Status and Trends of Pelagic Prey Fishes in Lake Huron, 2008

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Abstract

The USGS Great Lakes Science Center conducted acoustic/midwater trawl surveys of Lake Huron during 2004-2008. The 2008 survey was conducted during September and October, and included transects in Lake Huron's Main Basin, Georgian Bay, and North Channel. Main Basin estimates of pelagic fish density and biomass were higher in 2008 compared to surveys in 2004-2007 because of increases in both age-0 and adult bloater. Native species now comprise the majority of the Main Basin biomass. We also observed substantial increase in the abundance of threespine and ninespine sticklebacks, although they contributed little to total community biomass increase due to small size. Rainbow smelt densities and biomass appeared similar to other years, and both alewife and emerald shiner were scarce. Also notably absent was cisco which historically were an important pelagic prey fish in Lake Huron. Unlike previous surveys, we did not observe differences in fish density or biomass among Lake Huron's basins; during 2008 both density and biomass in the North Channel, Georgian Bay, and Main Basin were similar. This appeared to be a result of increases in the Main Basin and not declines in other areas. Main Basin prey availability for salmonids will depend largely on the extent of their predation on bloater which now comprise the majority of the prey biomass there. The Georgian Bay prey biomass had almost equal proportions of bloaters and rainbow smelt, while the North Channel pelagic biomass remained dominated by rainbow smelt. The present situation in Lake Huron where bloater is relatively abundant but alewife and other prey are scarce may result in dependence on bloater as the primary prey for salmonids.

Introduction

The U.S. Geological Survey's Great Lakes Science Center has conducted bottom trawl surveys of the Lake Huron fish community since the 1970's. While those data appeared to reflect broad-scale changes in the fish community, acoustic surveys were implemented because the bottom trawl surveys did not sample all bottom types or areas deeper than about 100 m, and no single gear is adequate for sampling pelagic fish (Fabrizio et al. 1997, Stockwell et al. 2007, Yule et al. 2008).

Acoustic surveys were first conducted during the 1970's (Argyle 1982), but the first lake-wide survey that included all of Lake Huron's distinct basins was conducted in 1997. Surveys of all basins were conducted again in 2004-2005 (Schaeffer et al. 2006). Only the Main Basin was sampled during 2006 (Schaeffer et al. 2007), but support from the Ontario Ministry of Natural Resources (OMNR) allowed all basins to be sampled again in 2007 and 2008. In this report, we focus on Main Basin trends (2004-2008), among-basin differences in fish communities observed during 2008, and apparent lakewide changes that occurred between 2007 and 2008.

Methods

The 2008 survey used a stratified and randomized systematic design with transects in five geographic strata: eastern Main Basin (ME), western Main Basin (MW), southern Main Basin (SB), Georgian Bay (GB), and the North Channel (NC) (Figure 1). Within each stratum, the first transect was selected randomly based on latitude or longitude;

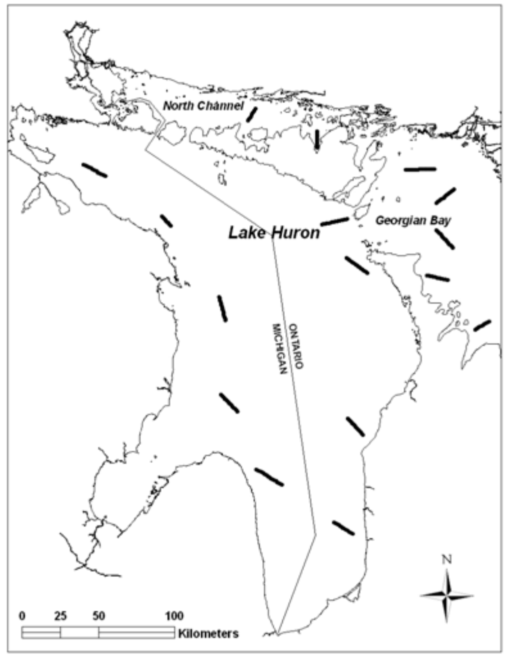

Figure 1. Map of Lake Huron showing 2008 acoustic transects.

subsequent transects were spaced evenly around the first. Effort (transects per strata) was allocated based on stratum area and the mean of standard deviations of total biomass in each stratum from previous surveys using an algorithm by Adams et al. (2006). For analysis, each transect was apportioned into 1,000 m long sampling units consisting of multiple 10-m depth layers. During 2004-2007 acoustic transects were predominantly parallel to each other. However, during 2008 transects were angled to reduce travel distance and fuel costs.

During all years except 2006, acoustic data were collected during September through October with a Biosonics split-beam 120 kHz echosounder deployed through a sonar tube from the R/V (Research Vessel) Sturgeon. During 2006, acoustic data were collected during August with a 70 kHz echosounder and a transducer deployed via a towfish from the R/V Grayling. In all years sampling was initiated 1 hour after sunset and ending 1 hour before sunrise. Echo integration thresholds of -80 dB were used throughout the surveys.

