Lake Superior Committee
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Status and Trends of Prey Fish Populations in Lake Superior, 2005[1]

Jason D. Stockwell, Owen T. Gorman, Daniel L. Yule, Lori M. Evrard, and Gary A. Cholwek
U.S. Geological Survey
Great Lakes Science Center
Lake Superior Biological Station
2800 Lakeshore Drive East
Ashland, Wisconsin 54806

Abstract: The Great Lakes Science Center conducts an annual daytime bottom trawl survey of the Lake Superior fish community every spring to provide a long-term index of relative abundance and biomass. The survey began in 1978 for U.S. waters and was expanded in 1989 to include Canadian waters. Currently, 86 fixed stations are distributed around the perimeter of Lake Superior. In 2005, a total of 51 stations were sampled with 12-m bottom trawls between April 27 and June 15. Trawls were deployed cross-contour at median start and end depths of 21 and 55 m, respectively. The lakewide mean relative biomass estimate for all species combined increased from 6.29 kg/ha in 2004 to 9.13 kg/ha in 2005. Most of this increase was a result of increased biomass estimates for lake whitefish, rainbow smelt, and lake trout. Lake whitefish made up the highest percent of the total mean biomass for any species (34%), followed by lake herring (21%), bloater (14%), and rainbow smelt (12%). Lake herring and bloater biomass remained at similar levels from 2004 to 2005. We predict that biomass estimates for lake herring in 2006 will drop as the moderately strong 2003 cohort matures and becomes less susceptible to day bottom trawling. Biomass of siscowets decreased in 2005, while wild and hatchery lake trout biomass increased by 5x and 42x, respectively. The increases were a result of increased catch of large (> 500 mm) lake trout (wild and hatchery) and higher frequency of non-zero catches in the trawls (wild lake trout). Year-class strengths for the 2004 lake herring (1 fish/ha) and bloater (< 1 fish/ha) cohorts were below their long-term (1977-2004) averages (76 and 11 fish/ha, respectively). Wisconsin waters continue to be the most productive (mean total biomass of 26.78 kg/ha), followed by western Ontario (10.96 kg/ha), eastern Ontario (2.29 kg/ha), Michigan (1.61 kg/ha), and Minnesota (0.02 kg/ha). Estimates of mean relative density from the spring survey indicate the biological impossibility of increased densities of age-2 lake herring in 2005 compared to age-1 lake herring in 2004. Age-2 rainbow smelt density in 2005 was also greater than age-1 density in 2004. These results suggest improvements to our sampling strategy and survey design should be considered. Additionally, qualitative comparisons of relative biomass estimates based on all stations versus a subset of stations reveal similar trends in biomass dynamics at the community and species levels. These results suggest reduced effort could provide similar information. Any savings in reduced effort could be directed at improving assessment strategies and/or adding new ecological investigations.

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Introduction

The Great Lakes Science Center's Lake Superior Biological Station (LSBS) conducts an annual daytime bottom trawl survey every spring in Lake Superior. The survey began in 1978 for U.S. waters and was expanded in 1989 to include Canadian waters. The survey is intended to provide a long-term index of relative abundance and biomass of Lake Superior's fish community in nearshore waters. In this report, we update the time series of relative density and biomass with data collected in 2005. Additionally, we qualitatively compare relative biomass of major species using all spring stations and a subset of stations to examine if reduced effort produces similar results in population trends.

Methods

Currently, 86 fixed sampling stations are distributed around the perimeter of Lake Superior. In 2005, 51 of the 86 stations were sampled with 12-m bottom trawls between April 27 and June 15 during daylight hours (Fig. 1). The reduction in effort enabled LSBS to allocate resources to evaluate the effectiveness of day bottom trawls to assess the Lake Superior fish community and to participate in a binational effort to monitor lower trophic levels. Results from these additional efforts will be reported at a future date.

To select stations for the 2005 spring bottom trawl survey, stations were grouped by regions (e.g., Whitefish Bay, north shore of Minnesota, etc.). Within each region, relative biomass estimates (kg/ha) were examined and those stations that appeared to be "outliers" (i.e., high and variable estimates over the time series) were selected to be sampled. For the remaining stations in a region, subsets (typically ¾ and ½ of the stations remaining) were randomly selected each year and the mean relative biomass estimates from these randomizations were calculated for each year. These estimates were then compared to the observed mean (± 1 SE) relative biomass for all of the stations in the region (excluding the "high and variable" stations). If the estimates based on random stations were within one standard error for most of the years, then this subset number was deemed acceptable. Outlier stations were given a weight of 1, while stations randomly selected in a region were given a weight based on the total number of stations from which they were randomly selected (e.g., 3 stations randomly selected to represent 6 stations were each given a weight of 2). These weights were used to calculate means (see below).

Trawls were deployed cross-contour. Median start and end depths for bottom trawl tows were 21 m (range 12-64 m, interquartile range 18-27 m) and 55 m (range 22-130 m, interquartile range 43-74 m), respectively. Median trawl tow duration was 21 minutes (range 5-51 minutes, interquartile range 13-32 minutes). One trawl tow was made at each station.

