan is much more limited than in Lake Huron,

where high densities of small bloater in 2007-2008 preceded increases in the abundance of larger bloater (Schaeffer et al. 2012).

Acknowledgements

We thank the crews of the research vessels M/V Spencer F. Baird, S/V Steelhead, and R/V Sturgeon as well as reviewers for their contributions to this work. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government. A portion of the funding for this work is funded through the Sport Fish Restoration funding, Project #230485.

Table 1. Biomass, RSE, and 95% CI for age-0, YAO, total alewife, rainbow smelt, and bloater estimated from acoustic and midwater trawl data collected in Lake Michigan in 2013.

Species	Biomass (kg/ha)	RSE (%)	95% CI
Total alewife	5.2	12.0	(4.1, 6.3)
Age-0 alewife	0.23	10.6	(0.2, 0.27)
YAO alewife	5.0	12.1	(4.0, 6.0)
Rainbow smelt	0.24	53.9	(0.02, 0.50)
Bloater	0.60	32.1	(0.27, 93)
Total	6.1	11.0	(4.9, 7.2)

REFERENCES

- Adams, J.V., R.L. Argyle, G.W. Fleischer, G.L. Curtis, and R.G. Stickel. 2006. Improving the design of acoustic and midwater trawl surveys through stratification, with an application to Lake Michigan prey fishes. *North American Journal of Fisheries Management* 26:612-621.
- Argyle, R.L. 1992. Acoustics as a tool for the assessment of Great Lakes Forage fishes. *Fisheries Research* 14:179-196.
- Argyle, R.L., G.W. Fleischer, G.L. Curtis, J.V. Adams, and R.G. Stickel. 1998. An integrated acoustic and trawl based prey fish assessment strategy for Lake Michigan. A report to the Illinois Department of Natural Resources, Indiana Department of Natural Resources, Michigan Department of Natural Resources, and Wisconsin Department of Natural Resources. U.S. Geological Survey, Biological Resource Division, Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI USA.
- Bunnell, D.B., C.P. Madenjian, and T.E. Croley III. 2006. Long-term trends in bloater recruitment in Lake Michigan: evidence for the effect of sex ratio. *Canadian Journal of Fisheries and Aquatic Sciences* 63:832-844.
- Collingsworth, P.D., D.B. Bunnell, C.P. Madenjian, and S.C. Riley. 2014. Comparative recruitment dynamics of alewife and bloater in Lakes Michigan and Huron. *Transactions of the American Fisheries Society* 143:294-309.
- Connors, M.E., and S.J. Schwager. 2002. The use of adaptive cluster sampling for hydroacoustic surveys. *ICES Journal of Marine Science* 59:1314-1325.
- Elliott, R.F. 1993. Feeding habits of Chinook salmon in eastern Lake Michigan. M.Sc. thesis. Michigan State University, East Lansing, MI.
- Eshenroder, R.L., M.E. Holey, T.K. Gorenflo, and R.D. Clark. 1995. Fish community objectives for Lake Michigan. *Great Lakes Fish. Comm. Spec. Pub.* 95-3. 56 p.
- Fabrizio, M.C., J.V. Adams, and G.L. Curtis. 1997. Assessing prey fish populations in Lake Michigan: comparison of simultaneous acoustic-midwater trawling with bottom trawling. *Fisheries Research* 33:37-54.

