

Resurgence of Emerald Shiners *Notropis atherinoides* in Lake Huron's Main Basin

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ABSTRACT. Emerald shiners *Notropis atherinoides* were formerly common in Lakes Huron and Michigan, but declined during the 1960s as the exotic alewife *Alosa pseudoharengus* proliferated. The Lake Huron emerald shiner population was chronically depressed through 2004; however, we detected resurgence in emerald shiner density and biomass in Lake Huron during acoustic and midwater trawl surveys conducted during 2004–2006. Emerald shiners were not found during 2004, but by 2006 main basin density exceeded 500 fish/ha, biomass estimates exceeded 0.5 kg/ha, and emerald shiners contributed more to pelagic biomass than alewives or rainbow smelt *Osmerus mordax*. Length frequency distributions suggested that increased density was the result of two consecutive strong year classes in 2005 and 2006. Emerald shiner distributions also expanded from a focus in western Lake Huron in 2005 to a lakewide distribution in 2006. Emerald shiners occurred offshore, but were nearly always associated with epilimnetic surface waters warmer than 19°C. Resurgence of emerald shiners was likely a consequence of reduced alewife abundance, as they declined concurrently with alewife proliferation during the early 1960s. Return of this species may benefit native nearshore piscivores; however, benefits to Pacific salmonids *Oncorhynchus* spp. are uncertain because emerald shiners are smaller and still less abundant than historically important prey species, and they may be thermally segregated from salmonines.

INDEX WORDS: Emerald shiner, recruitment, Lake Huron, reproductive success, restoration.

INTRODUCTION

Emerald shiners *Notropis atherinoides* were formerly abundant throughout the Great Lakes region, with wide distribution in both inland waters and the Great Lakes proper (Becker 1983). Emerald shiners served as forage for piscivores (Parsons 1971, Knight and Vondracek 1993), and have been an essential component of a regional bait industry (Meronek *et al.* 1997). In Lake Huron, they were especially prevalent in Saginaw Bay (Carr 1962, Keller *et al.* 1987).

Emerald shiners experienced widespread decline during the 1950s, with most authors agreeing that decreased abundance was associated with alewife *Alosa pseudoharengus* invasion. Alewife proliferation led to some combination of competition with emerald shiners for zooplankton or direct consumption of their eggs and larvae (Smith 1970, Wells and

McClain 1973, Crowder 1980, Jude and Tesar 1985, Madenjian *et al.* 2008). Loss of emerald shiners was so pervasive that none were collected in over 30 years of bottom trawling in Lake Michigan (1973–2004; Bunnell *et al.* 2006), and they remained rare in other concurrent Lake Michigan nearshore studies despite a 90% reduction in alewife biomass (Jude and Tesar 1985, Madenjian *et al.* 2002). Emerald shiners were also observed rarely in Lake Huron, with only 124 individuals collected during an annual bottom trawl survey that spanned a similar time period (1973–2006, Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI 48105, unpublished data).

However, during 2004–2006 emerald shiners increased rapidly in abundance in Lake Huron and once again became an important component of the pelagic fish community. Here, we document population increase, provide spatially explicit density and biomass estimates, and suggest that resurgence may have been caused by a reduction in alewife density.

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METHODS

Field Sampling

Acoustic surveys during 2004, 2005, and 2006 used a stratified and randomized systematic design with evenly spaced parallel transects in three main-basin regions (strata): eastern main basin, western main basin, and southern main basin (Fig. 1). Effort in each stratum was approximately proportional to its area, although there were always at least two transects within each stratum. Each transect was divided into 1,000 m long, elementary sampling units (ESU) consisting of multiple, 10-m depth layers. Acoustic data were collected at night during annual surveys in October 2004, September and October 2005, and August 2006, with a Biosonics split beam echosounder. Sampling was initiated 1 h after sunset and ended 1 h before sunrise. In 2004–2005, we used a 120-kHz split beam echosounder (half-power beam width = 6.8°) mounted on a towfish (2004), or deployed through a sonar tube (2005). In 2006 we used a 70 kHz echosounder (half-power beam width = 5.4°) mounted on a towfish. Raw acoustic data were collected using a -85 to -100 dB threshold. Sound speed was estimated using surface temperature measured with a bathythermograph. Echosounders were calibrated during surveys using 33 and 36 mm tungsten carbide spheres for 120-kHz and 70-kHz echosounders, respectively.