Species and size composition were determined using a 15-m headrope midwater trawl with a fishing mouth opening of 63 m^2 and 6.35-mm cod end mesh. Tow locations and depths were chosen to target fish aggregations, and we attempted to obtain multiple tows per transect so that data were available from the epilimnion, metalimnion, and hypolimnion. Trawl depth was monitored using a Netmind™ system. Most midwater trawl tows were of 10 minutes duration, although tow times were extended up to 20 minutes if few fish were present. Nineteen midwater tows were performed. Temperature profiles were obtained using a bathythermograph on each acoustic transect. All fish were identified, counted, and weighed in aggregate (g) by species. Up to 100 randomly selected individuals were measured (mm) per tow. Individual fish were assigned to length categories based on total length (alewife *Alosa pseudoharengus* <100 mm, ≥ 100 mm; rainbow smelt *Osmerus mordax* <90 mm, ≥ 90 mm; bloater *Coregonus hoyi* < 120 mm, ≥ 120 mm).

Acoustic data were analyzed using Echoview 4.6™, which provided fish density estimates for each sampling unit. Fish density was calculated as

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

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

Density (fish/ha) of individual species was estimated as the product of acoustic fish density and the proportion of each species (by number) in the midwater trawl catches at that location. Total density per species was subdivided into small and large size-classes by multiplying total density by the numeric proportions of each size group. Average weights of each species within size groups were calculated by dividing the number of individuals by weight for each size class of each species captured in each tow.

In order to assign species and size composition to acoustic data, we used different approaches depending on the vertical position in the water column. For cells with depth < 40 m, midwater trawl and acoustic data were matched according to transect, depth layer (0-10, 10-20 m, etc., depending on headrope depth or 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 geographic stratum. If acoustic data still had no matching trawl data, we used a basinwide mean for each depth layer-bottom depth combination. For any cell still lacking trawl composition data, we assigned the lakewide mean. Mean mass of species/size groups at depths < 40 m were estimated using weight-length equations from midwater trawl data. For depths ≥ 40 m, we assumed that acoustic targets were large bloater if mean TS was > -45 dB (Tewinkel and Fleischer 1999). Mean mass of bloater in these cells was estimated using the mass-TS equation of Fleischer et al. (1997). If mean TS was ≤ -45 dB, we assumed the fish were large rainbow smelt and estimated mean mass from mean length, which was predicted using the TS-length equation of Rudstam et al. (2003). This eliminated a bias inherent with deep midwater trawl tows- the capture of non-target species when the trawl is descending and ascending and it allowed us to characterize species composition in deep areas where fish tended to be close to the bottom and midwater trawling was problematic.

Biomass (kg/ha) was estimated as the product of total density (estimated acoustically) and the numeric proportions of each size class of each species and its respective average weight in the trawls. Mean and relative standard error (RSE= (SE/mean) ·100) for density and biomass in the survey area were calculated for each species. Mean density and biomass estimates were estimated for each transect, weighted for transect length. Annual and regional differences in abundance were compared using ANOVA, with alpha set at 0.05 and the assumption that data were independent. Tukey's multiple comparison test was used to evaluate significance of differences among years within the main basin, and then among regions in 2008. Natural log +1 transformations were used to meet ANOVA assumptions and address absence of some species in some years. SAS (SAS Institute Inc, 2007) was used for calculation of RSE and conducting ANOVA or paired comparisons.

We made several analytical changes during 2008. First, we modified the way we matched acoustic and trawl data so that cisco density and biomass were held to zero in basins where no ciscoes were caught. The previous method produced inflated estimates of cisco density and biomass during 2007, especially for the North Channel. Second, we modified the analytical process by which fish densities were calculated at depths ≥ 40 m after we determined that our previous approach overestimated bloater density and underestimated rainbow density. Revised density estimates for those species caused slight differences from previous reports, with the exception being 2004 and 2005 yearling and older bloater densities reported; densities for those years were about half that reported. Revised estimates were more accurate, and no revision caused us to change any conclusions reached in previous reports.

Results- Main Basin

<u>Alewife</u>

Alewives were an important prey species in the latter half of the 20th century, but have been scarce in recent years. Since 2004, we have captured few alewives, and of those nearly all were age-0 fish. Age-0 alewives were captured during 2008 at densities comparable to 2005 or 2006, but main basin density and biomass remained low. Age-0 alewife density was not significantly different among 2005, 2006, and 2008, but densities in those years were significantly higher than 2004 or 2007 (Figure 2, Tukey's test, 6 of 10 comparisons, $P<0.05$).