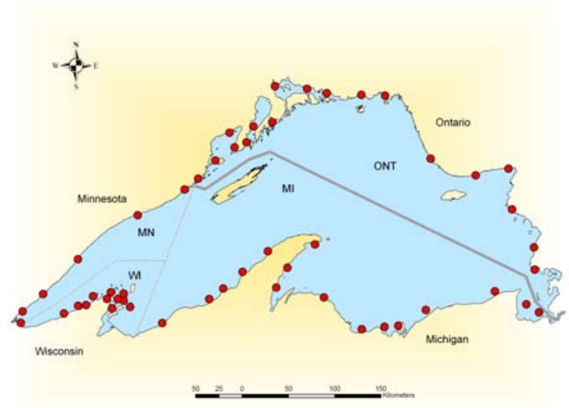


Figure 1. *Locations of 51 stations sampled during the 2005 annual spring bottom trawl survey in Lake Superior.*

For each trawl, fish were sorted and counted by species and weighed in total (for each species) to the nearest gram. Counts and biomass were standardized to the number of hectares swept to estimate relative density (fish/ha) and biomass (kg/ha). The weighted arithmetic mean was used to measure species-specific relative biomass and year-class strength of important prey species. Year-class strength is estimated as the relative density (fish/ha) of age-1 fish (the first age-class that recruits to the bottom trawl in the spring). To be consistent with past reports and to more easily identify the year in which a cohort was produced, year-class strength is plotted against the year in which the cohort was produced (year sampled minus 1) and not the year the age-1 fish were caught. Standard errors (SE) for years prior to 2005 were calculated as SD/√n, where SD = the sample standard deviation and n = number observations. Because weighted means were used in 2005, the denominator for calculating SE was the square root of the sum of the weights. The SE was standardized by the mean to generate relative standard error (RSE = SE/mean*100). An

RSE = 100% indicates the standard error was equal to the estimated mean. We also compared mean relative biomass over the time series using only the 51 stations sampled in 2005. In some years, not all 51 stations were sampled so we used only those stations (of the 51) that had been sampled for those years.

Lake herring (*Coregonus artedi*) were aged using otoliths or scales, depending on total fish length. In general, scales were used for fish < 250 mm and otoliths were used for fish ≥ 250 mm. Otoliths were aged using the crack and burn method (Schreiner and Schram 2001). Lake Superior was divided into nine regions, and ten lake herring per 10-mm length bin were targeted for aging for each region by a single experienced reader. Fifty-eight lake herring otoliths were sent to MN DNR for an independent assessment by an experienced reader. Fifty percent of the otoliths were identically aged by the two readers, 85% were ≤ 1 year difference, and 93% were ≤ 2 year difference. Length-frequency distributions were used to determine age-1 rainbow smelt (*Osmerus mordax*; < 90 mm), lake whitefish (*C. clupeaformis*; < 150 mm), and bloater (*C. hoyi*; < 100 mm).

Results

Lake Herring

Year-class strength for the 2004 lake herring cohort was estimated at 1 fish/ha. This value was the tenth lowest recorded over the 28-year survey and was a 25x decrease from year-class strength of the 2003 cohort (25 fish /ha; Fig. 2A). Relative standard error (RSE) fluctuated between 20 and 100% over the survey period, with the estimate for the 2004 year-class (58%) slightly above average (50%; Fig. 2B). The RSEs for lake herring year-class strength (Fig. 2B) exceed the level of precision (no greater than ± 30% of the mean) recommended by Walters and Ludwig (1981) for stock-recruit data sets. Year-class strength in 2004 was similar between U.S. and Canadian waters (1.2 and 0.8 fish/ha, respectively).

Mean relative biomass of lake herring was similar in 2005 (1.88 kg/ha) and 2004 (1.80 kg/ha; Fig. 3A), although current standing stock is still below the 1978-2005 average of 3.13 kg/ha. RSE was 37% in 2005, slightly lower than the survey average of 43% (Fig. 3B).

Mean relative biomass for lake herring decreased or remained steady in all political jurisdictions except western Ontario waters (Figs. 4 and 5). Relative lake herring biomass remained steady from 2004 to 2005 in Wisconsin waters (6.41 to 6.24 kg/ha, respectively), while relative biomass in Minnesota (0.16 to < 0.01 kg/ha) and Michigan (0.60 to 0.28 kg/ha) waters declined (Fig. 4). Relative biomass in Ontario waters increased from 0.99 to 2.00 kg/ha between 2004 and 2005 (Fig. 5). Only Ontario is above its long-term (1989-2005) average of 1.69 kg/ha, although Wisconsin is within 9% of its long-term average (1978-2005 average = 6.85 kg/ha).

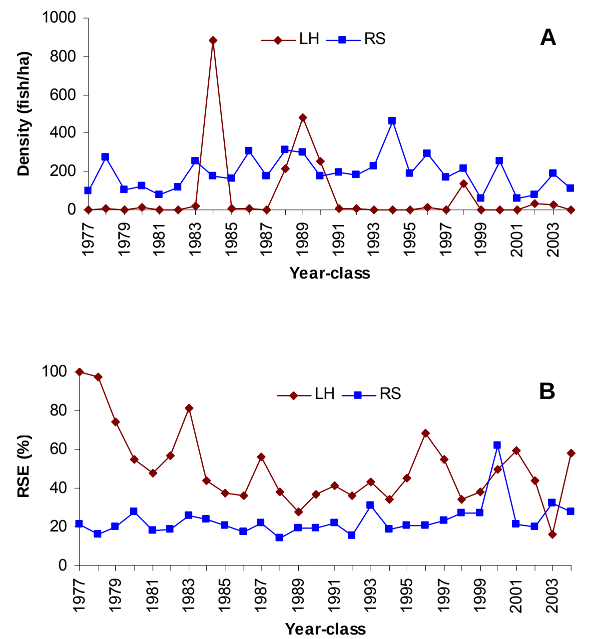
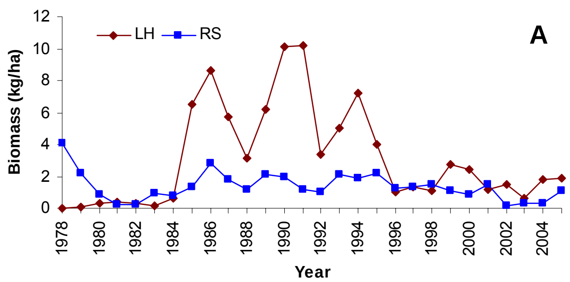