Species and size composition data were collected using a 15-m headrope midwater trawl with an opening of 63 m² and 6.35-mm, cod-end mesh. Tow locations and depths were chosen to target fish aggregations, but we attempted to obtain 1–3 tows per transect so that data were available from the epilimnion, metalimnion, and hypolimnion within each stratum. Trawl tows followed transect lines. Trawl depth was monitored using a Netmind™ system. Most midwater trawl tows were 10 min long but tow times were occasionally extended up to 20 min if few fish were present. Water temperature profiles were obtained using a bathythermograph after each trawl tow. All fish were identified, counted, and weighed in aggregate (g) by species. Up to 100 randomly selected individuals per species were measured (mm total length) per tow, and small fish (< 2 g) were frozen in water for measuring individual lengths and weights in the laboratory. Individual alewives, rainbow smelt *Osmerus mordax*, and bloaters *Coregonus hoyi* were assigned to size categories (small, large) based on total length (alewife < 100 mm, ≥ 100 mm; rainbow smelt < 90 mm, ≥ 90 mm; bloater < 120 mm, ≥ 120 mm).

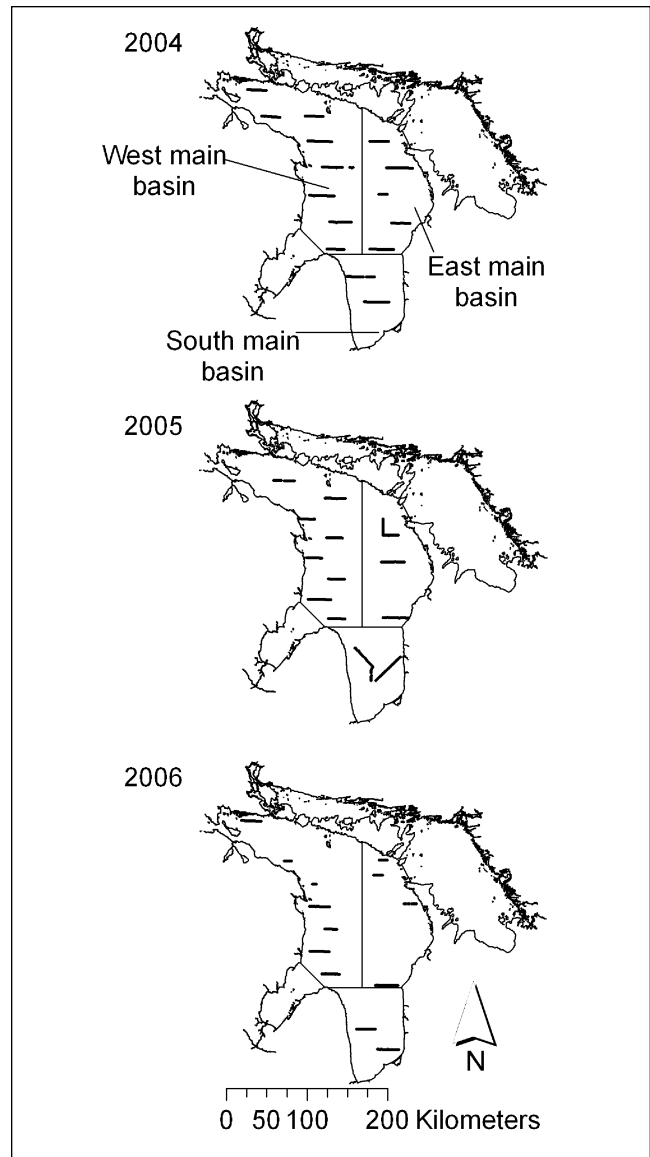


FIG. 1. Location of acoustic transects in Lake Huron's main basin, 2004–2006.

Acoustic Data Analysis

Trawl and acoustic data at water column depths < 40 m were linked using the closest trawl data to a given acoustic cell categorized by transect, depth layer (10-m bins), and bottom depth (10-m bins). First, trawl data were matched to acoustic data cells by transect, depth layer, and bottom depth category, which provided essentially a one-to-one match. Subsequent steps populated acoustic cells with trawl data that were aggregated by averaging over: 1) transect, depth layer, and bottom depth, 2) stratum, depth layer, and bottom depth, 3) depth layer and bottom depth, 4) depth layer, and 5) coarse

depth layers corresponding to epilimnion (0-20-m depths), metalimnion (20-50 m depths), and hypolimnion (depth > 50-m). Species composition of deep acoustic cells could be biased when deep trawl tows captured surface dwelling species during trawl set and retrieval.

