

**COMPILED REPORTS TO THE GREAT LAKES FISHERY
COMMISSION OF THE ANNUAL BOTTOM TRAWL AND
ACOUSTICS SURVEYS, 2014**



2015

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



Suggested Citation

USGS (U.S. Geological Survey). 2015 Compiled reports to the Great Lakes Fishery Commission of the annual bottom trawl and acoustics surveys for 2014 [online]. Available from http://www.glfsc.org/pubs/lake_committees/common_docs/CompiledReportsfromUSGS2015.pdf [accessed day-month-year].

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Fisheries Research and Monitoring Activities of the Lake Erie Biological Station, 2014¹

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To cite this report: LEBS. 2015. Fisheries Research and Monitoring Activities of the Lake Erie Biological Station, 2014. Prepared by B. Bodamer Scarbro, W.H. Edwards, C. Gawne, P.M. Kočovský, R.T. Kraus, M.R. Rogers, and T. R. Stewart. Report of the Lake Erie Biological Station (LEBS) to the Great Lakes Fishery Commission at the Annual Meeting of Lake Committees, Ypsilanti, Michigan. 31 pp.

¹Presented at: Great Lakes Fishery Commission
Lake Erie Committee Meeting
March 23-24, 2015

Scientific Names and Abbreviations

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

Scientific name	Common name
<i>Acipenser fulvescens</i>	Lake Sturgeon
<i>Alosa pseudoharengus</i>	Alewife
<i>Ambloplites rupestris</i>	Rock Bass
<i>Ameiurus nebulosus</i>	Brown Bullhead
<i>Aplodinotus grunniens</i>	Freshwater Drum
<i>Carassius auratus</i>	Goldfish
<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>Salvelinus namaycush</i>	Lake Trout
<i>Sander vitreus</i>	Walleye

The following abbreviations are used throughout this report:

Abbreviation	Expansion
CPH	Catch per Hectare
CSMI	Cooperative Science Monitoring Initiative
CWTG	Cold Water Task Group
DFO	Department of Fisheries and Oceans
FCGO	Fish Community Goals and Objectives
FTG	Forage Task Group
GLFC	Great Lakes Fishery Commission
GLSC	Great Lakes Science Center
KSU	Kent State University
LaMP	Lakewide Action and Management Plan
LEBS	Lake Erie Biological Station
LEC	Lake Erie Commission
LOA	Length Overall
LTLA	Lower Trophic Level Assessment
MSU	Michigan State University
NOAA	National Oceanic and Atmospheric Administration
ODNR	Ohio Department of Natural Resources
ODW	Ohio Division of Wildlife
OMNRF	Ontario Ministry of Natural Resources and Forestry
OSU	The Ohio State University
PU	Perdue University
UM	University of Michigan
USGS	United States Geological Survey
USNRL	US Naval Research Laboratory
UT	University of Toledo
YAO	Yearling and older (age-1 and older)
YOY	Young of the year (age-0)
YPTG	Yellow Perch Task Group

Executive Summary

In 2014, the USGS LEBS 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, the Eastern Basin Coldwater Community Assessment, and LTLA (see FTG, CWTG, and FTG reports, respectively). Results from the surveys contribute to Lake Erie Committee Task Group data needs and analyses of trends in Lake Erie's fish communities. The cruise survey schedule in 2014 was greatly increased by LEBS's participation in the Lake Erie CSMI, which consisted of up-to two weeks of additional sampling per month from April to October. CSMI is a bi-national effort that occurs at Lake Erie every five years with the purpose of addressing data and knowledge gaps necessary to management agencies and the Lake Erie LaMP. LEBS deepwater science capabilities also provided a platform for data collection by Lake Erie investigators from multiple agencies and universities including: the USGS GLSC, ODW, KSU, OSU, UM, PU, UT, and the USNRL. Samples from this survey are being processed and a separate report of the findings will be made available in a separate document.

Our 2014 vessel operations were initiated in mid-April, as soon after ice-out as possible, and continued into early December. During this time, crews of the R/V Muskie and R/V Bowfin deployed 196 bottom trawls covering 48.5 km of lake-bottom, nearly 6 km of gillnet, collected data from 60 hydroacoustics transects, 285 lower trophic (i.e., zooplankton and benthos) samples, and 330 water quality measures (e.g., temperature profiles, water samples). Thus, 2014 was an intensive year of field activity.

Our June and September bottom trawl surveys in the Western Basin were numerically dominated by Emerald Shiner, White Perch, and Yellow Perch; however, Freshwater Drum were dominant by biomass. Age-2+ Yellow Perch and White Perch diets from our western basin trawl had highest occurrences of benthic invertebrates in spring and fall. *Hexagenia* spp. accounted for $\geq 25\%$ of Yellow Perch and White Perch diet composition (dry weight) in spring. We conducted an analysis using data from the past 6 years of our East Harbor survey to determine to what degree our new research vessel and trawl is affecting our ability to detect trends across the 50+ year time series. We also evaluated trends in water temperature, dissolved oxygen, secchi depth and total Phosphorus from our LTLA sites near Vermilion, Ohio. Within the following report sections, we describe specific results from our primary surveys conducted in 2014.

1.0 Western Basin Forage Fish Assessment

Abstract

Assessing the distribution and abundance of both predator and prey (forage) fish species is a cornerstone of ecosystem-based based fishery management, and supports decision making that considers food-web interactions. The objectives of this survey 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. We sampled 41 stations with a bottom trawl during two surveys that occurred in June and September. Numerically, the dominant species were Emerald Shiner, White Perch, and Yellow Perch, and these species were patchily distributed across the sampling domain. In terms of biomass, Freshwater Drum dominated, representing 34% to 50% of the total catch, and this species occurred in every sample. Notably, a few early stage young-of-the-year Walleye were captured in June at six locations around the periphery of the sampling domain.

Introduction

Assessing the distribution and abundance of both predator and prey (forage) fish species is a cornerstone of ecosystem-based based fishery management, and supports decision making that considers food-web interactions. LEBS western basin bottom trawl survey contributes indices of abundance and data on spatial distributions of forage fish and percid species to the FTG and YPTG of the LEC of the GFLC. These inputs support improved population assessments, and augment data collected by OMNRF and ODNR, who have cooperatively sampled forage fishes throughout the western basin of Lake Erie in August since 1987. The 2014 season was the eleventh 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 2014 sampling effort.

Methods

We executed a grid-based sampling design in both June and September, referred to here as spring and fall, respectively. This sampling design complements the long-term series of combined trawling efforts between ODNR and OMNRF in August, 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 in 2013 to avoid conflict with large boats using the shipping lanes. The work was conducted from the R/V Muskie, a 70' LOA, purpose-built research vessel with a mono-hull and twin propellers. 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 dyneema mesh 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

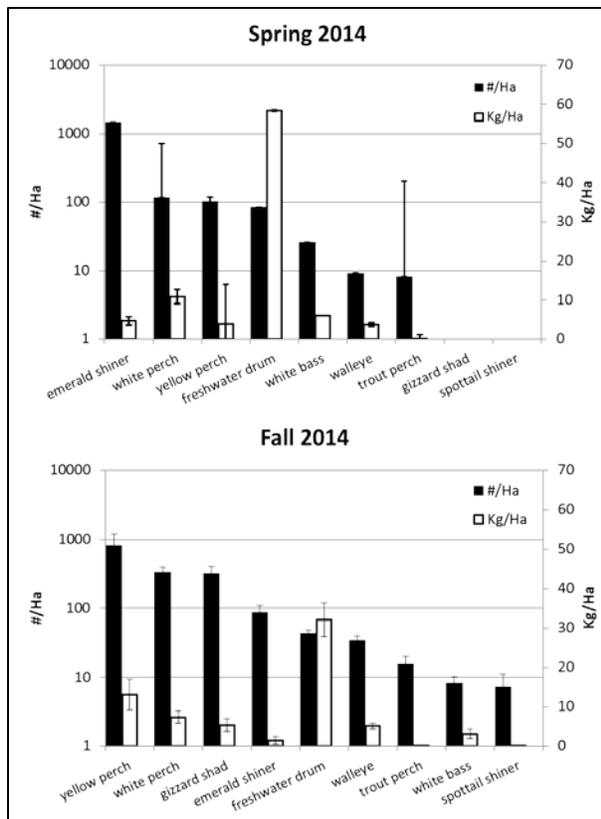
accommodate hard bottom habitats, the sweep was designed with 8" rubber discs interspersed between 2 $\frac{3}{8}$ " rubber discs in a configuration called a "rubber cookie sweep", known to be successful for trawling for squid on glacial moraines in the north Atlantic. The bridle length is 36.6 m overall with a junction between the top and middle bridle at 18.3 m. The bridle is constructed of wire rope, with $\frac{1}{2}$ " diameter cable on the bottom bridle, and $\frac{3}{8}$ " 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 Notus® acoustic mensuration gear during trawling. Average wing spread varied both as a function of depth and warp scope, as described in the previous year's 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 per trawl sample (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, conductivity, and bottom dissolved oxygen 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 (n=5) from each of these age-size categories was measured for individual lengths and weights (using a motion compensating scale with accuracy of 0.2g). 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

counted, and small fish with individual weights that were less than 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. Age-group specific information was determined by identifying modes in estimated length frequencies expanded to the total catch.

Results and Discussion

When comparing abundance versus biomass at a fundamental level, the rank order of species in the western basin looks dramatically different. In 2014, the most abundant species numerically were Emerald Shiner and Yellow Perch, respectively, in spring and fall (Figure 1.1). In terms of biomass, Freshwater Drum were more than an order of magnitude higher than the second ranked species (Figure 1.1). Changes in the numerical rank order of species from spring to fall reflect inherently more abundant YOY individuals that grew to a size that is retained by our bottom trawl. This effect is primarily reflected in Yellow Perch, and Gizzard Shad (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



spring and fall. Of particular note, was the capture of age-0 Walleye at 6 stations in June. These fish were recently transformed juveniles with little or no pigment. In September, age-0 Walleye biomass was widespread, albeit in low abundance, throughout the sampling domain. Age-1 Walleye biomass was concentrated near Marblehead during June, and was more widely distributed in September. Age-2+ Walleye biomass was similar overall between the two sampling events, but more concentrated in the southern half of the sampling domain during September (Figure 1.2).

Figure 1.1 (left) Mean catch per hectare (CPH, ± 1 standard error) by number and biomass (kg) of the most frequently captured fishes in western Lake Erie bottom trawl samples.

trophic levels of the western basin ecosystem.

Across seasons 25 fish species were captured (Table 1.1). Some rare species contributed to the diversity including: Lake Trout, two species of Redhorse suckers, and Lake Sturgeon, which have been recorded only sporadically and in low numbers historically on this survey. Of particular note is the absence of Alewife, both YOY and YAO ages. This contrasts with high catch rates in 2012 and 2013. The 2013-2014 winter was particularly severe, and may have resulted in substantial reduction in Alewife due to overwinter mortality. CPH are reported here (Table 1.1) to provide a reference for comparison with partner indices.

We examined the spatial distribution of biomass for percids (Figures 1.2 and 1.3), key forage species (Figure 1.3), and dominant fishes 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

Yellow Perch biomass was more broadly distributed across the sampling domain than Walleye. The age-1 and age-2+ biomass tended to be concentrated in the Sandusky sub-basin and/or north and west of the Lake Erie islands (Figure 1.3). By comparison, age-0 Yellow Perch were typically captured in low abundance everywhere during September, with the exception of two very large catches occurring in the middle of the western basin (Figure 1.3.).

Common forage species were patchily distributed. In June, large catches of Emerald Shiner occurred sporadically near Marblehead, OH, west of Leamington, Ontario, and east of the mouth of the Detroit River (Figure 1.4). In September, Emerald Shiner were less abundant overall, with sporadic large catches in the Sandusky sub-basin (Figure 1.4). Age-0 Gizzard Shad were primarily concentrated west of the islands in Ohio waters (Figure 1.4). Trout-perch were captured consistently in low numbers west of the islands (Figure

1.4). Troutperch catches in the Sandusky subbasin only occurred in shallower areas (Figure 1.4). White Perch, White Bass and Freshwater Drum were ubiquitous (Figure 1.5). White Perch and White Bass tended to be more concentrated in US waters (spring or fall). Freshwater Drum biomass often approached 40-50 kg/h (Figure 1.5).

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 bottom dissolved oxygen of the western basin.

The major pattern of water quality was warmer conditions in association with the Maumee River plume and Lake Erie islands (Figure 1.6). In both June and September, waters near the mouth of the Maumee River had the highest conductivity, followed by the Sandusky subbasin. By comparison, waters extending from the Detroit River tended to have lower conductivity and temperature relative to the rest of the western basin in both months. Water temperature was warmer in June than in September. (Figure 1.6). Bottom dissolved oxygen was high and normoxic throughout the survey area during June and September (Figure 1.6). By comparison, waters extending from the Detroit River tended to have lower conductivity and temperature relative to the rest of the western basin in both months. Water temperature was warmer in June than in September. (Figure 1.6). Bottom dissolved oxygen was high and normoxic throughout the survey area during June and September (Figure 1.6).

Table 1.1 Average catch rates (catch per hectare, CPH) of fishes from the western basin of Lake Erie in 2014.

Species		Spring CPH	Fall CPH
YOY	Emerald Shiner	2	41
	Gizzard Shad		282
	Yellow Perch		264
	White Perch		216
	Rainbow Smelt		127
	Walleye		28
	Spottail Shiner		<5
	White Bass		<5
	Trout Perch		<5
	Smallmouth Bass		<5
	Logperch		<5
YAO	Emerald Shiner	1440	47
Or	Rainbow Smelt	288	0
All	White Perch	114	111
Ages	Yellow Perch	103	550
	Freshwater Drum	80	43
	White Bass	25	6
	Walleye	9	6
	Trout-perch	8	13
	Channel Catfish	7	8
	White Sucker	<5	<5
	Silver Chub	<5	<5
	Common Carp	<5	<5
	Shorthead Redhorse	<5	<5
	Rock Bass	<5	
	Smallmouth Bass	<5	<5
	Gizzard Shad		17
	Quillback		<5
	Spottail Shiner		<5
	Golden Redhorse		<5
	Round Goby	<5	6
Quillback	<5		
Lake Sturgeon	<5		
Lake Trout	<5		
Rock Bass		<5	
Goldfish		<5	

YOY = young-of-the-year; YAO = yearling and older

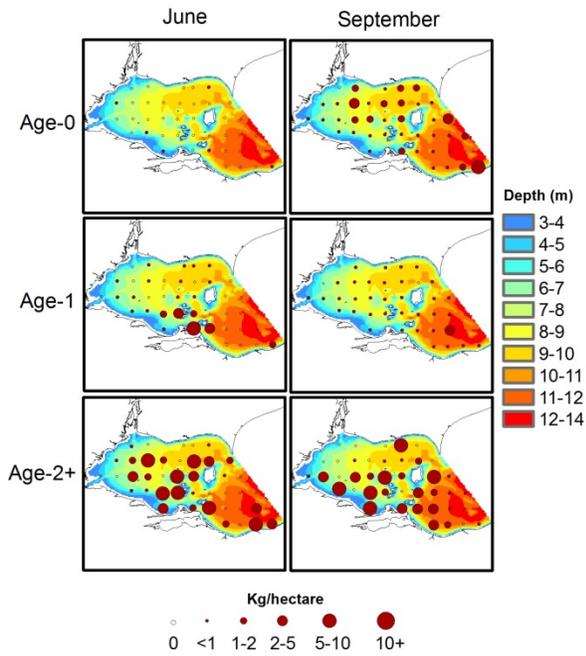


Figure 1.2 Distribution of Walleye biomass (per hectare) from bottom trawl samples in the western basin of Lake Erie during 2014.

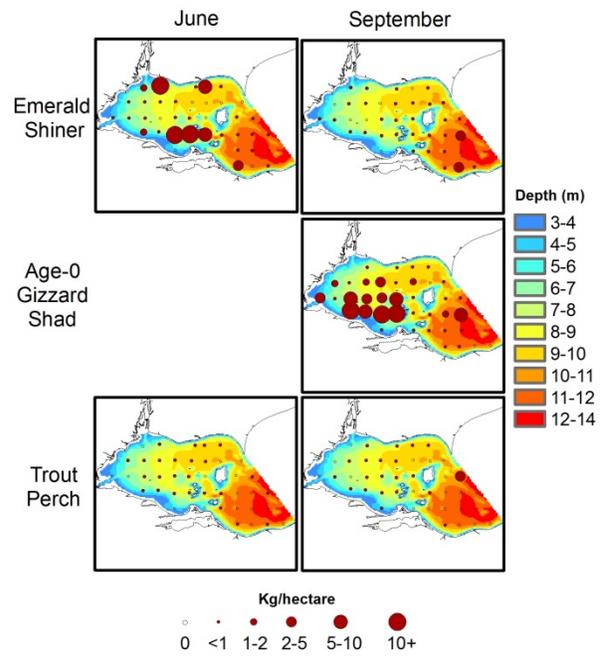


Figure 1.4 Distribution of forage fish biomass (per hectare) from bottom trawl samples in the western basin of Lake Erie during 2014.

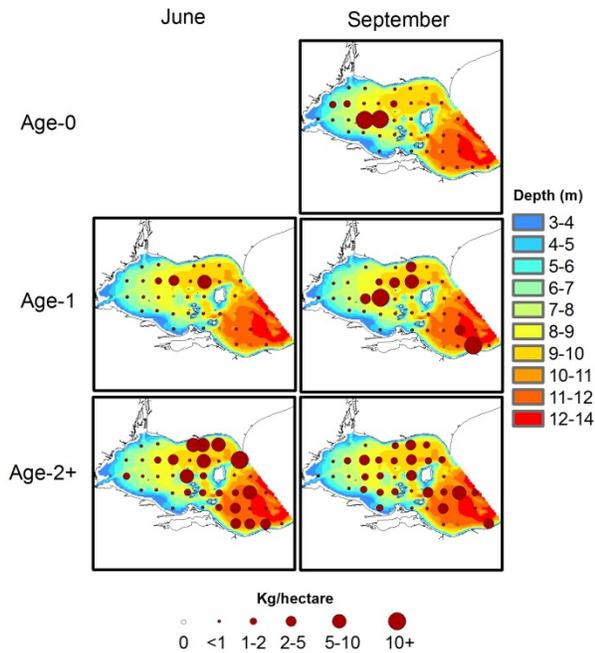


Figure 1.3 Distribution of Yellow Perch biomass (per hectare) from bottom trawl samples in the western basin of Lake Erie during 2014.

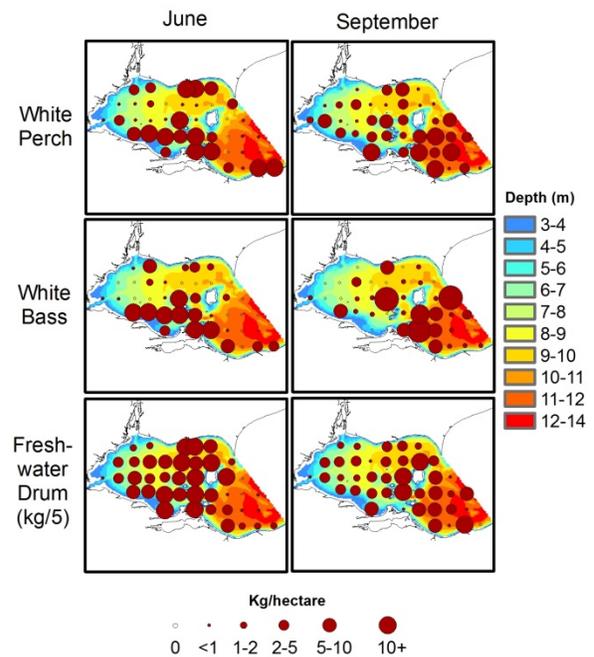


Figure 1.5 Distribution of fish biomass (per hectare) of selected species from bottom trawl samples in the western basin of Lake Erie during 2014. Freshwater Drum values were too large to display on the same scale with the other species; therefore, the values were divided by 5 for display in this figure.

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).

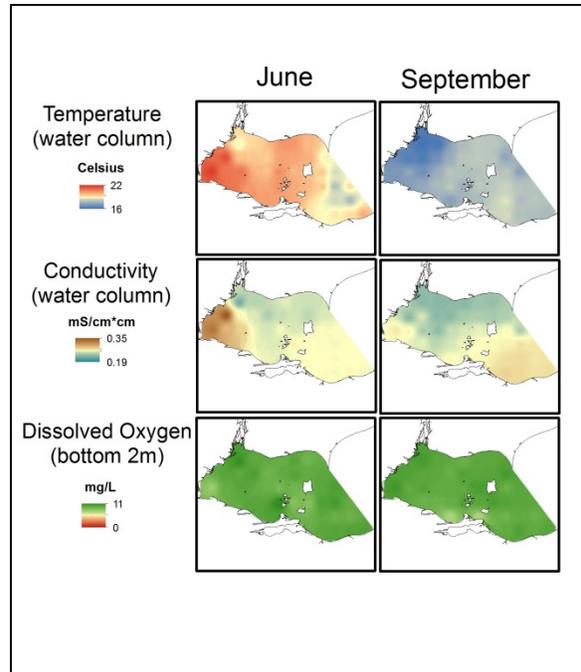


Figure 1.6 Temperature (upper), specific conductivity (middle), and dissolved oxygen (bottom) at bottom trawl sampling locations in the western basin of Lake Erie during 2014. Gradients were interpolated with inverse distance weighting.

2.0 Diet Analysis of Western Basin Age-2-and-Older Yellow Perch 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 fall. 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 and fall. *Bythotrephes* sp. occurrence in Yellow Perch and White Perch diets was low in spring and considerably increased in frequency in fall. Compiling results from 2014 with data dating back to 2005 suggested decreased utilization of zooplankton for both yellow and White Perch during spring and fall and increased utilization of fish prey during fall 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 (age-2+) 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 (Fall), 2014 (See Section 1.0). All trawl sampling occurred during daylight hours. A maximum of five age-2+ 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+ 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 obtain 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 2014 sampling was compared to results from 2005-2013. For the historical comparison, we only used data from 2014 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 2.1). Lengths of fish with diet contents were also similar between species, however a few extra-large Yellow Perch and White Perch (i.e., total length exceeding

300mm) were caught during fall sampling (Figure 2.1). The proportion of empty stomachs, relative to the number retained, was relatively low in the fall and spring, and thus, we subsampled the number of sites used for diet analysis in both spring and fall (N=21 and 27 sites, respectively). Subsampling was intended to allow diet description across the spatial extent of the survey (Figure 2.2).

Spring sampling provided 85 age-2+ Yellow Perch stomachs that were collected from fish ranging between 160-280 mm in length with 72 (84.7%) of the stomachs containing prey. In spring 2014, benthic macroinvertebrates were present in a majority of Yellow Perch stomachs (75.6%) and Chironomidae, *Dreissena* spp. and *Hexagenia* spp. were the most common benthic macroinvertebrates (Table 2.1). Zooplankton occurred in 20.5% of spring Yellow Perch diets with *Leptodora kindtii* and *Daphnia* spp. occurring most at 5.5% and 5.0%, respectively. Fish prey had a 4.2% occurrence in Yellow Perch diets during spring sampling with unidentified fish remains being the most common at 1.8% (Table 2.1). During fall sampling, 91 age-2+ Yellow Perch stomachs were collected from fish ranging from 170-320 mm in length with 62 (68.1%) of the stomachs containing prey. A decline in occurrence for benthic macroinvertebrates (51.1%) and an increase for zooplankton (28.3%) was observed in fall Yellow Perch diets relative to the spring. Occurrence of fish prey increased dramatically from spring to fall for Yellow Perch. Fish occurred in 20.4% of Yellow Perch diets, and unidentified fish remains was the most common fish prey occurring in 15.9% of stomachs. *Bythotrephes* sp. was detected at low occurrence in spring (3.6%) and increased frequency in fall (17.0%).

Spring sampling provided 71 stomachs from age-2+ White Perch ranging from 170-300 mm in length. A total of 63 (88.7%) of the White Perch stomachs contained prey items.

In spring, zooplankton was present in 44.5% of samples with *Daphnia retrocurva* occurring most frequently (14.4 %). Benthic macroinvertebrates occurred in 53.6% of spring stomach samples with *Hexagenia* spp. being most common (24.2%). Fish were present in 2.0% of White Perch stomachs with unidentified fish remains occurring most frequently during spring. During fall sampling, stomachs of 99 age-2+ White Perch were collected from fish ranging from 170-310 mm in length with 68 (68.7%) containing prey items. Benthic macroinvertebrates and fish were the most commonly occurring prey type in fall (both=34.5%), which was mostly comprised of *Hexagenia* spp. and unidentified

fish remains (Table 2.1). A decline in occurrence for zooplankton (30.9%) was observed in fall White Perch diets relative to the spring. *Bythotrephes* sp. was detected at low occurrence in spring (5.2%) and increased in fall (20.0%) (Table 2.1).

Frequency of occurrence of zooplankton and benthic macroinvertebrates was higher for both White Perch and Yellow Perch in 2014 than in 2013 during both seasons (Figure 2.3). Zooplankton occurrence has shown a declining trend over the past few years across both species in both seasons. Occurrence of zooplankton was higher in spring and fall 2014 compared to 2013. Occurrence of fish in Yellow Perch spring

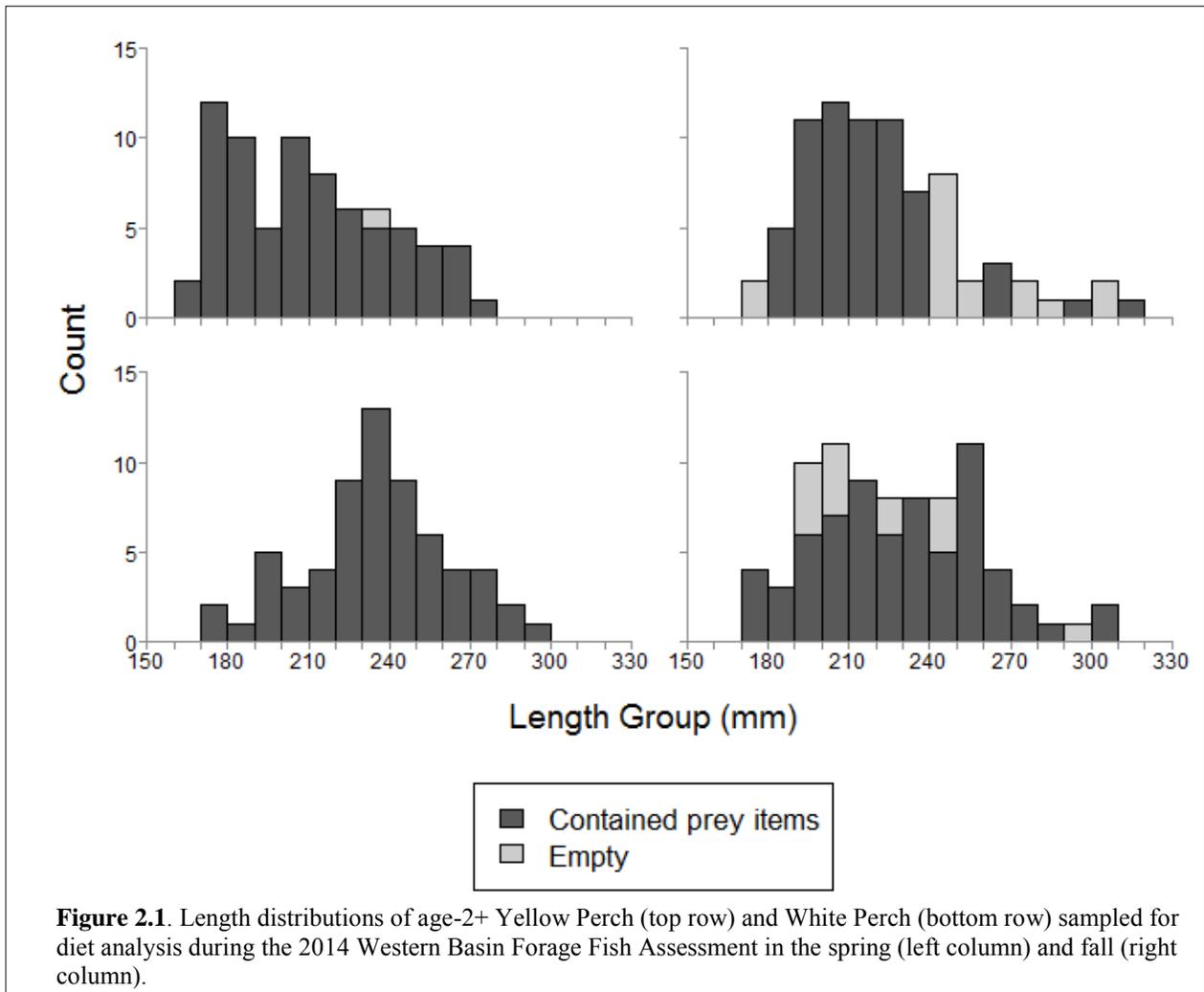


Figure 2.1. Length distributions of age-2+ Yellow Perch (top row) and White Perch (bottom row) sampled for diet analysis during the 2014 Western Basin Forage Fish Assessment in the spring (left column) and fall (right column).

Table 2.1 Percent occurrence of prey items in the diets of age-2+ Yellow Perch and White Perch collected during spring and fall 2014 in Ontario, Michigan, and Ohio waters of Lake Erie's western basin. Abbreviation: n=number of stomachs containing prey items.

Prey Type	Prey taxa	Yellow Perch		White Perch	
		2014 Spring n=72	2014 Fall n=62	2014 Spring n=63	2014 Fall n=68
Zooplankton		20.5	28.3	44.5	30.9
	<i>Bosmina</i> sp.	0.9	0.0	2.0	0.0
	<i>Bythotrephes</i> sp.	3.6	17.0	5.2	20.0
	Calanoida	1.8	1.1	3.9	0.9
	Cyclopoida	0.9	0.0	4.6	0.0
	<i>Daphnia retrocurva</i>	2.3	0.0	7.2	0.0
	<i>Daphnia</i> spp.	5.0	10.2	14.4	7.3
	<i>Diaphanosoma</i> spp.	0.5	0.0	1.3	0.0
	<i>Leptodora kindtii</i>	5.5	0.0	5.9	2.7
Benthic Macroinvertebrates		75.6	51.1	53.6	34.5
	Amphipoda	6.4	2.3	6.5	6.4
	Chironomidae	23.2	5.7	16.3	7.3
	<i>Dreissena</i> spp.	10.9	5.7	1.3	1.8
	Gastropoda	2.7	10.2	0.0	0.0
	<i>Hemimysis anomala</i>	0.5	0.0	0.0	0.0
	<i>Hexagenia</i> spp.	15.5	25.0	24.2	12.7
	Hirudinea	0.0	1.1	0.0	0.0
	Nematoda	2.7	0.0	1.3	0.9
	Oligochaeta	0.5	0.0	0.0	0.0
	Ostracoda	0.5	0.0	0.7	0.0
	Sphaeriidae	2.7	1.1	0.0	3.6
	<i>Trichoptera</i> spp.	10.0	0.0	3.3	1.8
Fishes		4.2	20.4	2.0	34.5
	Emerald Shiner	1.4	1.1	0.7	9.1
	Fish eggs	0.5	0.0	0.0	0.0
	Round Goby	0.5	0.0	0.0	0.9
	Rainbow Smelt	0.0	1.1	0.0	1.8
	Yellow Perch	0.0	2.3	0.0	0.0
	Unidentified fish	1.8	15.9	1.3	22.7



Figure 2.2. Percentage of stomachs with diet contents by site for Yellow Perch (top row) and White Perch (bottom row) during spring (left column) and fall (right column).