Figure 2. ***(A)*** *Year-class strength (number of age-1 fish/ha) for lake herring (LH) and rainbow smelt (RS) for all nearshore sampling stations in Lake Superior for cohorts produced from 1977 to 2004. Note only U.S. waters were sampled for the 1977-1988 year-classes. Also note that X-axis reflects the year the cohort was produced, not the year the year-class strength was estimated (year-class+1).* ***(B)*** *RSE (relative standard error) of year-class strengths in (A). RSE is calculated as SE/mean*100.*

The mean relative density for lake herring in 2005, as measured by the day bottom trawl survey, was 55 fish/ha. The 2003 year-class dominated the catch of lake herring in 2005, accounting for 77% of the mean relative density (42 fish/ha; Fig. 6). This estimate of age-2 fish in 2005 is greater than the estimate for age-1 fish in 2004 (25 fish/ha; Fig. 2). This biological conundrum suggests 1) age-1 lake herring do not fully recruit to day bottom trawls, and/or 2) fish behavior/movement from year-to-year can impact our estimates. The 2002 year-class represented 18% of the 2005 estimate,



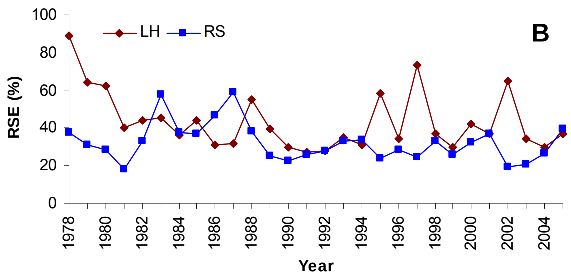


Figure 3. ***(A)*** *Mean relative biomass (kg/ha) of age-1 and older lake herring (LH) and rainbow smelt (RS) for all nearshore sampling stations in Lake Superior, 1978-2005. Note Canadian waters were not sampled until 1989.* ***(B)*** *RSE (relative standard error) of mean biomass in (A). RSE is calculated as SE/mean*100.*

while all older year-classes represented 3% of the estimate (Fig. 6). The lack of large lake herring in the bottom trawl survey (Fig. 6) is not surprising as Stockwell et al. (2006) demonstrated that the spring bottom trawl survey grossly underestimates abundance of adult lake herring. Consequently, unless the 2005 cohort is strong, we predict a drop in lake herring biomass in 2006 as the 2003 cohort matures and becomes less susceptible to day bottom trawling.

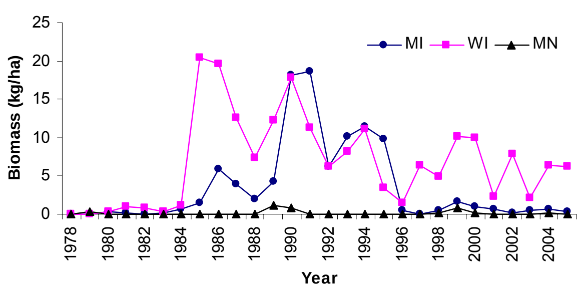


Figure 4. *Mean relative biomass (kg/ha) of lake herring (age-1 and older) in Michigan, Wisconsin, and Minnesota nearshore waters of Lake Superior, 1978-2005.*

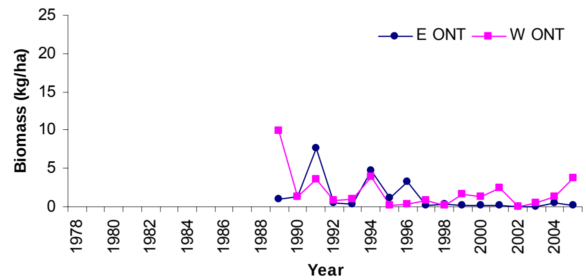


Figure 5. *Mean relative biomass (kg/ha) of lake herring (age-1 and older) in eastern and western Ontario nearshore waters of Lake Superior, 1989-2005. Eastern and western Ontario waters are divided in the northeast corner of Lake Superior near Marathon, Ontario. Axes are similar to Figure 4 to facilitate comparisons across jurisdictions.*