Thus, for depths > 40 m, we assumed that acoustic targets > -45 dB were large bloater (TeWinkel and Fleischer 1999) and targets ≤ -45 dB were large rainbow smelt. Mean mass of bloater in these cells was estimated using a mass-target strength (TS) equation of Fleischer *et al.* (1997). Mean mass of rainbow smelt in these cells was estimated from mean length, which was predicted from mean target strength (TS) using the length-TS equation of Rudstam *et al.* (2003). Density in each acoustic cell was estimated by scaling echo integration data with mean *in situ* acoustic fish size. To create echo integration data we applied a -64 dB lower threshold to TS data and converted the data to area backscattering coefficient (ABC, m²/m²). Rudstam *et al.* (2008) found that excluding scattering from targets larger than this threshold was effective at excluding most fish from acoustic estimates of *Mysis relicta* density. Density estimates were generated using the formula

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

where 10^4 = a conversion factor (m²/ha) to convert fish densities to number/ha and σ = the mean backscattering cross section (m²) of all targets between -60 and -30 dB in each cell. This TS range likely included most fish vulnerable to our trawl. However, the -60 dB threshold may exclude some young-of-the-year rainbow smelt (Parker Stetter *et al.* 2006). Single targets were detected using split-beam method 1 (Soule *et al.* 1997) and consistent detection settings (Table 1).

Densities (fish/ha) of the different species of fishes were estimated as the product of acoustic fish density and the numeric proportion of each species in the trawl data assigned to that acoustic cell. Densities of each species were further subdivided into size-specific densities by multiplying total species density by the numeric proportions in each size group present within that species. Biomass (kg/ha) for the different groups was then estimated from density and size-specific mean weights from the trawl data (except as described above for depths > 40 m). Mean and relative standard error (RSE = 100*SE/mean) for density and biomass in the survey area were estimated using stratified cluster

TABLE 1. Single target detection parameters used in analyses of acoustic data collected in Lake Huron during 2004–2006.

Parameter	Value
TS threshold (dB)	-85 to -100
Pulse length determination level (dB)	6
Minimum normalized pulse length	0.8
Maximum normalized pulse length	1.8
Maximum beam compensation (dB)	6
Maximum standard deviation of minor-axis angles	1
Maximum standard deviation of major-axis angles	1

analysis methods featured in the statistical routine PROC SURVEYMEANS (SAS Institute Inc. 2004). Cluster sampling techniques are appropriate for acoustic data, which represent a continuous stream of autocorrelated data (Williamson 1982, Connors and Schwager 2002). Density and biomass values for each elementary sampling unit in each stratum were weighted by dividing the stratum area (estimated using GIS) by the number of ESUs in the stratum. Annual differences in density and biomass were compared using ANOVA, with alpha set at 0.05. Tukey's multiple comparison tests were used to evaluate significance of differences between years. Interpolated maps of emerald shiner biomass were generated for each year using the inverse distance weighting interpolator and ArcMap 9.2 (ESRI™). Interpolation was done using a fixed-radius search area of 70,000 m to predict onto a grid consisting of 2-km² cells. We selected a search radius that was approximately twice the mean transect spacing to reduce the influence of any outliers. To compare the distribution of emerald shiners in 2005 with the distribution in 2006, we classified grid cells by biomass estimates using categories (break points = 0.06, 0.16, 0.26, and 0.52 kg/ha) and calculated the area occupied by cells in the highest category for each year. Area occupied was calculated as the (number of cells × (4 × 10⁶ m²)) / (1 × 10⁶ m²).

RESULTS

During 2004–2006, we sampled Lake Huron's main basin with 44 acoustic transects representing 1,033 km of acoustic data; each acoustic transect was sampled with 1 to 3 trawl tows to determine species composition (total: 83 trawl tows). No emerald shiners were observed in trawl catches dur-

