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Status and Trends of Prey Fish Populations in Lake Superior, 2006[1]

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Abstract: The Great Lakes Science Center conducts an annual daytime bottom trawl survey of the Lake Superior nearshore 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 2006, a total of 55 stations were sampled with 12-m bottom trawls between April 24 and June 19. Trawls were deployed cross-contour at median start and end depths of 18 and 56 m, respectively. The lakewide mean relative biomass estimate for all species combined decreased 26% from 9.13 kg/ha in 2005 to 6.80 kg/ha in 2006. Most of this decrease was a result of decreased biomass estimates for lake whitefish and lake trout (hatchery and wild). Cisco (formerly known as lake herring) made up the highest percent of the total mean biomass for any species (26%), followed by bloater (20%), lake whitefish (20%), and rainbow smelt (12%). Cisco and bloater biomass remained at similar levels from 2005 to 2006. Rainbow smelt and lake whitefish biomass decreased by 27% and 58% from 2005 to 2006, respectively. Biomass of siscowet lake trout increased 5-fold in 2006, while wild and hatchery lake trout biomass decreased by 45 and 83%, respectively. Year-class strength for the 2005 cisco cohort (25 fish/ha) was less than their long-term (1977-2005) average (74 fish/ha), while year-class strength for the 2005 bloater cohort (16 fish/ha) was greater than their long-term average (11 fish/ha). Wisconsin waters continue to be the most productive (mean total biomass of 12.69 kg/ha), followed by western Ontario (7.91 kg/ha), Michigan (6.27 kg/ha), eastern Ontario (4.77 kg/ha), and Minnesota (0.15 kg/ha). Day bottom trawl density estimates from four stations in each of Thunder and Black Bays, Ontario, suggested similar density estimates for rainbow smelt (1,181 and 983 fish/ha, respectively) but higher estimates for cisco in Black Bay (316 fish/ha) compared to Thunder Bay (1 fish/ha). Density estimates from night acoustic surveys that covered major portions of each bay were 3x greater for rainbow smelt (3,435 fish/ha) in Black Bay and 46% lower (530 fish/ha) in Thunder Bay in comparison to their respective day bottom trawl estimates. The acoustic density estimate for cisco in Black Bay (287 fish/ha) was similar to the day bottom trawl estimate, while that for Thunder Bay (327 fish/ha) was 327x greater than the day bottom trawl estimate. These results suggest using day bottom trawl data as a relative index across regions at current levels of effort is tenuous for both rainbow smelt and cisco. Comparisons of acoustic density estimates of spawning-sized cisco in Thunder Bay in November 2005 (78 fish/ha) with acoustic (28 fish/ha) and day bottom trawl estimates (0 fish/ha) in May 2006 indicate that 1) a majority of spawners leaves Thunder Bay after spawning, 2) efforts to estimate spawning stock in the spring using acoustics would be inaccurate, and 3) use of spring bottom trawl survey data to make assessments of or inferences about cisco spawning stock size is simply incorrect, further supporting conclusions of recently published studies.

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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 2006. Additionally, we compare day bottom trawl density estimates of cisco (*Coregonus artedi*) and rainbow smelt (*Osmerus mordax*) in Thunder (4 stations) and Black (4 stations) Bays, Ontario, to estimates from bay-wide acoustic and midwater trawls surveys conducted at night during the same time period. We examine if a limited number of day bottom trawls produces similar results to a more comprehensive approach to pelagic fish assessment.

Methods

Spring Survey

Currently, 86 fixed sampling stations are distributed around the perimeter of Lake Superior. In 2006, 55 of the 86 stations were sampled with 12-m bottom trawls between April 24 and June 19 during daylight hours (Fig. 1). The reduction in effort enabled LSBS to allocate resources to examine interactions between rainbow smelt and larval cisco, compare adult cisco densities from fall 2005 (Yule et al. 2006a) to spring 2006, and compare cisco spawner densities and number of eggs deposited with larval cisco emergence in Thunder and Black Bays. Results from these additional efforts will be reported in later publications.