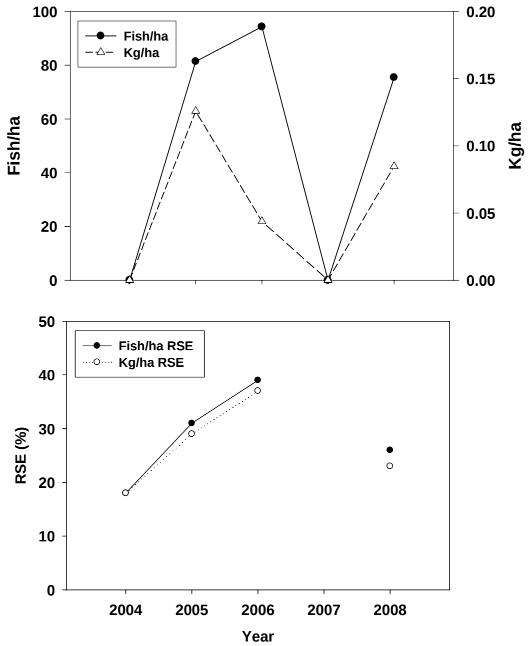

Figure 2. Acoustic estimates of age-0 alewife density and biomass in Lake Huron's Main Basin, 2004-2008 (upper panel), and relative standard error of density estimates (lower panel).

Age-0 alewife biomass was significantly higher in 2005 and 2008 compared with 2004 and 2007 (Tukey's test, 4 of 10 comparisons, *P* <0.05); however, it was chronically low between 2004 and 2008 in the sense that alewives never comprised more than 2.5 % of main basin pelagic fish biomass. Furthermore, age-0 alewives appeared to have low survival because we captured no adults between 2004 and 2008.

Rainbow smelt

Main Basin rainbow smelt density and biomass varied among years. Age-0 density was significantly higher during 2006 compared with other years (Figure 3, Tukey's test, four of 10 comparisons significant *P*<0.05); however, there were no differences in age-0 biomass among years during the time period studied.

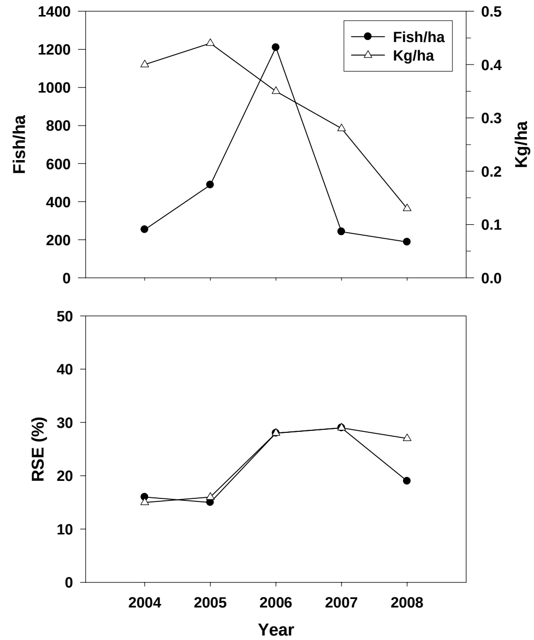

Figure 3. Acoustic estimates of age-0 rainbow smelt density and biomass in Lake Huron's Main Basin, 2004-2008, (upper panel), and relative standard error of estimates (lower panel).

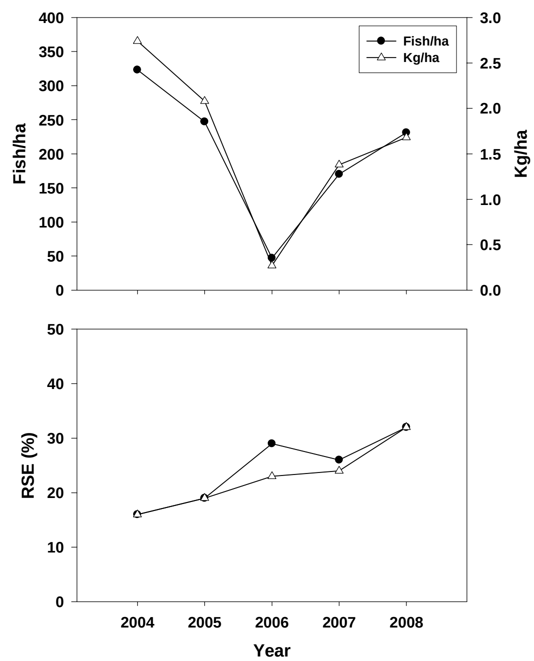

Figure 4. Acoustic estimates of yearling and older rainbow smelt density and biomass in Lake Huron's Main Basin, 2004-2008, (upper panel), and relative standard error of estimates (lower panel).

Both density and biomass of yearling and older smelt in 2008 were similar to what we observed in 2007 (Figure 4). Among all years, both density and biomass were significantly lower in 2006 than in other years (Tukey's test, density: 4 of 10 comparisons significant, $P<0.05$; biomass: 4 of 10 comparisons significant, $P<0.05$) (Figure 4).