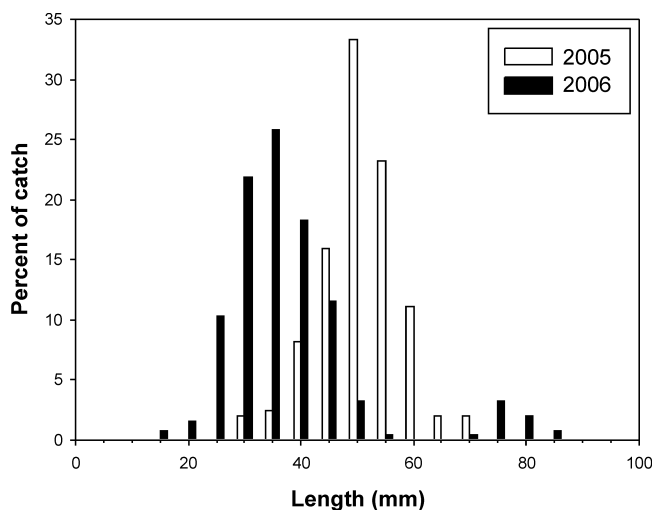


FIG. 2. Length frequency distributions of emerald shiners captured in midwater trawls, Lake Huron, 2005–2006.

ing 2004 (0 of 19 tows); in 2005 they were caught in 7 of 34 tows with a mean catch of 6.6 fish per 10-min tow. Highest abundance was observed in 2006, when we observed emerald shiners in 13 of 30 tows with a mean catch of 24 fish per 10-min tow.

Size distributions of trawl-captured emerald shiners differed among years. In 2005, most emerald shiners ranged between 30 and 60 mm (Fig 2). During 2006, two distinct size classes were present with a smaller mode ranging from 15 to 55 mm total length and a larger group of 70–85 mm.

Emerald shiners were nearly always captured in epilimnetic trawl tows in water that exceeded 19°C. Of the 20 tows that captured them, 15 were tows targeting small acoustic targets above the thermocline and less than 23-m below the surface. Five deeper tows below the thermocline did catch small numbers of emerald shiners, but this occurred only when surface temperatures exceeded 19°C, and indicated that they were probably captured during trawl set or retrieval.

Emerald shiner density, biomass, and range increased significantly between 2004 and 2006. Emerald shiners were not detected at all during the 2004 survey, but by 2006 mean density was 523 fish/ha (RSE = 21.6%) and mean biomass was 0.65 kg/ha (RSE = 24.3%, Fig 3). Both density and biomass increased relative to other species; by 2006 emerald shiners contributed more to pelagic biomass than alewives and rainbow smelt (Fig 4).

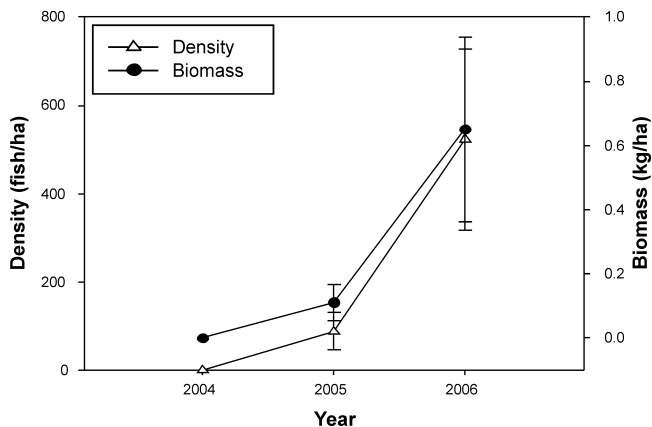


FIG. 3. Density and biomass of emerald shiners based on both acoustic and midwater trawl data, Lake Huron, 2004–2006, with 95% confidence intervals for each estimate. Scale on right axis (biomass) offset for clarity.

Alewife density varied from 0.1 fish/ha in 2004 to 88.5 fish/ha in 2006 (RSE = 30.5%). Density of alewife > 100 mm was greater than zero in 2004 but in 2005–2006, all measurable alewife density consisted of fish < 100 mm in length. Rainbow smelt density increased from 550 fish/ha (RSE = 16.0%) in 2004, to 1,210 fish/ha (RSE = 31.8%) in 2006 and was the result of greater density of small rainbow smelt. Rainbow smelt biomass was similar in 2004 and 2005, but declined to 0.64 kg/ha in 2006 (RSE = 23.0%). Bloater density was lowest in 2006 (63 fish/ha, RSE = 16.8%) and highest in 2005 (200 fish/ha, RSE = 13.0%).

In 2005, emerald shiner abundance was localized and densities were highest in western Lake Huron, but by 2006 they occurred throughout U.S. waters and their range expanded to Canadian waters in the southern basin (Fig 5). In 2005, emerald shiner biomass > 0.53 kg/ha was limited to an area of 140 km² (< 1% of our survey area), whereas in 2006 biomass > 0.53 kg/ha occurred in an area > 12,356 km² (~41% of our survey area).