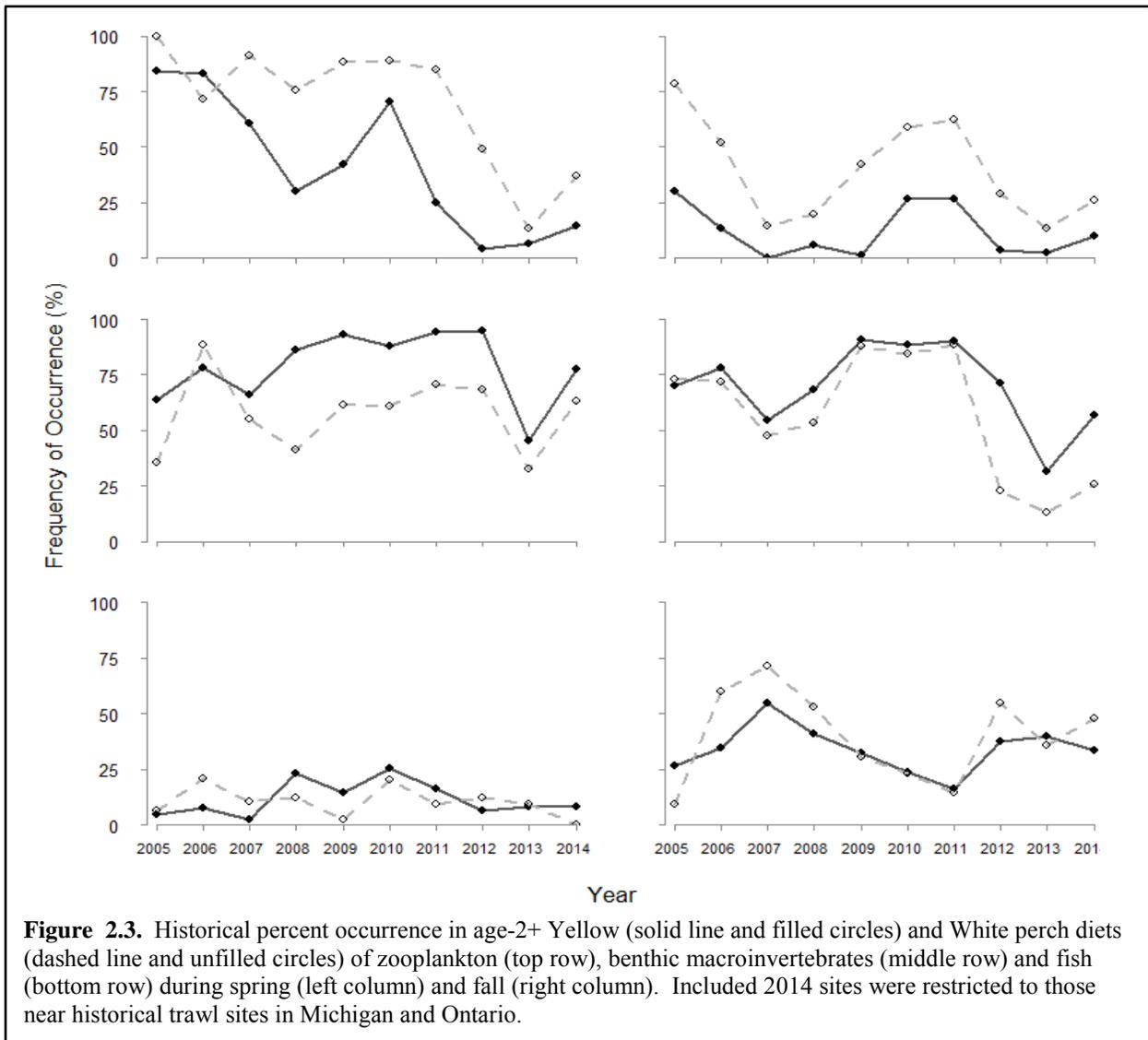
diets remained low (7.8%) and increased in the fall (33.3%). Historically, zooplankton was found in at least half of White Perch sampled in spring (maximum 100% in 2005), but they were only found in 37% of spring diets in 2014. Benthic macroinvertebrates were found about twice as often as in 2013 across both seasons and species (Figure 2.3). Occurrence of fish prey in diets has not shown unfamiliar change over recent years (Figure 2.3).

Percent composition by weight

Benthic macroinvertebrates contributed most to age-2+ Yellow Perch diets in spring (81.1%), followed by zooplankton (13.7%) and fish prey (5.2%, Figure 2.4). *Dreissena* spp., *Hexagenia* spp. and Chironomidae were the predominate benthic macroinvertebrate contributors by weight in the spring (Figure 2.5). *Daphnia retrocurva* and *Daphnia* spp. were the dominant zooplankton taxa, while Emerald Shiners were the most prominent identifiable fish prey in spring Yellow Perch diets (Figure 2.5). In fall, benthic macroinvertebrate taxa continued to show the highest contribution to diet weights (53.4%), followed by zooplankton

(23.0%) and fish prey (23.7%) (Figure 2.4). The major benthic macroinvertebrate taxa contributors in fall were *Hexagenia* spp. and Gastropoda (29.0%, and 14.5%, respectively). *Bythotrephes* sp. accounted for almost 100% of total zooplankton observed in diets. The major fish prey taxa contributors in fall was unidentified fish remains (18.4%) (Figure 2.5).

Spring White Perch diets were predominately composed of benthic macroinvertebrates (64.0%), followed by zooplankton (34.0%) and fish (2.0%) (Figure 2.4). *Hexagenia* spp. was the dominant benthic macroinvertebrate taxon contributing 48.6% to diet weight on average in spring (Figure 2.4). *Daphnia* spp. and Emerald Shiner were the dominant contributors for their respective prey groups. White Perch showed a shift towards increased piscivory in the fall, while zooplankton (28.0%) and benthic macroinvertebrates (24.9%) made lower contributions to their diet weights (Figure 2.4). Emerald Shiner and unidentified fish remains were the major fish prey taxa (14.7% and 28.6%) during fall. *Hexagenia* spp.



was the predominate benthic macroinvertebrate taxa and *Bythotrephes* sp. was the predominate zooplankton taxa during fall (Figure 2.5).

In summary, Yellow Perch and White Perch diets in spring were collected across our western basin sampling area. In fall, the north shore near the Detroit River was under-represented due to a high number of empty stomachs (Figure 2.2). Yellow Perch and White Perch showed a higher occurrence of

zooplankton and benthic invertebrates in diets in both the spring and the fall. In contrast, both species exhibited increased occurrence of fish in diets in the fall relative to the spring, and frequency of fish in fall-collected diet samples has increased in the past few years relative to historical data. *Hexagenia* spp. occurred frequently in diets in 2014 and contributed 39.7% to diet composition by weight in the spring. The timing of our spring sampling in 2014 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 2014, invasive *Bythotrephes* sp. was frequently observed in diets (maximum 20.0% of diets in White Perch in fall). We observed only one *Hemimysis* sp. In a Yellow Perch diet in spring and no *Cercopagis* sp. in any fish diets.

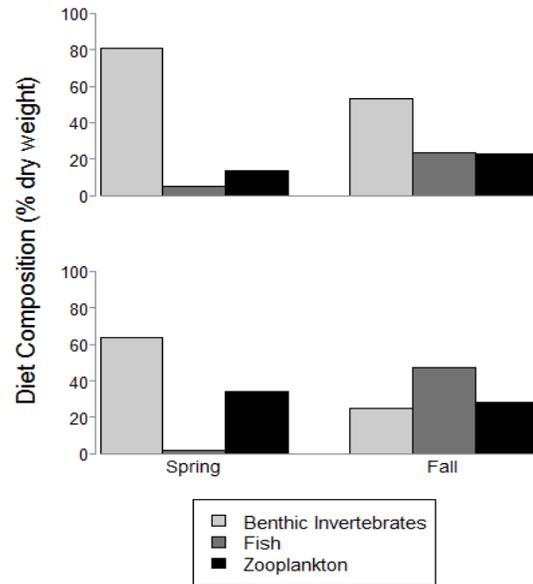


Figure 2.4 (right). Age-2+ Yellow Perch (top panel) and White Perch (bottom panel) mean diet composition (% dry weight) by prey type and season.

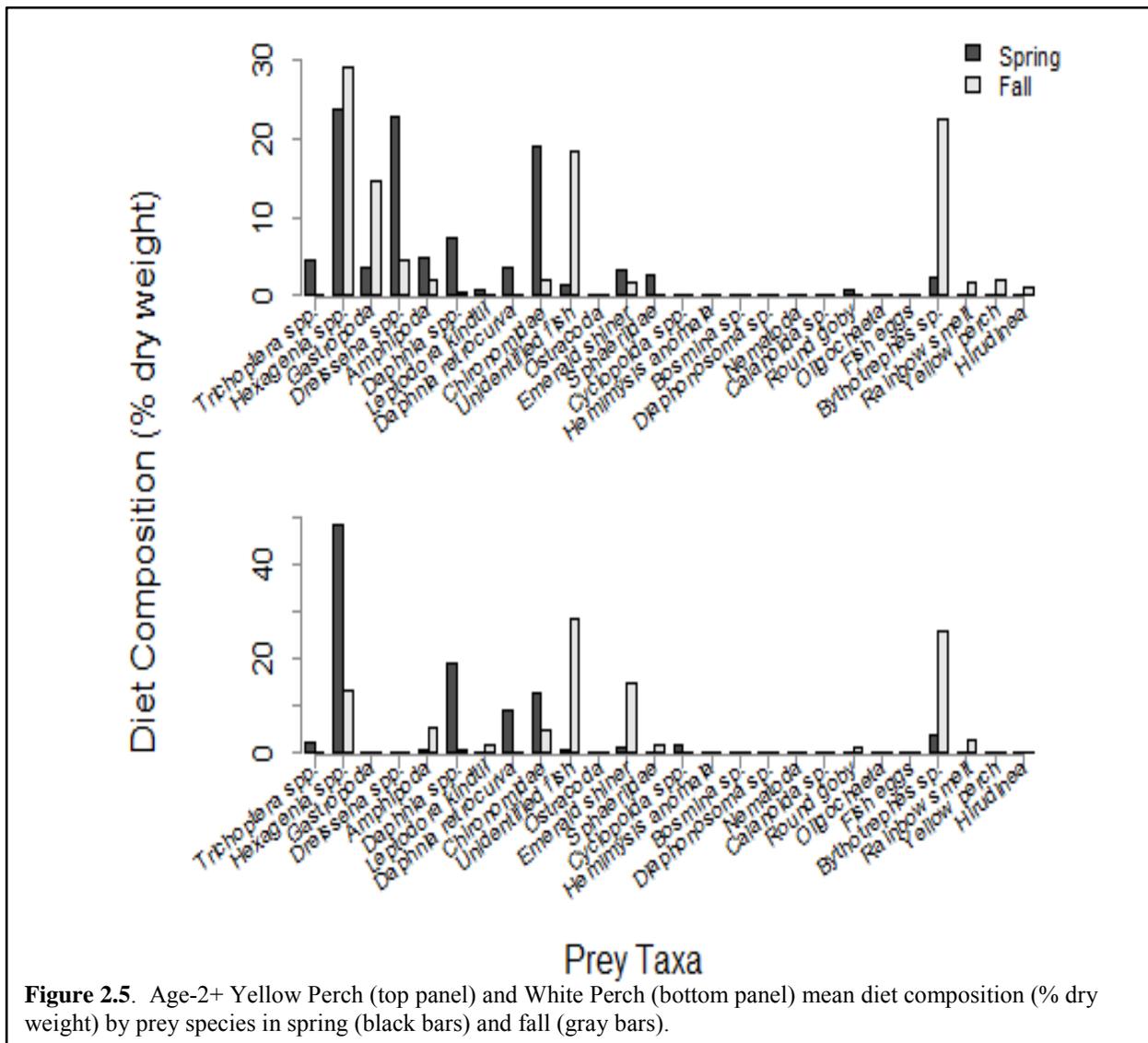


Figure 2.5. Age-2+ Yellow Perch (top panel) and White Perch (bottom panel) mean diet composition (% dry weight) by prey species in spring (black bars) and fall (gray bars).

3.0 Yellow Perch Maturity

In 2013, LEBS updated sampling objectives in order to obtain information on Yellow Perch maturation following macroscopic staging categories used by Lake Erie management agencies. This objective continued in 2014 and a subsample of 153 Yellow Perch was collected and analyzed for a sexual maturity during our fall Western Basin Forage Assessment. Predicted lengths at both 50% and 90% mature were calculated using a bootstrap estimation routine to provide 95% confidence intervals of length with the *glm* and *bootCase* routines in R (R version 3.1.2, ©2014, The R Foundation for Statistical Computing). Results here pertain primarily to management unit 1 as defined by the Yellow Perch Task Group.

Male Yellow Perch started to mature as small as 83 mm, while the smallest mature female Yellow Perch was 161 mm. The logistic regression for male Yellow Perch

portrayed a more gradual increase in maturation with size than for females (Fig 3.1). The total length at which 50% of male Yellow Perch were mature was significantly smaller (103 mm; 95% CI: 91-115 mm) than that for females (171 mm, 95% CI: 165-180 mm). Likewise, 90% of Yellow Perch were mature at 148 mm (135-163 mm) and 181 mm (95% CI: 167-193 mm) for males and females, respectively. These results were not significantly different from those obtained in 2013 (Table 3.1).

Table 3.1: Comparison of length at maturity (mm and 95% confidence interval) of male and female Yellow Perch in 2013 and 2014.

sex	% mature	2013		2014	
		mm (95% C.I.)	N	mm (95% C.I.)	N
M	50%	97 (86-106)	145	103.5 (91-115)	129
	90%	146 (131-162)		148.5 (135-163)	
F	50%	166 (160-174)	173	171.6 (165-180)	72
	90%	189 (178-202)		181.7 (168-194)	

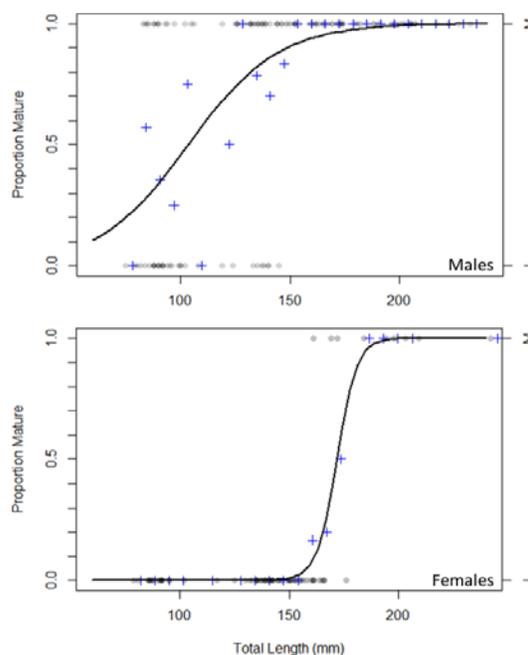


Figure 3.1. Maturity probability model based on observations of male (top, 75-232 mm) and female (bottom, 79-242 mm) yellow perch collected during our Western Basin Forage Assessment (129 males, 72 females). Dots signify individual observations, while blue crosses represent the observed proportion mature for each length bin.

4.0 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 and have contributed to a better understanding of biology and status of Silver Chub, for which a recovery plan for the Lake Erie population is being developed. 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 examine the time series from 2009-2014 for our two vessels to determine if and to what degree indices of abundance have changed since beginning trawling with the new vessel.

Introduction

The USGS LEBS 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 three prominent features: 1) three depth strata are sampled; 2) replicate trawl samples are collected at each site; and 3) samples are taken during daylight and nighttime. 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 practices in a data series.

The current East Harbor sampling site was originally part of a larger set of 15-16 sites throughout western Lake Erie established in the late 1950s, all of which were sampled in the same manner with multiple depth strata at each site, replicate trawl samples, and sampling at night. The purpose of the program was to index abundance of YOY fishes for projecting future year class strength of commercial species. Sampling multiple depths at each site, taking replicate trawl samples, and sampling in the morning, afternoon, and night were included in the design to ensure comprehensive sampling that would best represent relative abundances (H. van Meter

and W. D. N. Busch, personal communication).

Development of the basin-wide sampling program followed several years after Edward Coyle Kinney's pioneering work on Trout-perch (Kinney 1950) and Silver Chub (Kinney 1954) 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 influential in the decision to develop trawling methods in western Lake Erie to index abundance of young-of-year fishes.

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 revealed effects of dreissenid mussels on growth of YOY fish (Trometer and Busch 1999), indices of abundance of YOY Yellow Perch (Stapanian et al. 2009), shifts in catchability of benthic fishes (Kočovský and Stapanian 2011; Stapanian and Kočovský 2013), and the effect of sampling in daylight versus nighttime on abundance 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 (e.g., doors, bridles) needed to tow it (LEBS 2013). Those changes essentially ended the original time series and began a new one. Here we compare time series of the first 3 years of sampling with the Muskie to the last 3 years of sampling with the Musky II 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 4.1). 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 (LEBS, 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. Trawl width when fishing averages 5 m as estimated using Notus® net mensuration gear. The 3-bridle configuration allows for the headrope to reach a targeted height of 2.5 m from the bottom and 6-m wingspread. Acoustic net mensuration and sidescan sonar analysis of the gear during operation showed that the net consistently achieved this target at a wide range of trawling speeds.

We examine trends in YOY catch (number per hectare) of the most abundant benthic and pelagic species, YOY Walleyes (as a species of management interest) and Silver Chub, which was recently downgraded from special concern to endangered in Ontario (McCulloch et al. 2013). We compare Z-scores from before and after retirement of the Musky II to qualitatively assess trends and differences in CPH.

Results

Weak trends in Z-scores of CPH were evident for most species. There was a slight positive trend for Emerald Shiner despite a drastic decline in CPH compared to 2013 (Figure 4.2). Gizzard Shad CPH had no trend, due in part to a similarly sharp decline in 2014. Yellow Perch, Trout-perch, and Round Goby had declining trends. The trend for White Perch was flat for 2009-2013, but there

was a steep decline in CPH in 2014. There was no apparent trend in Z-score for Walleyes. For Silver Chub, Z-score for CPH was increasing for the last three years trawling with the Musky II and declining for the first three years with the Muskie.

Pelagic-species Z-scores were positive for 2012 and 2013 but negative for 2014. Yellow Perch, Trout-perch, and Round Goby Z-scores were negative for all 3 years sampling with the Muskie. White Perch Z-scores were negative only in 2014. Walleye Z-scores were negative in 2012 and 2014. Silver Chub were positive in 2012 and 2013 and negative in 2014.

Discussion

Trawls are among the crudest 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 are a temporal examination of trends before and after the change to the new net and vessel and comparison to another vessel sampling a similar area with the same gear over the same time period to attempt to assess whether there is evidence of a change in the time series related to the new vessel/trawl combination. In this report we focus on the former.

The vessel/gear combination for the Muskie requires trawling at faster speeds than for the Musky II, and that difference in speed

may confound interpretation of trends through time (LEBS, 2014) owing to differential effects on catchability (i.e., trawl avoidance may be lower when speeds are higher). Despite the negative effects of variable speeds in interpreting temporal trends and effects of the new vessel/trawl combination on the time series, there is evidence catches of some species were likely affected by the change in vessel and gear. Z-scores of catch per effort of Yellow Perch, Trout-perch, and Round Goby have been negative for all three years trawling with the Muskie. These trends seem qualitatively consistent with those for trawling throughout the western basin except for Yellow Perch, which had high CPH in Ontario and Ohio waters near the international boundary (see section 1.0 of this report). Similarly, Z-scores for Walleye were negative except for 2013, which was a stronger year class at the scale of western basin than the previous two years (Walleye Task Group 2014). Higher CPH, hence mean Z-scores, for Emerald Shiner and Gizzard Shad are consistent with the headrope of the net fished from the Muskie fishing 1.5 m higher off the bottom. At our shallow site (3 m) the net fishes nearly the entire water column, which would necessarily capture more pelagic fish. As was the case in 2013 (LEBS, 2014), we captured unionid mussels in our net, hence the net fishes close enough to the bottom to capture strongly benthically-oriented species, suggesting net design (e.g., larger body mesh), sounds produced by the net or boat, vessel avoidance, or pressure waves rather than proximity of the footrope to the bottom might be causal in catching fewer strongly benthically-oriented species. Whatever the mechanism, data for the first three years continued the general impression from 2013 (LEBS 2014) that our ability to index benthic species has declined and our ability to index pelagic species has increased.

Contrary to 2013 data which suggested no change in ability to index Silver Chub

abundance, the third year of post-Musky II data suggests a diminished capture efficiency. As a species of concern in Canada for which recovery potential has been evaluated (McCulloch et al. 2013), diminishment of

ability to index Silver Chub warrants consideration of alternative collection methods to inform recovery plans.

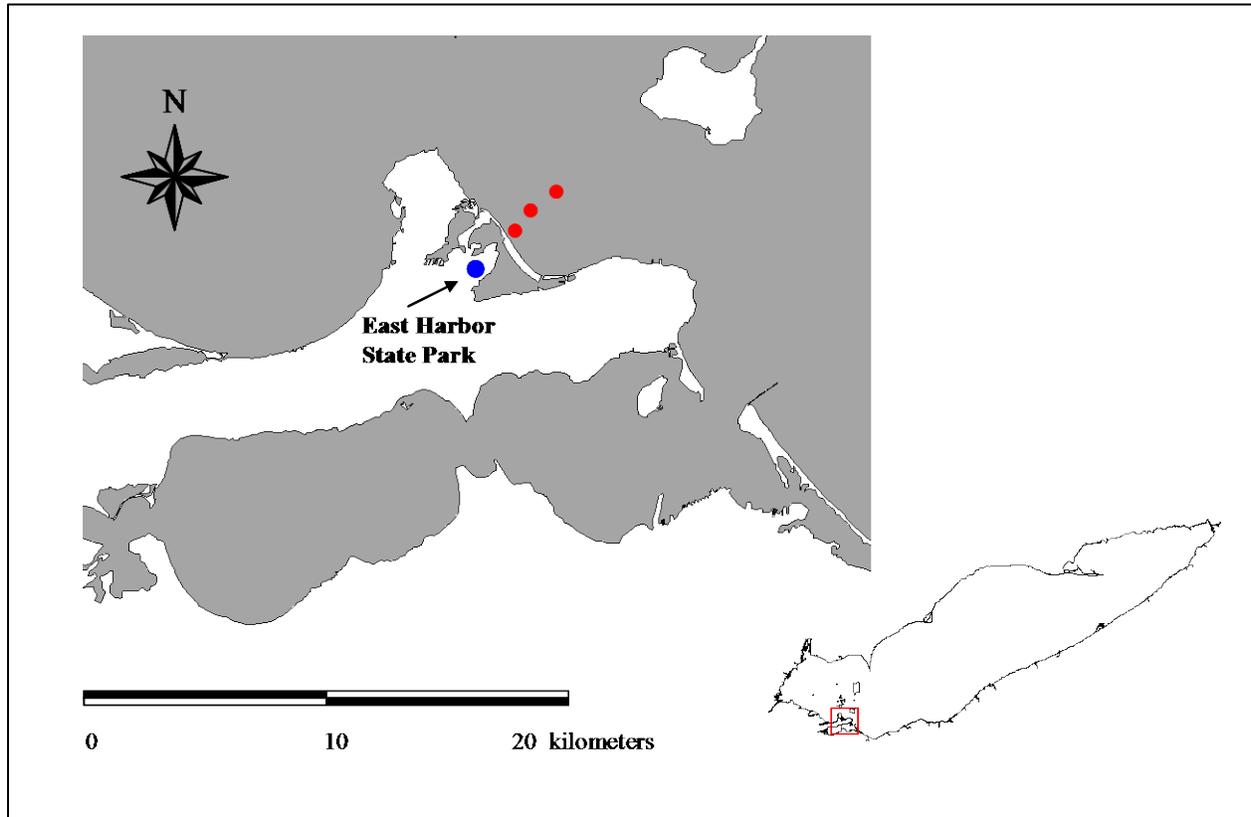


Figure 4.1. Location of sites sampled by the USGS Lake Erie Biological Station (red filled circles) offshore of East Harbor State Park (blue filled circle) in the western basin of Lake Erie.

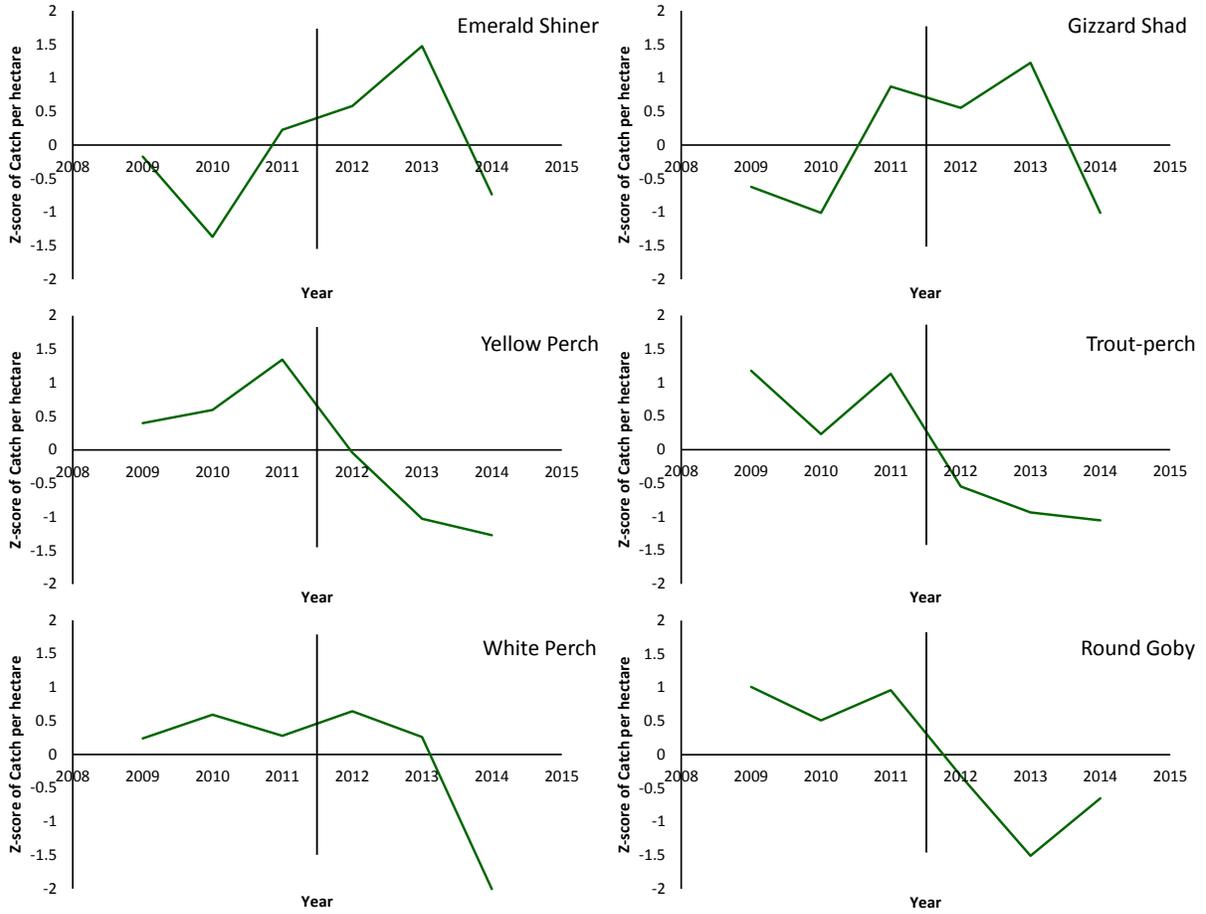


Figure 4.2. Trends in Z-scores of estimated density of the most abundant benthic and pelagic fish species at the USGS East Harbor monitoring site in western Lake Erie from 3 years prior (left of vertical lines) and subsequent to (right of vertical lines) retirement of the Musky II.

5.0 Lower Trophic Assessment in the Central Basin of Lake Erie

Abstract

The Lake Erie Biological Station has participated in the LTLA program, which is administered by the FTG of the LEC, since 2003. The purpose of the program is to monitor and report on nutrient levels and 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 within 1 km of shore, the other approximately 8 km from shore, following standard methods established by the FTG. During our 12 years of monitoring, there were no sustained trends in mean surface and bottom water temperatures, mean bottom dissolved oxygen, and mean total phosphorus in summer (July-September). Secchi disk depths did not vary among years at either site, but there was an overall trend of decreasing water clarity at our nearshore site, which is likely influenced by highly turbid inflows from the Vermilion River. Secchi disk depths remained within, or had confidence limits that overlapped, the desired range at the offshore site most years. Mean total phosphorus remained higher than desired most years at both sites; in 2014 at the offshore site total phosphorus was within the desired range at the offshore site. Our data suggest borderline and fairly constant eutrophic conditions at these sites in central Lake Erie.

Introduction

The LTLA program to monitor nutrient levels and to assess the phytoplankton and zooplankton communities throughout Lake Erie (Forage Task Group 2015), was begun by the LEC of the GLFC in 1999. Conduct of the sampling program is overseen by the 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 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 FTG to monitor and report on status and composition of forage fish community throughout Lake Erie.

Like all other task groups under the umbrella of the LEC, the FTG exists largely to support the economically important commercial and recreational fisheries in Lake Erie, which are supported mostly by Yellow Perch and Walleye. FCGO 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 2015). Hence, an important goal of the LTLA is to determine whether the goal of mesotrophic conditions is being met.

Here we report on 12 years of data collection focusing on annual trends at two sites we monitor in central Lake Erie.

Methods

Data were collected bi-weekly between May and October 2003-2013 at two sites in central Lake Erie near Vermilion, Ohio (Figure 5.1). The vessel used from 2003 through 2012 was the RV Bowfin, a 26-ft Pacific Skiff with twin outboard motors and < 1 m freeboard. Beginning in 2013 some data were collected from the 70-ft RV Muskie, 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 YSI 6600 V2 Sonde beginning 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. Water samples for chlorophyll-a, phytoplankton, and total phosphorus were taken from an aggregate sample composed of 1-L each from 4 discrete depths spaced equally from 1 m below the surface to 1 m above the bottom. If the water column was stratified, samples were taken from 1 m below the surface, 1 m above the thermocline, and at two equally-spaced intermediate depths. Samples were collected with a Niskin 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 also collected water samples for chlorophyll-a and total phytoplankton, zooplankton samples, and benthic samples, but those are not reported on here.

We report mean summer (July-September) bottom and surface temperatures, mean bottom dissolved oxygen, mean Secchi disk depth and mean total phosphorus for each site. Differences among years for these variables were tested by ANOVA using PROC GLM in SAS. We modeled Secchi depth as a function of year, phosphorus (\log_{10} -transformed), and Vermilion River discharge (Q) 2 days prior to sampling (also \log_{10} -transformed) to determine whether proximity to the mouth of the Vermilion River might be influencing the apparent annual decreasing trend observed in the past (LEBS 2014) using PROC REG in SAS. Discharge two days prior to sampling was used because a preliminary analysis determined it was the

most strongly correlated with Secchi disk depth.

Results

Nearshore site

Mean total phosphorus values were always near or greater than the desired upper limit for mesotrophic conditions (Figure 5.2). Secchi disk depths were statistically significantly lower than the desired range of 3-6 m in 2006, 2008, and 2012-2014 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.

Surface temperature and bottom temperature did not differ among years (Figure 5.3). Bottom DO (ANOVA, $F_{11, 60}=1.92$ $P=0.055$) was marginally higher in 2003 (8.4 mg/L), 2012 (8.05 mg/L), and 2013 (8.20 mg/L) than in 2004 (5.99 mg/L), but there were no other inter-annual differences. Regression analysis of Secchi depth by year (t-test for slope $t = 2.74$, $P = 0.007$), phosphorus ($t = 7.72$, $P < 0.0001$), and Vermilion River discharge ($t = 4.15$, $P < 0.0001$) was significant (Secchi = $-2.76\log(\text{phosphorus}) - 0.448\log(Q) - 0.055\text{Year} + 118.0$, $r^2 = 0.5$, $P < 0.0001$).