Bloater

Main Basin bloater densities increased during 2008. Age-0 density increased almost nine-fold from 2007, with a four-fold increase in biomass (Figure 5). Both age-0 density and biomass were similar in 2005 and 2007 and had significantly higher values during 2004 and 2006, but 2008 values were significantly higher than all other years (Tukey's test, density: 9 of 10 comparisons significant, $P<0.05$; biomass: 9 of 10 comparisons significant, $P<0.05$). Relative standard errors (RSE's) for both age-0 density and biomass decreased between 2007 and 2008, likely due to a wider and more even spatial distribution. Age-0 bloaters were especially prevalent in Canadian Main Basin waters near Goderich and Tobermory, Ontario.

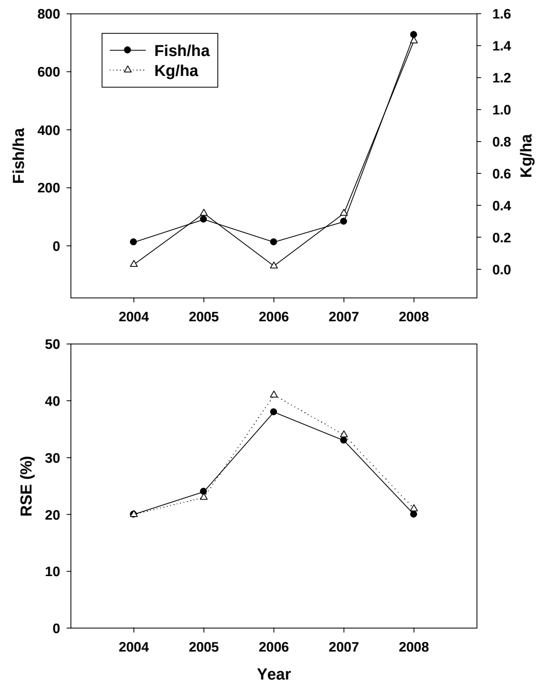

Figure 5. Acoustic estimates of age-0 bloater density and biomass in Lake Huron's Main Basin, 2004-2008, (upper panel), and relative standard error of estimates (lower panel).

We also observed density and biomass increases in both yearling and older bloaters (Figure 6). Main Basin density of yearling and older bloaters was significantly higher during 2007 and 2008 compared with other years (Tukey's test, density: 4 of 10 comparisons significant, $P<0.05$); furthermore, biomass was significantly higher during 2008 compared with 2004-2006, but did not differ from the 2007 estimate (Tukey's test, 3 of 10 comparisons significant, $P<0.05$). Higher yearling and older bloater abundance was likely the result of recent recruitment because yearling and older bloaters captured in trawls ranged only from 120 to 144 mm total length (TL) and may represent the large year classes observed during the 2005 and 2007 bottom trawl surveys (Roseman et al. 2008).

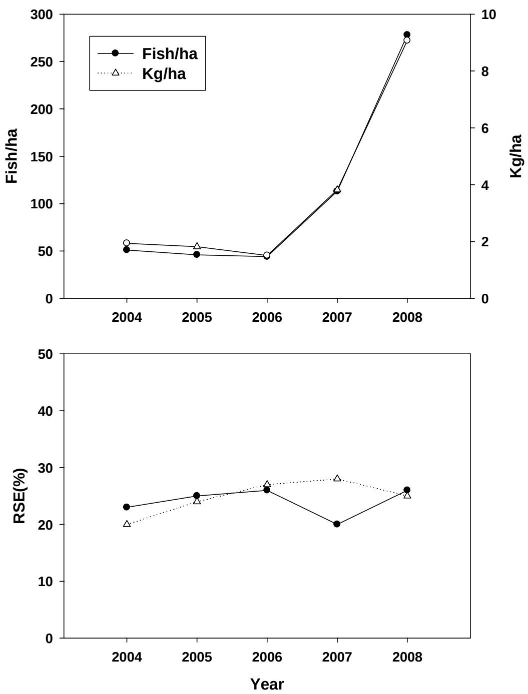

Figure 6. Acoustic estimates of yearling and older bloater density and biomass in Lake Huron, 2004-2008, (upper panel), and relative standard error of estimates (lower panel).

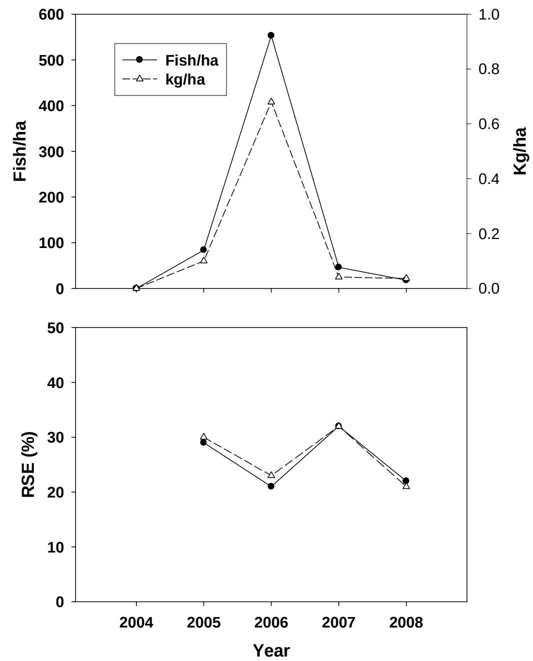

Figure 7. Acoustic estimates of emerald shiner density and biomass in Lake Huron, 2004-2008, (upper panel), and relative standard error of estimates (lower panel).