DISCUSSION

Our results suggest that emerald shiners were rare in Lake Huron's main basin offshore waters during 2004 and increasingly common in 2005–2006. Density, biomass, and spatial distribution increased. Increased densities were likely a result of strong year classes in both years. By 2006, emerald shiners were found in all regions of the main basin,

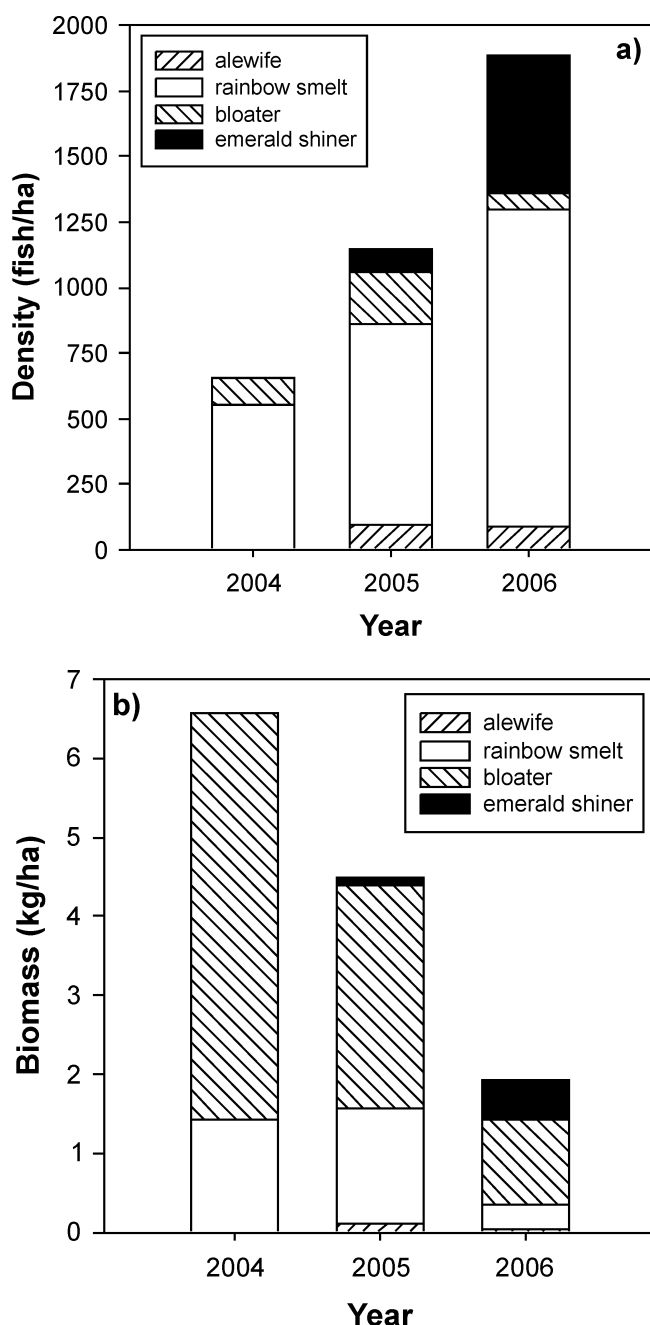


FIG. 4. Density (a) and biomass (b) of main basin pelagic fishes estimated from both acoustic and midwater trawl data, Lake Huron, 2004–2006.

but were nearly always associated with surface waters exceeding 19°C.

Size-at-age data compiled by Becker (1983) indicate that if Lake Huron emerald shiners are similar to other emerald shiner populations then nearly all emerald shiners captured in our study during 2005 were likely age-0. Those captured during 2006 ex-

hibited a bimodal length-frequency distribution and likely corresponded to age-0 fish hatched in 2006, and age-1 fish from the 2005 year class. Putative age-0 fish collected in 2006 were smaller than those collected during 2005. This may be an artifact of seasonal sampling; we sampled during September and October in 2005, but during August in 2006. Thus, age-0 fish collected during 2006 would have had less time to grow that year. Alternatively, there could have been slower individual growth rates during 2006 in the presence of higher densities of conspecifics. In either case, length-frequency distributions were consistent with the hypothesis that resurgence began with a strong year class produced during 2005.