Offshore site

Bottom temperature, bottom DO, and Secchi disk depth did not vary among years. Total phosphorus (ANOVA $F_{11, 69}=2.11$, $P=0.03$) was highest in 2004 (35 $\mu\text{g/L}$) and lowest in 2010 (13.6 $\mu\text{g/L}$). There were no trends through time for any of these variables.

Mean total phosphorus values exceeded the desired upper limit of 18 $\mu\text{g/L}$ in all years except 2010 and 2014. Mean Secchi disk depths were in the preferred mesotrophic range of 3-6 m in 2003, 2005, 2007, 2008, 2010, 2011, and 2014. 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 FCGO (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 phosphorus levels were almost always higher. Mean total phosphorus and mean Secchi disk depths were within the desired ranges at the offshore site in 2010 and 2014. At the nearshore site mean total phosphorus was in the desired 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.

The lack of significant 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 in an opposite direction to the management target. Secchi disk depth decreased by approximately 10 cm annually 2003-2014. Although our larger research vessel, whose deck is ~1 m farther from the water surface than the smaller vessel, has been used occasionally since 2012, Secchi disk depths from the larger vessel were always within the range of depths from the smaller vessel, hence there was likely no vessel effect.

Secchi disk depths at our nearshore sampling site were affected by high discharge events from the Vermilion River. That site is only a few km northeast of the mouth, where a breakwall only ~90 meters from the mouth deflects flow either west or east. Prevailing wind and water currents typically carry water to the east directly toward our sampling site. Secchi disk depths at our nearshore site were most strongly controlled by phosphorus levels, which accounted for 40% of the total variation explained by the regression model. Vermilion River discharge accounted for another 6% of

variation explained. The year term was significant, hence there is an annual decrease in Secchi disk depth independent of phosphorus and discharge, but the magnitude is weak as the year term accounted for only an additional 3% of the variation explained. Phosphorus levels were positively but weakly correlated to discharge, slightly confounding the individual relationships. The strong effect of Vermilion River discharge on Secchi disk depths suggests this site is not representative of lake conditions, rather of conditions in the Vermilion River plume. We will discuss the option of changing this site with partner agencies through the FTG.

Significant differences in bottom DO among years were observed only at the nearshore site. Despite those differences, mean bottom DO was always sufficiently high for fish, never falling, on average, below 5.99 mg/L. The lowest value recorded nearshore was 2.44 mg/L, above the 2 mg/L threshold considered critical for Yellow Perch (FTG 2015). At the offshore site, DO was frequently lower than 1 mg/L in July and August. 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 probable prolonged periods of hypoxia. The only year we did not observe DO below 2 mg/L was 2003.

There were no significant differences or trends in surface or bottom temperatures at the site scale. Ten of the 11 warmest years globally since record keeping began in 1880 (NOAA 2015) 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 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).

Trophic conditions over the period 2003-2014 at these two sites has generally been eutrophic and contrary to goals expressed in the Fish Community Goals and

Objectives for Lake Erie. These are only 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 sights are placed in a lake-wide context in FTG (2015).



Figure 5.1. Lower trophic sites sampled by the Lake Erie Biological Station 2003-2014. Red box in inset shows approximate location on Lake Erie.

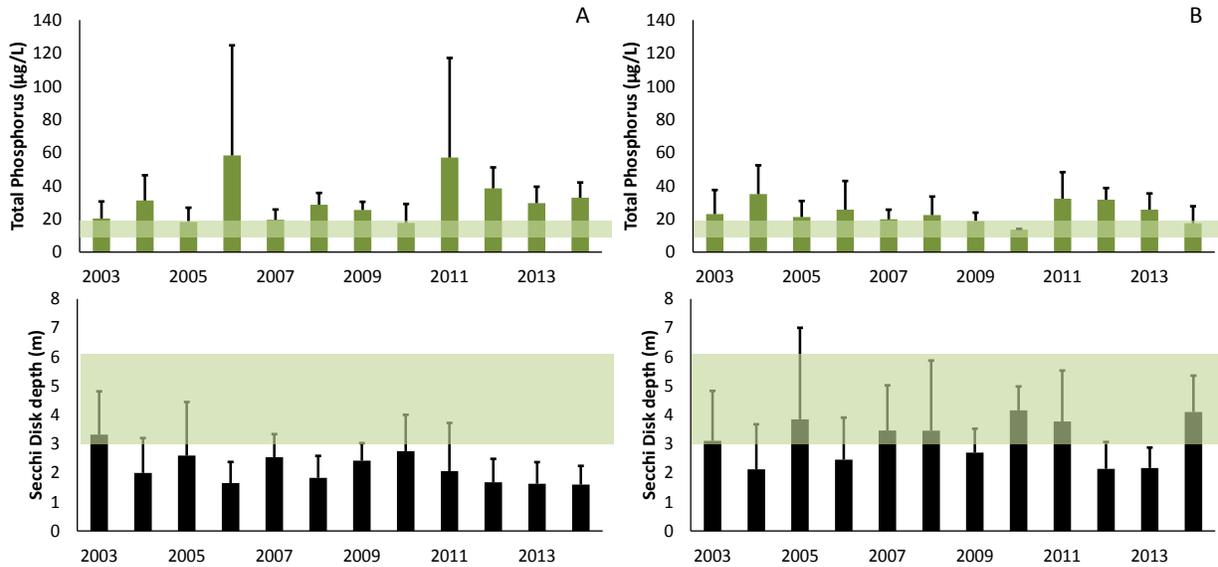


Figure 5.2. Mean total Phosphorus in water samples and Secchi disk depth collected at one nearshore site (depth ~5.2 m; A) and one offshore site (depth ~13.6 m, B) in central Lake Erie, 2003-2013. Green shaded bands indicate desired ranges of values to maintain mesotrophic conditions desirable for percid communities.

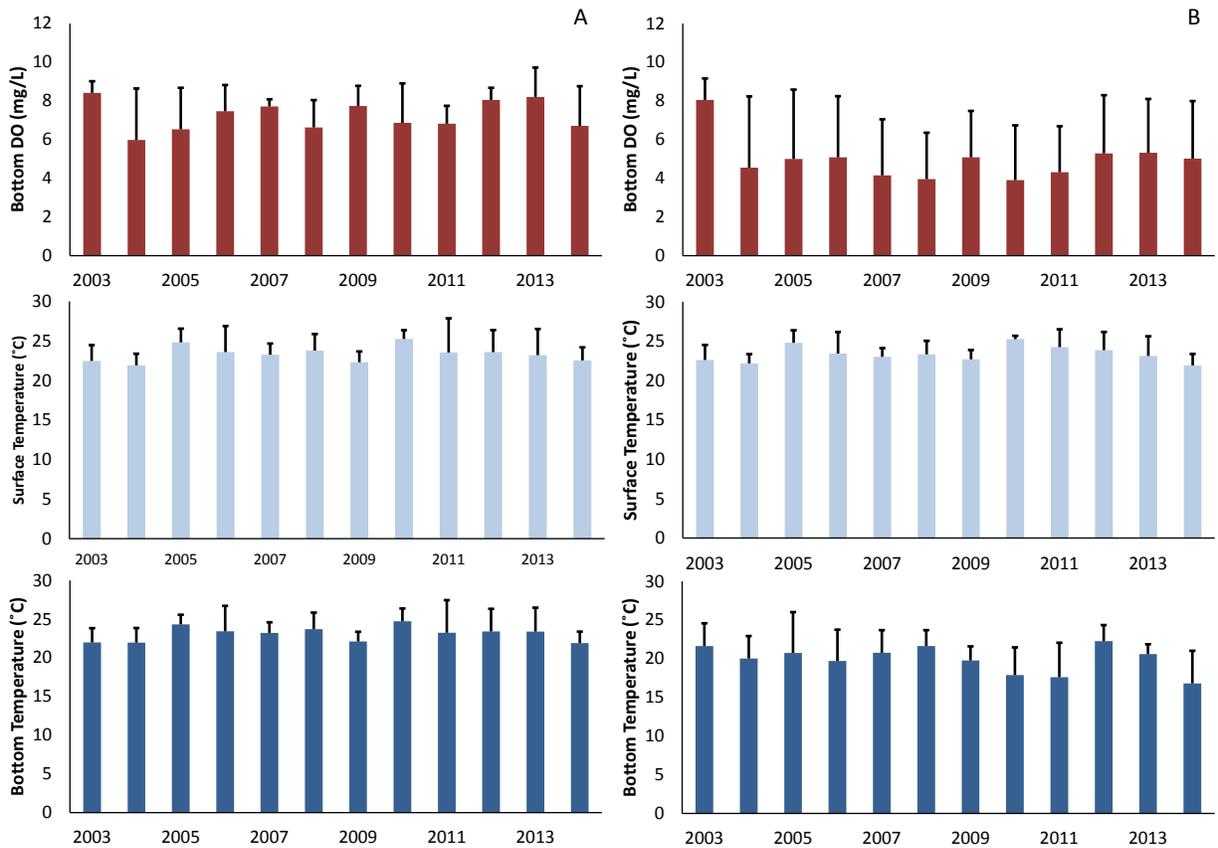


Figure 5.3. Mean bottom dissolved oxygen (DO) and mean surface and bottom temperatures at one nearshore site (depth ~5.2 m; A) and one offshore site (depth ~13.6 m, B) in central Lake Erie, 2003-2014.

6.0 Acknowledgements

We thank T. Cherry, G. Rutz and D. Hall for assistance in the field. Constructive reviews were provided by J. Deller, A.M. Gorman, C. Knight, B. Leonhardt, 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.

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**Great Lakes Prey Fish Populations:
A Cross-Basin Overview of Status and Trends
Based on Bottom Trawl Surveys, 1978-2014¹**

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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. To compare population trends of Cisco in Lakes Superior and Ontario, we calculated relative indices of density for fish >140 mm total length. This was done because Cisco numbers were very low in Lake Ontario, and density is less variable than biomass at very low population levels. Smaller, age-1 fish were eliminated in the comparison to avoid the influence of extremely large year classes in Lake Superior. 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.

¹ Prepared for: Upper and Lower Lakes Committee Meetings
Great Lakes Fishery Commission
Ypsilanti, Michigan, March 23-27, 2015

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 to assess concordance of ranks, ranging from 0 (complete discordance or disagreement) to 1 (complete 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.

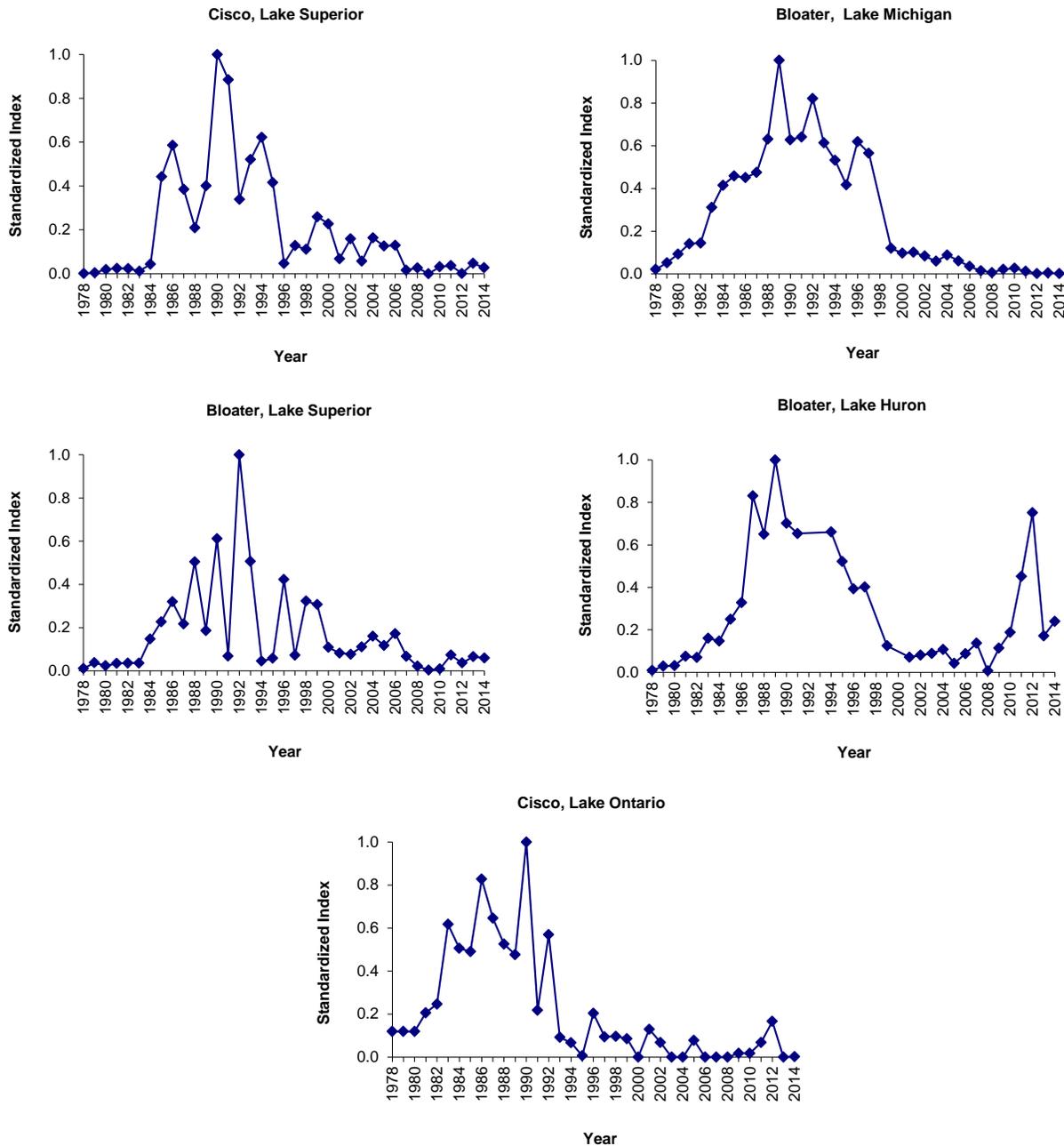


Figure 1. – Standardized indices of biomass for age-1 and older Cisco in Lakes Superior and Ontario and age-1 and older Bloater in Lakes Superior, Michigan, and Huron, 1978-2014.

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.

Results

Relative Biomass, Age-1 and Older Coregonids

Trends in relative biomass of age-1 and older coregonids (Cisco in Lake Superior and Bloater in Lakes Superior, Michigan, and Huron) among the 1978-2014 time series were significantly concordant (Fig. 1; $W = 0.67$; $P < 0.0001$). Although Cisco is a rare species in Lake Ontario, (maximum mean biomass of 0.06 kg/ha), it was regularly captured in low numbers throughout the time series. When trends in relative Cisco biomass in Lake Ontario are compared with trends in coregonids in the other Lakes, the trends remain significantly concordant (Fig. 1; $W = 0.34$; $P < 0.01$). Comparison of trends in biomass of Bloater in Lakes Superior, Michigan, Huron, showed significant concordance ($W = 0.65$; $P = 0.001$). Trends in Cisco and Bloater biomass in Lake Superior showed strong agreement ($r = 0.71$, $P < 0.01$) and trends in density of age-1 and older Cisco in Lakes Superior and Ontario were concordant (Fig. 2; $r = 0.34$, $P < 0.05$). In all four lakes, coregonid biomass reached peak levels in the late 1980s through the early 1990s. Afterwards, coregonid biomass declined and reached historically low levels in Lakes Superior and Michigan in 2007-2011. Cisco biomass in Lake Ontario declined after 1992 and remained low for the remainder of the time series. 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, 6). Bloater were absent from survey catches in Lakes Erie and Ontario, and Cisco were rarely encountered in Lakes Michigan, Huron, and Erie.

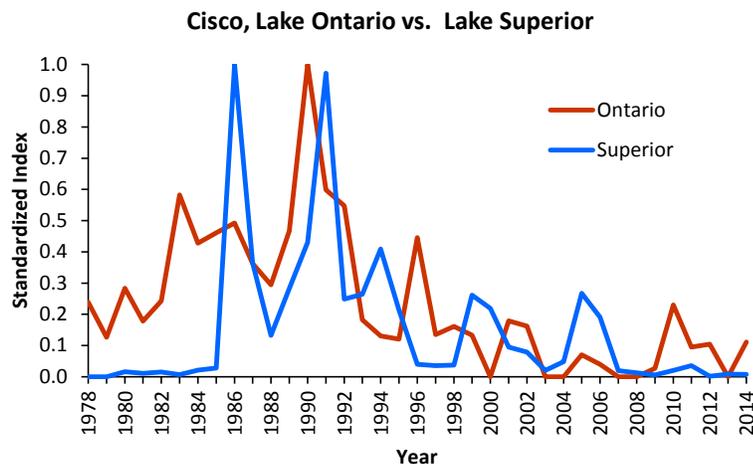


Figure 2. – Standardized indices of density for Cisco > 140 mm total length in Lakes Superior and Ontario, 1978-2014.

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. 3). For all three lakes, there was moderate concordance ($W = 0.62$; $P = 0.002$) among the 1978-2014 time series. In Lake Michigan, biomass of Alewife was high in the late 1970s and rapidly declined to lower levels by the mid-1980s. After a minor peak in 2002, the result of recruitment of the extremely large 1998 year-class, Alewife biomass remained relatively low during the late 1980s, 1990s, and early 2000s. After 2002, Alewife biomass continued declining and reached the lowest level in the time series in 2014. The minor peak observed in 2013 was due to a very large Alewife catch at the 9-m station at Saugatuck, and consequently there was a high degree of uncertainty associated with this 2013 observation. 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 2013-2014, 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.

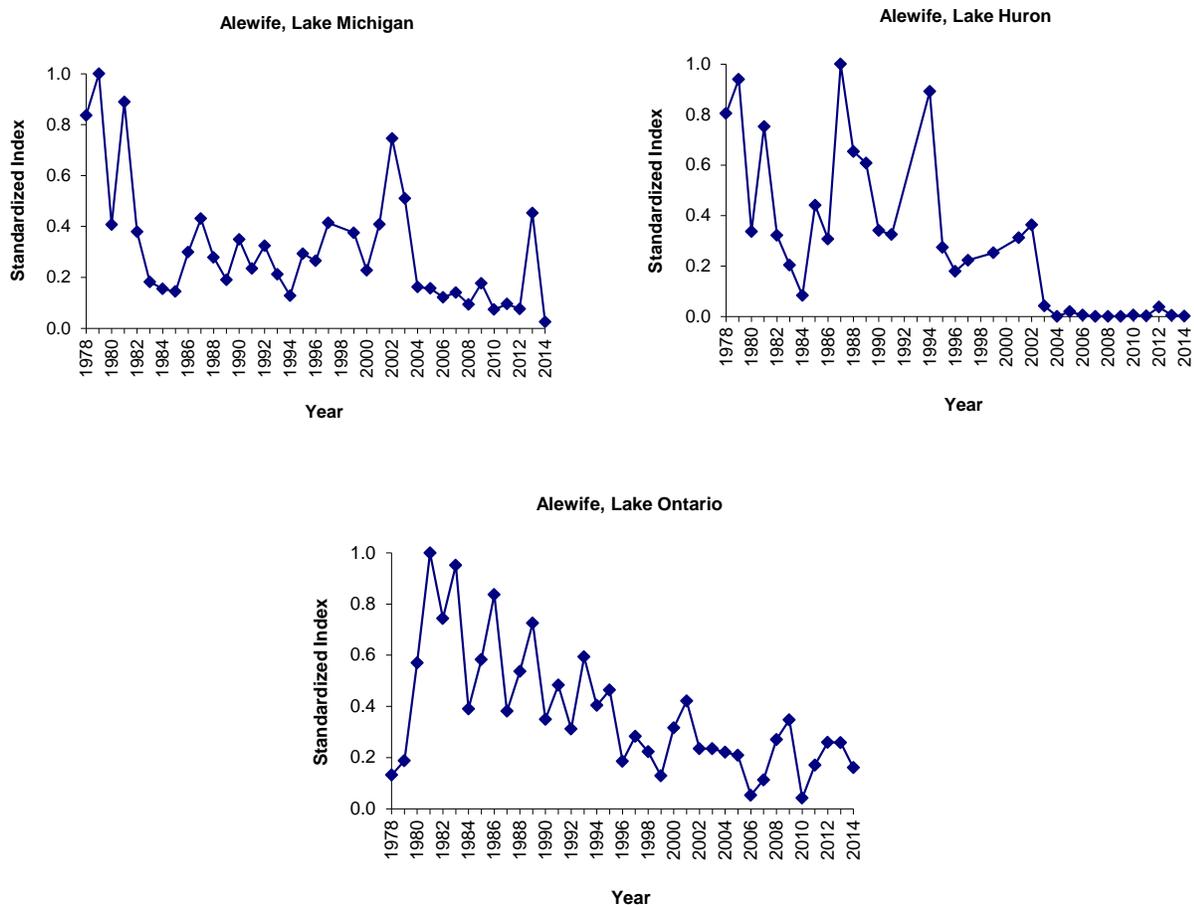


Figure 3. – Standardized indices of biomass for age-1 and older Alewife in Lakes Michigan, Huron, and Ontario, 1978-2014.

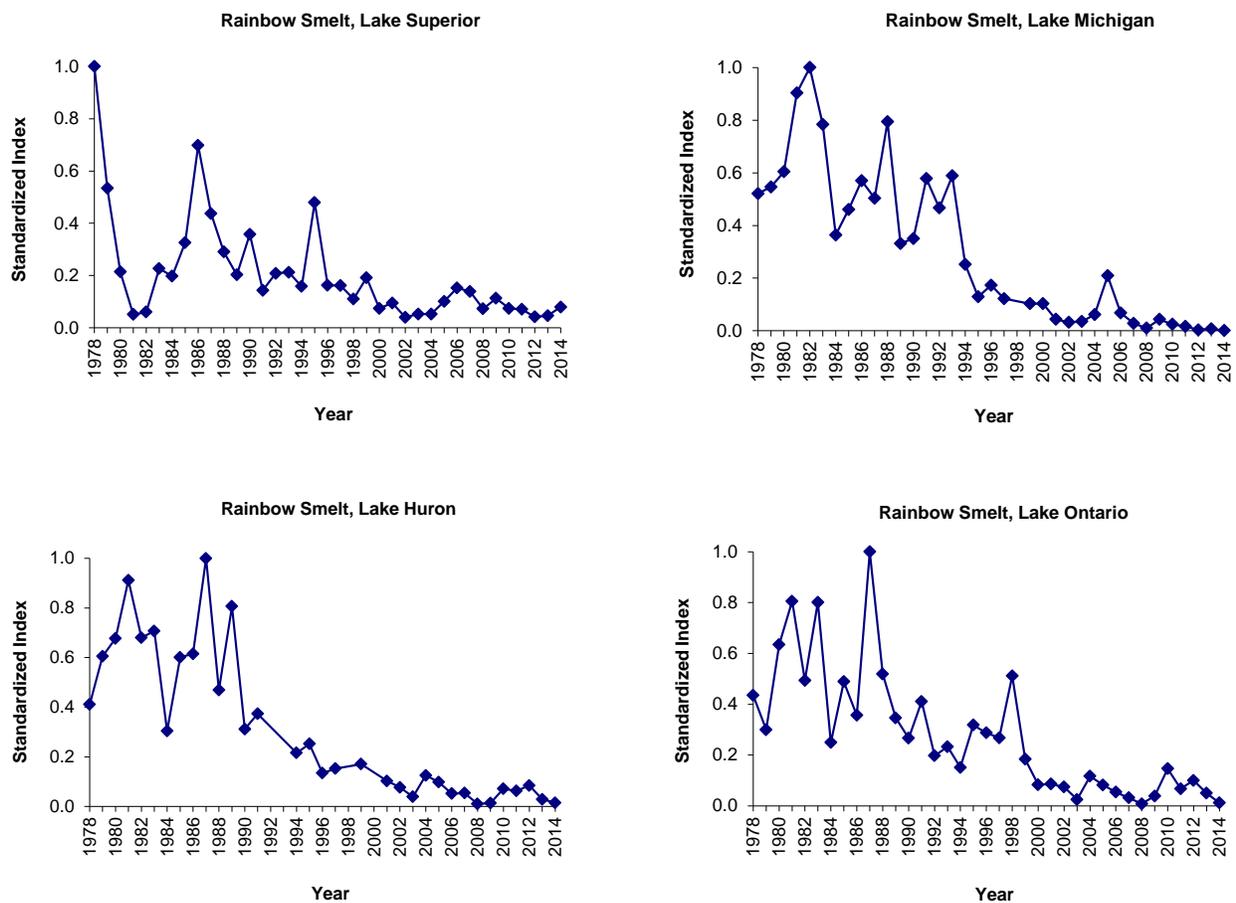


Figure 4. – Standardized indices of biomass for age-1 and older Rainbow Smelt in Lakes Superior, Michigan, Huron, and Ontario, 1978-2014.

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 1978-2014 (Fig. 4; $W = 0.81$; $P < 0.0001$). 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 declined to record lows in 2012-2014. 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 2013-2014, biomass dropped again, approaching record lows. 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.

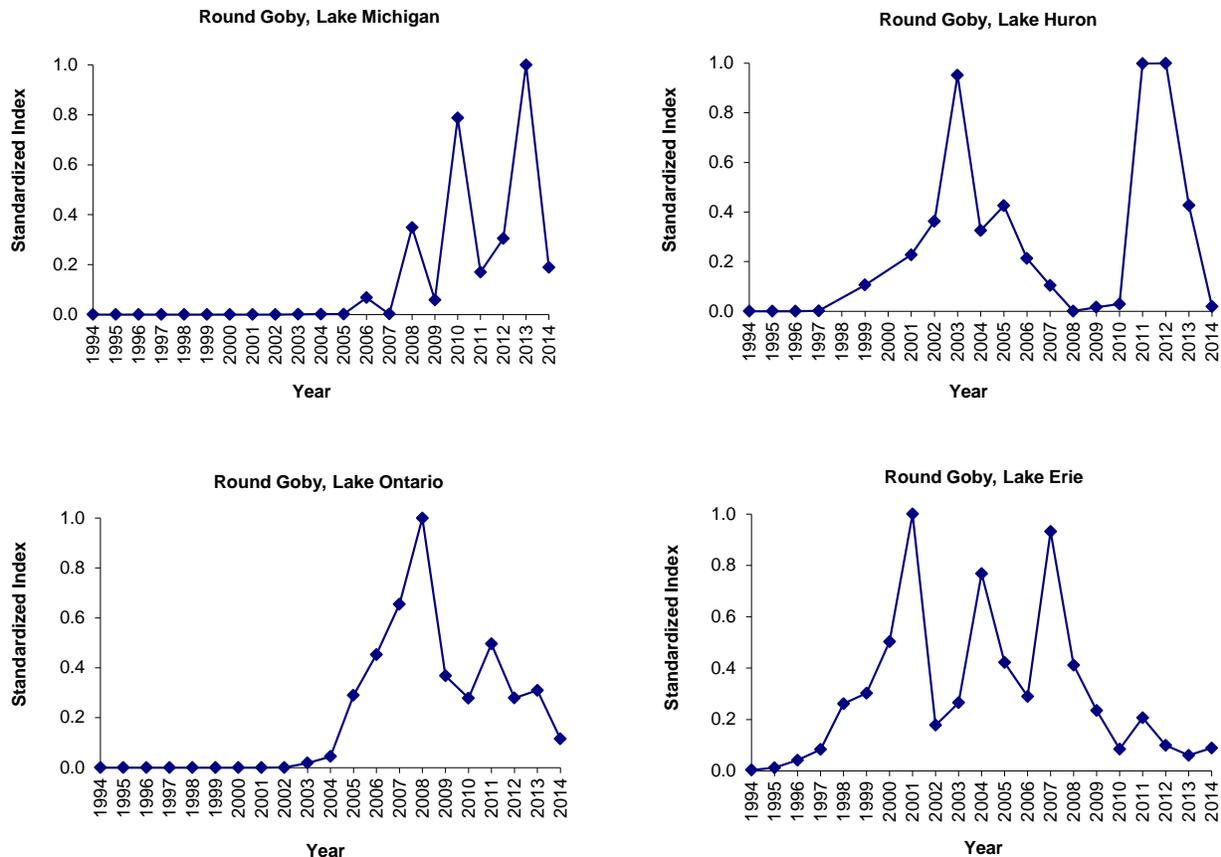


Figure 5. – Standardized indices of abundance for Round Goby in Lakes Michigan, Huron, Ontario, and Erie, 1994-2014. Indices are computed from number caught in Lake Erie and weight caught in all other lakes.

Relative Abundance, Age-0 and older Round Goby

Moderate agreement in trends in relative biomass of age-0 and older Round Goby ($W = 0.53$; $P < 0.004$) was observed among lakes where this species has become established (Lakes Michigan, Huron, Erie, and Ontario; Fig. 5). 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 in 2012-2014 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 2012 and then declined 88% by 2014. The peak in biomass of Round Goby observed in 2013 in Lake Michigan was followed by an 81% decline in 2014, indicating that the population size remains highly volatile. Round Goby biomass in Lake Ontario declined in steps from a maximum in 2008 to 11% by 2014. Although Round Goby biomass showed a considerable amount of year-to-year variability in the Lake Michigan time series, the population may be approaching an equilibrium level. Similarly, the populations in the other three lakes are likely either approaching an equilibrium level or have already reached equilibrium. Round Goby have not been caught in annual bottom trawl surveys in Lake Superior.

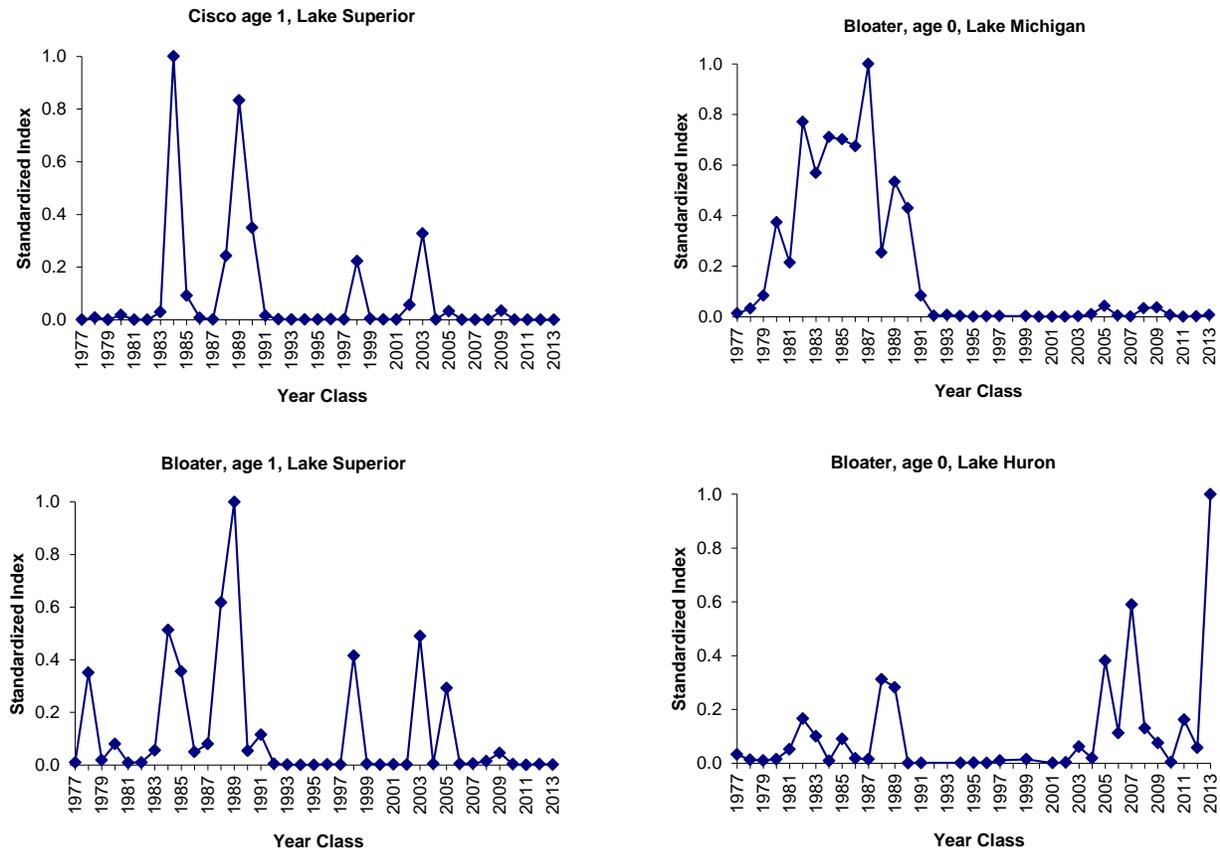


Figure 6. – Standardized indices of densities for age ≤ 1 ciscoes (Cisco and Bloater) in Lakes Superior, Michigan, and Huron, 1977-2013.