Emerald shiner

Emerald shiner *Notropis atherinoides* were collected in all years except 2004. Main Basin density and biomass were lower during 2008 compared with 2007 (Figure 7). Density and biomass varied significantly among years; density was significantly higher in 2006 compared with other years, and densities were similar in 2005 and 2007. (Tukey's test, 7 of 10 comparisons significant, $P<0.05$) Biomass was higher during 2006 compared with all other years (Tukey's test, 4 of 10 comparisons significant, $P<0.05$).

Cisco

Cisco were absent from our survey collections from 2004-2006 and were collected for the first time in 2007, in both the Main Basin and Georgian Bay. Cisco densities in 2007 were >8 fish/ha, and their biomass of (2.7 kg/ha) comprised 30% of Main Basin pelagic fish biomass (Figure 8). Cisco density in 2008 was less than 1 fish/ha, and biomass was less than 0.05 kg/ha. During 2008 no adult cisco were captured while trawling; however, we did capture small coregonids at the most northern Georgian Bay transect that we could not identify with certainty as either bloater or cisco.

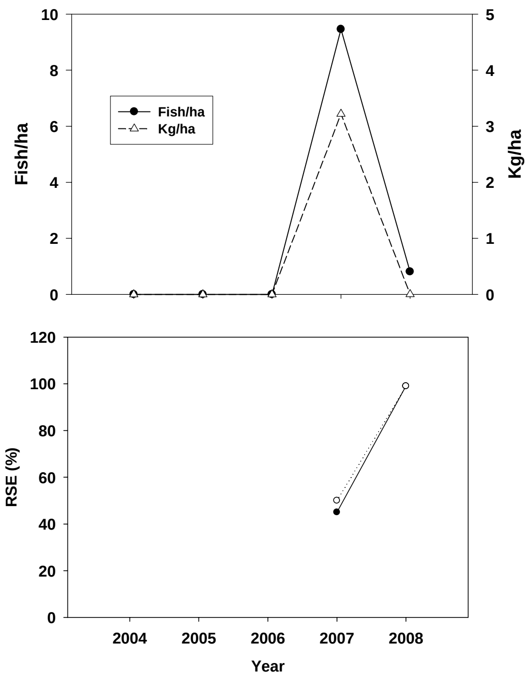

Figure 8. Acoustic estimates of cisco (2007) and unidentified coregonid (2008) density and biomass in Lake Huron, 2004-2008, (upper panel), and relative standard error of estimates (lower panel).

We ascribed them as cisco based on bottom depth and individual size. Average bottom depth where they were caught was 40.3 m while main basin bottom depths that produced trawled bloaters of any size ranged from 45 to 95 m with a mean bottom depth of 68 m. Additionally mean length of putative cisco was significantly larger (137 mm TL) than bloater mean length (78 mm TL) (*t* test, *P* <0.05). This was largely due to differences in size distribution; 84% of the Georgian Bay coregonids were larger than the largest identifiable bloater (122 mm TL) captured during the survey.

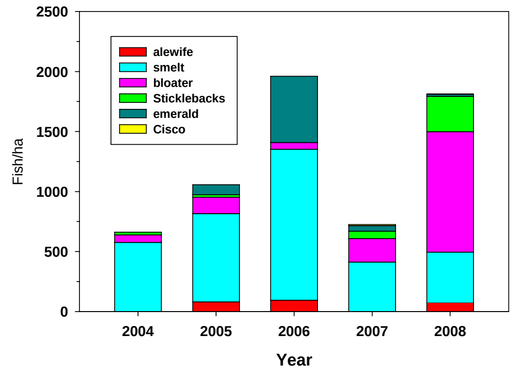

Figure 9. Acoustic estimates of total pelagic fish density in Lake Huron's Main Basin, 2004-2008.

Main Basin Fish Community

Main Basin pelagic fish density more than doubled between 2007 and 2008 and we observed changes in species composition (Figure 9). Total density increased because bloater density increased, but also because of increased densities of non-native alewife and threespine stickleback *Gasterosteus aculeatus*, and some native ninespine stickleback *Pungitius pungitius*. Those three species were rare or absent during 2007 but comprised about 20% of pelagic fish density during 2008. Total fish density in 2006 and 2008 was significantly higher than in 2004 or 2007 (Tukey's test, density: 4 of 10 comparisons significant, *P*<0.005).