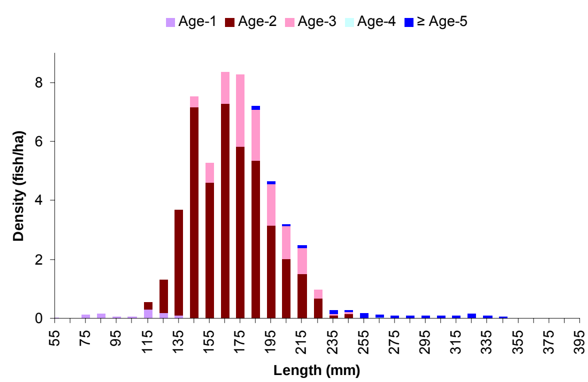


Figure 6. *Mean relative density (fish/ha) as a function of length and age for lake herring caught at all nearshore sampling stations in Lake Superior in 2005. A total of 619 lake herring were aged, and an age-length key was applied to density data for each length bin. The oldest lake herring aged was 13 years.*

Rainbow Smelt

Year-class strength of rainbow smelt decreased from 187 fish/ha for the 2003 cohort to 107 fish/ha for the 2004 cohort (Fig. 2A). Year-class strength for the 2004 cohort is 56% of the average over the entire survey period (190 fish/ha). RSE has remained fairly constant over the entire survey period at roughly 20% with the 2000 year-class being the only exception at 60% (Fig. 2B). The 2004 year-class was much stronger in Ontario waters (218 fish/ha) compared to U.S. waters (40 fish/ha).

Lakewide mean relative biomass for rainbow smelt increased 3x from 2004 (0.31 kg/ha) to 2005

(1.09 kg/ha; Fig. 3A). This increase in 2005 ends a three-year period of low biomass that was similar to the low estimates in 1981 and 1982 (Fig. 3A). RSE has fluctuated between 20 and 60% over the survey period (Fig. 3B).

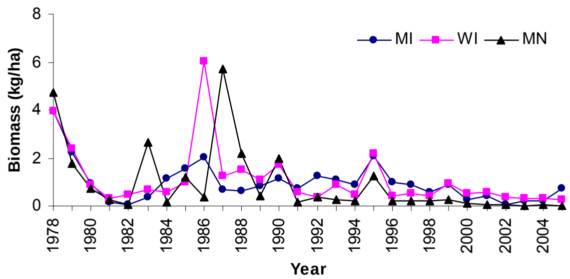


Figure 7. *Mean relative biomass (kg/ha) of rainbow smelt (age-1 and older) in Michigan, Wisconsin, and Minnesota nearshore waters of Lake Superior, 1978-2005.*

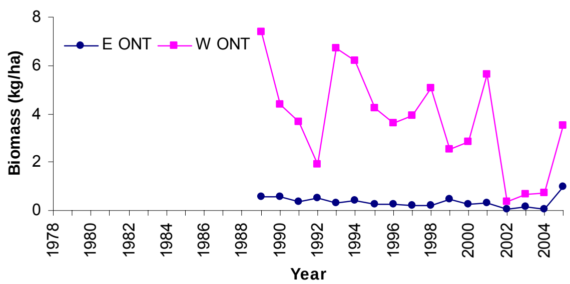


Figure 8. *Mean relative biomass (kg/ha) of rainbow smelt (age-1 and older) in eastern and western Ontario nearshore waters of Lake Superior, 1989-2005. Axes are similar to Figure 7 to facilitate comparisons across jurisdictions.*

Relative biomass of rainbow smelt increased by 3x from 2004 (0.22 kg/ha) to 2005 (0.73 kg/ha) in Michigan waters, remained the same in Wisconsin waters (0.29 to 0.28 kg/ha in 2004 and 2005, respectively), and decreased by 3x from 2004 (0.07 kg/ha) to 2005 (0.02 kg/ha) in Minnesota waters (Fig. 7). Rainbow smelt relative biomass in Ontario waters increased from 0.46 kg/ha in 2004 to 2.33 kg/ha in 2005. Increases were evident in both eastern and western portions of Ontario (Fig. 8), and accounted for most of the lakewide increase from 2004 to 2005 (Fig. 3A). The increase in Ontario waters can be attributed to higher densities of age-2 and older fish in 2005 compared to 2004 (Fig. 9). In fact, the density of age-2 fish (95-135 mm) in 2005 was greater than the density of age-1 fish in 2004 (Fig. 9). We observed a similar pattern in estimates of the 2003 lake herring year-class in 2004 (25 fish/ha) and 2005 (42 fish/ha; Figs. 2A and 6). These results suggest improvements to our sampling strategy and survey design should be considered.

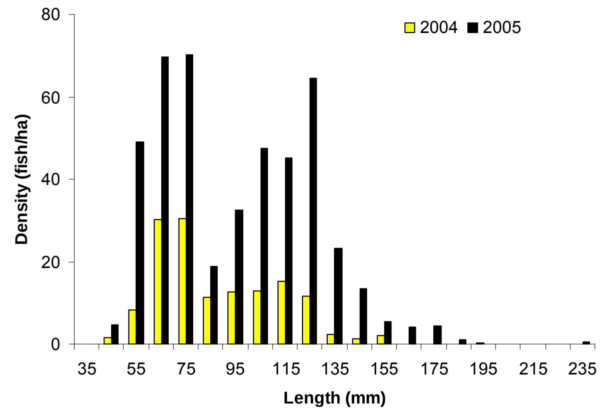


Figure 9. *Mean relative density (fish/ha) as a function of 10-mm length bins for rainbow smelt in Ontario waters of Lake Superior, 2004-2005.*