Year-Class Strengths, Coregonids

Trends in relative strengths of 1977-2014 coregonid year-classes showed moderate agreement ($W = 0.50$; $P < 0.001$) among Lakes Superior, Michigan, and Huron (Fig. 6). Restricting the comparison to Bloater improved the agreement slightly ($W = 0.59$; $P < 0.006$). 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 after 2004 (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 ($W = 0.40$; $P = 0.21$) among the Lakes for 1977-2011 year-classes (Fig. 7). 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 ($r = 0.040$; $P = 0.22$).

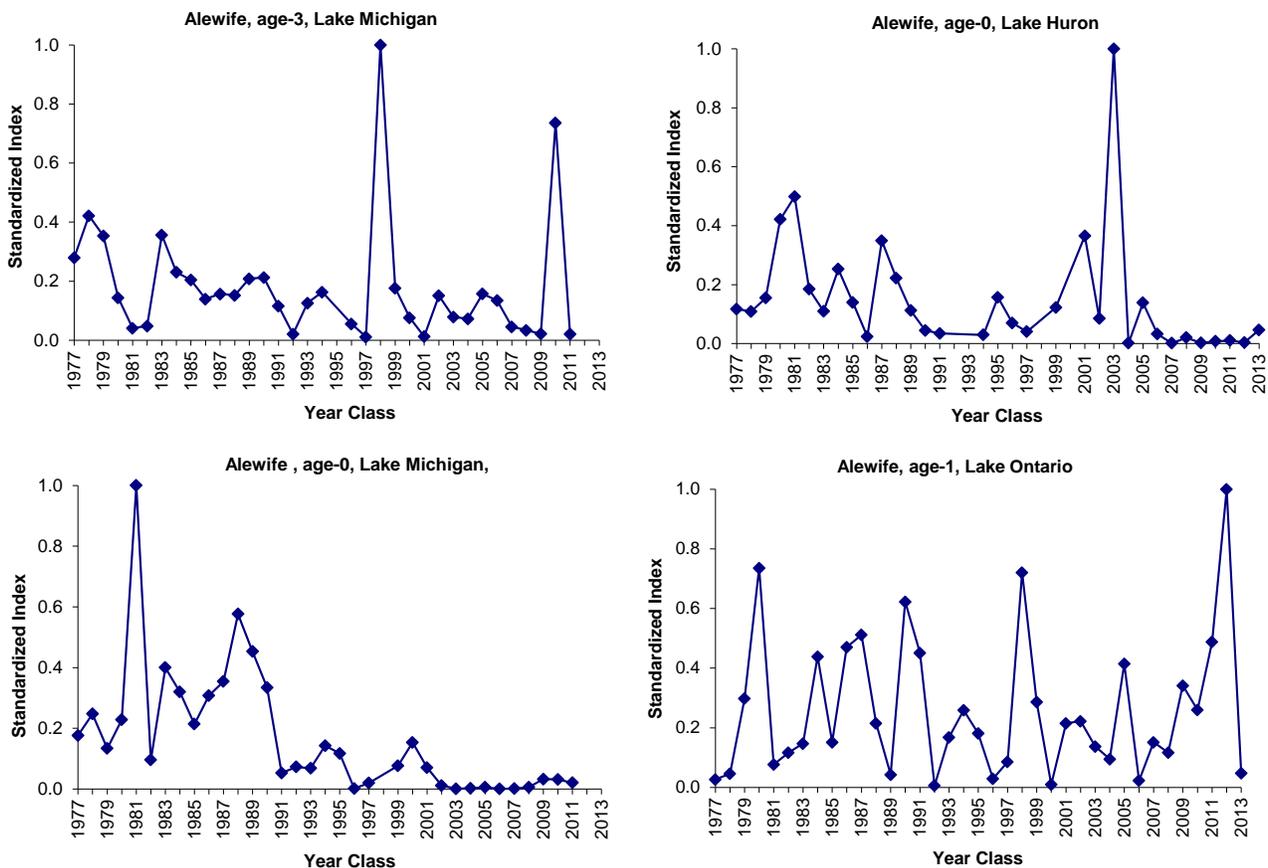


Figure 7. – Standardized indices of Alewife densities measured at age 0, 1 or 3 in Lakes Michigan, Huron, and Ontario, 1977-2013.

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 2013 showed weak agreement (Fig. 8; $W = 0.36$; $P = 0.05$). When the comparison was limited to Lakes Superior, Michigan, and Huron, the agreement was not significant ($W = 0.36$; $P = 0.35$). Paired comparisons among the three lakes showed that only Lakes Superior and Michigan were in agreement ($r = 0.54$; $P < 0.01$). In Lake Superior, year-class strengths varied from moderate to strong during 1977-1996, subsequently declined to weak levels in

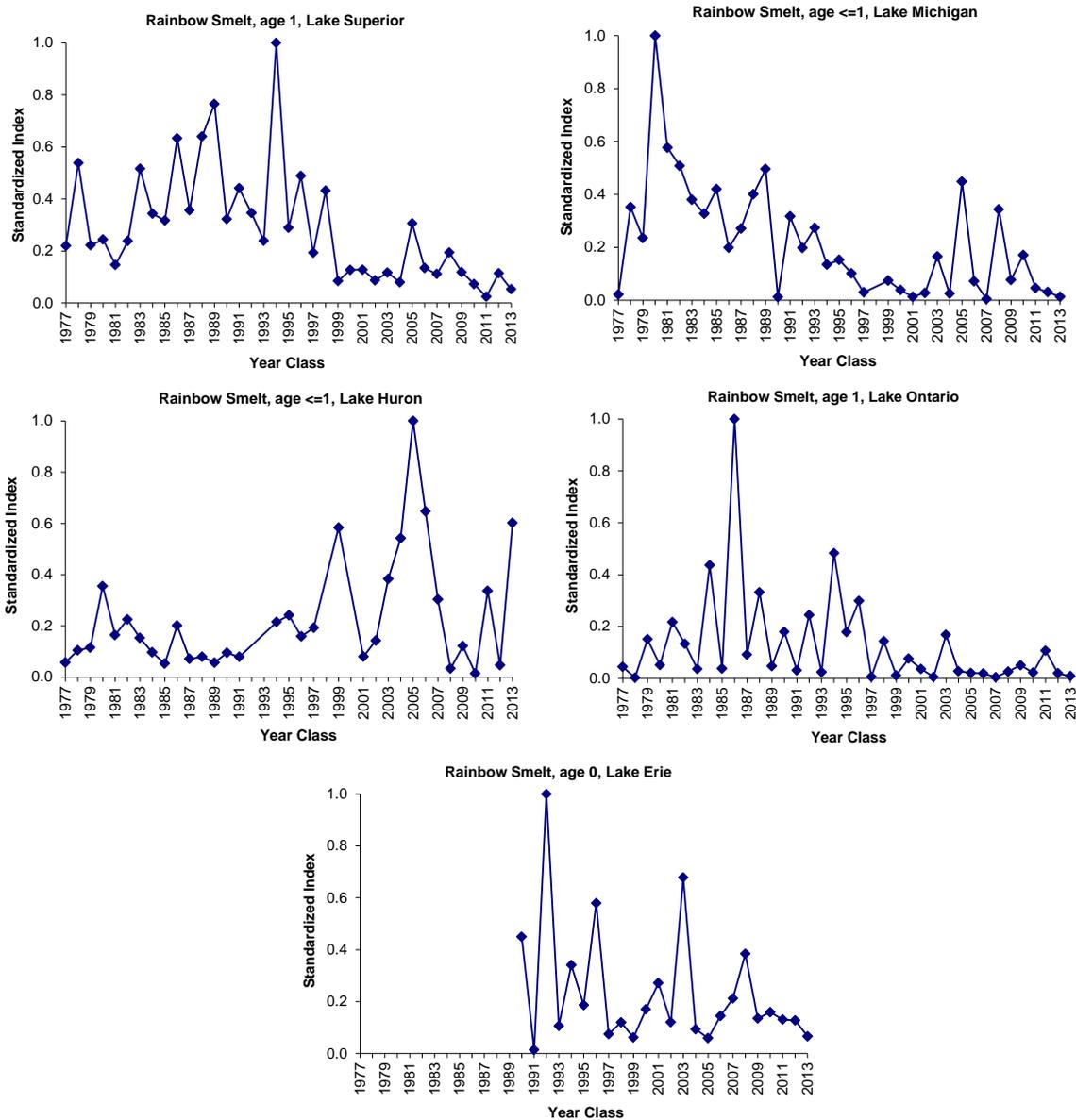


Figure 8. – Standardized indices of Rainbow Smelt densities measured at age-1 in Lakes Superior and Ontario and at age-0 in Lakes Michigan, Huron and Erie, 1977-2013.

1999-2002, and varied from weak to moderate in 2003-2009 and reached a record low in 2011 and near record lows in 2010 and 2013. In Lake Michigan, year-class strengths declined steadily from 1980 to 1997 and thereafter 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 37-year time series, and then increased rapidly to a peak in 2005 followed by a steep decline to record lows in 2008 and 2010 and then rebounded to 34% of the record in 2011, plunged to 5% in 2012, and rebounded to 60% in 2013. 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 1999-2013 due to a succession of weak year classes punctuated by moderate year classes in 2003 and 2011. To include Lake Erie in our analysis, the comparison was restricted to the 1990-2013 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 ($r = 0.57$; $P < 0.05$) and Lakes Ontario and Superior ($r = 0.49$; $P < 0.05$). Agreement between Lakes Erie and Ontario was caused by concordance in up and down patterns of year-class strengths between 1990 and 2005 (Fig. 8). 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. 8).

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 Cisco and Bloater, the highest biomass occurred from the late 1980s to the early 1990s. Rainbow Smelt biomass declined slowly and erratically during the last quarter century. In general, Alewife biomass was substantially higher during the 1980s and 1990s compared with the post-2003 era.

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 and the largest on record in 2013. The resurgence of Bloater in Lake Huron notwithstanding, the general concordance in population trends of Bloater and Cisco across the Great Lakes supports hypotheses for large-scale environmental factors influencing the synchrony of recruitment in Great Lakes coregonids. Especially notable in this regard is concordance in trends of Cisco in Ontario, where it is a rare species, with Cisco and Bloater in Lakes Superior, Michigan, and Huron.

In general, trends in year-class strengths of prey fishes were less concordant than population biomass across the basin and only coregonids showed statistical agreement across the upper Great Lakes (data on year-class strengths for Lake Ontario Cisco were not available). The appearance of strong and moderate year-classes of Bloater in Lake Huron in 2005-2013 countered the common trend of continuing weak year-classes of coregonids in Lakes Michigan and Superior. 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. Nonetheless, Round Goby biomass may be nearing equilibrium levels in all four of these lakes, as Round Goby has become increasingly important in 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, 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, 2014¹

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Abstract

In 2014, the Lake Superior fish community was sampled with daytime bottom trawls at 73 nearshore and 30 offshore stations. Spring and summer water temperatures were the coldest measured for the period of records for the surveys. In the nearshore zone, a total of 15,372 individuals from 28 species or morphotypes were collected. Nearshore lakewide mean biomass was 6.9 kg/ha, which was higher than that observed in the past few years, but below the long-term average of 9.2 kg/ha. In the offshore zone, a total 12,462 individuals from 11 species were collected lakewide. Offshore lakewide mean biomass was 6.6 kg/ha. The mean of the three previous years was 8.6 kg/ha. We collected larval *Coregonus* in surface trawls at 94 locations and estimated a lakewide average density of 577 fish/ha with a total lakewide population estimate of 14.2 billion (standard error \pm 30 million).

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. We report population biomass estimates for a number of common species and recruitment indices of the density of age-1 fish for selected commercial and recreational species (Rainbow smelt, Cisco, Bloater, Lake Whitefish, and Lake Trout) from nearshore surveys, and population biomass estimates from offshore surveys. 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 adult Cisco, and adult Lake Trout (scientific names are provided in Table 1). In addition to benthic fish sampling we collected larval fish, vertical zooplankton samples, and water profiles for a number of physical and chemical attributes. We report on larval fish collections and water temperatures.

Methods

Nearshore survey

Nearshore sites are located around the perimeter of the lake (Figure 1). We used bottom trawls towed in cross-contour fashion to sample fish at depths ranging from 15-80 m. In 2014, 73 of the 83 long-term sampling locations were sampled between 19 May and 18 June 2014 (Figure 1). Ten locations were not sampled due to commercial fishing operations or mechanical problems. At each location, a single trawl tow was conducted with a 12-m Yankee bottom trawl. The median start and end depths for bottom trawl tows were 17 m (range 11-40 m) and 55 m (range 19-144 m), respectively. The median trawl distance was 1.7 km (range 0.4-3.8 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 maximum of 50 individuals per species per trawl. Length data for these individuals were then expanded 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 estimates 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. 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, 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 (Figure 1). Sample sites were selected in 2011 and the same sites have been sampled thereafter. In 2014, 30 of 35 established trawl locations were sampled during daylight hours between 6 and 21 July. Five sites were not sampled due mechanical issues. A single bottom trawl tow was conducted at each site using a 12-m Yankee bottom trawl towed on-contour during daylight hours. Station depths ranged from 87 to 315 m. The mean and median trawl distance was 1.4 km (range 1.2-1.5 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. These three species make up >95% of the total biomass.

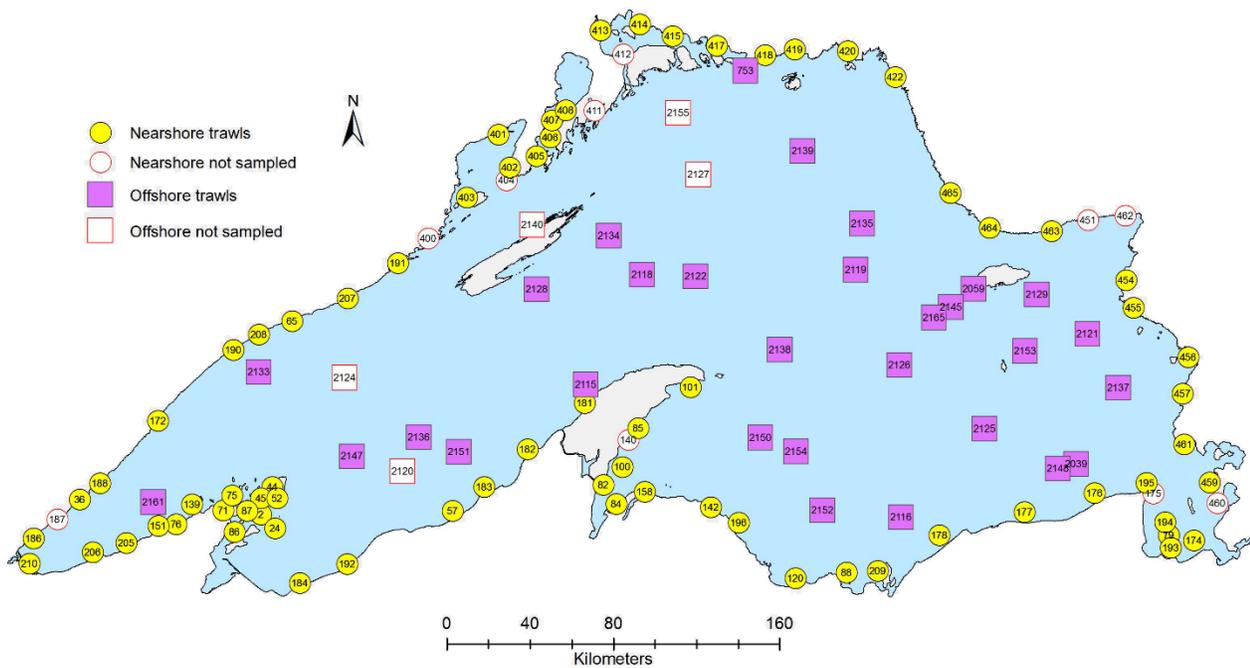


Figure 1. Location of 83 nearshore and 35 offshore bottom trawl stations established for sampling the Lake Superior fish community. In 2014, 73 nearshore and 30 offshore sites were sampled. Numbers are station numbers. Nearshore and offshore sites that were not sampled in 2014 are shown in white circles and squares, respectively.

Larval *Coregonus* collections

A paired 1 m² 500 micron mesh neuston net was fished at the lake surface for 10 minutes at the same time we were bottom trawling at 94 locations (most sites shown in Figure 1, all sites shown in Figure 7) between 19 May and 24 July. The purpose of this sampling was to describe the spatial distribution of larval *Coregonus*. We think most of these fish are Cisco, other possible species are Bloater and Kiyi. At this time they cannot be differentiated.

Results

Nearshore survey

Mean water temperatures throughout the survey period were 3.5 C (range = 1.9-12.5 C) at the surface and 2.5 C (range = 2.4-2.6 C) at 100 m (Figure 2). The long-term mean (1991-2014) water temperatures for these same locations and dates is 5.9 C at the surface and 3.5 C at 100 m. A total of 15,372 individuals from 28 species or morphotypes were collected (Table 1). The number of species collected at each station ranged from 0 to 14, with a mean of 6.3 and median of 6. Lakewide mean biomass was 6.9 kg/ha, which was higher than that observed in the past few years, but below the long-term average of 9.2 kg/ha (Table 2, Figure 3). Lakewide median biomass was 1.7 kg/ha in 2014 which was slightly less than the long-term average median of 2.0 kg/ha (Figure 3). Individual station biomass was non-normally distributed and skewed to the left (Figure 4). The skewness of the population mean biomass estimates in 2014 was 6.3, which was above the long-term mean of 3.6 (Figure 4). The highest individual stations biomass was estimated from stations 86 and 87 in the Apostle Islands.

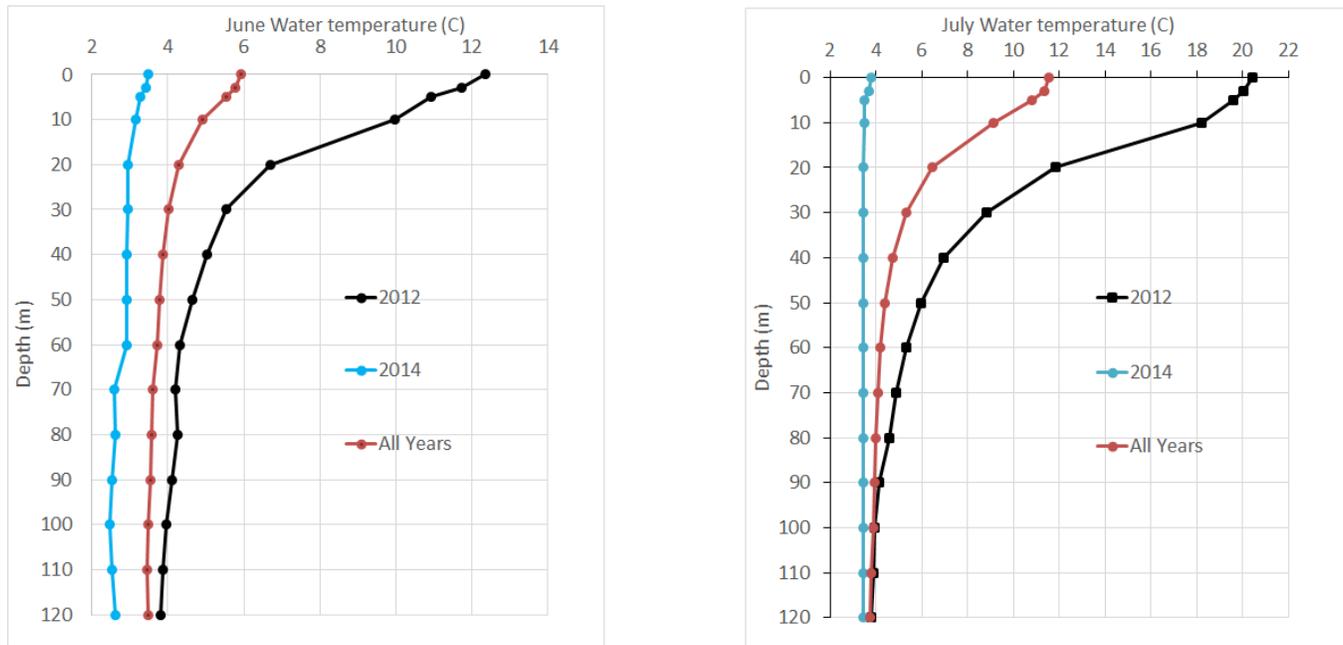


Figure 2 Water temperature profiles for nearshore samples collected in June (left) and for offshore sites collected in July (right). Lines are shown for 2014, 2012 - the warmest year on record, and the period of record mean. For nearshore sites the mean was calculated for the years 2001-2014. For offshore sites the mean was calculated for the years 2011-2014.

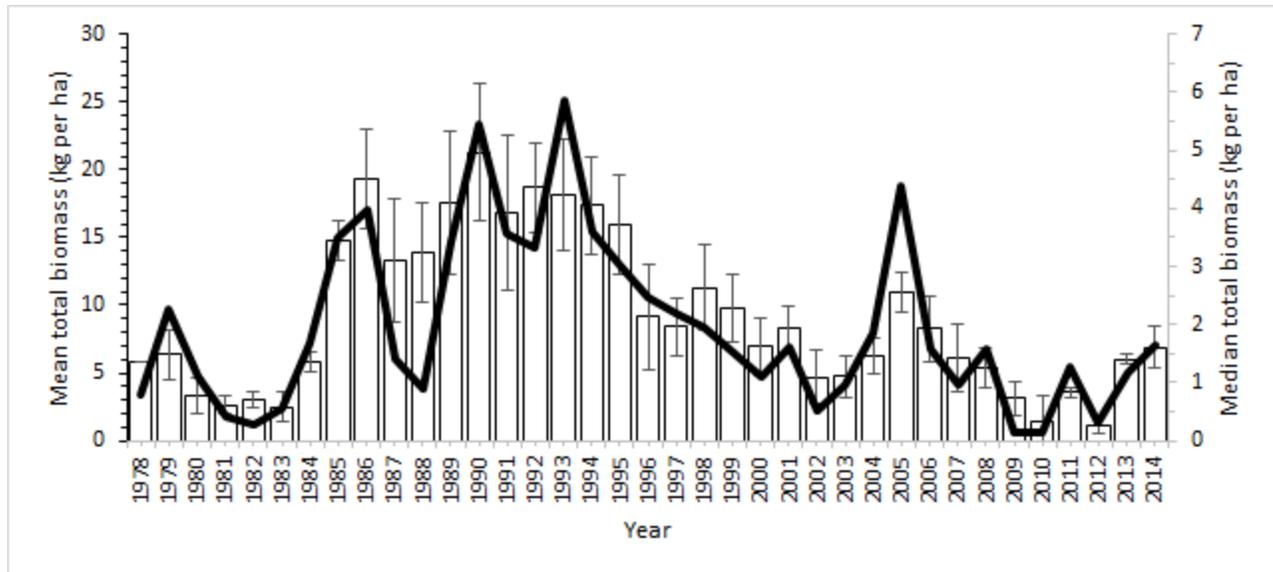


Figure 3. Bars denote the mean \pm SE (left axis) and the line is the annual median (right axis) lakewide biomass of all fish species collected in bottom trawls in nearshore stations from 1978-2014.

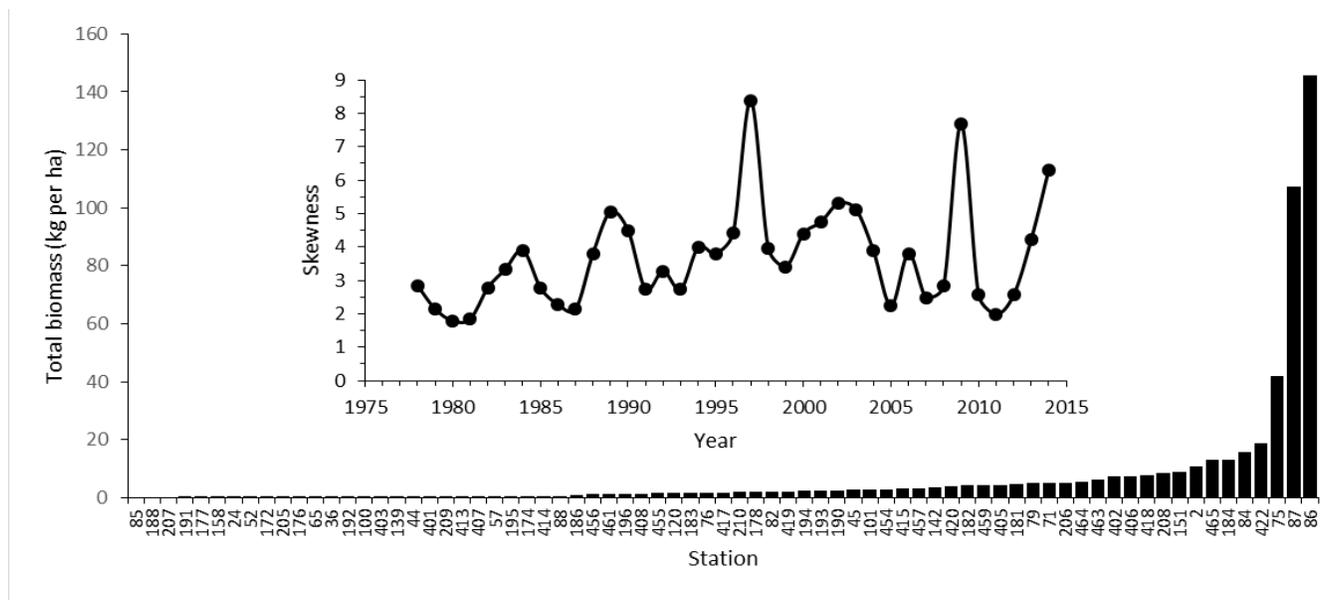


Figure 4. Bars denote the estimated biomass at individual sampling stations in 2014. Station locations are shown on Figure 1. The inset line graph shows the skewness in the distribution of individual station annual biomass estimates.

Cisco – Lakewide mean nearshore biomass of Cisco was 0.35 kg/ha in 2014. This was well below the long-term average of 2.51 kg/ha and similar to that observed since 2007 (Table 2). Density of age-1 fish was 0.01 fish/ha in 2014, which was well below population estimates observed during good recruitment years when estimates typically exceed 175 fish/ha (Table 3). The last strong year class was produced in 2003.

Bloater – Lakewide mean nearshore biomass for bloater was 0.50 kg/ha in 2014. This was well below the long-term average of 1.73 kg/ha (Table 2). Density of age-1 fish was 0.06 fish/ha in 2014, which was well below the population estimates observed during good recruitment years when estimates typically exceed 20 fish/ha (Table 3). The last strong year class was produced in 2003.

Lake Whitefish – Lakewide mean nearshore biomass for Lake Whitefish was 4.31 kg/ha in 2014. This was greater than the long-term average of 2.19 kg/ha (Table 2). Density of age-1 fish was 2.27 fish/ha in 2014, which was below the long-term average of 7.48 fish/ha (Table 3). The majority (80%) of all Lake Whitefish were collected in management unit WI-2 in 2014. The mean biomass estimate in WI-2 in 2014 was 22.8 kg/ha and the median was 0.15 kg/ha.

Rainbow Smelt – Lakewide mean nearshore biomass for Rainbow Smelt was 0.43 kg/ha in 2014. This was less than the long-term average of 1.20 kg/ha and in the range of that observed since 2009 (Table 2). Density of age-1 fish was 68.46 fish/ha in 2014, which was less than the long-term average of 162.54 fish/ha (Table 3).

Sculpin – Lakewide mean nearshore biomass for Sculpin was 0.02 kg/ha in 2014. This was below the long-term average of 0.06 kg/ha. Sculpin biomass has not exceeded 0.06 kg/ha since 1998 (Table 2).

Other species – The combined mean nearshore lakewide biomass for other species was 0.59 kg/ha in 2014. This was less than the long-term mean of 0.70 kg/ha. Other species include Ninespine Stickleback, Trout-perch, Kiyi, Shortjaw Cisco, Pygmy Whitefish, Round Whitefish, and Longnose Sucker.

Burbot – Lakewide mean nearshore biomass for Burbot was 0.08 kg/ha in 2014. This was below the long-term average of 0.13 kg/ha. Burbot biomass has not exceeded 0.13 kg/ha since 2008. Burbot biomass has been erratic throughout the long-term time series (Table 2).

Lake Trout – Lakewide mean nearshore biomass for hatchery Lake Trout was near zero in 2014; one fish was caught in both surveys. Hatchery Lake Trout biomass has for the most part been near zero since 2002 (Figure 5). Lean Lake Trout biomass was 0.37 kg/ha; similar to the long-term mean (Table 2). Siscowet Lake Trout nearshore biomass was 0.27 kg/ha. This was higher than the long-term mean and similar to that observed in 2013 (Table 2). Density of age-3 and younger lean and siscowet Lake Trout were zero and 0.06 fish/ha in 2014, respectively. Young lean Lake Trout densities were less than the long-term average and siscowet Lake Trout densities were similar to the long-term average (Table 3).

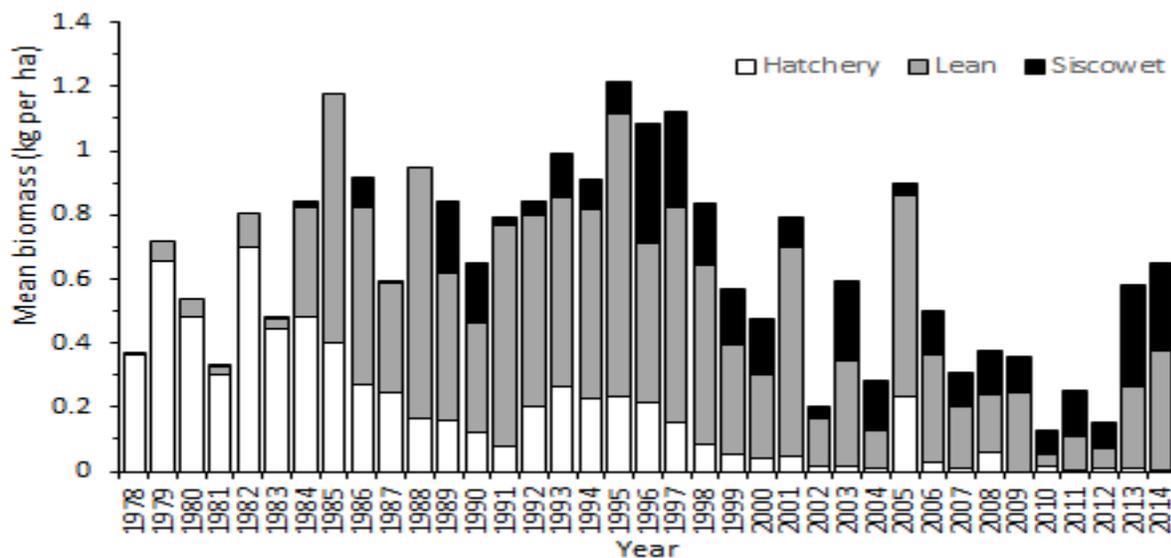


Figure 5. Mean annual lakewide biomass estimates for hatchery, lean, and siscowet Lake Trout estimated from bottom trawls in nearshore locations from 1978-2014.