Main Basin pelagic fish biomass increased to just over 12 kg/ha and is now dominated by native species (Figure 10). Rainbow smelt biomass was similar to 2007, but bloater biomass increased. Cisco biomass declined primarily because no large adults were captured during 2008. Pelagic fish biomass during 2008 was significantly greater than that observed in 2004, 2005, or 2006, but did not differ significantly from the 2007 estimate (Tukey's test, density: 4 of 10 comparisons significant, *P*<0.005).

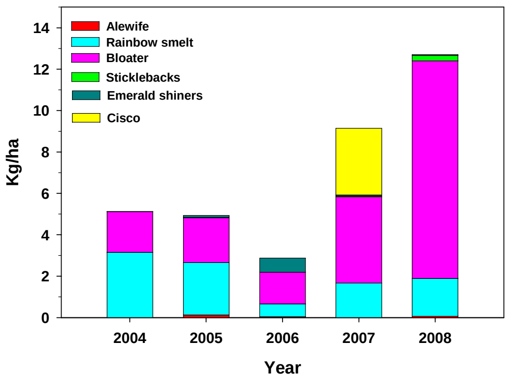

Figure 10. Acoustic estimates of total pelagic fish biomass in Lake Huron's Main Basin, 2004-2008.

Among-Basin Comparisons

Between 2004-2007 we observed consistent differences in total fish density and biomass among Lake Huron's three basins, with the North Channel having higher biomass than the Main Basin or Georgian Bay (Warner et al. 2005, Schaeffer et al. 2008). This pattern was not evident in 2008; there were no significant density or biomass differences among basins during 2008 (Tukey's test for density and biomass, density: none of 6 comparisons significant, *P*<0.05) (Figures 11, 12). This was not due to temporal trends in Georgian Bay or North Channel because we detected no differences in fish densities among years within those geographic strata (Tukey's test, density: 0 of 20 comparisons significant, *P*<0.005).

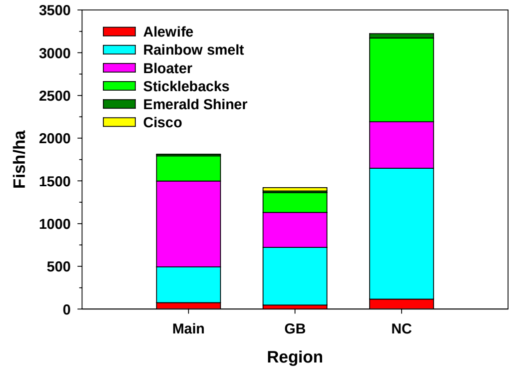

Figure 11. Acoustic estimates of total pelagic fish densities in Lake Huron's Main Basin (Main), Georgian Bay (GB) and North Channel (NC), 2008.

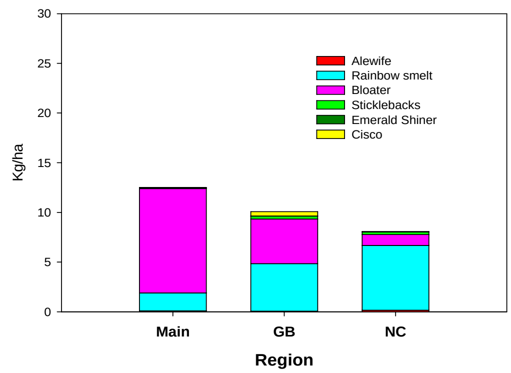

Figure 12. Acoustic estimates of total pelagic fish biomass in Lake Huron's Main Basin (Main), Georgian Bay (GB) and North Channel (NC), 2008.

Discussion

Lake Huron's Main Basin pelagic fish density and biomass increased during 2007 and 2008 compared to 2004-2006. Most of the change was due to increased cisco (2007) and bloater (2007, 2008) abundance. Both age-0 and yearling and older bloater increased during 2008; age-0 densities suggest that the 2008 year class was strong, and density increases of older fish likely can be attributed to strong year-classes in 2005 and 2007 (Roseman et al. 2008). However, even with increases during the past two years, pelagic fish biomass is substantially lower than in the past. In 2008, mean fish biomass in the main basin was about 15 kg/ha. In 1997, Warner et al. (accepted) determined lakewide biomass to be 72.3 kg/ha, nearly six times higher than our 2008 Main Basin estimate. The 1997 survey occurred at a time when large bloaters were abundant. Alewife was relatively rare in 1997 as well, comprising less than 5% of the pelagic biomass. Hence, the relatively low fish biomass that we have observed since 2004 is not solely due to loss of alewives, but also to a reduction in bloater and rainbow smelt biomass .

Although alewife were more abundant during 2008 than 2007, that increase is not indicative of a return to their former abundance. We observed similar densities in 2005 and 2006, but alewife have never exceeded 2.5 % of total fish density since 2004, and will likely remain scarce during 2009. Furthermore, almost all alewife captured since 2004 have been age-0; although some reproduction is occurring, this has not translated into increased adult densities.