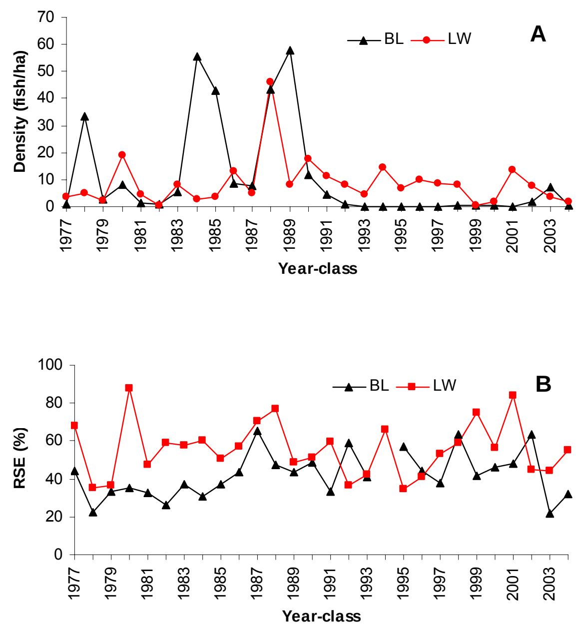


Figure 10. ***(A)*** *Year-class strength (number of age-1 fish/ha) for bloater (BL) and lake whitefish (LW) for all nearshore sampling stations in Lake Superior for cohorts produced from 1977 to 2004. Note only U.S. waters were sampled for the 1977-1988 year-classes. Also note that X-axis reflects the year the cohort was produced, not the year the year-class strength was estimated (year-class+1).* ***(B)*** *RSE (relative standard error) of year-class strengths in (A). RSE is calculated as SE/mean*100.*

Bloater

The 2004 year-class strength for bloater was < 1 fish/ha, lower than the 7 fish/ha for the 2003 year-class (Fig. 10A). The decrease in year-class strength from the 2003 to the 2004 cohorts was evident in both U.S. (9 to < 1 fish/ha) and Canadian (5 to < 1 fish/ha) waters. RSE has fluctuated between 20 and 60% over the survey period (Fig. 10B).

Bloater mean relative biomass increased slightly from 1.14 kg/ha in 2004 to 1.28 kg/ha in 2005 (Fig. 11A). This is a third straight year of increase, but the 2005 mean biomass still remains well below the 1978-2004 average of 2.05 kg/ha. Decreases from 2004 to 2005 were evident in Michigan (0.90 to 0.55 kg/ha) and Minnesota (0.06 to 0 kg/ha) waters (Fig. 12). Mean relative biomass did not change in Wisconsin waters from 2004 to 2005 (4.44 to 4.37 kg/ha; Fig. 12) and increased in Ontario waters (0.18 to 1.16 kg/ha; Fig. 13). Mean relative biomass of bloater for each jurisdiction over the survey period was 1.09 kg/ha in Ontario, 3.26 kg/ha in Michigan, 0.01 kg/ha in Minnesota, and 2.62 kg/ha in Wisconsin.

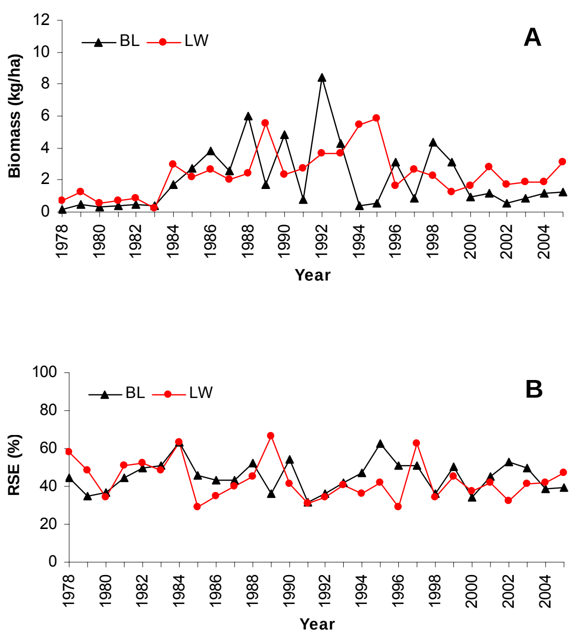


Figure 11. ***(A)*** *Mean relative biomass (kg/ha) of age-1 and older bloater (BL) and lake whitefish (LW) for all nearshore sampling stations in Lake Superior, 1978-2005. Note Canadian waters were not sampled until 1989.* ***(B)*** *RSE (relative standard error) of mean biomass in (A). RSE is calculated asSE/ mean*100. Y-axis is similar to Figure 3 to facilitate comparisons across major prey species.*

Lake Whitefish

Lake whitefish year-class strength for the 2004 cohort (2 fish/ha) was less than that for the 2003 cohort (3 fish/ha), and represents a third straight year of decrease (Fig. 10A). RSE for lake whitefish year-class strength has fluctuated between 40 and 80% over the survey period (Fig. 10B). The 2004 year-class was stronger in U.S. waters (3 fish/ha) compared to Canadian waters (< 1 fish/ha). Average year-class strength for lake whitefish over the survey period is 9 fish/ha.