Our results suggest higher abundance and broader distribution of emerald shiners than was found by other Great Lakes investigators since the 1960s. Although emerald shiners are abundant enough to support a substantial bait industry (Meronek *et al.* 1997), Great Lakes populations have been considered chronically depressed since the establishment and proliferation of alewives (Smith 1970, Wells and McClain 1973, Jude and Tesar 1985, Madenjian *et al.* 2008). Madenjian *et al.* (2002) and Wells and McClain (1973) considered emerald shiners to be the species most affected by alewife in terms of magnitude of decrease. Bunnell *et al.* (2006) noted lack of recovery by Lake Michigan emerald shiners during 1973–2004 despite a 90% decrease in alewife abundance or biomass during the same time period, and suggested that emerald shiner recovery might require even greater reduction in alewife density. This probably occurred in Lake Huron during 2004–2006; we observed large scale reduction (> 99%) in alewife densities in annual USGS bottom trawl and low abundance in acoustic-midwater trawl surveys (Schaeffer *et al.* 2005, Warner *et al.* 2005). Although we have no direct evidence for deleterious effects of alewife on emerald shiners, reductions in emerald shiner abundance occurred immediately after alewife proliferation during the early 1960s and they did increase until alewife abundance decreased in 2004–2005 (Roseman *et al.* 2006). Two consecutive strong year classes were produced immediately after reductions in age-0 alewife to unprecedented low densities and undetectable levels of adult alewife. The temporal association suggests strongly that alewives played some role in suppression of emerald shiners. Increased emerald shiner density in Lake Huron was also consistent with a general increase in recruitment by other native