- Fleischer, G.W., R.L. Argyle, and G.L. Curtis. 1997. In situ relations of target strength to fish size for Great Lakes pelagic planktivores. *Transactions of the American Fisheries Society* 126:784-796.
- Fleischer, G.W., R.L. Argyle, R.T. Nester, and J.J. Dawson. 2002. Evaluation of a rubber-compound diaphragm for acoustic fisheries surveys: Effects on dual-beam signal intensity and beam patterns. *Journal of Sound and Vibration* 258:763-772.
- Fleischer, G.W., J. Dettmers, and R.M. Claramunt. 2001. Original acoustics LWAP adopted by the Lake Michigan Technical Committee at the summer 2001 meeting in Sturgeon Bay, Wisconsin.
- Foote, K.G., H.P. Knudsen, G. Vestnes, D.N. MacLennan, and E.J. Simmonds. 1987. Calibration of acoustic instruments for fish density estimation. 1987. International Council for the Exploration of the Sea Cooperative Research Report number 144.
- Jacobs, G.R., C.P. Madenjian, D.B. Bunnell, D.M. Warner, and R.M. Claramunt. 2013. Chinook salmon foraging patterns in a changing Lake Michigan. *Transactions of the American Fisheries Society* 142:362-372.
- MacLennan, D.N., and E.J. Simmonds. 1992. Fisheries Acoustics. Chapman and Hall. London.
- Madenjian, C.P., D.B. Bunnell, T.J. DeSorcie, and J.V. Adams. 2014. Status and trends of preyfish populations in Lake Michigan, 2013. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Windsor, Ontario 2010.
- Madenjian, C.P., D.B. Bunnell, T.J. DeSorcie, and J.V. Adams. 2012. Status and trends of preyfish populations in Lake Michigan, 2011. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Windsor, Ontario 2010.
- Madenjian, C.P., G.L. Fahnenstiel, T.H. Johengen, T.F. Nalepa, H.A. Vanderploeg, G.W. Fleischer, P.J. Schneeberger, D.M. Benjamin, E.B. Smith, J.R. Bence, E.S. Rutherford, D.S. Lavis, D.M. Robertson, D.J. Jude, and M.P. Ebener. 2002. Dynamics of the Lake Michigan food web, 1970-2000. *Canadian Journal of Fisheries and Aquatic Sciences* 59:736-753.
- Madenjian, C.P., T.O. Höök, E.S. Rutherford, D.M. Mason, T.E. Croley II, E.B. Szalai, and J.R. Bence. 2005. Recruitment variability of alewives in Lake Michigan. *Transactions of the American Fisheries Society* 134:218-230.
- Madenjian, C.P., R. O’Gorman, D.B. Bunnell, R.L. Argyle, D.M. Warner, J.D. Stockwell, and M.A. Stapanian. 2008. Adverse effects of alewives on Laurentian Great Lakes fish communities. *North American Journal of Fish Management* 28:263-282.
- O’Brien, T.P., D.M. Warner, and S. Farha. 2014. Status and trends of pelagic fish in Lake Huron 2012. A report to the Great Lakes Fishery Commission, Lake Huron Committee, Windsor, ON, March, 2014.
- Parker-Stetter, S.L., L.G. Rudstam, P.J. Sullivan, and D.M. Warner. 2009. Standard operating procedures for fisheries acoustic surveys in the Great Lakes. *Great Lakes Fish. Comm. Spec. Pub.* 09-01.
- Rudstam, L.G., S.L. Parker, D.W. Einhouse, L. Witzel, D.M. Warner, J. Stritzel, D.L. Parrish, and P. Sullivan. 2003. Application of in situ target strength to abundance estimations in lakes- examples from rainbow smelt surveys in Lakes Erie and Champlain. *ICES Journal of Marine Science* 60:500-507.
- Rudstam, L.G., S.L. Parker-Stetter, P.J. Sullivan, and D.M. Warner. 2009. Towards a standard operating procedure for fishery acoustic surveys in the Laurentian Great Lakes, North America. *ICES Journal of Marine Science* 66:1391-1397.
- Rybicki, R.W., and D.F. Clapp. 1996. Diet of Chinook salmon in eastern Lake Michigan, 1991-1993. Michigan Department of Natural Resources, Fisheries Division. Research Report 2027, Ann Arbor, MI.
- SAS Institute Inc. 2004. SAS OnlineDoc®9.1.2. Cary, NC.
- Sawada, K., M. Furusawa, and N.J. Williamson. 1993. Conditions for the precise measurement of fish target strength in situ. *Journal of the Marine Acoustical Society of Japan* 20:73-79.
- Schaeffer, J.S., T.P. O’Brien, and S. Lenart. 2012. Status and trends of pelagic fish in Lake Huron 2012. A report to the Great Lakes Fishery Commission, Lake Huron Committee, Windsor, ON, March, 2012.

Schaeffer, J.S., D.M. Warner, and T.P. O'Brien. 2008. Resurgence of emerald shiners *Notropis atherinoides* in Lake Huron's main basin. *Journal of Great Lakes Research* 34:395-403.

TeWinkel, L.M., and G.W. Fleischer. 1999. Vertical migration and nighttime distribution of adult bloaters in Lake Michigan. *Transactions of the American Fisheries Society* 128:459-474.

Tsehaye, I., M.L. Jones, J.R. Bence, T.O. Brendan, C.P. Madenjian, and D.M. Warner. 2014. A multispecies statistical age-structured model to assess predator-prey balance: application to an intensively managed Lake Michigan fish community. *Canadian Journal of Fisheries and Aquatic Sciences*, in press.