During 2008, threespine sticklebacks were abundant in all three basins and some ninespine sticklebacks were collected as well. Sticklebacks comprised a substantial fraction of Main Basin density. Threespine stickleback is not native to the upper Great Lakes, but have been present since the early 1980's (Stedman and Bowen 1985). They appear to reside in the offshore epilimnion, and have been collected rarely in bottom trawl surveys (GLSC, unpublished data) and prior to 2008 they comprised only a small fraction of total density in acoustic surveys. The reason for their apparent increase is unknown. Although densities increased during 2008, their effect on biomass was minimal due to their small size relative to adult rainbow smelt and bloaters.

We have observed few differences in rainbow smelt density or biomass among years; 2008 density and biomass estimates were similar to most other years during 2004-2007. Rainbow smelt are an important prey for salmonids (Diana 1990), but their Main Basin biomass has ranged only between about 1.5 and 3.0 kg/ha since 2004, and they may be less important than bloaters which had a higher biomass in 2008 (10.51 kg/ha).

The low abundance of emerald shiners during 2007 and 2008 remains perplexing. Because alewives are scarce, conditions for emerald shiner recruitment should be better (Schaeffer et al. 2008). One possible explanation is that emerald shiners may be the only prey species inhabiting the upper levels of the water column and the focus of predation by salmonids and walleyes *Sander vitreus*. High spatial overlap with predators combined with the absence of alternative prey (especially alewife) may be a reason for their current low numbers.

The 2008 fish community contrasted with other years in one key way. During 2004-2007, density and biomass in the North Channel were higher than that in either Georgian Bay or the Main Basin, but in 2008 there were no significant differences among basins. We do not believe that our results are an artifact of survey design or transect location. Within the North Channel, the initial transect was randomly selected based on longitude, then additional transects are spaced as evenly as possible around the random selection. The randomly selected transect occurred in West Bay, an area somewhat isolated from the main portion of the North Channel. However, 2008 fish densities there and at the second transect were well within the range of fish densities sampled previously in the North Channel during 2004-2007. Thus, the lack of among basin differences during 2008 appears to be substantiated. We do note that changes in species composition may have also contributed to the lack of among-basin differences in biomass. High stickleback density in the North Channel could have reduced biomass estimates there because sticklebacks are smaller than the yearling and older rainbow smelt that have been prevalent historically.

We ascribed some Georgian Bay coregonids as cisco based on size and capture depth. They could have been bloater. Had we misidentified them it would not change any of our conclusions about trends in density or biomass because cisco comprised only a small fraction of density and biomass in Georgian Bay. Furthermore, it would not change our conclusions that cisco remain scarce.

This survey sampled offshore areas of Lake Huron from 10 to 250 m in depth. This depth range encompassed about 85% of the total surface area of Lake Huron. However, this survey did not address nearshore zones and large embayments, especially Thunder Bay, Saginaw Bay, and Parry Sound. These areas could be responsible for a substantial amount of pelagic fish production, but could not be sampled safely due to the draft of our research vessel (3 m). We believe that our biomass estimates may have been higher had these areas been included because nearshore areas are well known as nursery habitats and could have supported higher densities of age-0 fishes than offshore waters (Fielder and Thomas 2006, Höök et al. 2001, Klumb et al. 2003).

During 2009, forage availability for piscivores will likely depend on the level of predation on bloater. In Lake Michigan, age-1 Chinook salmon *Oncorhynchus tshawytscha* were shown to feed selectively on bloaters at times of high bloater density even in the presence of other prey, however alewife were likely never scarce enough to imply bloater dependence (Warner et al. 2008). The present situation in Lake Huron where bloater is relatively abundant but alewife and other prey are scarce may result in dependence on bloater as the primary prey. For 2009, we suggest monitoring Chinook salmon diet and growth to evaluate their response to a novel prey base in Lake Huron.

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Literature Cited

Adams J.V., R. L. Argyle, G. W. Fleischer, G. L. Curtis, and R. G. Stickel. 2006. Improving the design and efficiency of acoustic and midwater trawl surveys through stratification, with an application to Lake Michigan prey fishes. North American Journal of Fisheries Management 26: 612-621.

Argyle, R. L.. 1982. Alewives and rainbow smelt in Lake Huron: midwater and bottom aggregations and estimates of standing stocks. Transactions of the American Fisheries Society 111: 267-285.

DesJardine, R. L., T. K. Gorenflo, R. N. Payne, and J. D. Schrouder. 1995. Fish-community objectives for Lake Huron. Great Lakes Fishery Commission Special Publication 95-1. 38 pages.

Diana, J. S. 1990. Food habits of angler-caught salmonines in western Lake Huron. Journal of Great Lakes Research 16: 271-278.