Offshore survey

Mean water temperatures throughout the survey period were 3.8 C at the surface, 3.4 C at 100 m, and 3.3 C at 200 m (Figure 2). The long-term mean (2011-2014) water temperatures for these same locations and dates are 11.6 C at the surface, 4.0 C at 100 m, and 3.6 C at 200 m. A total 12,462 individuals of 11 species were collected lakewide at 30 offshore sites (Table 1). The number of species collected at each station ranged from 1-7. The mean and median number of species collected per site was four. Deepwater Sculpin, Kiyi, and siscowet Lake Trout made up 97% of the total biomass collected in offshore waters (Figure 6). Mean lakewide biomass was 6.6 kg/ha. In comparison, total mean biomass was 9.1 in 2011, 7.5 in 2012, and 9.3 kg/ha in 2013. The median biomass was 5.5 kg/ha. In comparison, total median biomass was 8.0 in 2011, 5.8 in 2012, and 7.7 kg/ha in 2013.

Deepwater Sculpin – Lakewide mean offshore biomass of Deepwater Sculpin was 1.9 kg/ha. This was less than that observed in previous years; 2.6, 3.1, and 2.9 kg/ha in 2011, 2012, and 2013, respectively.

Kiyi – Lakewide mean offshore biomass of Kiyi was 1.5 kg/ha. This was less than that observed in previous years; 2.8, 1.8, and 2.2 kg/ha in 2011, 2012, and 2013, respectively.

Siscowet Lake Trout – Lakewide mean offshore biomass of siscowet Lake Trout was 3.0 kg/ha. This was less than that observed in previous years; 3.6, 2.3, 3.9 kg/ha 2011, 2012, and 2013, respectively.

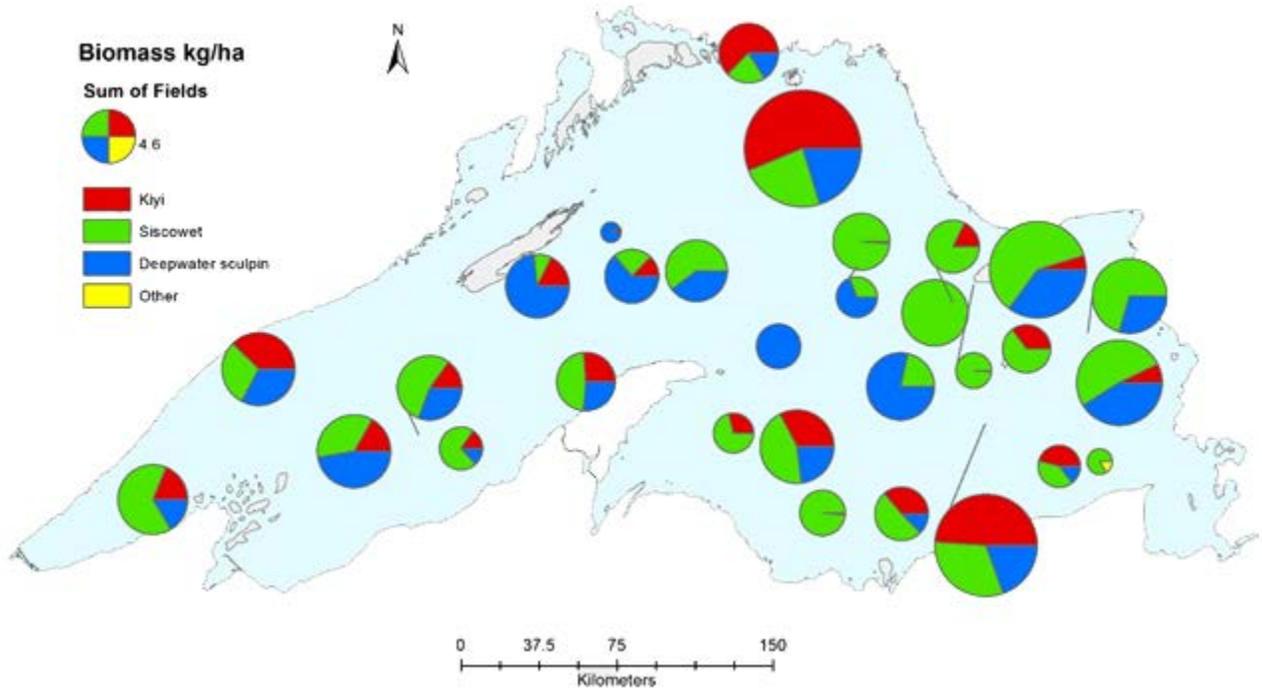


Figure 6. Mean lakewide biomass estimates for Kiyi, siscowet Lake Trout, Deepwater Sculpin, and other species estimated from bottom trawls in offshore locations in 2014. Pie diameter is proportional to the biomass collected at that site and ranged from 0.6-22.1 kg/ha. The pie in the legend is proportional to 4.6 kg/ha with the size of the pies on the map scaled accordingly.

Larval Coregonus collections

A total of 7,432 larval *Coregonus* were collected. The lakewide average density was 577 fish/ha and ranged from 0 to 19,263 fish/ha (Figure 7). The total number of estimated larval *Coregonus* lakewide was 14.2 billion with a standard error of ± 30 million. Fish collected at the start of the survey were 8-10 mm in length suggesting they hatched around May 1st (Oyadomari and Auer 2008, CJFAS 65:1447-1358). Fish were >20 mm in July.

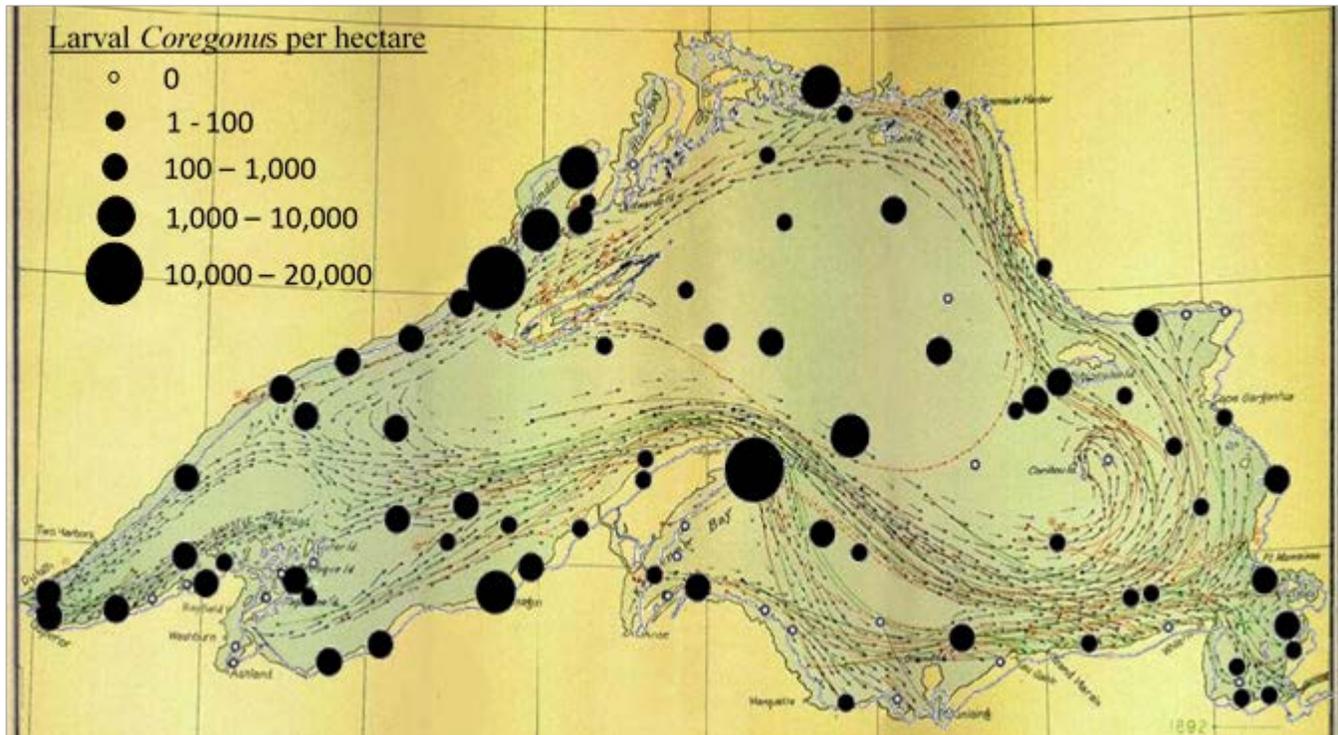


Figure 7. Estimated larval *Coregonus* abundances (number/ha) collected in 2014 from surface trawling. Surface water current depictions are from an unknown source that were determined in 1892-1894.

Summary

Over the 37 year history of the nearshore survey, total reported biomass has been largely dependent on recruitment of age-1+ 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 fishery managers. The continued increase in siscowet Lake Trout in the nearshore zone is something of interest as well. Less variation has been observed in the offshore zone which has a smaller complement of species. The combination of the two surveys provide a lakewide picture of the Lake Superior fish community that are susceptible to bottom trawls. It is hopeful that continued collection of our new surface trawl survey for larval fish will improve our understanding of *Coregonus* recruitment dynamics.

Table 1. Fish species and the number of individuals collected in nearshore and offshore surveys in Lake Superior in 2014.

Fish	Scientific name	Nearshore	Offshore
Alewife	<i>Alosa pseudoharengus</i>	4	0
Blackfin Cisco	<i>Coregonus nigripinnis</i>	1	0
Bloater	<i>Coregonus hoyi</i>	485	24
Burbot	<i>Lota lota</i>	19	1
Cisco	<i>Coregonus artedii</i>	97	0
Deepwater Sculpin	<i>Myoxocephalus thompsonii</i>	94	11199
Emerald Shiner	<i>Notropis atherinoides</i>	2	0
Eurasian Ruffe	<i>Gymnocephalus cernuus</i>	1	0
hatchery Lake Trout	<i>Salvelinus namaycush</i>	1	0
Johnny Darter	<i>Etheostoma nigrum</i>	1	0
Kiyi	<i>Coregonus kiyi</i>	50	928
Lake Whitefish	<i>Coregonus clupeaformis</i>	1492	0
lean Lake Trout	<i>Salvelinus namaycush</i>	98	10
Longnose Sucker	<i>Catostomus catostomus</i>	68	0
Ninespine Stickleback	<i>Pungitius pungitius</i>	698	25
Pygmy Whitefish	<i>Prosopium coulteri</i>	1682	23
Rainbow Smelt	<i>Osmerus mordax</i>	8904	1
Round Whitefish	<i>Prosopium cylindraceum</i>	5	0
Sea Lamprey	<i>Petromyzon marinus</i>	1	0
Shortjaw Cisco	<i>Coregonus zenithicus</i>	21	0
siscowet Lake Trout	<i>Salvelinus namaycush siscowet</i>	56	226
Slimy Sculpin	<i>Cottus cognatus</i>	528	23
Spoonhead Sculpin	<i>Cottus ricei</i>	65	0
Spottail Shiner	<i>Notropis hudsonius</i>	2	0
Trout-perch	<i>Percopsis omiscomaycus</i>	991	0
unidentified chubs	<i>Coregonus</i>	2	2
White Sucker	<i>Catostomus commersoni</i>	1	0
Yellow Perch	<i>Perca flavescens</i>	3	0
Total number of species		28	11
Total number of individuals		15,372	12,462

Table 2. U.S. Geological Survey spring bottom trawl estimated nearshore mean lakewide biomass (kg/ha) of common fishes in Lake Superior, 1978-2014. Sculpin includes Slimy, Spoonhead, and Deepwater sculpin. All fish is the mean and median total biomass for all species. Other species includes Ninespine Stickleback, Trout-Perch, Kiyi, Shortjaw Cisco, Pygmy Whitefish, Round Whitefish, and Longnose Sucker.

Year	Sites	Species	All Fish Mean	All Fish Median	Rainbow Smelt	Cisco	Lake Whitefish	Bloater	hatchery Lake Trout	lean Lake Trout	siscowet Lake Trout	Burbot	Sculpin	Other species
1978	43	17	5.88	0.78	4.07	0.01	0.70	0.13	0.37	0.00	0.00	0.17	0.14	0.29
1979	49	17	6.33	2.25	2.17	0.06	1.27	0.45	0.66	0.06	0.00	0.30	0.20	1.15
1980	48	16	3.28	1.11	0.87	0.28	0.58	0.28	0.48	0.05	0.00	0.19	0.19	0.35
1981	48	19	2.62	0.42	0.21	0.36	0.67	0.41	0.30	0.02	0.00	0.24	0.18	0.22
1982	32	18	3.06	0.29	0.25	0.35	0.85	0.43	0.70	0.10	0.00	0.06	0.03	0.29
1983	50	19	2.48	0.54	0.92	0.17	0.20	0.43	0.45	0.03	0.00	0.07	0.06	0.15
1984	53	21	5.82	1.67	0.80	0.65	1.27	1.75	0.48	0.34	0.02	0.20	0.06	0.25
1985	53	19	14.77	3.50	1.33	6.53	2.14	2.69	0.40	0.78	0.00	0.05	0.08	0.77
1986	53	19	19.28	3.97	2.84	8.65	2.65	3.79	0.27	0.55	0.09	0.18	0.07	0.19
1987	53	16	13.26	1.40	1.78	5.69	2.00	2.57	0.25	0.34	0.00	0.14	0.07	0.44
1988	53	19	13.89	0.90	1.18	3.10	2.40	5.97	0.16	0.78	0.00	0.08	0.04	0.17
1989	76	21	17.60	3.41	2.08	6.21	5.54	1.71	0.16	0.46	0.23	0.21	0.08	0.93
1990	81	22	21.28	5.44	1.95	10.12	2.36	4.85	0.12	0.34	0.19	0.11	0.08	1.17
1991	84	22	16.83	3.57	1.17	10.23	2.74	0.81	0.08	0.69	0.02	0.21	0.10	0.78
1992	85	24	18.65	3.33	1.02	3.40	3.70	8.39	0.20	0.59	0.05	0.17	0.07	1.06
1993	87	23	18.12	5.86	2.12	4.99	3.67	4.28	0.27	0.59	0.14	0.27	0.08	1.71
1994	87	23	17.39	3.59	1.89	7.24	5.42	0.42	0.23	0.59	0.09	0.11	0.08	1.32
1995	87	27	15.95	3.02	2.21	3.96	5.84	0.57	0.23	0.88	0.10	0.14	0.09	1.92
1996	87	26	9.13	2.48	1.28	1.04	1.63	3.09	0.22	0.50	0.37	0.19	0.11	0.69
1997	85	30	8.41	2.20	1.35	1.35	2.77	0.86	0.15	0.67	0.30	0.10	0.06	0.80
1998	87	22	11.29	1.95	1.47	1.09	2.26	4.37	0.08	0.56	0.19	0.07	0.07	1.12
1999	83	23	9.76	1.54	1.11	2.73	1.28	3.13	0.05	0.35	0.17	0.07	0.04	0.83
2000	85	25	6.92	1.10	0.83	2.42	1.60	0.94	0.04	0.27	0.17	0.02	0.04	0.59
2001	83	32	8.24	1.63	1.52	1.15	2.78	1.19	0.05	0.65	0.09	0.13	0.04	0.63
2002	84	26	4.68	0.53	0.18	1.48	1.69	0.57	0.02	0.15	0.04	0.10	0.02	0.44
2003	86	26	4.74	0.98	0.31	0.64	1.84	0.88	0.01	0.33	0.24	0.01	0.02	0.45
2004	75	25	6.31	1.87	0.32	1.80	1.88	1.15	0.01	0.12	0.15	0.20	0.03	0.65
2005	52	27	10.97	4.39	1.00	2.23	4.37	1.65	0.23	0.63	0.04	0.31	0.01	0.51
2006	55	24	8.29	1.57	0.95	2.25	1.70	1.79	0.03	0.33	0.14	0.08	0.02	1.00
2007	56	31	6.09	0.97	1.77	0.27	1.86	0.90	0.01	0.19	0.11	0.12	0.02	0.84
2008	59	23	5.37	1.57	0.94	0.38	2.37	0.17	0.06	0.18	0.14	0.29	0.02	0.83
2009	64	20	3.14	0.14	0.38	0.30	0.15	1.18	0.00	0.25	0.11	0.04	0.02	0.72
2010	76	24	1.46	0.13	0.22	0.31	0.27	0.23	0.01	0.04	0.08	0.03	0.05	0.23
2011	82	21	3.56	1.28	0.62	0.41	0.94	0.56	0.01	0.11	0.14	0.02	0.05	0.70
2012	72	25	1.14	0.31	0.16	0.02	0.15	0.35	0.01	0.07	0.08	0.02	0.03	0.26
2013	79	27	6.03	1.17	0.53	0.52	2.98	0.49	0.01	0.26	0.31	0.10	0.02	0.81
2014	73	27	6.91	1.66	0.43	0.35	4.31	0.50	0.00	0.37	0.27	0.08	0.02	0.59
Mean	68.78	22.86	9.16	1.96	1.20	2.51	2.19	1.73	0.18	0.36	0.11	0.13	0.06	0.70

Table 3. U.S. Geological Survey spring bottom trawl estimated nearshore mean lakewide density (number/ha) 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 <226 mm, ca. < age 3.

Year class	Sites	Rainbow Smelt	Cisco	Bloater	Lake Whitefish	lean Lake Trout	Siscowet Lake Trout
1977	43	95.76	0.03	0.82	2.62	0.21	0.00
1978	49	234.14	6.30	30.08	3.90	0.35	0.00
1979	48	96.79	0.11	1.57	1.97	0.25	0.00
1980	48	106.26	13.48	6.85	16.43	0.57	0.07
1981	32	63.81	0.16	0.75	4.16	0.44	0.00
1982	50	103.58	0.05	0.82	0.45	0.41	0.00
1983	53	224.39	21.76	4.74	8.04	1.18	0.00
1984	53	149.51	748.02	44.00	2.47	1.30	0.00
1985	53	150.41	68.92	30.55	3.45	0.86	0.12
1986	53	275.59	5.44	4.23	11.91	0.72	0.04
1987	53	155.27	0.52	6.86	6.11	0.52	0.00
1988	76	274.78	226.80	37.69	36.08	0.26	0.13
1989	81	272.04	425.64	57.26	8.78	0.44	0.05
1990	84	162.03	236.87	11.38	17.54	0.67	0.01
1991	85	176.94	9.08	10.71	11.84	0.81	0.05
1992	87	155.24	3.34	0.22	7.68	0.84	0.20
1993	87	198.62	0.76	0.06	4.95	1.14	0.01
1994	87	401.83	1.47	0.00	13.52	1.71	0.05
1995	87	168.25	0.96	0.05	6.33	2.26	0.21
1996	85	253.04	11.09	0.18	8.80	0.77	0.07
1997	87	145.01	1.18	0.12	7.74	1.21	0.04
1998	83	216.18	90.76	0.40	9.17	0.33	0.10
1999	85	58.40	3.85	0.48	0.77	0.36	0.01
2000	83	256.32	0.83	0.12	2.37	0.52	0.03
2001	84	56.79	0.53	0.12	13.68	0.24	0.06
2002	86	77.83	33.20	0.58	7.74	0.18	0.03
2003	75	70.28	175.34	27.22	6.36	0.25	0.03
2004	52	110.39	8.19	12.07	2.97	0.60	0.07
2005	55	249.53	18.58	13.61	5.43	0.37	0.21
2006	56	360.93	0.41	0.32	19.74	0.10	0.05
2007	59	280.69	0.20	0.28	0.63	0.20	0.09
2008	64	71.64	0.27	0.59	3.00	0.07	0.07
2009	76	45.22	14.03	2.46	6.64	0.03	0.05
2010	82	73.98	0.30	0.76	3.98	0.43	0.03
2011	72	11.05	0.03	0.06	1.90	0.40	0.06
2012	79	142.90	0.17	0.22	5.46	0.36	0.06
2013	73	68.46	0.01	0.06	2.27	0.00	0.06
Mean	69	162.54	57.53	8.33	7.48	0.58	0.06

Status and Trends of Pelagic Prey Fish in Lake Huron, 2014[†]

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Abstract

The USGS Great Lakes Science Center conducted acoustic and mid-water trawl surveys of Lake Huron during 1997 and annually during 2004-2014. The 2014 survey was conducted during September and October and included transects in Lake Huron's main basin, Georgian Bay, and North Channel. Mean pelagic fish density was 729 fish/ha in 2014, which was roughly a 30% decrease from the 2013 estimate. However, mean biomass increased by 55 % between 2013 and 2014 from 6.1 to 9.49 kg/ha. Lakewide biomass of pelagic fish species was 44.4 kt – bloater (30.14 kt) and rainbow smelt (14.05 kt) made up most (i.e., >99%) of the standing stock biomass. Biomass density of alewife (<1 kg/ha) remained near record low levels. Age-0 rainbow smelt abundance decreased between 2013 and 2014 (366 to 129 fish/ha), however biomass of age-1+ rainbow smelt increased (1.7 to 2.8 kg/ha). Age-0 bloater abundance decreased in 2014, but biomass of large bloater (6.24 kg/ha) showed a two-fold increase over 2013 estimates. Emerald shiner density and biomass was the lowest recorded for the time series. Based on biomass estimates during 2014, prey fish available to offshore predators during 2015 will consist of increased numbers of larger rainbow smelt and bloater. Lake Huron now has pelagic fish biomass greater than that observed in recent lakewide acoustic surveys of Lake Michigan and Lake Superior, but species composition differs among the three lakes. Of the three upper Great Lakes, Lake Superior had the greatest pelagic prey fish species diversity and greatest occurrence of native pelagic species while Lake Michigan had the lowest species diversity and lowest native fish prevalence, whereas Lake Huron was intermediate along this gradient.

[†]Presented at: Great Lakes Fishery Commission
Lake Huron Committee Meeting
Ypsilanti, MI, March 26, 2015

Introduction

The U.S. Geological Survey's Great Lakes Science Center (GLSC) has conducted bottom trawl surveys of the Lake Huron fish community since the 1970s. These surveys have tracked broad-scale changes in the fish community and provided valuable information on changing prey fish dynamics to fishery managers tasked with balancing predatory demand by native and introduced salmonines (Roseman and Riley 2009, Riley et al. 2008). Although bottom trawling has been an important tool for monitoring long-term trends in fish populations, acoustic and mid-water trawl surveys were implemented because it was recognized that variable yet substantial proportions of prey fish biomass were distributed in pelagic zones, where this biomass would not be available to bottom trawl gear (Wells 1968; Argyle 1982). Recent research has further shown that acoustic and mid-water trawling methods are better at assessing species or life stages that are pelagic, particularly over lake areas with rough bottom (Fabrizio et al. 1997, Stockwell et al. 2007, Yule et al. 2008). Acoustic surveys were first conducted during the 1970s (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 acoustic 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). Saginaw Bay was omitted because of its shallow depth and its prey fish community is surveyed by other methods (Fielder and Thomas 2014). Within each stratum, the first transect was selected randomly based on latitude and 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 (2012-2014).

The 2014 pelagic fisheries survey was completed during 2 September – 13 October, with sampling conducted by both the GLSC (R/V *Sturgeon*) and USFWS (M/V *Spencer F. Baird*). Twenty-two acoustic transects of roughly 20 km in length were sampled, resulting in approximately 440 km of acoustic data. Thirty-four mid-water trawl tows were conducted in conjunction with acoustic data collection.

Fish species and size composition were determined using a 15-m headrope mid-water trawl (USGS) and a 21-m headrope mid-water trawl (USFWS). Mid-water trawl 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 fishing depth was monitored using a NetmindTM system (GLSC) and a Simrad PI44 catch monitoring system (USFWS). Most mid-water 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 mid-water trawl tows were identified, counted, and weighed in aggregate (g) by

species. Total length in millimeters was measured on a random subsample (100-200 fish) per species per tow. Individual fish were assigned to age categories (age-0 or age 1+) based on size using the following length cutoffs: alewife *Alosa pseudoharengus* =100 mm; rainbow smelt *Osmerus mordax* = 90 mm; bloater *Coregonus hoyi* = 120 mm. Based on previous age estimates for these species, these lengths approximate the lengths of the smallest age-1 fish of these species.

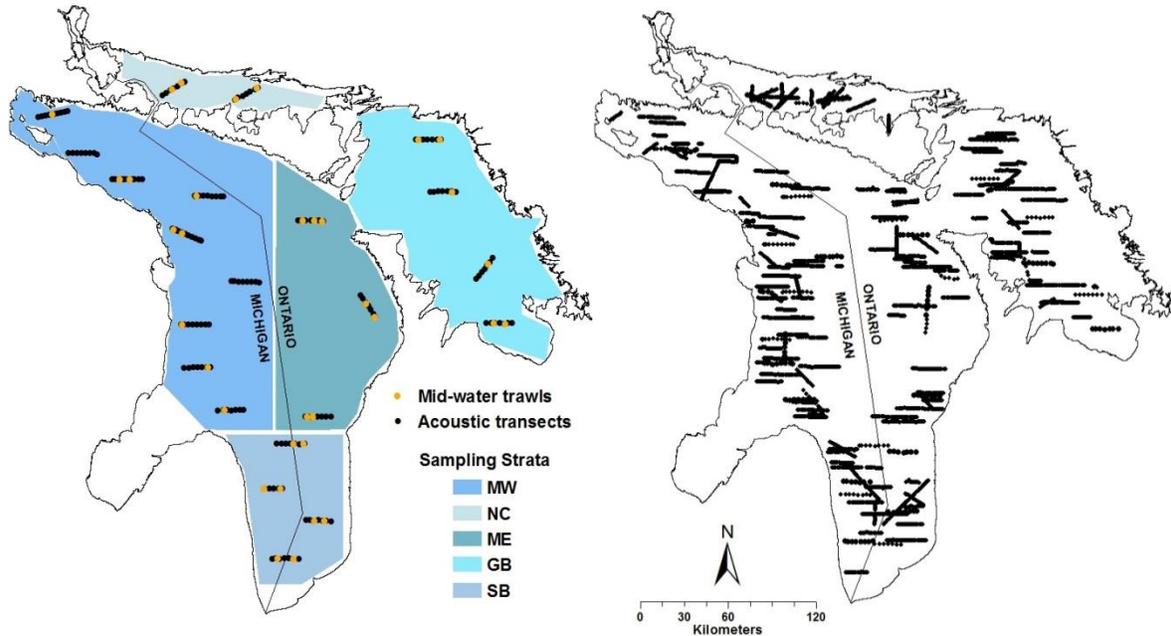


Figure 1. Location of acoustic transects and mid-water trawls, and delineation of sampling strata in Lake Huron during 2014 (left) and location of acoustic transects during surveys in 2004-2013 (right).

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 mid-water 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, standard error, 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.

Acoustic equipment specifications, software versions, single target detection parameters, noise levels, and detection limits can be found in appendices 1 and 2. Supplemental methods on acoustic analysis methods and acoustic equipment can be found in appendix 3.

Density and biomass by species

Alewife – Alewives proliferated in the Lake Huron fish community during the 1950s and became a major component of the diet of native and introduced salmonines following their establishment (Diana 1990). Following several decades of high biomass (i.e., $\approx 30\%$ of total biomass on average), the long-term bottom trawl survey in Lake Huron (1973-present) detected substantial declines in alewife biomass beginning in 2003; biomass remained extremely low during 2004-2014 when adult alewife averaged less than 1.5% of total fish biomass (Roseman et al. 2015).

Since 2004, few alewives have been captured in acoustic and mid-water trawl surveys, and almost all have been age-0 fish. During 2014, density of alewives returned to low levels observed during 2009-2012 (< 1 fish/ha; Figure 2) following increased density during 2013. Alewife densities estimated in 1997, 2005-2006, 2008, and 2013 were considerably higher than other years in the time series. However, we note that density differences, though substantial, did not mean that alewives have been especially abundant in any survey year (Figure 2). During 1997, the year of highest abundance, alewives were only 3.1% of total fish density.

Acoustic estimates of alewife biomass have remained low for the last decade despite large fluctuations in density during 2004-2013 (Figure 2). Temporal biomass differences were largely due to differences in size and age structure between 1997 and other years. In 1997 age 1+ alewife were captured, but low biomass during 2004-2014 is the result of trawl catches dominated by age-0 fish (Figure 2). Since 2004, alewives have never comprised more than 1.75% of pelagic fish biomass. Although mid-water trawl catches of age-0 alewives occurred during some acoustic surveys, recruitment has been limited and alewives have shown no sign of returning to higher abundance. During the 2014 survey, two alewives were captured in the mid-water trawl. Our findings are consistent with results from the 2014 annual bottom trawl survey (Roseman et al. 2015), which indicated that alewife density and biomass remain low (i.e., < 1 fish/ha, < 1 kg/ha, respectively).

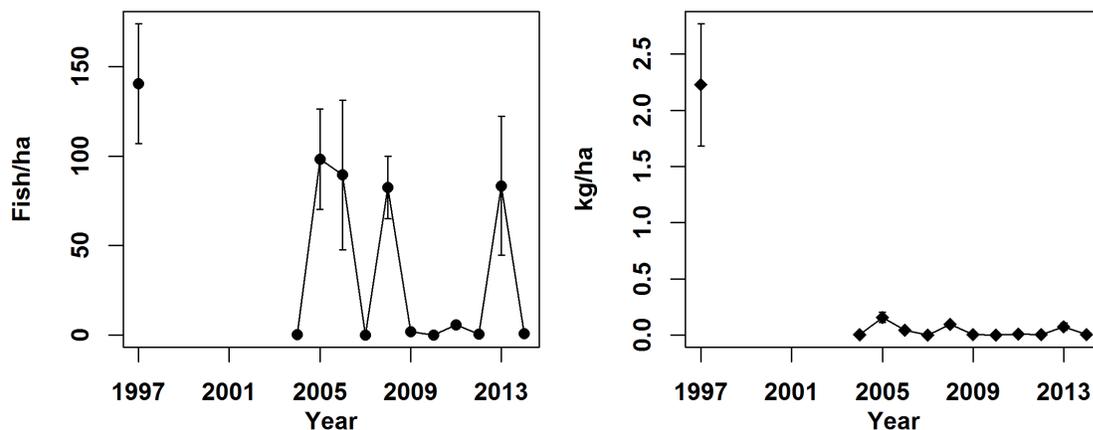


Figure 2. Acoustic and mid-water trawl estimates of alewife numeric density (fish/ha; left panel) and biomass (kg/ha; right panel) in Lake Huron, 1997-2014. Error bars represent ± 1 standard error.

Rainbow smelt – Intentionally introduced as a prey species for inland salmonines, rainbow smelt invaded Lake Huron where populations rapidly expanded during the 1930’s (Berst and Spangler 1972). Similar to alewives, rainbow smelt became a key component in Lake Huron’s prey fish community following their invasion. Long-term bottom trawl surveys in Lake Huron tracked the gradual decline of rainbow smelt beginning in 1990; however, their decline has not been as pronounced as alewives. Rainbow smelt remain common in bottom trawl catches and have averaged roughly 16% of total prey fish biomass annually since 2004. Furthermore, rainbow smelt remain important in diets of Lake Huron piscivores (Roseman et. al 2014).

Acoustic and mid-water trawl survey estimates of age-0 rainbow smelt density have been variable over the time series with the highest density occurring during 1997, followed by 2009 and 2006 (Figure 3). During 2014, age-0 rainbow smelt density decreased from 2013 estimates to 17% of the long-term mean and was the lowest observed during the time series (Figure 3). Following the highest observed age-1+ biomass in 1997, estimates of rainbow smelt biomass were substantially lower during 2004-2013. Age 1+ rainbow smelt biomass increased in 2014 but remains at roughly 60% of the long-term mean of 4.6 kg/ha (Figure 3). Although the decline in density and biomass during 2004-2014 was considerable relative to 1997, no trend is evident for age-0 or age-1+ rainbow smelt during 2004-2014.