Warner, D.M., R.M. Claramunt, J.S. Schaeffer, D.L. Yule, T.R. Hrabik, B. Pientka, L.G. Rudstam, J.D. Holuszko, and T.P. O'Brien. 2012. Relationship between mid-water trawling effort and catch composition uncertainty in two large lakes (Huron and Michigan) dominated by alosines, osmerids, and coregonines. *Fisheries Research* 123/124:62-69.

Warner, D.M., R.M. Claramunt, D.F. Clapp, and C.S. Kiley. 2008. The influence of alewife year-class strength on prey selection and abundance of age-1 Chinook salmon in Lake Michigan. *Transactions of the American Fisheries Society* 137:1683-1700.

Warner, D.M., R.M. Claramunt, C. Faul, and T.P. O'Brien. 2005. Status of pelagic prey fish in Lake Michigan, 2001-2004. A report to the Great Lakes Fishery Commission, Lake Michigan Committee, Ypsilanti, MI March , 2005.

Warner, D.M., L.G. Rudstam, and R.A. Klumb. 2002. In situ target strength of alewives in freshwater. *Transactions of the American Fisheries Society* 131:212-223.

Warner, D.M., J.S. Schaeffer, and T.P. O'Brien. 2009. The Lake Huron pelagic fish community: persistent spatial pattern along biomass and species composition gradients. *Canadian Journal of Fisheries and Aquatic Sciences* 66:1199-1215.

Williamson, N.J. 1982. Cluster sampling estimation of the variance of abundance estimates derived from quantitative echo sounder surveys. *Canadian Journal of Fisheries and Aquatic Sciences* 39:228-231.

Yule, D.L., J.V. Adams, T.R. Hrabik, M.R. Vinson, Z. Woiak, and T.D. Ahrenstorff. 2013. Use of classification trees to apportion single echo detections to species: application to the pelagic fish community of Lake Superior. *Fisheries Research* 140:123-132.

Yule, D.L., J.V. Adams, J.D. Stockwell, and O.T. Gorman. 2008. Factors affecting bottom trawl catches: implications for monitoring the fishes of Lake Superior. *North American Journal of Fisheries Management* 28:109-123.

Yule, D.L., J.V. Adams, J.D. Stockwell, and O.T. Gorman. 2007. Using multiple gears to assess acoustic detectability and biomass of fish species in Lake Superior. *North American Journal of Fisheries Management* 27:106-126.

Appendix 1. Single target detection parameters used in acoustic data analyses in 1992-1996, 2001-2005, and 2013.

Parameter	Dual beam 1992-1996	Dual beam 2001-2005 ¹	Split ²
TS threshold (dB)	-60	-77 ³	-77
Pulse length determination level (dB)	6	6	6
Minimum normalized pulse length	0.32	0.8	0.7
Maximum normalized pulse length	0.72	1.8	1.5
Maximum beam compensation (dB)	6	6	6
Maximum standard deviation of minor-axis angles	NA	NA	0.6
Maximum standard deviation of major-axis angles	NA	NA	0.6
Over-axis angle threshold (dB)	NA	-1.0	NA

¹Dual beam system was only used on the MDNR vessel Steelhead in 2001-2005.

²Split beam systems were used on all vessels in 2006-2013.

³Although a lower threshold was used in 2001-2013 only targets ≥ -60 dB were included in analyses.

Appendix 2. Noise levels (mean and range of Sv and TS at 1 m), detection limits, and acoustic equipment specifications in 2012 for the R/V Sturgeon, S/V Steelhead, and M/V Spencer F. Baird.

Vessel	R/V Sturgeon	S/V Steelhead	M/V Spencer F. Baird
Collection software	Visual Acquisition 6.0	Visual Acquisition 6.0	ER60 2.2
Transducer beam angle (3dB)	8.2° split beam	6.9° split beam	6.49 ° x 6.53 ° split beam
Frequency (kHz)	120	123	120
Pulse length (ms)	0.4	0.4	0.256
Mean of Sv noise at 1 m (dB)	-122	-122	-121
Mean of TS noise at 1 m (dB)	-149	-149	-148
Two-way equivalent beam angle (dB)	-19.34	-20	-20.1
Detection limit (m) for -60 dB target ¹	54	56	52

¹ Assuming 3 dB signal-to-noise ratio.