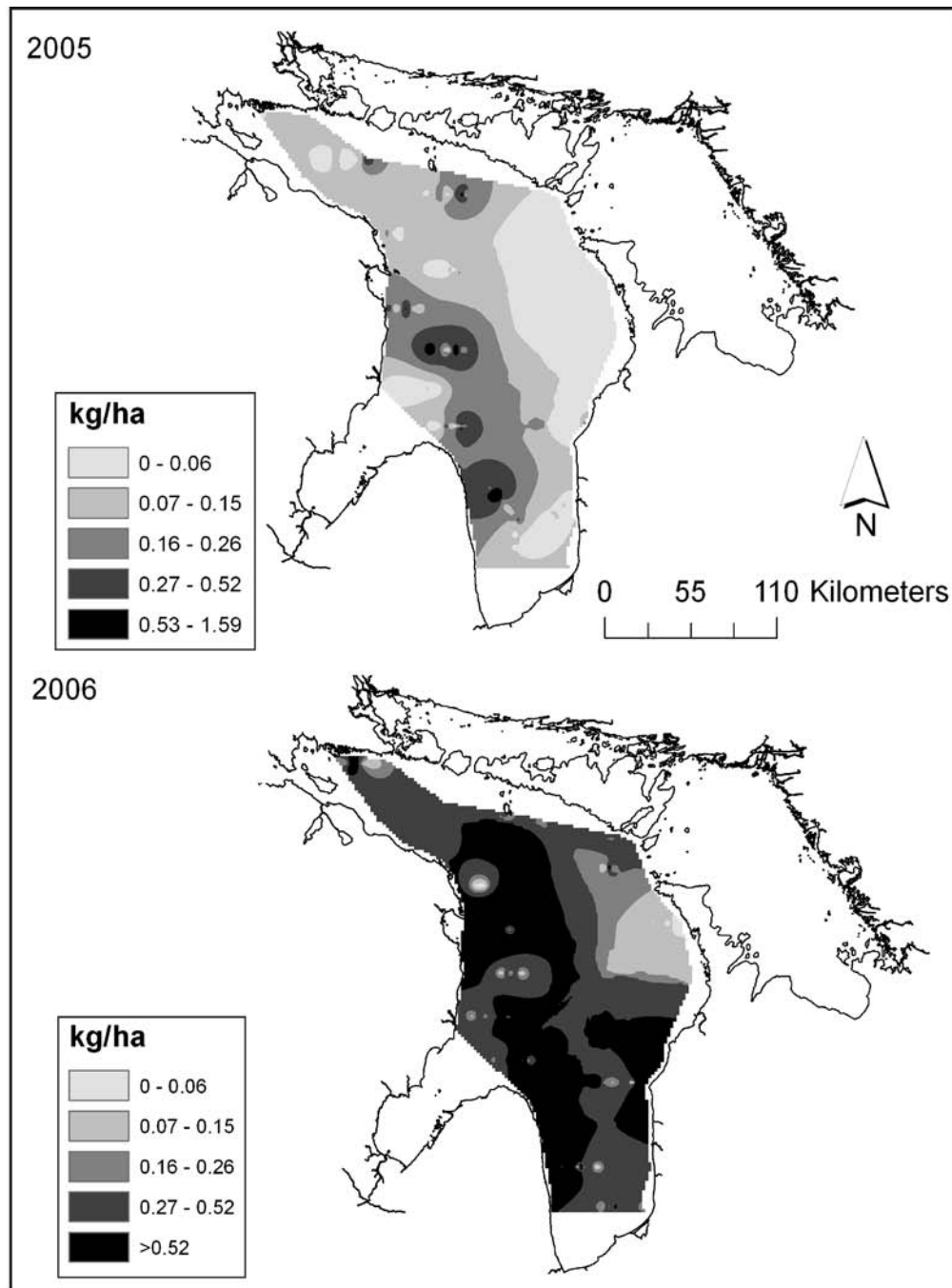


FIG. 5. Spatial distribution of emerald shiner biomass estimated from both acoustic and midwater trawl data within Lake Huron's main basin, 2005–2006.

species following decreased alewife abundance in Lake Huron including percids (Fielder *et al.* 2007), deepwater sculpins *Myoxocephalus thompsoni*, and lake trout *Salvelinus namaycush* (Schaeffer *et al.* 2005). One putative mechanism may be alewife predation on eggs or larvae of emerald shiners. Emerald shiners have pelagic eggs and larvae (Auer

1982), and alewives have been implicated in egg and larval predation on many species throughout the Great Lakes (Madenjian *et al.* 2008)

Our conclusions drawn from the acoustic and midwater trawl data collected during 2004–2006 assumed that seasonal differences in survey timing among years had minimal effect on density or bio-

mass estimates and distribution. That assumption was likely violated. The 2004 survey was performed during October when water temperatures were 12–16°C but the 2005–2006 surveys conducted in August–September and surface temperatures were 4–5°C warmer. Emerald shiners prefer warm temperatures (Campell and MacCrimmon 1970), and colder 2004 temperatures could have prevented detection if they moved to warmer waters we did not sample (very nearshore, stream mouths). This seems unlikely because: a) the only areas we did not sample were nearshore (< 10-m bottom depth) and Saginaw Bay where sea surface temperatures (from NASA's Goddard Earth Sciences Data and Information Services Center, <http://g0dup05u.ecs.nasa.gov/Giovanni/>) were similar to those we measured, b) the area of tributary mouth habitat was likely too small to support the numbers of emerald shiners observed in 2005–2006, and c) emerald shiners are known to tolerate cold water quite well (Colby 1973).

Differences in seasonal sampling likely biased our estimates of density and biomass in that the 2006 survey occurred 1 month earlier (August) than the 2005 survey (September). Biomass estimates during 2006 may have been even higher had they been made in September, because individuals from both putative year classes would have had an additional month to grow. Alternatively, mortality rates of emerald shiners are not known; high mortality rates in the absence of alternative prey may have reduced density estimates. Magnitudes of these biases are unknown, but neither would be likely to change our central conclusion that emerald shiners increased during 2004–2005.

Unbiased acoustic estimates of fish density in the area sampled in a multi-species community require knowledge of the acoustic size (TS) of the fishes being sampled. Acoustic size of emerald shiners is not known, but given the size range we observed, we surmise that TS was in the same range as small rainbow smelt (–68 to –45 dB; Parker Stetter *et al.* (2006)]. Because our TS threshold may have excluded some of the smallest rainbow smelt, it is possible that our estimates of emerald shiner density and biomass were biased low. Correction of such a bias would probably result in even higher estimates and lend further support to our conclusion that density and biomass have increased greatly. A similar bias may have resulted from seasonal differences in catchability; if significant numbers of emerald shiners were too small to be retained by our trawl in 2006, biomass was likely underestimated.