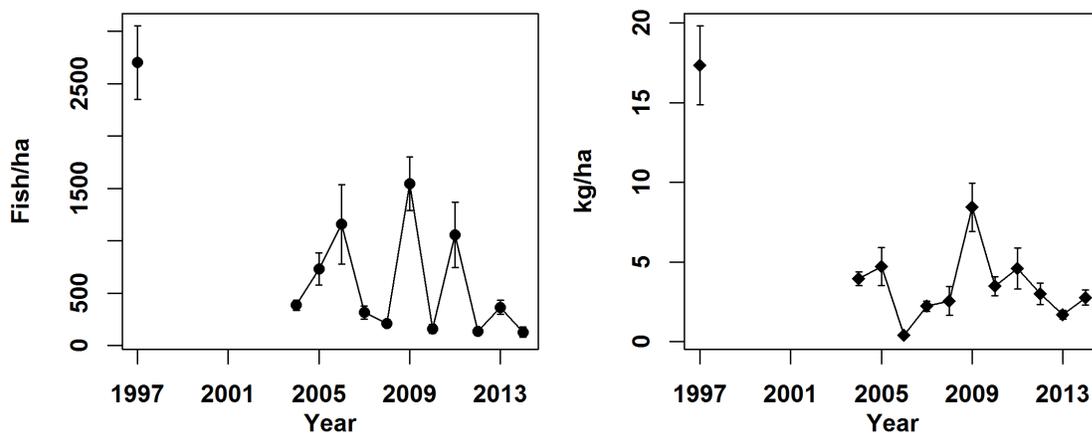


Figure 3. Acoustic and mid-water trawl estimates of rainbow smelt age-0 numeric density (fish/ha; left panel) and age-1+ biomass (kg/ha; right panel) in Lake Huron, 1997-2014. Error bars represent ± 1 standard error.

Bloater – Of the deepwater cisco species historically present in Lake Huron (see Koelz 1929), the bloater is the sole member still found in appreciable numbers. Bloater are prey for offshore predators in Lake Huron but are considerably less common in diets than alewife or rainbow smelt (Diana 1990; Madenjian et al. 2006; Roseman et al. 2014). Age-1+ bloater biomass estimated from long-term bottom trawl surveys was low during the 1970s, but increased during the 1980s and 1990s. Age-1+ bloater biomass remained lower during 2000-2009 but increased substantially during 2010-2012 (Roseman et al. 2015). Density of age-0 bloater estimated from bottom trawl surveys typically remained low during 1976-2005 except when large bloater biomass peaked during 1987-89. However, since 2005 age-0 bloater density has increased

(Roseman et al. 2015). Bloater production in Lake Huron increased during 2004-2009, when planktivorous alewife and rainbow smelt were at reduced levels of abundance.

Acoustic estimates of age-0 bloater were low during 1997 (<4 fish/ha, Figure 4). Similar to results from bottom trawl surveys, age-0 bloater density was variable but increased during 2004-2013 (average density > 170 fish/ha). Estimates of age-0 bloater numeric density showed a 6.5-fold decrease between 2013 and 2014 and were roughly 24% of the long-term mean of 149 fish/ha (Figure 4). Estimated biomass of age-1+ bloater in 2014 showed a 2.3-fold increase relative to 2013 (Figure 4). The 2014 estimate was 123% of the long-term mean; however, it should be noted that while this increase in large bloater biomass was significant, standard errors around estimates were large, indicating lower precision. Biomass estimates of age-1+ bloater were less variable than age-0 bloater abundance during 2004-2013, but were lower than the 1997 estimate (Figure 4). 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. During 2014, both acoustic and bottom trawl surveys detected an increase in age-1+ bloater biomass, and a decrease in age-0 density.

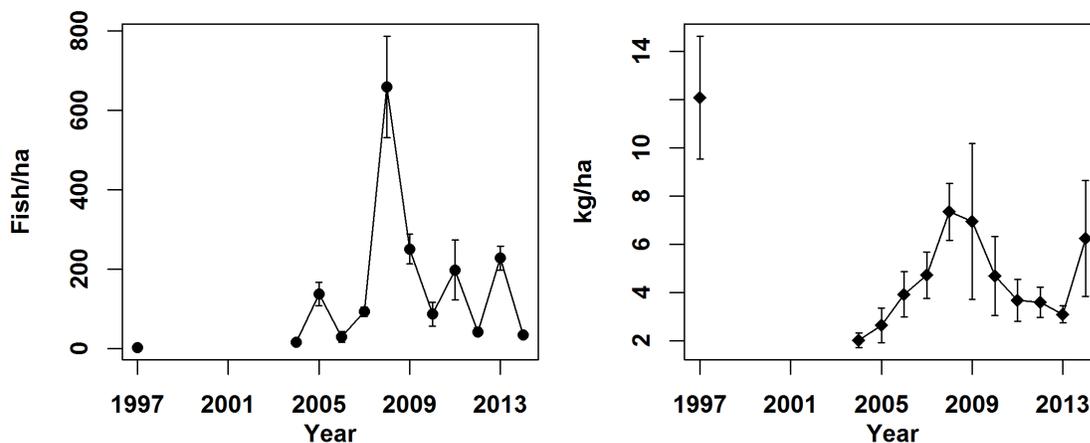


Figure 4. Acoustic and mid-water trawl estimates of bloater age-0 numeric density (fish/ha; left panel) and age-1+ biomass (kg/ha; right panel) in Lake Huron, 1997-2014. Error bars represent ± 1 standard error.

Emerald shiner – Emerald shiner *Notropis atherinoides* is captured primarily in the main basin of Lake Huron during acoustic surveys and their occurrence in offshore waters is associated with warmer surface temperatures (18-19 C, Schaeffer et al. 2008) which can persist into September following summer stratification. In 1997, density and biomass were not estimated, and in 2004 no emerald shiners were captured in mid-water trawls. Density of emerald shiner increased in 2005 and peaked in 2006 at over 500 fish/ha (Figure 5).

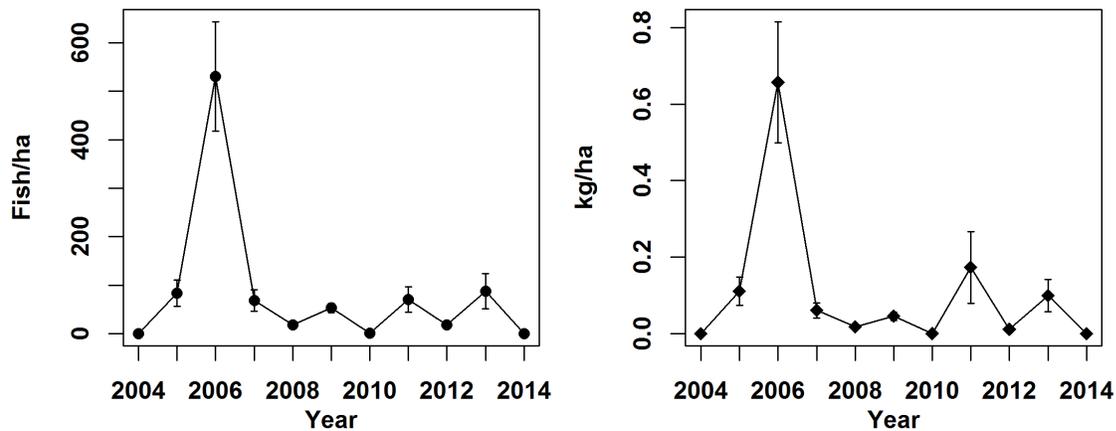


Figure 5. Acoustic and mid-water trawl estimates of emerald shiner numeric density (fish/ha; left panel) and biomass (kg/ha; right panel) in Lake Huron, 2004-2014. Error bars represent ± 1 standard error.

Abundance and biomass declined after 2006 and has been variable in recent years. In 2014, emerald shiner biomass was the lowest observed since 2005 and represented $< 1\%$ of the long-term mean of 0.10 kg/ha (Figure 5). Mean biomass of emerald shiner was estimated to be 1.6% of total pelagic fish biomass in 2013, but decreased to less than 0.01% of total biomass in 2014. Emerald shiner biomass averaged 1.8% of total fish biomass during 2004-2013, but with the exception of 2006, rarely exceeded 1% of total fish biomass in a given year.

In addition to common pelagic fish species, other species captured during acoustic and mid-water trawl surveys include three-spined stickleback *Gasterosteus aculeatus*, lake whitefish *Coregonus clupeaformis*, and cisco *Coregonus artedii*. These species compose a small proportion of the mid-water trawl catch. In the case of cisco, catches have occurred in most years during acoustic surveys but their density remains low in open waters of the lake during September and October. During October in northern Lake Huron, cisco are primarily distributed in shallow, near shore areas (M.P. Ebener, Chippewa Ottawa Resource Authority, personal communication). Our acoustic and mid-water trawl surveys primarily operate in deeper waters (>15 m) during the fall, and therefore do not effectively sample cisco that are likely concentrated in nearshore spawning areas. Cisco are occasionally caught in mid-water trawls but catches are too sporadic to be able to use trawl proportions to apportion acoustic densities. For example, 10 small cisco were caught during 2014, and during 2004-2013, catches were similarly low during acoustic surveys.

Among-basin comparisons of fish biomass

Lake Huron has 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 2014, pelagic fish biomass increased in all basins and was highest in the North Channel, followed by the main basin and Georgian Bay. Biomass in the North Channel (18.8 kg/ha) showed a two-fold increase

over 2013 estimates, largely as a result of increases in age-1+ rainbow smelt. Main basin biomass (10.1 kg/ha) showed a 26% increase from 2013 due to increases in age-1+ bloater. Biomass in Georgian Bay (5.9 kg/ha) increased roughly two-fold from 2013, and was approximately 50% of the long-term mean for that basin. 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 and remains at lower levels, but there is no evidence of a declining trend in the North Channel (Figure 6). Community composition differences are predominantly the result of variation in the proportion of biomass comprised by rainbow smelt and bloater. Most biomass in Georgian Bay has been in the form of rainbow smelt (54% average), while biomass in the main basin has consisted of varying proportions of rainbow smelt and bloater. Since 2012, bloater has been the dominant contributor in the main basin, averaging 70% of pelagic fish biomass (Figure 6). North Channel, where rainbow smelt have comprised 72% of biomass on average, has had even greater rainbow smelt dominance than Georgian Bay. To date, the only factor identified as having consistently influenced among-basin biomass and community composition differences is bottom depth (Warner et al. 2009).

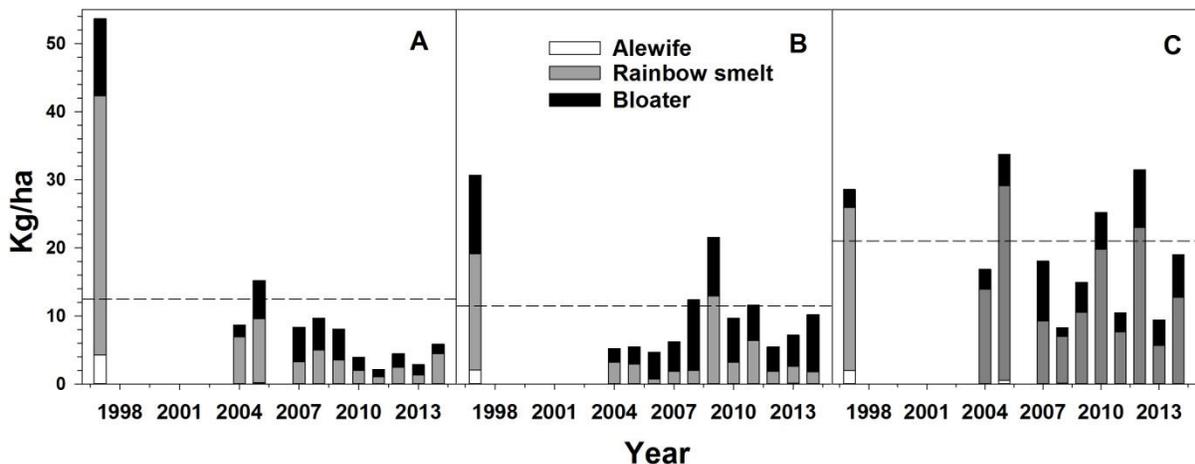


Figure 6. Biomass (kg/ha) of major pelagic fish species in Georgian Bay (panel A), main basin (panel B), and North Channel (panel C) during 1997-2014. Horizontal lines denote 1997-2013 mean density.

Lakewide fish density and biomass

During 2004-2014, mean pelagic fish density was variable across years, but remained at lower levels relative to 1997 (Figure 7). Lakewide mean pelagic fish density in 2014 was the second lowest observed for the time series, declining by 29% from the 2013 estimate and representing 42% of the long term mean (Figure 7). The 2014 pelagic fish density estimate represents only 14% of that observed in 1997. The lake-wide mean pelagic fish biomass estimate in Lake Huron during 2014 was 9.5 kg/ha, a 55% increase from 2013. Standing stock biomass in 2014 was estimated at 44.4 kt; roughly 82% of the long-term mean (Figure 7). This increase in standing stock biomass was driven largely by higher biomass of age-1+ bloater and a moderate increase in age-1+ rainbow smelt biomass. However, standard error associated with this estimate indicated no significant increase in biomass (Figure 7). Acoustic estimates of pelagic fish biomass in Lake Huron have shown no consistent trend between 2004 and 2014. However, biomass remains

considerably lower than in 1997 when rainbow smelt and bloater were more abundant in Georgian Bay and the main basin, and alewife still contributed substantially to total biomass.

Estimates derived from the lakewide acoustic survey, as with any other type of fishery survey, include assumptions about the sampling and data analysis techniques. For example, we assumed that the areas sampled were representative of the respective basins. 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, nearshore zones and large shallow embayments, especially Thunder Bay, Saginaw Bay, and Parry Sound, are not sampled. These areas could be responsible for high rates of pelagic fish production (Fielder and Thomas 2014, 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 sufficient mid-water trawls to achieve an acceptable degree of confidence in fish community composition, according to guidelines in Warner et al. (2012). An additional assumption was that fish size was a reasonable proxy for age-0 or age-1+ groupings. 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 versus age-1+ density and biomass, it would have no impact on our estimates of total density or biomass for a species.

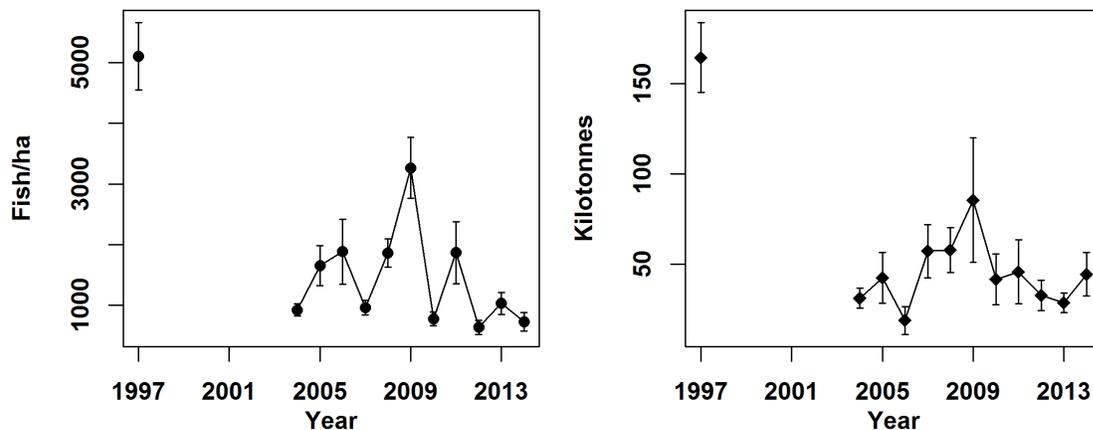


Figure 7. Acoustic and mid-water trawl estimates of lakewide numeric density (fish/ha; left panel) and standing stock biomass (kilotonnes; right panel) in Lake Huron, 1997-2014. Error bars represent ± 1 standard error.

Conclusions

During 2014, low numbers of age-0 fish were captured in mid-water trawls indicating that year-class strength for rainbow smelt and bloater was likely poor. Lower density of age-0 fish during 2014 was contrasted by increased biomass of age-1+ bloater and rainbow smelt. Although lakewide biomass increased during 2014, we note that biomass in 2014 was only 27% of the 1997 estimate.

During 2015, pelagic prey available to piscivores will likely be similar to that seen in recent years, though offshore predators such as lake trout will have increased numbers of adult bloater and rainbow smelt available as forage. Alewife biomass remains low, and there has been no trend in pelagic fish biomass since 2004. The Lake Huron pelagic prey base still remains low compared to previous decades when alewife, rainbow smelt, and bloater were more abundant.

Lakewide pelagic biomass in Lake Huron during 2014 was higher than that estimated for Lake Michigan during 2014 (6.2 kg/ha, 30 kt, Warner et al. 2015) and Lake Superior during 2011 (6.8 kg/ha, Yule et al. 2013). In addition to differences in lakewide biomass in recent years, pelagic fish community composition differs considerably between the three lakes. In Lake Michigan, alewife is still prevalent and comprises about 70% of the pelagic biomass, while in lakes Huron and Superior, the biomass of this species is negligible. Additionally, native coregonines and other species are at historic low levels in Lake Michigan. Native species constitute much higher proportions of total biomass in lakes Huron and Superior. In the case of Lake Superior, kiyi (*Coregonus kiyi*) are numerically dominant at depths > 100 m, while cisco are most of the biomass (Yule et al. 2013). In Lake Huron, rainbow smelt are numerically more abundant, while rainbow smelt and bloater have been alternating roles as the dominant contributor to total biomass, with bloater contributing more in recent years. Additionally, there have been relatively consistent (but low) catches of emerald shiner and cisco in Lake Huron mid-water 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).

To provide accurate estimates of available prey fish resources in Lake Huron, the continuation of acoustic surveys will be instrumental in assessing the pelagic component of the prey fish community, while complementing bottom trawl surveys that better estimate benthic prey resources. The information gathered from acoustic surveys that sample areas where bottom trawling is not feasible will increase our understanding of variation in prey fish biomass across large temporal and spatial scales (i.e., all of Lake Huron's basins). As no single gear is best for assessing all species, life stages, or habitats, estimates of fish biomass from multiple gear types will lead to a better understanding of ecosystem dynamics.

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. We thank Capt. Joe Bergan, Lyle Grivicich, and Dave Paavola for their support of 2014 field operations. Scott Nelson, Dan Benes, and Limei Zhang provided computer and database support. Dave Fielder and Chuck Madenjian 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.

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Appendix 1. Single target detection parameters used in acoustic data analyses in 2014.

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, 2014.

Vessel	R/V Sturgeon	M/V Spencer Baird
Collection software	Visual Acquisition 6.0	ER60 2.2
Transducer beam angle (3dB)	8.53° split beam	6.35° split beam
Frequency (kHz)	120	70
Pulse length (ms)	0.4	0.256
Sv noise at 1 m (dB)	-125	-125
2 way equivalent beam angle	-19.39	-20.90
Detection limit (m) for -60 dB target ²	>100	>100

² Assuming 3 dB signal-to-noise ratio.

Appendix 3. Supplement to methods

Acoustic data collected in 1997 were analyzed using custom software (Argyle et al. 1998). Data collected in 2004 and later years were analyzed using EchoviewTM 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 any 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.

In 1997, a BioSonics model 102 dual-beam echosounder was used to collect acoustic data during pelagic fish surveys. 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*. 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 120

kHz transducer failed field calibration tests. In 2010-2014, we used both a 38 and 120 kHz echosounder to facilitate frequency comparisons, but with the exception of 2009, only 120 kHz data are presented in this report. Comparison of paired 120 kHz and 38 kHz data revealed 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. During 2011-2012 and 2014, the survey was carried out jointly between GLSC and the United States Fish and Wildlife Service (USFWS). USFWS used 70 kHz and 120 kHz split-beam echosounders (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.

In order to assign fish 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, mid-water 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 the same geographic stratum. 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 mid-water 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 Standard Operating Procedures (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 S_v 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.

Status and Trends of Prey Fish Populations in Lake Michigan, 2014¹

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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 2014. 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 2014 was estimated at 1.6 kilotonnes (kt, 1 kt = 1000 metric tonnes), which was a record low and only 16% of the average biomass estimated since 2005. Moreover, the age distribution of alewives remained truncated with no alewife exceeding an age of 5. Record low biomass was also observed for nearly every other prey fish species: bloater (0.3 kt), rainbow smelt (0.02 kt), slimy sculpin (0.09 kt), deepwater sculpin (1.0 kt) and ninespine stickleback (0.004 kt). Round goby was the only prey fish species to avoid a record-low biomass estimate (2.04 kt); the 2014 estimate was 58% of the average lakewide biomass observed since 2006 when round gobies became relatively abundant in our catches. Burbot lake-wide biomass (0.5 kt in 2014) has remained below 3 kt since 2001. No age-0 yellow perch (i.e., < 100 mm) were captured during the survey, which is indicative of a poor year-class. Lake-wide biomass estimate of dreissenid mussels in 2014 was 23.9 kt, not different from 2013 (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 2014 was only 5.1 kt, compared to the previous record-low prey fish biomass of 15.2 kt in 2012. In 2014, alewives and round gobies constituted 71% of this total, following a trend of dominance by these species since 2012.

¹ Presented at: Great Lakes Fishery Commission
Lake Michigan Committee Meeting
Ypsilanti, MI
March 26, 2015

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, 25 to 45-mm bar mesh in net body, 6.4-mm bar mesh in cod end) 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. In 2013, we began adding tows at deeper depths (i.e., 128-132 m), when logistics permitted, to evaluate the extent to which populations of deepwater sculpins and bloater have migrated outside of our traditional survey range. Since then, we have sampled deeper depths offshore of Manistique (N=1), Port Washington (N=2), and Frankfort (N=2).

Ages 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 2014.

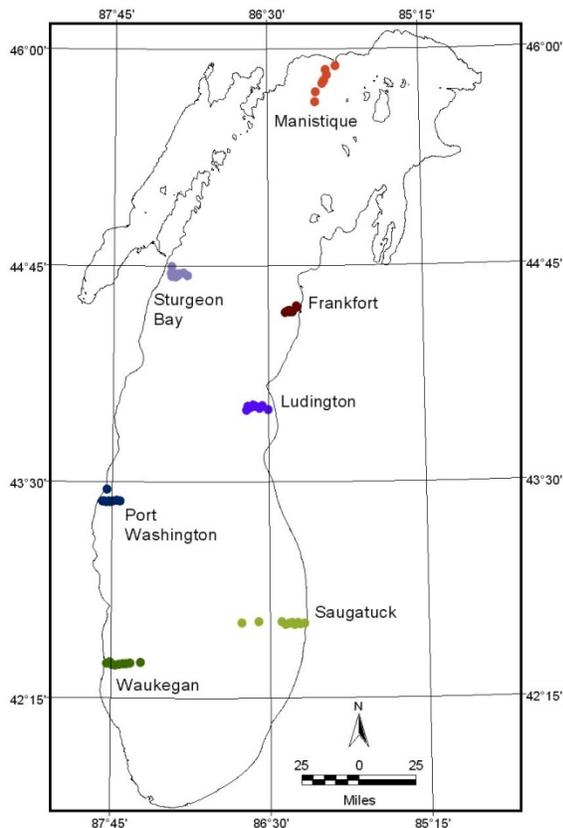


Figure 1. Established sampling locations for GLSC bottom trawls in Lake Michigan.

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.

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; Tsehaye et al. 2014). 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 Toneys, 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 equaled 0.4 kg per ha in 2014 (Figure 2a), only 17% of the average biomass since 2005. Similarly, adult alewife numeric density in 2014 equaled a record-low estimate of 19 fish per ha (Figure 2b).

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).

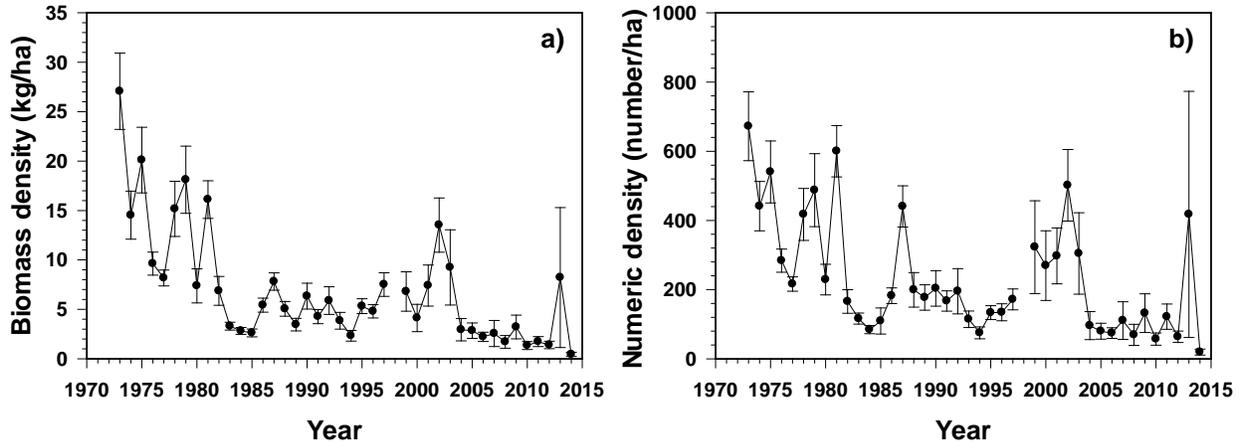


Figure 2. Density of adult alewives as biomass (a) and number (b) per ha (+/- standard error) in Lake Michigan, 1973-2014.

We estimated that 39% of adult alewives were age 4 (2010 year-class), while age-2 (2012 year-class) and age-3 (2011 year-class) fish each represented 29% of the adult alewives in 2014 (Figure 3). The relatively high proportion of age-3 alewives was somewhat surprising given that the acoustic survey identified the 2010 and 2012 year-classes to be relatively strong, but initially estimated the 2011 year-class to be weak. Of the 149 alewives aged from the 2014 bottom trawl survey, only 3 were age-5. Thus, the recent trend of age truncation in the alewife population continued in 2014, with the oldest alewife being only 5 years old (Figure 3). Prior to 2008, age-8 alewives were routinely captured.

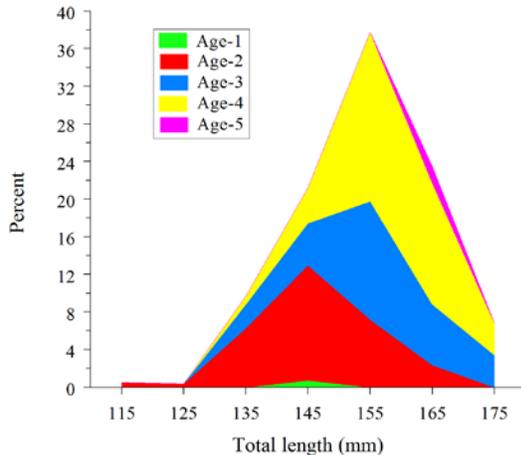


Figure 3. Age-length distribution of alewives ≥ 100 mm total length caught in bottom trawls in Lake Michigan, 2014. Note that smaller alewives were captured but were not included herein.

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 2004-2014 to be relatively low in comparison to the biomass during 1994-1996 (Warner et al. 2015). However, Warner et al. (2015) 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 has exceeded the bottom trawl estimate by a factor of 4.5. In 2014, the acoustic estimate (4.6 kg per ha) was more than 10 times greater than the bottom trawl estimate (0.4 kg per ha), although both estimates indicate alewife biomass is at relatively low levels.

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 (≥ 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.

Adult bloater biomass density in our survey has been < 10 kg per ha since 1999 (Figure 4a). In 2014, bloater biomass equaled only 0.09 kg per ha. Numeric density of age-0 bloaters (< 120 mm TL) was less than 1 fish per ha in 2014 (Figure 4b), suggesting continued poor bloater recruitment, aside from 2005, 2008, and 2009 when age-0 bloaters exceeded 25 fish per ha.

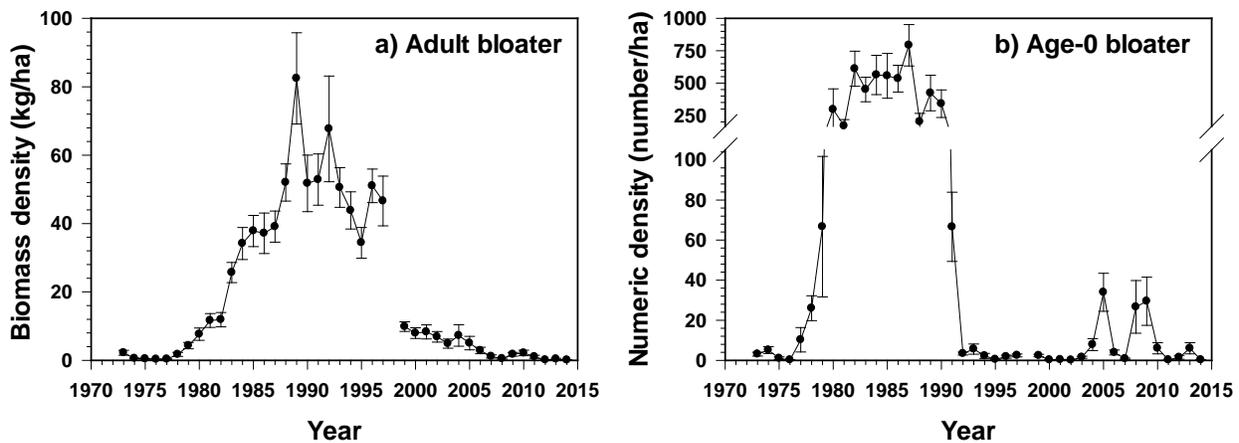


Figure 4. Panel (a) depicts biomass density (+/- standard error) of adult bloater in Lake Michigan, 1973-2014. Panel (b) depicts numeric density (+/- standard error) of age-0 bloater in Lake Michigan, 1973-2014.

The exact mechanisms underlying the relatively poor bloater recruitment since 1992, and the resultant low biomass of adult bloater, remain unknown. 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. 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. 2014a) are likely contributing to the reduced bloater recruitment, but none is the primary regulating factor.

One additional consideration when interpreting the 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. One hypothesis is that some portion of the bloater population has 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 in 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). Our exploratory sampling at deeper depths (i.e., 128-132 m) revealed that bloater biomass was highest at

the deepest depth only 20% of the time. Likewise, data from the acoustic survey (which regularly samples deeper waters than the bottom trawl survey) do not support the deeper water hypothesis; Warner et al. (2015) observed no trend in mean depth of capture between 2005 and 2014, and determined that 95% of all large bloaters were at depths < 130 m. Hence this hypothesis requires additional evaluation. An alternative hypothesis is that the bloater population remains largely within our sampling area, but bloaters are less vulnerable to our bottom trawls either owing to behavioral changes (more pelagic during the day) or increased ability to avoid the net while on the bottom (due to clearer water).

A comparison of the two surveys revealed that the bloater biomass estimate from the bottom trawl always exceeded that of the acoustic survey between 1992-2006. Since 2007, however, the biomass for the acoustic survey has exceeded that of the bottom trawl survey by a factor of 4.8, on average. In 2014, the estimate for the acoustic survey (1.8 kg per ha) was 18 times greater than that of the bottom trawl survey (0.1 kg per ha). The two surveys detected similar trends, however, with adult bloater decreasing by an order of magnitude between 1992-1996 and 2001-2014. Similarly, low densities of age-0 bloaters in the 1990s and strong interannual variability in the 2000s were detected in both surveys.

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).