We sampled the same 51 stations as in 2005. An additional 4 stations were also sampled because of favorable logistics. Each station was given a weight for calculation of means (see below). Details regarding sub-sampling the 86 stations and assignment of weightings are given in Stockwell et al. (2006a).

One trawl tow was made at each station. Trawls were deployed cross-contour. Median start and end depths for bottom trawl tows were 18 m (range 12-45 m, interquartile range 15-20 m) and 56 m (range 19-130 m, interquartile range 44-74 m), respectively. Median trawl tow duration was 21 minutes (range 7-56 minutes, interquartile range 14-33 minutes).

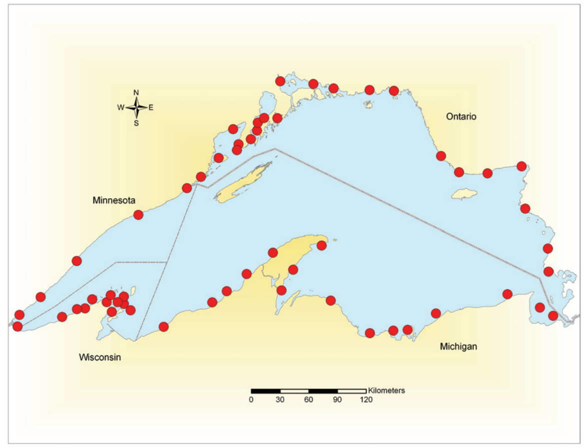


Figure 1. *Locations of 55 stations sampled during the 2006 annual spring bottom trawl survey in Lake Superior.*

For each trawl, fish were sorted by species, counted, and the aggregate of each species was weighed to the nearest gram. Counts and weight were divided by 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 (the first year sub-sampling of stations occurred) were calculated as SD/√n, where SD = the sample standard deviation and n = number of observations. Because weighted means were used in 2005 and 2006, 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.

Cisco 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 because scales become less reliable as cisco mature (Lake Superior Technical Committee, unpublished data). Otoliths were aged using the crack and burn method (Schreiner and Schram 2001). Lake Superior was divided into nine regions, and ten cisco per 10-mm length bin were targeted for aging for each region. All cisco were aged by a single trained reader. We pooled all cisco ageing data to generate a length-age key to estimate relative density of each age-class as a function of length. Length-frequency distributions were used to determine age-1 rainbow smelt (< 105 mm), lake whitefish (*C. clupeaformis*; < 160 mm), and bloater (*C. hoyi*; < 140 mm). We used 170 mm as a cutoff for age-1 cisco, which was confirmed through ageing scales and otoliths for this species.

Gear Comparison in Thunder and Black Bays

A comprehensive acoustic and midwater trawl survey of Thunder and Black Bays in November 2005 revealed large differences in the densities of rainbow smelt and cisco between the two bays (Yule et al. 2006a). Black Bay was characterized by relatively high rainbow smelt densities and low cisco densities compared to Thunder Bay. The contrast in population abundances provides an opportunity to examine if day bottom trawls from the spring survey provide a relative index for comparing population trends across space – an inherent assumption of the spring survey. We thus repeated the comprehensive acoustic and midwater trawl survey of both bays in May 2006 during the spring survey. Our expectation was that if the spring bottom trawl survey provides a relative index across space, then the patterns in density estimates from the day bottom trawls across the two bays should be consistent with the patterns from the acoustic and midwater trawl survey.

Four bottom trawls were made from each of Thunder and Black Bays between May 13 and 15 as part of the annual spring survey. Mean relative densities for cisco and rainbow smelt were calculated as described above.

Night acoustic sampling and midwater trawling were conducted between May 17 and 22. The depth distribution, acoustic size, and densities of fish were estimated using a DT-X digital echosounder (BioSonics, Inc., Seattle, Washington) equipped with a 120 kHz spherical split-beam transducer with a half-power beam width of 6.7°. The transducer was mounted on a 1.2-m-long tow body and was deployed 1 m below the surface. The transducer emitted 3 pings/s with the pulse duration set at 0.4 ms.