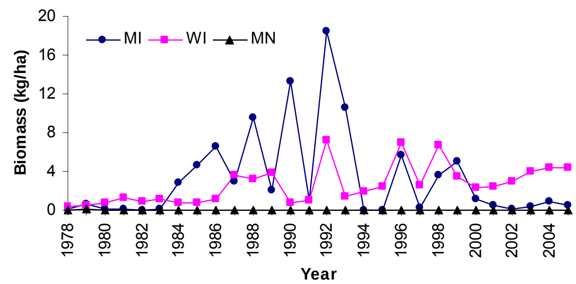


Figure 12. *Mean relative biomass (kg/ha) of bloater (age-1 and older) in Michigan, Wisconsin, and Minnesota nearshore waters of Lake Superior, 1978-2005.*

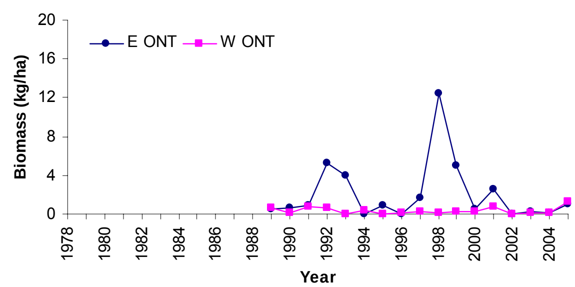


Figure 13. *Mean relative biomass (kg/ha) of bloater (age-1 and older) in eastern and western Ontario nearshore waters of Lake Superior, 1989-2005. Axes are similar to Figure 12 to facilitate comparisons across jurisdictions.*

Despite the decreased recruitment of age-1 fish to the bottom trawl, the mean relative biomass for lake whitefish in all waters increased from 2004 (1.88 kg/ha) to 2005 (3.14 kg/ha; Fig. 11A). Mean relative biomass has remained steady since 1996, averaging 2.08 kg/ha over this period. RSE for lake whitefish biomass has remained fairly constant, fluctuating between 25 and 60% (Fig. 11B). At the jurisdiction level, lake whitefish have only been caught once (1995) in Minnesota waters over the entire time series (Fig. 14). Most lake whitefish biomass came from Wisconsin waters (Fig. 14), which showed a major increase from 7.20 kg/ha in 2004 to 15.89 kg/ha in 2005. Relative biomass decreased by over an order of magnitude in Michigan waters from 0.76 kg/ha in 2004 to 0.05 kg/ha in 2005 (Fig. 14). Biomass of lake whitefish in western Ontario waters increased from 2004 to 2005 (1.05 to 2.56 kg/ha, respectively) while biomass in eastern Ontario waters decreased from 0.31 to 0.12 kg/ha over the same time period (Fig. 15).

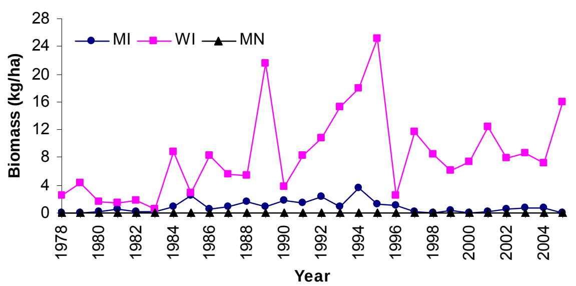


Figure 14. *Mean relative biomass (kg/ha) of lake whitefish (age-1 and older) in Michigan, Wisconsin, and Minnesota nearshore waters of Lake Superior, 1978-2005.*

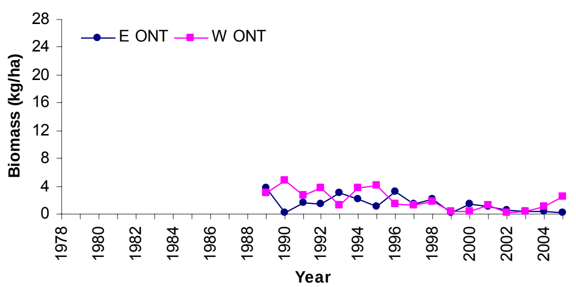


Figure 15. *Mean relative biomass (kg/ha) of lake whitefish (age-1 and older) in eastern and western Ontario nearshore waters of Lake Superior, 1989-2005. Axes are similar to Figure 14 to facilitate comparisons across jurisdictions.*

Other Species

Ninespine stickleback – Lakewide mean relative biomass for ninespine sticklebacks (*Pungitius pungitius*) decreased in 2005 after a rebound in 2004 from persistently low and decreasing estimates since 1993 (Fig. 16). Mean relative biomass for all waters in 2005 was 0.01 kg/ha compared to 0.08 kg/ha in 2004.

Sculpins – Mean relative biomass for all three sculpin species combined (spoonhead *Cottus ricei*, deepwater *Myoxocephalus thompsoni*, and slimy *C. cognatus*) has followed the same trajectory as ninespine sticklebacks since 1993 (Fig. 16). After a slight increase from 2003 to 2004, relative biomass decreased in 2005 (0.03 to 0.01 kg/ha). Slimy sculpins averaged 65% of the total sculpin biomass across all years, but represented a higher percentage in the earlier years (81% from 1978 to 1983 compared to 61% from 1984 to 2005).