Fabrizio, M. C., J. V. Adams, and G. L. Curtis. 1997. Assessing prey fish populations in Lake Michigan: comparison of simultaneous acoustic-midwater trawling with bottom trawling. Fisheries Research 33: 37-54.

Fielder, D. G., and M. V. Thomas. 2006. Fish Population Dynamics of Saginaw Bay, Lake Huron 1998 – 2004. Michigan Department of Natural Resources, Fisheries Research Report. No. 2083. Ann Arbor.

Fleischer, G. W., R. L. Argyle, and G. L. Curtis. 1997 . *In situ* relations of target strength to fish size for Great Lakes pelagic planktivores. Transactions of the American Fisheries Society 126: 784-796.

Höök, T.O., N.M. Eagan, and P.W. Webb. 2001. Habitat and human influences on larval fish assemblages in northern Lake Huron coastal marsh bays. Wetlands 21:281–291.

Klumb, R.A., Rudstam, L.G., Mills, E.L., Schneider, C.P., and Sawko, P.M. 2003. Importance of Lake Ontario embayments and nearshore habitats as nurseries for larval fish with emphasis on alewife (*Alosa pseudoharengus*). J. Great Lakes Res. 29:181-198.

Roseman E.F., T. J. Desorcie, J. R.P. French III, T. P. O'Brien, A. Simon, S. C. Riley, and J. S. Schaeffer. 2008. Status and Trends of the Lake Huron Deepwater Demersal Fish Community, 2007. Great Lakes Science Center Annual Lake Committee Report.

Rudstam, L. G., S. L. Parker, D. W. Einhouse, L. Witzel, D. M. Warner, J. Stritzel, D. L. Parrish, and P. Sullivan. 2003. Application of *in-situ* target strength to abundance estimations in lakes- examples from rainbow smelt surveys in Lakes Erie and Champlain. ICES Journal of Marine Science 60: 500-507.

SAS Institute,, Inc. 2007. OnlineDoc 9.1.2. Cary, NC, SAS Institute, Inc.

Schaeffer, J.S., T. P. O'Brien, D. M. Warner, and E. F. Roseman. 2006. Status and Trends of Pelagic Prey Fish in Lake Huron, 2005: Results From a Lake-Wide Acoustic Survey. Great Lakes Science Center Annual Lake Committee Report.

Schaeffer, J. S., D. W. Warner, T. P. O'Brien, and Edward F. Roseman. 2007. Status and Trends of Pelagic Prey Fish in Lake Huron's Main Basin, 2006: Great Lakes Science Center Annual Lake Committee Report.

Schaeffer, J. S., and D. W. Warner. 2008. Status and Trends of Pelagic Prey Fish in Lake Huron, 2007. Great Lakes Science Center Annual Lake Committee Report.

Schaeffer, J. S., D. M. Warner, and T. P. O'Brien. 2008. Resurgence of Emerald Shiners *Notropis atherinoides* in Lake Huron's Main Basin. Journal of Great Lakes Research 34:395–403.

Stedman, R. M., and C. A. Bowen II. 1985. Introduction and spread of the threespine stickleback (*Gasterosteus aculeatus*) in lakes Huron and Michigan. Journal of Great Lakes Research. 11: 508-511.

Stockwell, J. D., D. L. Yule, T. R. Hrabik, J. V. Adams, O. T. Gorman, and B. V. Holbrook. 2007. Vertical distribution of fish biomass in Lake Superior; implications for day bottom trawl surveys. North American Journal of Fisheries Management 27: 735-749.

TeWinkel, L. M., and G. W. Fleischer. 1999. Vertical Migration and Nighttime
Distribution of Adult Bloaters in Lake Michigan. Trans. Am. Fish. Soc. 128: 459-474.

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

Warner, D. M., T. P. O'Brien, C. S. Faul, and R. G. Stickel. 2005. Status of pelagic prey fish in Lake Huron in 1997 and 2004. Great Lakes Science Center Annual Lake Committee Report.

Warner, D.W., C.S. Kiley, R. M. Claramunt, and D. F. Clapp. 2008. The Influence of Alewife Year-Class Strength on Prey Selection and Abundance of Age-1 Chinook Salmon in Lake Michigan. Transactions of the American Fisheries Society 137:1683–1700.

Warner, D. W., J. Holusczko, and T. Desorcie. 2009. Status of pelagic prey fish in Lake Michigan in 2008. Great Lakes Science Center Annual Lake Committee Report.

Warner, D. W., J. Schaeffer, and T. P. O'Brien. In review. The Lake Huron pelagic fish community: Persistent spatial pattern along biomass and species composition gradients. Canadian Journal of Fisheries and Aquatic Sciences.

Yule, D.L., J. V. Adams, J. D. Stockwell, and O.T. Gorman. 2008. Factors affecting bottom trawl catches; implications for monitoring the fishes in Lake Superior. North American Journal of Fisheries Management 28: 109-122.