Acoustic estimates of fish density and biomass can also be biased because echosounders cannot sample near the lakebed, and in the case of our surveys, in the upper 2–3 m of the lake (areas referred to as acoustic deadzones). The upper portion of the lake was not sampled because of a combination of transducer depth and inability to use data within the 1–1.5 m of water column closest to the transducer face (near-field). Trawl data collected in the study suggested that the bias associated with the bottom deadzone had no effect on emerald shiner density and biomass estimates, because virtually all emerald shiners resided in the epilimnion. The bottom deadzone likely resulted in underestimates of bloater density and biomass, but it probably had minimal influence on rainbow smelt estimates (Yule *et al.* 2007). Small alewives tend to reside in the epilimnion, so it is doubtful the bottom deadzone influenced alewife estimates because the alewife population during 2004–2006 was dominated by small fish. The surface deadzone may have contributed bias to estimates for emerald shiners, small rainbow smelt, and alewife, and it is likely that estimates are biased low. It is not clear what the magnitude of this bias may be, but correction of such a bias would result in higher estimates for emerald shiner and support for our conclusion that this species has exhibited resurgence.

Independent observations of emerald shiners were consistent with our observations of progressive increased abundance and formation of bi-modal size distributions. Commercial bait fishers observed low abundance of emerald shiners in 2004, but reported unprecedented high abundances beginning in 2005 (Mr. Tony Gordon, Gordon's Live Bait, 6095 N. M-65, Glennie, MI 48737, personal communication; Mr. Dale Sikkema, Dale's Bait, 1440 N. Summers Rd., Imlay City, MI 48444, personal communication). These individuals reported higher abundances in 2005 than previously observed in 35 years of bait harvesting, further increase in abundance during 2006, and presence of two distinct size groups during 2006 (both "yellow perch" and "walleye" bait-sized shiners available) compared to a single size group in 2005 (smaller "yellow perch" bait-sized shiners predominating). Emerald shiners were also captured during the USGS Autumn bottom trawl survey during 2006. Although only 18 individuals were captured, it was the first time any had been captured since 1999, and the first time that both adult and putative age-0 emerald shiners had been observed since that survey began in 1973 (Great Lakes Science Center,

1451 Green Road, Ann Arbor, MI 48105, unpublished data). Given the low numbers captured in bottom trawling efforts in Lake Huron and the inadequacy of bottom trawling for cisco (Yule *et al.* 2007), it is clear that for these two native pelagic species, acoustic sampling is a valuable complement to bottom trawling.

Resurgence of emerald shiners in Lake Huron suggests that Lake Huron may be returning to the simpler, epilimnetic pelagic fish community that existed prior to invasion and proliferation of alewife and rainbow smelt (Eshenroder and Burnham-Curtis 1999). That community was dominated by emerald shiners, yellow perch *Perca flavescens*, and lake herring *Coregonus artedii* and supported a broad range of nearshore predators that included walleyes *Sander vitreus*, adult yellow perch *Perca flavescens*, basses *Micropterus* spp., and esocids *Esox* spp. (Keller *et al.* 1987). Presumably native predators will benefit from the return of a native forage species, but we can not predict if the emerald shiner population will continue to expand or stabilize at abundances lower than the high densities described by Flittner (1964) or Wells and McClain (1973). It also seems likely that a future return to even moderate alewife abundance might eliminate them again.

One aspect of emerald shiner resurgence that we cannot predict is their role as forage for lake trout or stocked pacific salmonids. The two traditional prey species of stocked salmonids in Lakes Huron have been alewife and rainbow smelt (Diana 1990) and emerald shiners have probably been too scarce to be important in salmonine diets. Emerald shiners probably have energy density similar to adult rainbow smelt (Bryan 1995), but we found emerald shiners in epilimnetic waters warmer than 19°C, considerably warmer than temperatures occupied or preferred by salmonids (Stewart *et al.* 1981). While salmonids could presumably venture into warm surface waters to pursue them, predators and prey would be thermally segregated at least part of the year. During fall, winter, and spring, strength of predator-prey interactions between emerald shiners and salmonines may depend on cold-temperature habitat use, but evidence of cold-weather habitat use by emerald shiners is contradictory. Both Hubbs and Lagler (1964) and Campbell and Macrimmon (1970) observed inshore movement of emerald shiners during fall. In contrast, Thomas (1985) observed abandonment of the nearshore zone and aggregation at mid-depths in the St. Marys River near northern Lake Huron. Flittner (1964) observed evi-

dence of offshore movement during fall in Lake Erie, but also noted large numbers of fish associated with inshore-protected areas during winter. This increases uncertainty about how salmonids will utilize emerald shiner; however, its widespread presence in 2006 represents a positive step toward restoration of the original native fish community of Lake Huron.

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