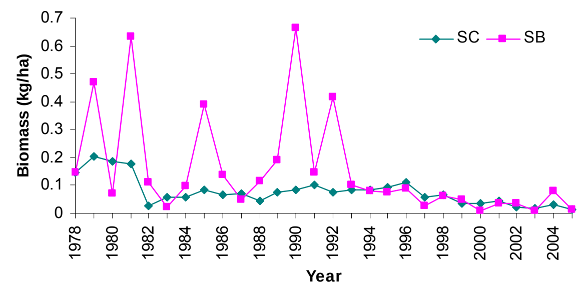


Figure 16. *Mean relative biomass (kg/ha) of age-1 and older sculpins (slimy, spoonhead, and deepwater combined; SC) and ninespine sticklebacks (SB) for all nearshore sampling stations in Lake Superior, 1978-2005. Note Canadian waters were not sampled until 1989.*

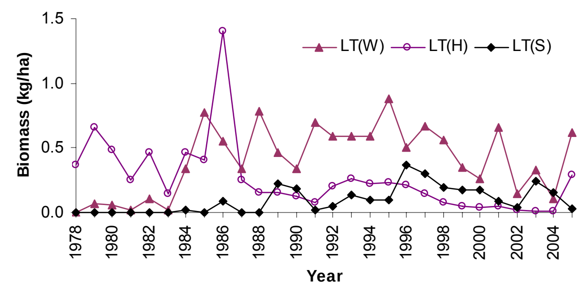


Figure 17. *Mean relative biomass (kg/ha) of age-1 and older wild lake trout (LT(W)), hatchery lake trout (LT(H)), and siscowet (LT(S)) for all nearshore sampling stations in Lake Superior, 1978-2005. Note Canadian waters were not sampled until 1989.*

Lake Trout – Mean relative biomass of siscowet lake trout (*Salvelinus namaycush siscowet*) decreased 80% from 2004 to 2005 (0.15 to 0.03 kg/ha, respectively), but increased 5x for wild lean lake trout (*S. namaycush*) (0.11 to 0.61 kg/ha; Fig.

17). Mean relative biomass of hatchery lake trout increased 42x from 2004 to 2005 (< 0.01 to 0.29 kg/ha, respectively; Fig. 17). The 2005 estimate for hatchery lake trout is the highest since 1986 (Fig. 17). The observed increase in biomass of hatchery lake trout is a result of three stations where at least one fish > 500 mm was collected. These three stations accounted for 86% of the mean relative biomass estimate (i.e., removing these three stations dropped the biomass estimate by 86%). We attribute the increase for wild lean lake trout from 2004 to 2005 to two factors. First, large fish (> 500 mm) were captured more frequently in 2005 (n = 14) compared to 2004 (n = 1). These large fish accounted for 37% of the mean relative biomass estimate. Second, the percent of all stations where wild lean lake trout were captured increased in 2005 (53% of all stations sampled) compared to 2004 (23%). These results suggest interpretations of year-to-year differences in lake trout biomass from the bottom trawl survey should be done cautiously.

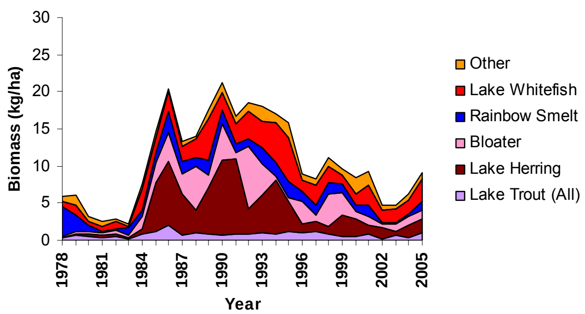


Figure 18. *Cumulative area plot of mean relative biomass (kg/ha) of fish community for all nearshore sampling stations in Lake Superior, 1978-2005. Note Canadian waters were not sampled until 1989. Other category consists of: kiyi (C. kiyi), round whitefish (Prosopium cylindraceum), pygmy whitefish (P. coulteri), spoonhead sculpin, slimy sculpin, deepwater sculpin, longnose sucker (Catostomus catostomus), burbot (Lota lota), ninespine stickleback, and trout-perch (Percopsis omiscomaycus).*

Fish Community

Mean biomass of all fish species caught by the spring bottom trawl survey increased from 6.29 kg/ha in 2004 to 9.13 kg/ha in 2005 (Fig. 18). This 45% increase follows a 34% increase from 2003 to 2004. Increased biomass in 2005 was a result of increases in rainbow smelt (increase of 0.77 kg/ha from 2004), lake whitefish (1.26 kg/ha increase), and lake trout (0.78 kg/ha increase for wild and hatchery lake trout combined). Lake whitefish, lake herring, rainbow smelt, and bloater represented 81% of the mean relative biomass for all nearshore waters of Lake Superior in 2005. Lake whitefish made up the highest percentage of biomass for any species (34%), followed by lake herring (21%), bloater (14%), and rainbow smelt (12%). In 2004, lake whitefish represented 30% of the average lakewide biomass, followed by lake herring at 29%, and bloater at 18%.

Evaluation of Sub-sampling Spring Survey Stations

General patterns in fish community biomass over the time series appear similar whether all (Fig. 18) or a subset (Fig. 19) of stations was used. Similar patterns were evident when the four major species were examined individually, although estimates tended to be slightly higher on average using the subset of 51 stations (Figs. 20-23). This tendency for higher estimates was a result of not using weighted means for the subset data (to account for inclusion of "outlier" stations) across the time series. Comparisons for other species (not shown) revealed similar patterns.