Night sampling started 30 min after the beginning of nautical twilight and sampling ended 1-2 hours before the end of nautical twilight. We sampled in a systematic fashion conducting a series of parallel acoustic transects spaced at roughly 3 km intervals (Fig. 2).

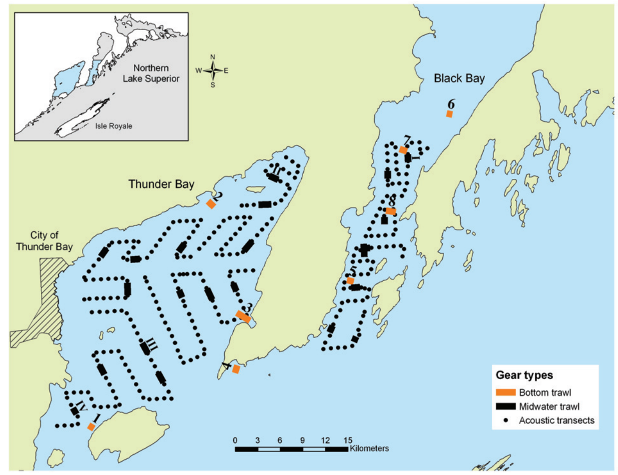


Figure 2. *Map showing locations of day bottom trawls, night midwater trawls and night acoustic transects conducted in Thunder and Black Bays, Ontario, between May 13-22, 2006. The location of two nearly-pure rainbow smelt midwater trawl samples (I and II) and two nearly-pure cisco samples (III and IV) and eight day bottom trawls (1-8) are shown.*

Midwater trawl samples were collected periodically along the survey path in both bays. The midwater trawl (Gourock Trawls, Ferndale, Washington) had 15.2-m headrope and footrope lines and 13.7 m breast lines. The nylon mesh graduated from 300 mm stretch measure at the mouth to 12 mm at the cod end. We monitored trawl mouth widths using wingspread sensors manufactured by Northstar Technical Inc. (St. John's, Newfoundland, Canada). We placed miniature depth and temperature loggers (VEMCO, Shad Bay, Nova Scotia) on the midwater trawl headrope and footrope to measure the trawl mouth height and trawl depth when fishing. Trawl mensuration data were stored at 10 s intervals.

Midwater trawl catches were sorted by species, and the aggregate of each species was weighed to the nearest gram. For small catches (< 100 individuals per species) all fish were measured to the nearest millimeter total length. For larger catches at least 100 individuals per species were selected randomly and measured and the remaining fish were counted.

We used procedures for estimating fish densities described by Yule et al. (2006b) with one minor exception. Yule et al. (2006b) used a -60 decibel (dB) threshold when measuring total backscattering (i.e., S_v) and -55 dB when measuring σ (the average backscattering cross section of the average individual fish). The goal of the Yule et al. (2006a) study was to assess adult cisco densities with less emphasis placed on measuring rainbow smelt densities accurately. From a cursory analysis of the densities of fish caught by midwater trawling in the present study compared to densities measured acoustically, we determined that a -65 dB and -60 dB threshold was more appropriate for measuring mean S_v and σ, respectively, because the lower thresholds allowed more complete acoustic detection of small (< 100 mm) rainbow smelt. Fish densities were calculated in cells measuring 1,000 m in length and 10 m in height as described by Yule et al. (2006b). Acoustic density estimates were apportioned to species based on comparisons of length-frequency distributions from midwater trawls and concurrent target strength distributions from the trawl paths.

To provide an additional gear comparison, we calculated catch-per-unit-effort (CPUE) for rainbow smelt and cisco using night midwater trawl data. We summed total catch and total tow duration for each bay and estimated CPUE as individuals/min. Because midwater trawl data were used only to determine a size threshold for classifying acoustic targets as rainbow smelt or cisco, this metric was deemed an independent measure of relative density.