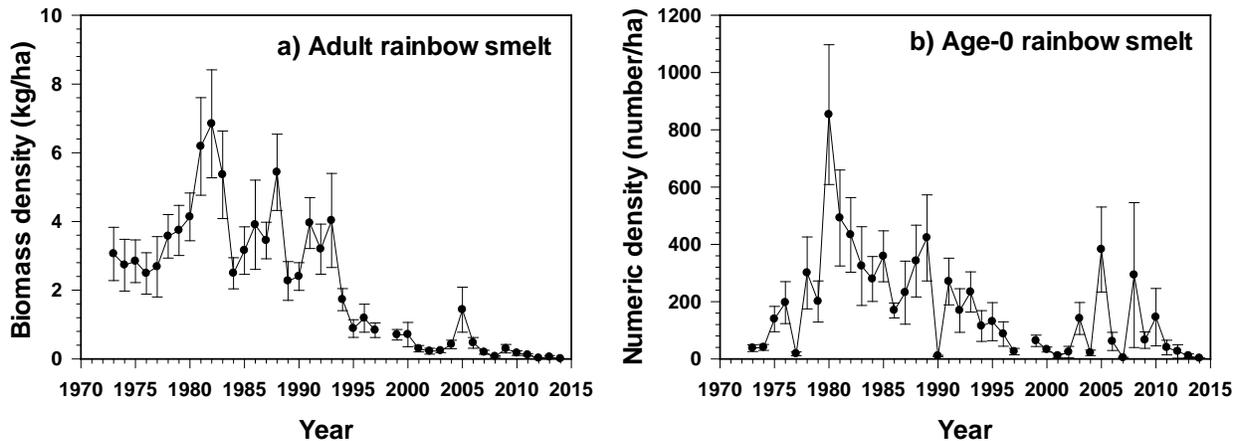


Figure 5. Biomass density (+/- standard error) of adult (a) and age-0 (b) rainbow smelt in Lake Michigan, 1973-2014.

Adult rainbow smelt biomass density has remained at low levels since 2001, aside from a relatively high estimate in 2005 (Figure 5a). Biomass density in 2014 equaled a record-low 0.004 kg per ha, which was only 1% of the average since 2005. Age-0 rainbow smelt numeric density has been highly variable since 1999 (Figure 5b), but equaled only 2 fish per ha in 2014, marking four consecutive year-classes with <40 fish per ha. 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). Furthermore, a recent analysis of our time series

suggested that the productivity of the population has actually increased since 2000 (relative to 1982-1999), yet those recruits do not appear to be surviving to the adult population (Feiner et al. 2015).

A comparison of the two surveys revealed that the rainbow smelt biomass estimate from the acoustic survey always exceeds that of the bottom trawl survey, on average by a factor of 5. This difference is not surprising given that rainbow smelt tend to be more pelagic than other prey species, especially for juveniles. In 2014, the estimate for the acoustic survey (0.08 kg per ha, Warner et al. 2015) was 13 times greater than that of the bottom trawl survey (0.006 kg/ha). The two surveys detected similar trends, however, with adult rainbow smelt attaining biomass densities an order of magnitude higher in 1992-1996 than in 2001-2014 for both surveys.

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).

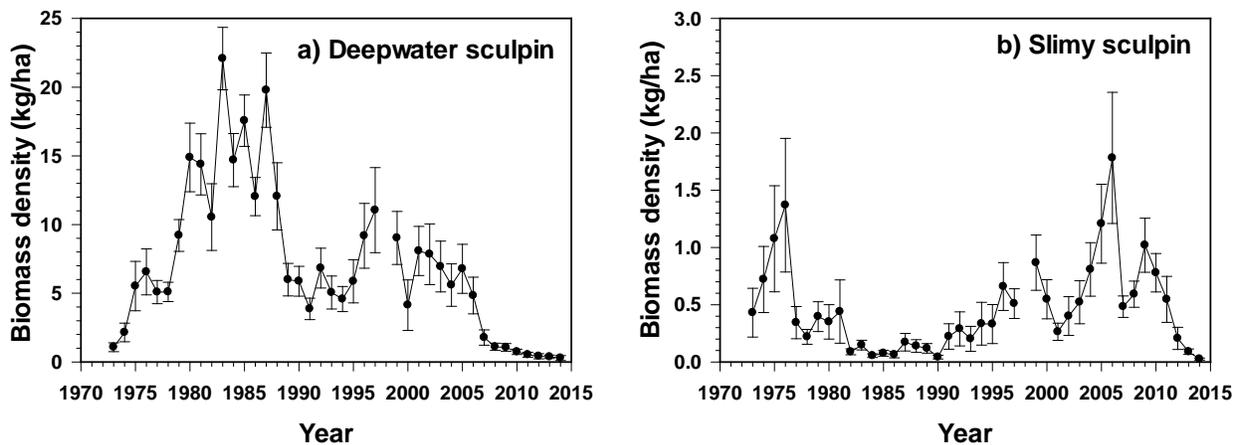


Figure 6. Biomass density (+/- standard error) for deepwater (a) and slimy sculpin (b) in Lake Michigan, 1973-2014.

Deepwater sculpin biomass density was 0.29 kg per ha in 2014 (Figure 6a), which was only 16% of the average biomass since 2005. For every year since 2009, this biomass estimate has reached a record low. 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. Following no clear trend between 1990 and 2005, the 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), perhaps in response to the decline of *Diporeia* and proliferation of dreissenid mussels. 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. Our exploratory sampling at deeper depths (i.e., 128-132 m) was partially supportive of this hypothesis: deepwater sculpin biomass was highest at the deepest depth 60% of the time.

Slimy sculpin biomass density was 0.03 kg per ha in 2014, which was only 4% of the average biomass since 2005 and the fifth consecutive year of a decline (Figure 6b). 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; our survey likely markedly underestimates round goby abundance given their preferred habitat includes rocky and inshore (i.e., < 9 m bottom depth) areas that we do not sample. By 2002, round gobies had become an integral component of yellow perch diets at nearshore sites (i.e., < 15 m depth) in southern Lake Michigan. Recent studies have revealed round gobies are an important constituent of the diets of Lake Michigan burbot (Hensler et al. 2008; Jacobs et al. 2010), yellow perch (Truemper et al. 2006), smallmouth bass (*Micropterus dolomieu*, T. Galarowicz, Central Michigan University, personal communication), lake trout (McKenna 2014), and even lake whitefish (S. Hansen, Wisconsin DNR, personal communication).

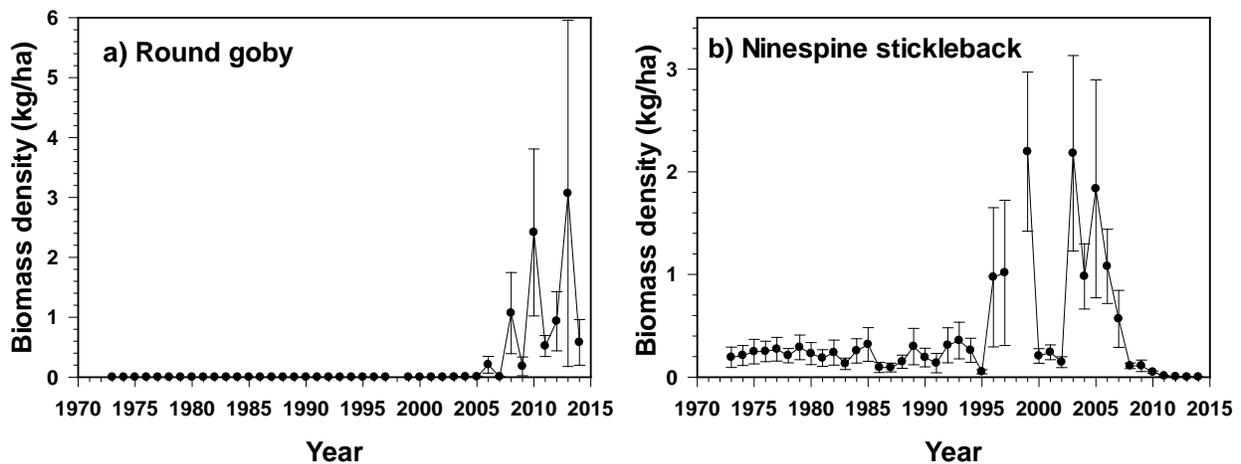


Figure 7. Biomass density (+/- standard error) of round goby (a) and ninespine stickleback (b) in Lake Michigan, 1973-2014.

Round goby biomass density equaled 0.6 kg per ha in 2014, which was only 65% of the average biomass since 2005 (Figure 7a). Round goby abundance in Lake Michigan appears to be leveling off in response to control by piscivores. This hypothesis was supported by recent estimates of annual mortality rates of between 75 and 85% (Huo et al. 2014), which are comparable to the mortality rates currently experienced by Lake Michigan adult alewives (Tsehaye et al. 2014).

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), but has been extremely rare in recent sampling years. Biomass density of ninespine stickleback remained only 1 g per ha in 2014 (Figure 7b), not different from 2013 and only 0.3% of the average since 2005. Biomass of ninespine stickleback remained fairly low from 1973-1995 and then increased dramatically through 2007, perhaps attributable to dreissenid mussels enhancing ninespine stickleback spawning and nursery habitat through proliferation of *Cladophora* (Madenjian et al. 2010b). Since 2008, however, biomass has been maintained at near record-low levels. 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. For example, Jacobs et al. (2013) found ninespine sticklebacks to show up in large Chinook salmon diets (i.e., 2% occurrence) after 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 5 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). Total biomass first dropped below 30 kt in 2007, and has since remained below that level with the exception of 2013 (when the biomass estimates for alewife and round goby were highly uncertain).

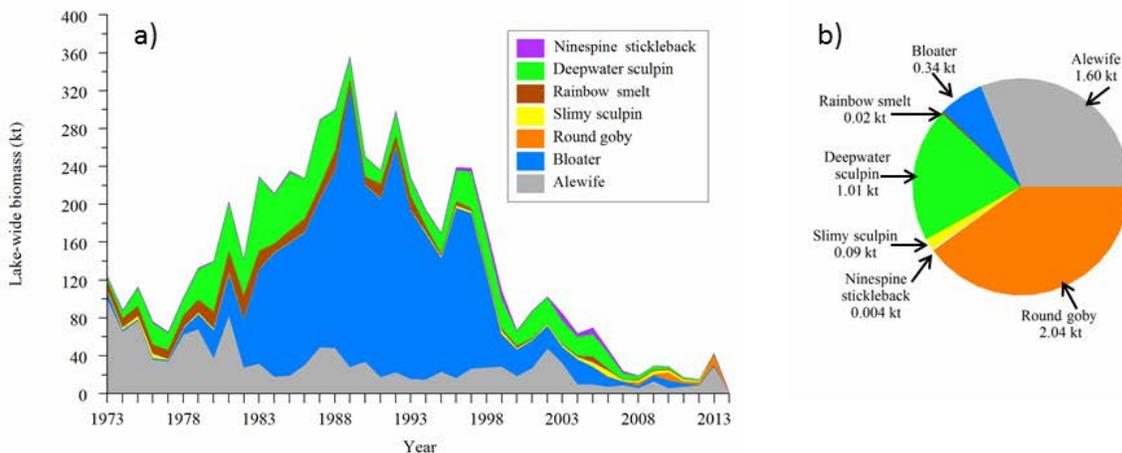


Figure 8. Estimated lake-wide (i.e., 5-114 m depth region) biomass of prey fishes in Lake Michigan, 1973-2014 (a) and species composition in 2014 (b).

As Figure 8b depicts, the 2014 prey fish biomass was apportioned as: round goby 40.0% (2.0 kt), alewife 31.3% (1.6 kt), deepwater sculpin 19.8% (1.0 kt), bloater 6.6% (0.3 kt), slimy sculpin 1.8% (0.1 kt), rainbow smelt 0.4% (0.02 kt), and ninespine stickleback 0.1% (0.004 kt).

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 2014, which was 49% of the average biomass since 2005. 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-

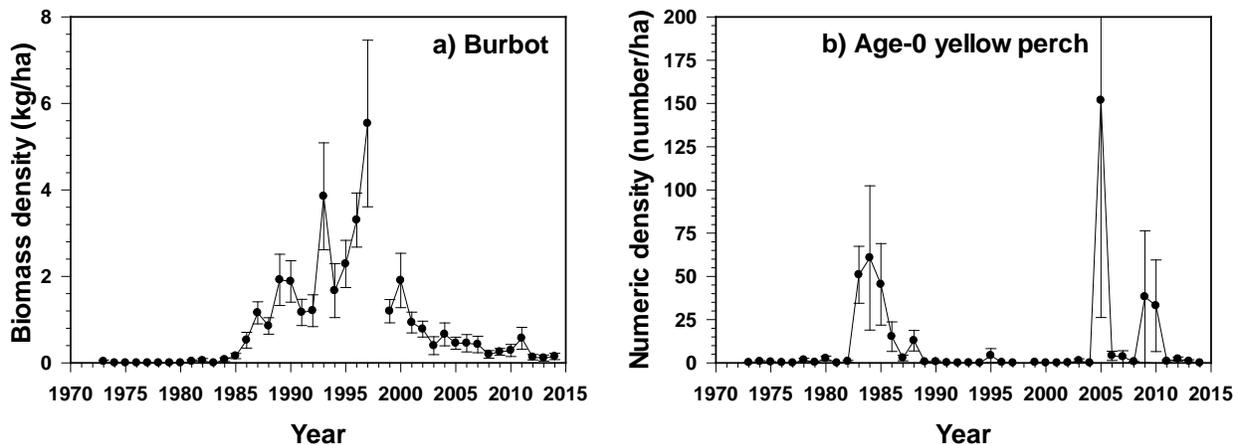


Figure 9. Biomass density (+/- standard error) of burbot (a) and numeric density (+/- standard error) of age-0 yellow perch (b) in Lake Michigan, 1973-2014.

2014 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. However, our exploratory sampling at deeper depths (i.e, 128-132 m) has not revealed any support for this hypothesis.

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. However, no age-0 yellow perch were sampled in 2014, indicative of a 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 2014 was 6.8 kg per ha (Figure

10a), which was remarkably similar to the 2013 estimate (6.6 kg per ha). 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, as lakewide quagga mussel densities continued to increase through 2010 (Nalepa et al. 2014).

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 quagga mussel expansion), shifts in fish habitat, and increased fish predation by Chinook salmon and lake trout.

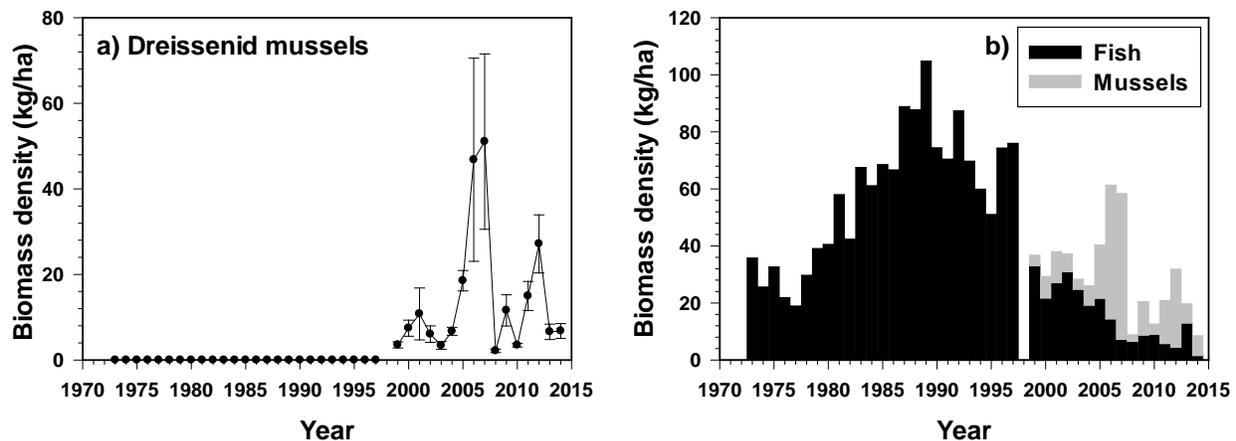


Figure 10. Panel (a) depicts biomass density (+/- standard error) of dreissenid mussels in the bottom trawl in Lake Michigan between 1999 (first year mussels were weighed) and 2014. Panel (b) depicts biomass of dreissenids and total fish biomass estimated by the bottom trawl between 1973 and 2014.

A comparison of the biomass density of dreissenid mussels (6.7 kg per ha) with biomass density of all species of fish (1.6 kg per ha) caught in the bottom trawl in 2014 indicated that 81% of the daytime benthic biomass available to the bottom trawl was dreissenid mussels (Figure 10b).

CONCLUSIONS

Total prey fish biomass estimated by the bottom trawl has revealed a record-low number every year since 2010, with the exception of 2013 when locally high catches of alewife and round goby caused a relatively high estimate (e.g., 43 kt) with wide uncertainty. In 2014, total prey fish biomass was estimated to be only 5 kt. Prudently, we conclude that, based on the bottom trawl survey results, total prey fish biomass in Lake Michigan has remained at a low level since 2007.

This low level of prey fish biomass can be attributable to a suite of factors, two of which can be clearly identified: (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 2013-2014 was age 5.

In addition to the importance of top-down forces, prey fishes also may be negatively influenced by reduced prey resources (i.e., “bottom-up” effects). For example, many data sets are indicating a reduction in the base of the food-web- particularly for offshore total phosphorus and phytoplankton- as a consequence of long-term declines in phosphorus inputs and the proliferation of dreissenid mussels (Evans et al. 2011; Bunnell et al. 2014b). The evidence for declines in “fish food” (e.g., zooplankton, benthic invertebrates) in Lake Michigan is somewhat less clear. *Diporeia* has undoubtedly declined in abundance (Nalepa et al. 2014), but whether or not crustacean zooplankton and mysids have declined depends on which data set is examined (e.g., Pothoven et al. 2010; Bunnell et al. 2014; Madenjian et al. in review). Even if limited food has not directly led to reductions in abundance, it has been hypothesized to underlie lower-than-expected physiological condition of deepwater sculpins (Pothoven et al. 2011) and bloaters (Pothoven et al. 2012).

Whether or not the alewife population in Lake Michigan will undergo a complete collapse in coming years (similar to what occurred in Lake Huron) ultimately depends on the consumptive demand of the salmonines, and this estimate is based on many inputs (stocking rates, wild recruitment rates, immigration rates from Lake Huron). Lake Michigan managers reduced Chinook salmon stocking lakewide by 50% from 2012 baseline values beginning in 2013 to lower salmon consumption on alewives and try to maintain predator:prey balance (Lake Michigan Committee 2014). In addition, alewife sustainability will depend on the ability of alewife spawning stock to produce another strong year-class, which will at least partially depend on appropriate environmental factors being met (Madenjian et al. 2005b).

ACKNOWLEDGMENTS

We thank Capt. Shawn Parsons and Engineer Jim Page for their seamanship on our 2014 survey. Reviews provided by Dave Warner and Vic Santucci improved this report.

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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 2014. 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	4.46 (3.93)	0.010 (0.008)	0.035 (0.030)
adult alewife	19.33 (8.66)	0.443 (0.205)	1.561 (0.722)
age-0 bloater	0.25 (0.13)	0.002 (0.001)	0.007 (0.005)
adult bloater	2.72 (1.62)	0.094 (0.062)	0.330 (0.219)
age-0 rainbow smelt	2.27 (1.64)	0.002 (0.002)	0.009 (0.008)
adult rainbow smelt	0.81 (0.66)	0.004 (0.003)	0.013 (0.010)
deepwater sculpin	30.77 (18.84)	0.287 (0.181)	1.011 (0.639)
slimy sculpin	5.25 (1.80)	0.026 (0.009)	0.091 (0.031)
ninespine stickleback	0.70 (0.39)	0.001 (0.001)	0.004 (0.002)
burbot	0.09 (0.05)	0.147 (0.072)	0.519 (0.255)
age-0 yellow perch	0.00 (0.00)	0.000 (0.000)	0.000 (0.000)
round goby	91.89 (57.73)	0.580 (0.381)	2.042 (1.340)
dreissenid mussels	NA	6.785 (1.725)	23.896 (6.074)

Status and Trends of the Lake Huron Offshore Demersal Fish Community, 1976-2014¹

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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 2014 fall bottom trawl survey was carried out between 12 October – 3 November 2014 and included all U.S. ports, as well as Goderich, ON. The 2014 main basin prey fish biomass estimate for Lake Huron was 36 kilotonnes, less than half of the estimate in 2012 (97 Kt), and approximately 10 percent of the maximum estimate in the time series. The biomass estimate for adult alewife in 2014 was lower than in 2013 and much lower than levels observed before the crash in 2004. Estimated biomass of rainbow smelt also decreased and was the second lowest observed in the time series. Estimated adult bloater biomass in Lake Huron increased slightly over the 2013 estimate but remains lower than the long-term average. YOY alewife, rainbow smelt, and bloater abundance and biomass decreased over 2013. Biomass estimates for deepwater sculpins, trout-perch, and ninespine stickleback in 2014 were lower than in 2013 and remained low compared to historic estimates. The 2014 biomass estimate for round goby was lower than 2013. Wild juvenile lake trout were captured again in 2014, suggesting that natural reproduction by lake trout continues to occur.

¹Prepared for the Great Lakes Fishery Commission Lake Huron Committee Meeting, Windsor, ON, 26 March 2015.

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* spp. (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), 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 1973-2014 using 12-m headrope (1973-1991) and 21-m headrope (1992-2014) 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 (Detour, 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 1978-2014; 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 2014.

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 equivalent 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 kg/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. To do this, year-specific length cutoffs were predetermined from length-frequency data and then used to apportion the catches into age-0 fish (young-of-the-year, or YOY) and those age-1 or older (yearling and older, or YAO).

To make density estimates from the 12 m headrope (1973-1991) and 21 m headrope (1992-2014) 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 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.

Results

The 2014 Lake Huron fall bottom trawl survey was carried out during 12 October – 3 November. Forty-three trawl tows were completed and all standard ports were sampled, including Goderich, Ontario. Eleven fish species were captured in the 2014 survey: rainbow smelt, alewife, bloater, deepwater sculpin, trout-perch, lake whitefish, ninespine stickleback, lake trout, round goby, yellow perch *Perca flavescens*, and common carp *Cyprinus carpio*.

Alewife abundance in Lake Huron remained low in 2014. Yearling and older (YAO) alewife density and biomass estimates decreased from 2013 and remained much below levels observed before the population crashed (Fig. 2). Age-0 alewife density and biomass during 2014 were the lowest in the time series (Fig. 2). YAO rainbow smelt density in Lake Huron in 2014 was the second lowest level observed (Fig. 3). Young-of-the-year (YOY) rainbow smelt abundance and biomass decreased to about 1/3 of 2013 values. YAO bloater density and biomass decreased sharply in 2013 from levels observed during 2011 - 2012, though 2014 values showed a modest increase (Fig. 4)

Abundance and biomass estimates for deepwater sculpins in Lake Huron in 2014 were also lower than the previous two years and remained relatively low compared to historic estimates (Fig. 5). The 2014 abundance and biomass estimates for ninespine stickleback and trout-perch were also lower than in

previous years and were among the lowest in the time series (Fig. 6). Round goby abundance and biomass estimates for 2014 were lower than those observed in 2012 and 2013 (Fig. 7).

The total main basin prey biomass estimate (5 - 114 m) in 2014 was 36 kilotonnes, a decrease of about 23% from the 2013 estimate (Fig. 8). This estimate is higher than the extreme low estimates that occurred during 2006-2010 and represents approximately 10 percent of the maximum lakewide biomass estimate observed in 1987. Approximately 2/3 of the 2014 biomass estimate was composed of YAO bloater.

Discussion

The abundance of prey fish in Lake Huron has remained at very low levels since the collapse of the offshore demersal fish community in 2004 (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 observed since 2001, while the 2013 estimate was approximately half as high as 2012 and 2014 was even lower. The estimated biomass of YAO rainbow smelt and alewife in 2014 were lower than in 2013 and remained low compared to earlier data. 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 almost solely 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, while 2014 showed a modest increase over the 2013 levels. The abundance of this native species is currently at a moderate level, higher than the extreme low estimates observed in 2001-2006. Bloaters 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 coregonines. Pertinent questions related to bloater population dynamics include a need for age estimates of collected samples to evaluate year-class performance and assess why large bloaters remain scarce.

Deepwater and slimy sculpins, ninespine sticklebacks, and trout-perch are typically minor components of lake trout diets in the Great Lakes (Diana 1990; Roseman et al. 2014), but were probably more important before the invasion of the lakes by alewife, rainbow smelt (e.g., Van Oosten and Deason 1938) and round goby (Schaeffer et al. 2005). In 2014, biomass estimates for deepwater sculpins, sticklebacks, and trout-perch were lower than in recent years and remained relatively low compared to historical peak estimates. Deepwater sculpin diet analysis is taking place at the GLSC to help determine how changes in invertebrate communities may be affecting this species.

Round goby have become a significant part of lake trout diets in some areas of the Great Lakes (Dietrich et al. 2006), including Lake Huron (Ji He, MDNR Alpena, pers. comm.; Roseman et al. 2014). Round goby were first captured in the Lake Huron trawl survey in 1997, reached peak abundance in 2003 (Schaeffer et al. 2005), and declined in abundance until 2011. Our results suggest that they are currently at a moderate to low level of abundance in the offshore waters of Lake Huron, although sharp fluctuations in the time series indicate that abundance estimates for this species may be particularly sensitive to various environmental factors.

The estimated lakewide biomass of common offshore prey species in Lake Huron increased from 2009 - 2012, but then decreased in 2013 and 2014. 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 (Madenjian et al. 2014). It is possible that these declines are associated with the invasion of the lakes by several exotic species, including the spiny water flea (*Bythotrephes*), zebra mussels, quagga mussels, and round gobies, all of which have been introduced since the mid-1980s. However, similar declines in some species (particularly coregonines) have occurred in Lake Superior (Gorman and Bunnell 2009; Gorman et al. 2009), which has felt less of an impact from the invasive species mentioned above.

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 and/or the distribution of fish off the bottom. Many individuals of some demersal species may be pelagic at certain 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 the estimated abundance of individual species 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 vulnerable to 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.

The results of this survey demonstrate that there has been great variability in the abundance or biomass of a number of fish species (YOY benthopelagic planktivores, round goby) over the last decade. Low levels of prey fish abundance have persisted since approximately 2006, although the 2012-2014 surveys provide evidence that the abundance of some species (e.g. YAO bloater) 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.

Acknowledgments

We thank Shawn Parsons and Jim Page for their seamanship and dedication to completing the survey. S. Nelson, L. Zhang, and D. Benes provided database and computer support. S. Lenart and C. Prichard provided useful reviews of this report.

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Figures



Figure 1. Bottom trawl sampling locations in Lake Huron.

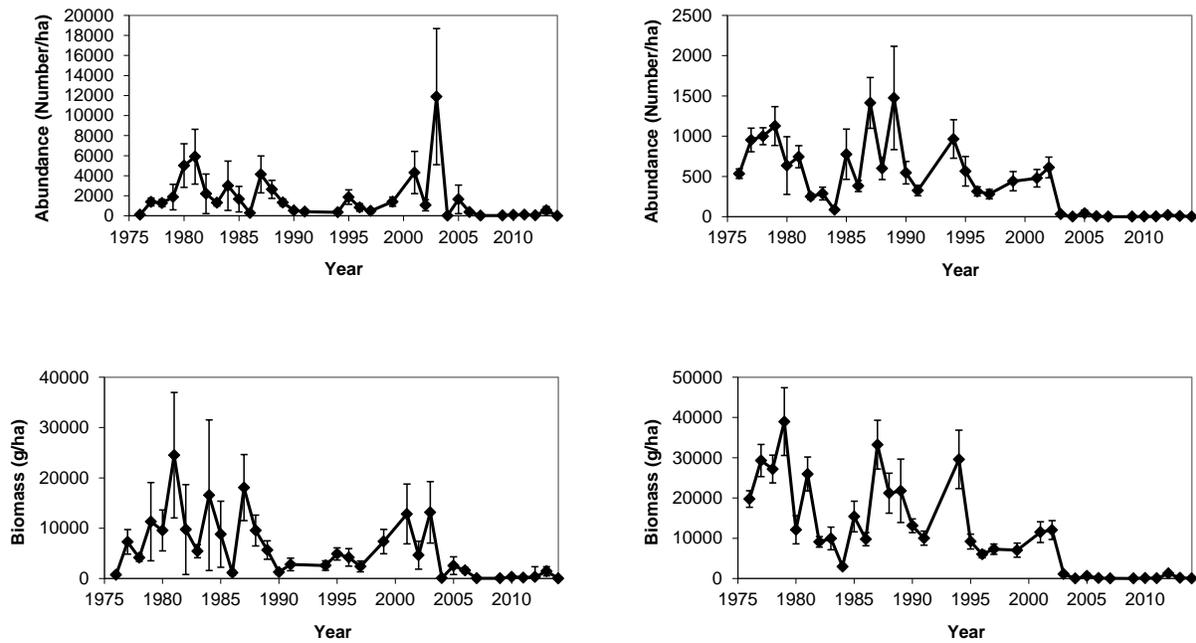


Figure 2. Density of young-of-the-year (YOY: left panels) and adult (YAO: right panels) alewives as number (top panels) and biomass (bottom panels) of fish per hectare in Lake Huron, 1976-2014. 1976-1991 estimates were corrected using fishing power corrections developed by Adams et al. (2009). Error bars are 95% confidence intervals.

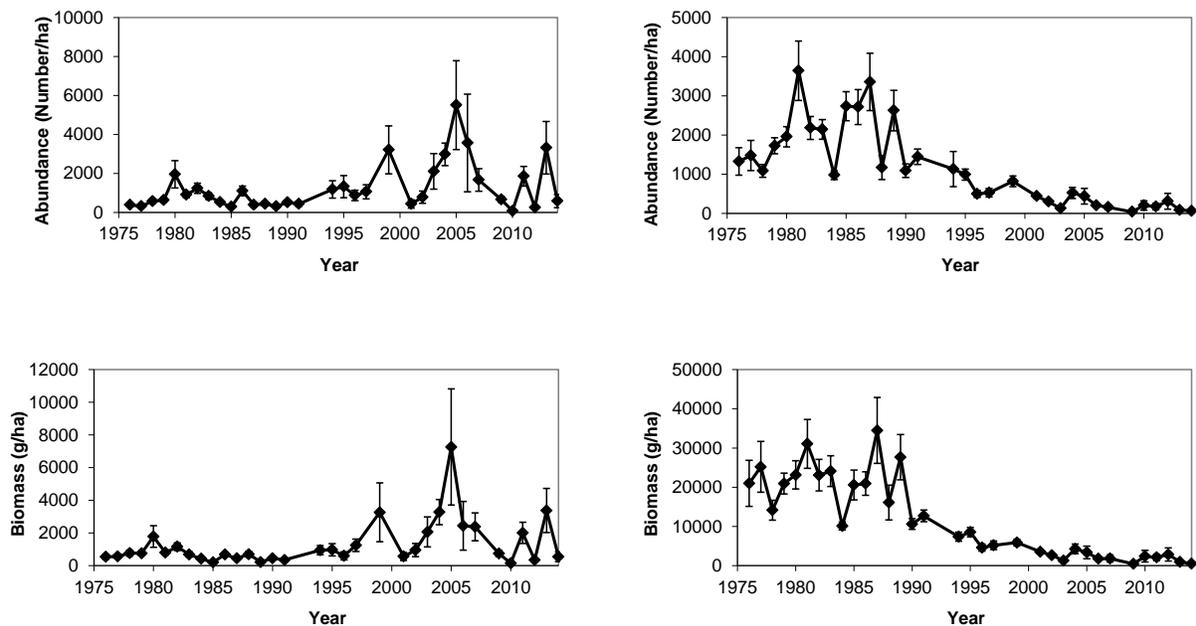


Figure 3. Density of young-of-the-year (YOY: left panels) and adult (YAO: right panels) rainbow smelt as number (top panels) and biomass (bottom panels) of fish per hectare in Lake Huron, 1976-2014. 1976-1991 estimates for YAO were corrected using fishing power corrections developed by Adams et al. (2009); YOY data are uncorrected. Error bars are 95% confidence intervals.