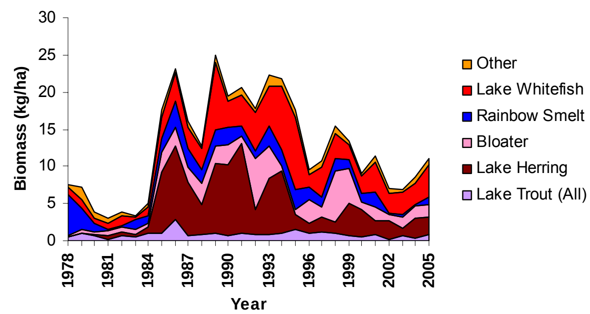


Figure 19. *Same as Figure 18 except mean relative biomass (kg/ha) estimates were calculated from only the 51 stations sampled in 2005 for each of the years, and weights were not applied when calculating means.*

These results suggest that the status and trends of the nearshore fish community of Lake Superior, as measured by the spring bottom trawl survey, could be captured with at least a 41% reduction in effort. Such savings in resources could be allocated to sampling offshore habitats of Lake Superior with acoustic gear, midwater trawls, and bottom trawls, and/or initiating new ecological investigations. For example, in spring 2005 we were able to sample day and night with bottom trawls, acoustic gear, and midwater trawls (night only) at nine spring survey stations and an additional nine offshore stations. From this effort we learned that day bottom trawling is not an effective strategy to assess adult lake herring and offshore waters contain substantial numbers of adult lake herring (Stockwell et al. 2006). Results from comparisons of sampling strategies for demersal and other pelagic species and recommendations for improvements to sampling Lake Superior fish communities will be forthcoming.

In 2006, we plan to repeat the 51 stations sampled in the 2005 spring bottom trawl survey. We will allocate the saved effort to perform a follow-up survey (during May 2006) of the November 2005 spawning lake herring survey in Thunder and Black bays to 1) examine the re-distribution of lake herring spawning populations, 2) compare the adequacy of the four standard spring bottom trawl stations in each bay to represent the entirety of each bay, and 3) test hypotheses about the effects of rainbow smelt on lake herring population dynamics.

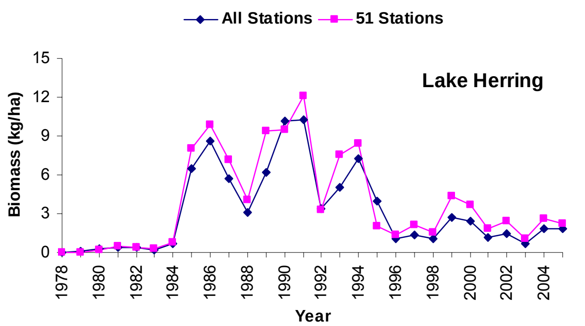


Figure 20. *Mean relative biomass (kg/ha) for lake herring using all or a subset (51) of nearshore stations during the spring bottom trawl survey on Lake Superior, 1978-2005.*

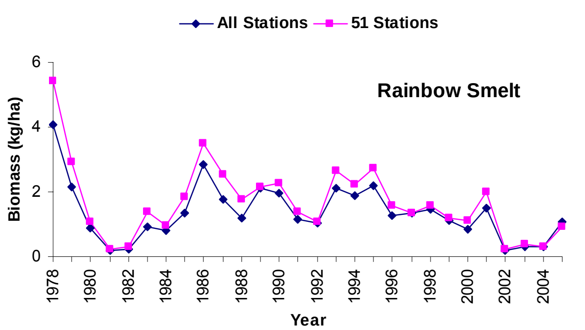


Figure 21. *Mean relative biomass (kg/ha) for rainbow smelt using all or a subset (51) of nearshore stations during the spring bottom trawl survey on Lake Superior, 1978-2005.*

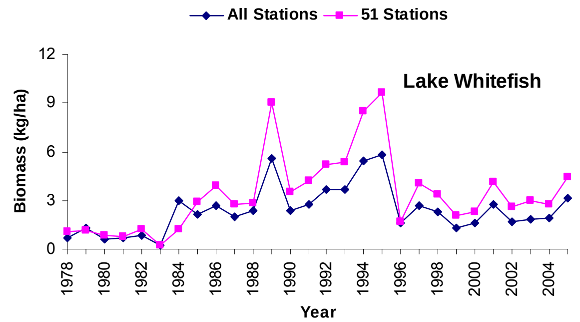


Figure 22. *Mean relative biomass (kg/ha) for lake whitefish using all or a subset (51) of nearshore stations during the spring bottom trawl survey on Lake Superior, 1978-2005.*

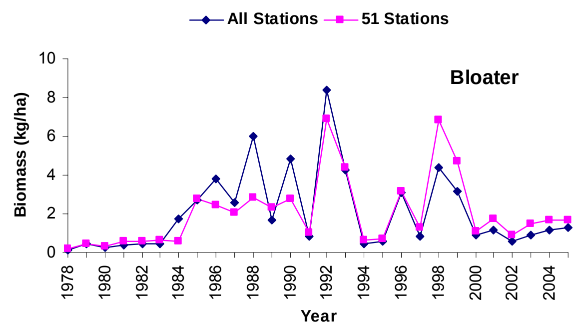


Figure 23. *Mean relative biomass (kg/ha) for bloater using all or a subset (51) of nearshore stations during the spring bottom trawl survey on Lake Superior, 1978-2005.*

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