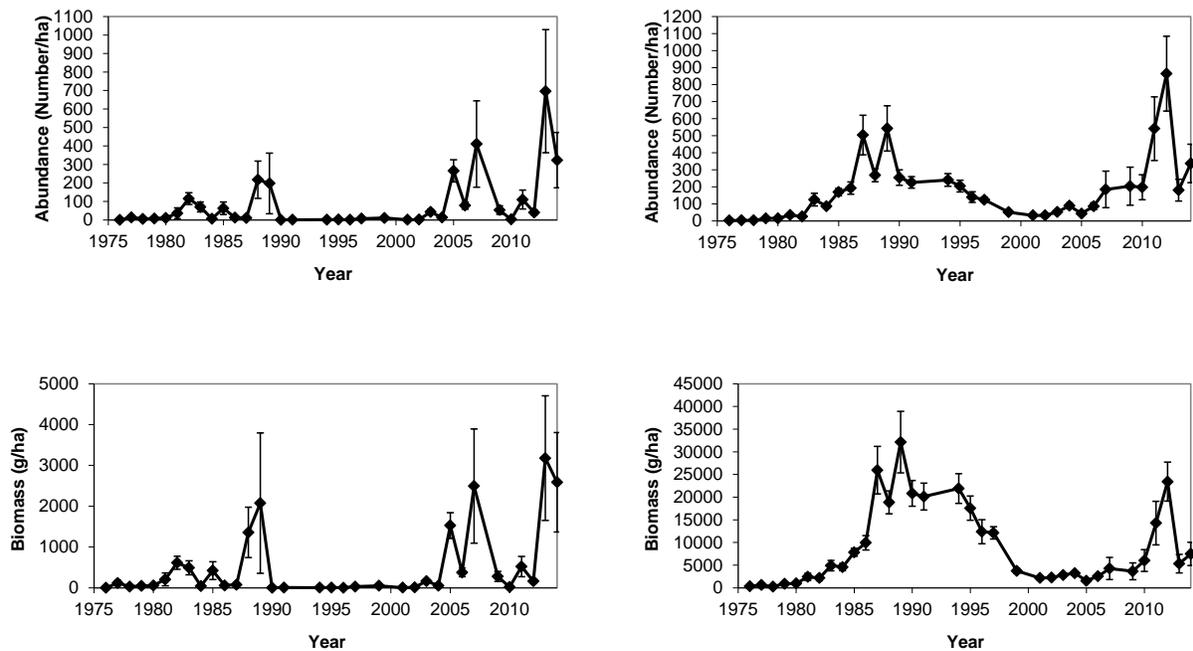


Figure 4. Density of young-of-the-year (YOY: left panels) and adult (YAO: right panels) bloater as number (top panels) and biomass (bottom panels) of fish per hectare in Lake Huron, 1976-2014. 1976-1991 estimates were corrected using fishing power corrections developed by Adams et al. (2009). Error bars are 95% confidence intervals.

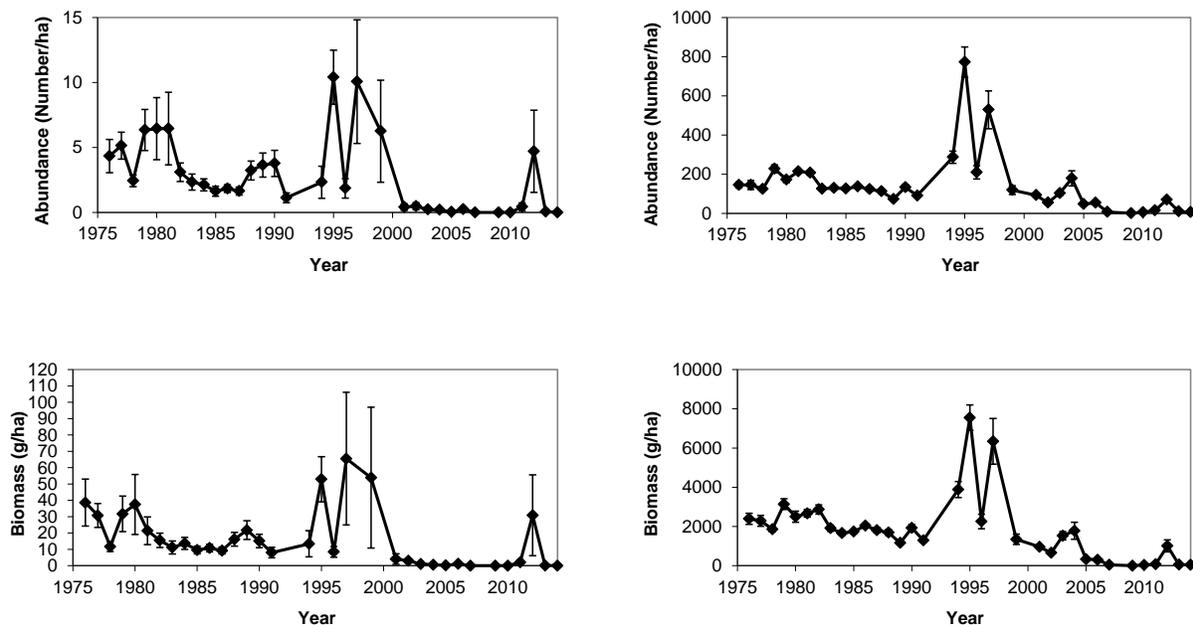


Figure 5. Density of slimy (left panels) and deepwater (right panels) sculpins as number (top panels) and biomass (bottom panels) of fish per hectare in Lake Huron, 1976-2014. 1976-1991 estimates were corrected using fishing power corrections developed by Adams et al. (2009). Error bars are 95% confidence intervals.

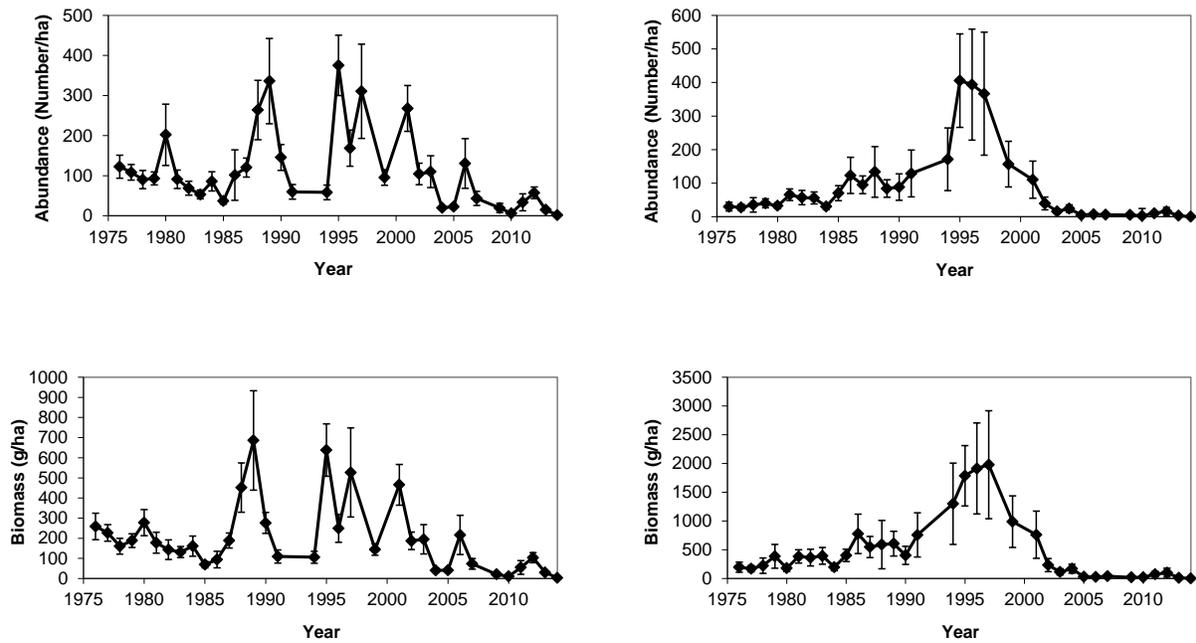


Figure 6. Density of ninespine stickleback (left panels) and trout-perch (right panels) as number (top panels) and biomass (bottom panels) of fish per hectare in Lake Huron, 1976-2014. Error bars are 95% confidence intervals.

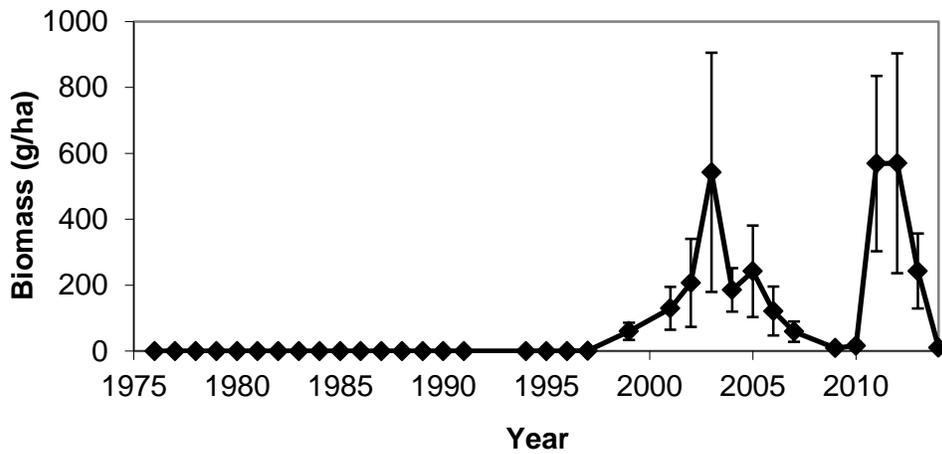
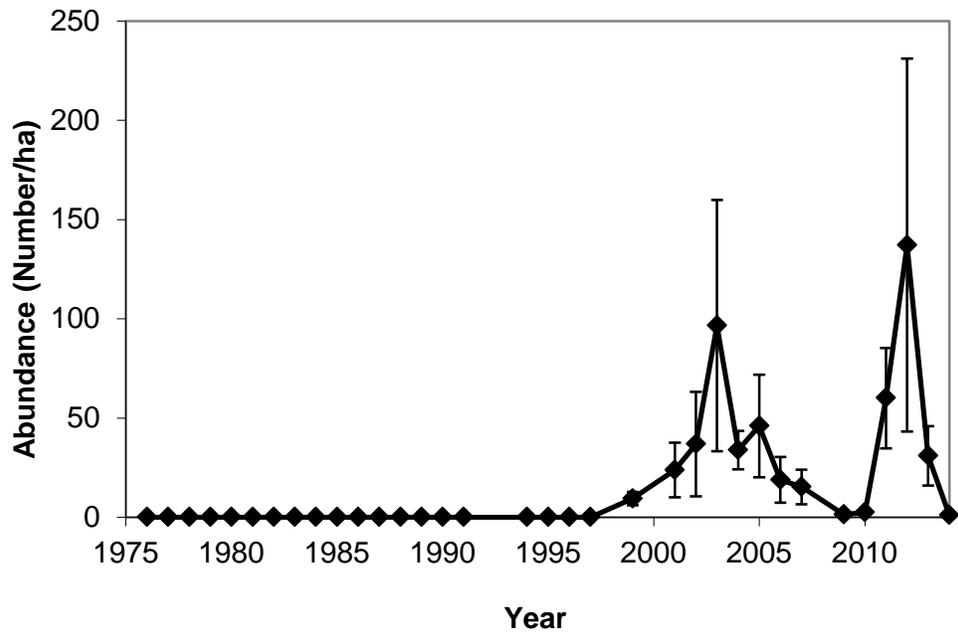


Figure 7. Density of round goby as number (top panel) and biomass (bottom panel) of fish per hectare in Lake Huron, 1976-2014.

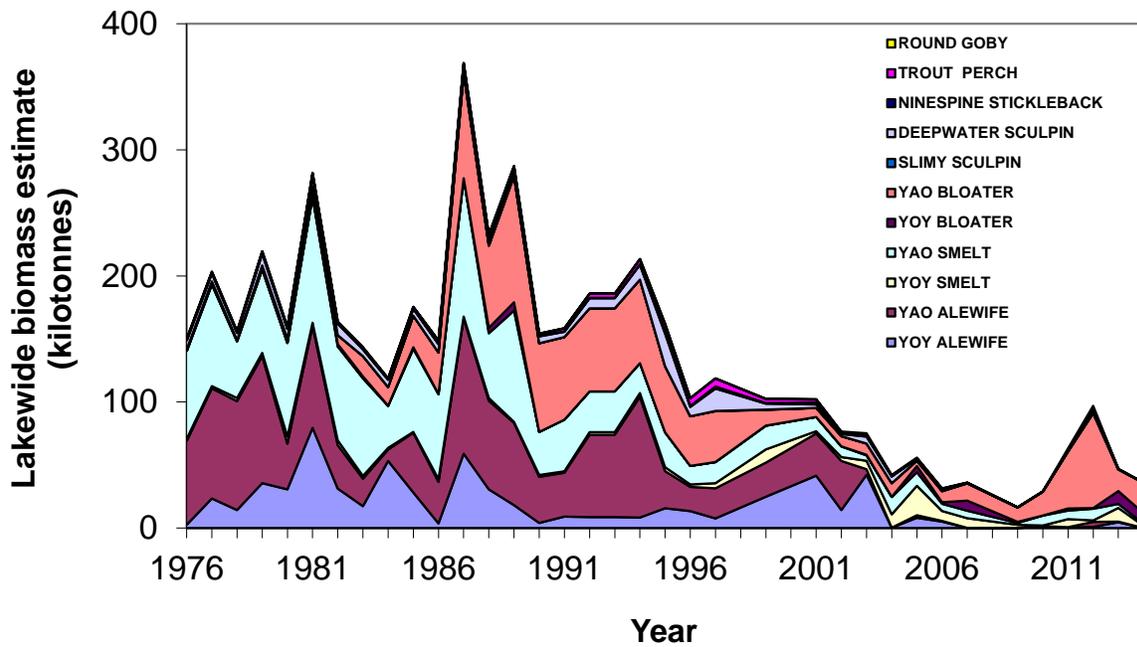


Figure 8. Offshore demersal fish community biomass in the main basin of Lake Huron, 1976-2014. Valid data were not collected in 1992, 1993, 1998, 2000, and 2008; biomass estimates for those years represent interpolated values.

Status of Pelagic Prey Fishes in Lake Michigan, 2014¹

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ABSTRACT

Acoustic surveys were conducted in late summer/early fall during the years 1992-1996 and 2001-2014 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 2014 survey consisted of 27 acoustic transects (603 km total) and 31 midwater trawl tows. Four additional transects were sampled in Green Bay but were not included in lakewide estimates. Mean prey fish biomass was 6.5 kg/ha [31.7 kilotonnes (kt = 1,000 metric tons)], equivalent to 69.9 million pounds, which was similar to the estimate in 2013 (29.6 kt) and 25% of the long-term (19 years) mean. The numeric density of the 2014 alewife year-class was 3% of the time series average and was the lowest observed in the 19 years of sampling. This year-class contributed <1% of total alewife biomass (4.6 kg/ha). Alewife \geq age-1 comprised 99.5% of alewife biomass. Numeric density of alewife in Green Bay was more than three times that of the main lake. In 2014, alewife comprised 71% of total prey fish biomass, while rainbow smelt and bloater were 1% and 28% of total biomass, respectively. Rainbow smelt biomass in 2014 (0.08 kg/ha) was 66% lower than in 2013, 2% of the long-term mean, and lower than in any previous year. Bloater biomass in 2014 was 1.8 kg/ha, nearly three times more than the 2013 biomass, and 20% of the long-term mean. Mean density of small bloater in 2014 (122 fish/ha) was lower than peak values observed in 2007-2009 but was similar to the time series mean (124 fish/ha). In 2014, pelagic prey fish biomass in Lake Michigan was 71% of that in Lake Huron (all basins), where the community is dominated by bloater.

¹Presented at: Great Lakes Fishery Commission
Lake Michigan Committee Meeting
Ypsilanti, MI, March 26-27, 2015

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), however they are also predators of larval fish and are tied to thiamine deficiencies that contribute to recruitment bottlenecks in native fishes including lake trout (*Salvelinus namaycush*). As such, alewives constitute an important component of the food-web. 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 are largely driven by the year-classes that are not effectively sampled by bottom trawls; 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. Further, these two long-term surveys have enabled the development of a stock assessment model for alewife (Tsehaye et al. 2014).

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 (Adams et al. 2006). A modified design 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 2007-2014, 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). The collection and analytical approach for 2014 acoustic and midwater trawl data was similar to that in 2004-2013. For a detailed description of the methods see Warner et al. (2009) and Warner et al. (2014).

RESULTS

The 2014 acoustic survey of Lake Michigan was conducted by USGS, USFWS, and MDNR. The main basin sampling consisted of 27 transects (Figure 1) for a total transect distance of 603 km, which was 4 times the sampling distance of the most recent lakewide acoustic survey of Lake Superior (Yule et al. 2013) and similar to the sampling distance in Lake Huron in 2014 (O'Brien et al. 2015). The bottom range over which acoustic data were collected was 6-240 m (20-787 ft), and the mean bottom depth of sampling was 84 m (276 ft). In addition to the main basin effort, USFWS collected data from four transects in Green Bay.

Alewife – The numeric density of the 2014 alewife year-class was the lowest recorded in the 19 years of sampling. At 33 fish/ha, the 2014 estimate was only 3% of the long-term mean. While this indicates that the 2014 year class is the smallest on record, it is possible that we underestimated the density of age-0 in 2014 because of delayed hatching, growth, and dispersal from nearshore areas caused by unusually cool water temperatures in spring and summer 2014. This possibility is supported by the fact that there were 212 mm age-0 alewife 40-60 mm total length caught in the September bottom trawl survey. Alewife in this size range are typically the most common alewife observed in the August acoustic survey. The

biomass density of age-1 or older alewife was 4.6 kg/ha (Figure 2), which was 46% of the long-term mean of 10 kg/ha and similar to the biomass density in 2013. Numeric density of large alewife (>100 mm) in Green Bay was more than three times that in the main lake. However, the lakewide estimates presented here did not include data from Green Bay. The biomass of the portion of the alewife population \geq age-1 was split relatively evenly among the 2013, 2012, 2011, and 2010 year-classes, which suggests a more even age composition than in previous years. Two key similarities between the acoustic and bottom trawl surveys were that both indicate alewife biomass is lower than in the 1990s and neither caught alewife older than age-5. The acoustic biomass density estimate for age-1 or older alewife was more than 10 times the bottom trawl estimate in 2014 and over the time series, the acoustic estimates have been 4.5 times the bottom trawl estimates. Although we observed lower than average density of alewife in Lake Michigan, the density is still much higher than the density of alewife in Lake Huron (O'Brien et al. 2015).



Figure 1. Map of the 2014 acoustic survey track (left panel), the 2012-2014 surveys (center panel), and the 2004-2014 acoustic survey tracks (right panel).

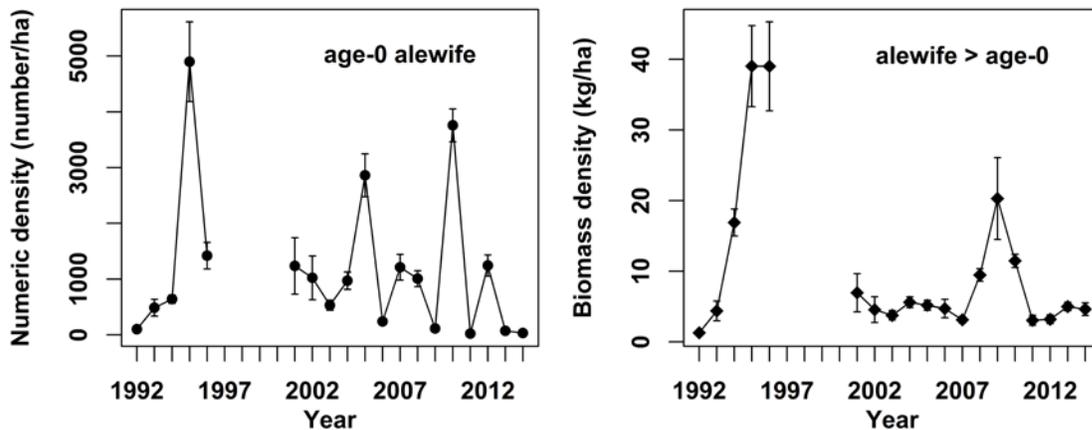


Figure 2. Numeric density of age-0 alewife (left panel) and biomass density of age-1 or older alewife (right panel) in Lake Michigan during 1992-1996 and 2001-2014. Error bars show one standard error.

Rainbow smelt –At 1 fish/ha, numeric density of small rainbow smelt (<90 mm) in 2014 (Figure 3) was the second lowest in the time series (the lowest was 2002). This density was <1% of the time series mean of 213 fish/ha. Similarly, at 0.08 kg/ha, biomass density of large rainbow smelt (\geq 90 mm) was

the lowest in the 19 year survey time series and was 2% of the time series mean, indicating that smelt biomass remains low relative to the early years of the acoustic survey (1992-1996). Even though acoustic biomass density estimates of large smelt have always exceeded bottom trawl estimates, both surveys show there has been an order of magnitude decrease from 1992-1996 to 2001-2014 (Bunnell et al. 2015). In addition to highlighting the large decline in rainbow smelt biomass in Lake Michigan, these data provide strong evidence that biomass density in Lake Michigan is lower than in Lake Huron, where the 2014 acoustic estimate of large rainbow smelt biomass density was 34 times that in Lake Michigan (O'Brien et al. 2015).

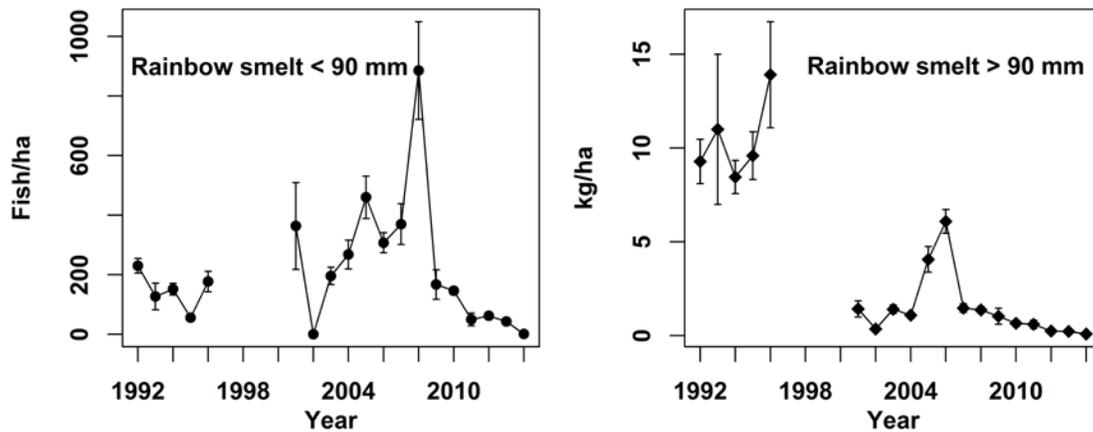


Figure 3. Numeric density of small rainbow smelt (<90 mm, left panel) and biomass density of large rainbow smelt (right panel) in Lake Michigan during 1992-1996 and 2001-2014. Error bars show one standard error.

Bloater –Densities of both small and large bloater have been variable in 2001-2014. Mean numeric density of small bloater in 2014 (122 fish/ha) was nearly equal to the time series mean of 124 fish/ha (Figure 4). Biomass density of large bloater in 2014 was 1.8 kg/ha, which, in spite of being nearly four times higher than in 2013, was only 20% of the time series mean and 6% of the mean in 1992-1996. Bloater biomass has been only 16% of total prey fish biomass density in 2001-2014, on average. This is in contrast to the 1992-1996 period, when bloater made up 48% of total prey fish biomass density. For much of the acoustic time series (1992-2006), estimates of biomass density of large bloater were lower than estimates from the bottom trawl survey. However, from 2007-2014, acoustic estimates have been nearly five times bottom trawl estimates, on average (Bunnell et al. 2015). Bunnell et al. (2013) suggested that the continued decrease in bottom trawl biomass density of bloater might be the result of a shift in bloater bathymetric distribution to depths that are now deeper than the bottom trawl sampling. Support for this conclusion includes the fact that bloomers have shown plasticity in bottom depths occupied, with an increase from the 1930s to 2004-2007 (Bunnell et al. 2012) as well as observations from commercial fishermen that the depth at which they capture bloomers has increased (Bunnell et al. 2013). Data from the acoustic survey, which regularly samples deeper than the bottom trawl survey, did not support this hypothesis, however (Figure 5). Further, based on a Mann-Kendall test there is no evidence for a trend in mean bottom depth for large bloater biomass over the 2005-2014 period ($P=0.47$).

DISCUSSION

The results of the 2014 Lake Michigan acoustic survey indicate continued variability in alewife recruitment, 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 2001-2014 (2009-2010) were only half as high as in 1995-1996. Total prey fish biomass in 2014 was the second lowest ever observed in the acoustic survey. Total pelagic fish biomass in Lake Michigan

(6.5 kg/ha) was lower than in Lake Huron in 2014 (9.5 kg/ha, O'Brien et al. 2014) but similar to Lake Superior in 2011 (6.8 kg/ha, Yule et al. 2013).

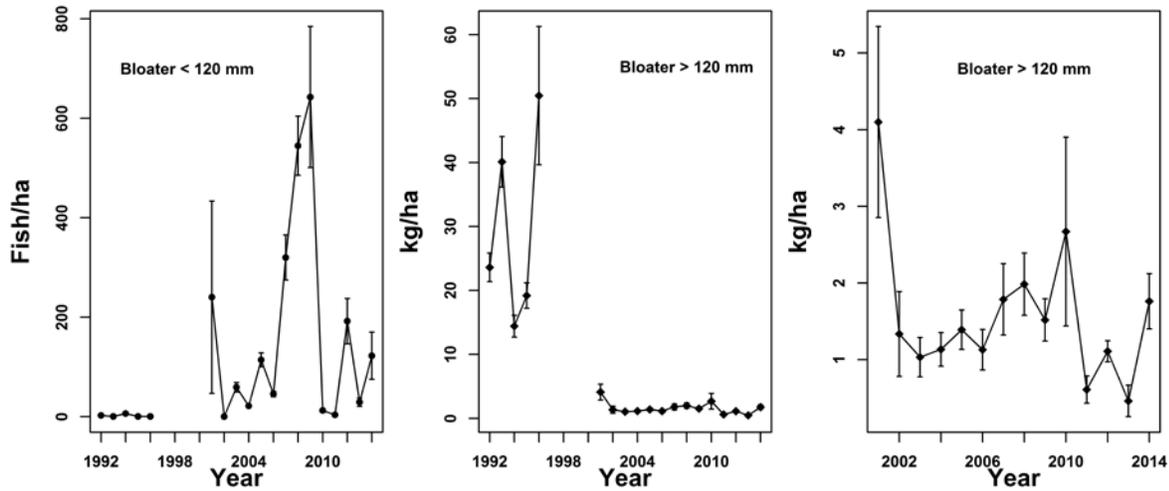


Figure 4. Numeric density of small bloater (<120 mm, left panel) biomass density of large bloater from 1992-2014 (middle panel), and biomass density of large bloater for the years 2001-2014(right panel) in Lake Michigan. Error bars show one standard error.

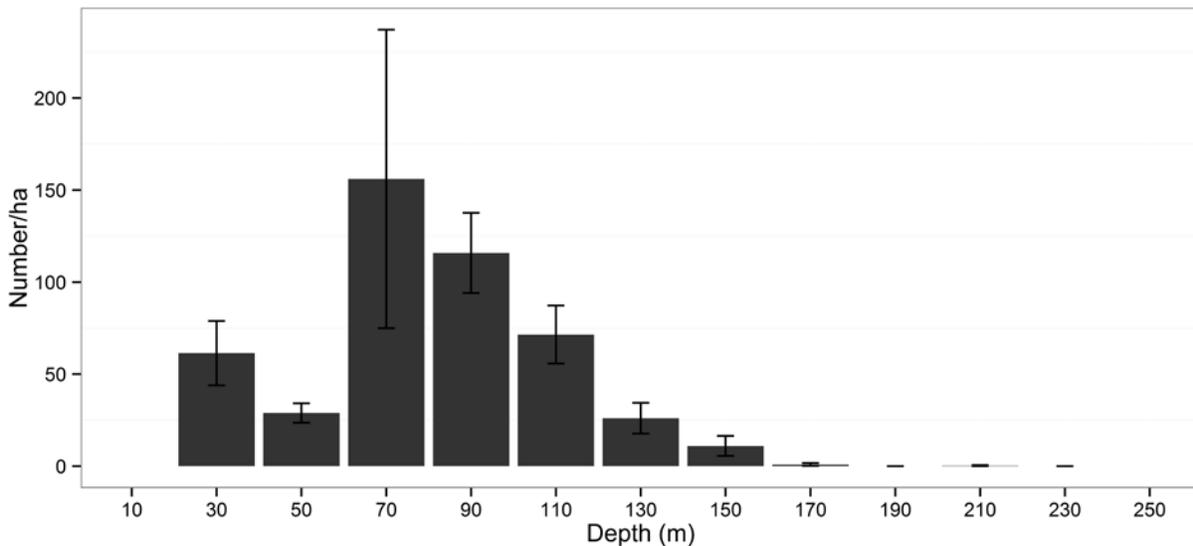


Figure 5. Biomass density of large bloater (\pm one standard error) in bottom depth intervals measured during the 2014 acoustic survey of Lake Michigan.

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 near the surface (upper blind zone 0-4 m) or near the bottom (bottom dead zone, bottom 0.3-1 m) are not sampled well or at all. The density of fish in these areas therefore is unknown. Recent technological advances allow for acoustic sampling of the upper blind zone over large spatial areas but the cost of this technology has been prohibitive. While our 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), it is possible that some are located in the top 4 m and can't be captured with trawls because the ship displaces this water and the fish.

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. These data indicate 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. However, bloaters tend to be more demersal; in Lake Superior, night acoustic/midwater trawl sampling may detect only 60% of bloater present (Yule et al. 2007). The 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.

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 N_v and found only two cells had $N_v > 0.1$, 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 (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 and do not represent 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 (31.7 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). The recent decline, resulting primarily from decreased alewife biomass, demonstrates the dynamic nature of the pelagic fish community in Lake Michigan. Because of predation by salmonines and a weak 2014 alewife year-class, it seems likely that biomass of alewife will be lower in 2015 than in 2014. However, a strong 2015 year-class could offset mortality of older fish, and it is possible that we underestimated the density of the 2014 year-class. 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 2014 (Table 1). 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 kiyi 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 artedi*, (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. Recent stock-recruit modeling for bloater in Lakes Michigan and Huron indicated that bloater sex ratio and alewife abundance were related to recruitment (Collingsworth et al. 2014). It is also possible 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). However, the increase in biomass of large bloater in 2014 may be a sign that recruitment has improved over the past few years.

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 provided through the Sport Fish Restoration Project #230485.

Table 1. Numeric or biomass density, 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 2014.

Species	Density	RSE (%)	95% CI
Total alewife	4.6 kg/ha	19	(3.1, 6.2)
Age-0 alewife	32 fish/ha	29	(16, 48)
YAO alewife	4.6 kg/ha	19	(3.1, 6.2)
Rainbow smelt	35 fish/ha	43	(9, 61)
Bloater	1.8 kg/ha	20	(1.2, 2.4)
Total	6.5 kg/ha	16	(4.7, 8.3)

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Appendix 1. Single target detection parameters used in acoustic data analyses in 1992-1996, 2001-2005, and 2014.

Parameter	Dual beam 1992-1996	Dual beam 2001-2005 ¹	2014 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 2006-2014.

³Although a lower threshold was used in 2001-2014 only targets ≥ -60 dB were included in analyses.

Appendix 2. Noise levels (mean and range of Sv at 1 m), detection limits, and acoustic equipment specifications in 2014 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	6.38° x 6.35° split beam
Frequency (kHz)	120	123	70
Pulse length (ms)	0.4	0.4	0.256
Mean of Sv noise at 1 m (dB)	-122	-122	-126
Two-way equivalent beam angle (dB)	-19.34	-20	-20.9
Sv detection limit (m) for -60 dB target ¹	>100	>100	>100 m

¹Assuming 3 dB signal-to-noise ratio.