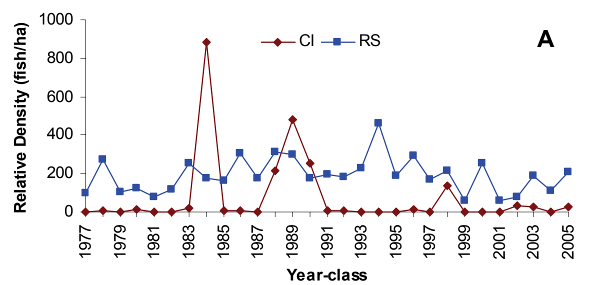
Results

Cisco

Year-class strength for the 2005 cisco cohort was estimated at 25 fish/ha. This value was the seventh highest recorded year-class strength over the 29-year survey and was 25x greater than the 2004 cohort (1 fish/ha; Fig. 3A). Three out of the four year classes from 2002-2005 resulted in density estimates ≥ 25 fish/ha and represent the fourth most productive period for age-1 cisco over the 29-year time series (i.e., 1984, 1988-1990, and 1998 year classes were stronger; Fig. 3A). Relative standard error (RSE) fluctuated between 20 and 100% over the survey period, with the estimate for the 2005 year-class (51%) similar to the series average (50%; Fig. 3B). The RSEs for cisco year-class strength (Fig. 3B) 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 for the 2005 cohort was greater in U.S. (29 fish/ha) than in Canadian (18 fish/ha) waters.

Mean relative biomass of age-1 and older cisco was similar in 2006 (1.79 kg/ha) and 2005 (1.88 kg/ha; Fig. 4A), although current standing stock is still below the 1978-2006 average of 3.08 kg/ha. RSE was 45% in 2006, similar to the survey average of 44% (Fig. 4B).

Relative cisco biomass increased from 2005 to 2006 in Michigan waters (0.28 to 1.68 kg/ha, respectively), while it decreased in Wisconsin (6.24 to 3.64 kg/ha) and western Ontario (3.66 to 2.65 kg/ha) waters (Figs. 5 and 6). Only western Ontario is above (134%) its long-term (1989-2006) average of 1.97 kg/ha. Michigan (48%), Wisconsin (54%), and eastern Ontario (13%) are all below their respective long-term averages. Cisco were not captured in Minnesota waters during the 2006 spring survey.



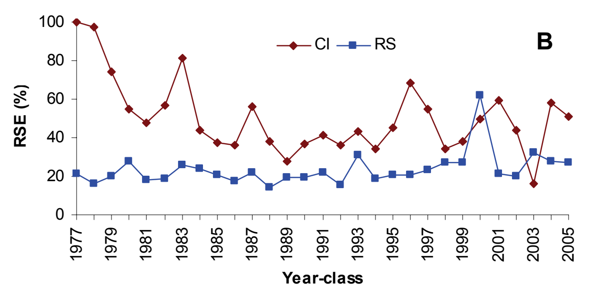
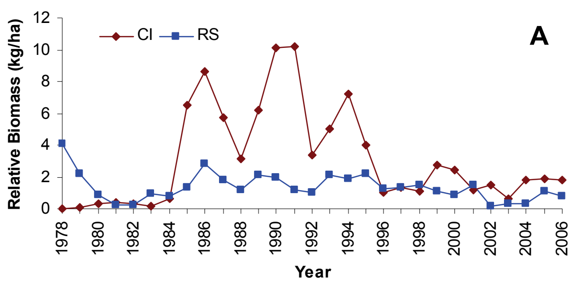


Figure 3. ***(A)*** *Year-class strength (number of age-1 fish/ha) for cisco (CI) and rainbow smelt (RS) for all nearshore sampling stations in Lake Superior for cohorts produced from 1977 to 2005. Note only U.S. waters were sampled for the 1977-1988 year classes. Also note that X-axis reflects the year 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).*

The mean relative density of all cisco, as measured by the day bottom trawl survey, decreased from 55 fish/ha in 2005 to 45 fish/ha in 2006. Based on the 2006 age-length key, the 2005 cohort dominated the catch of cisco in 2006, accounting for 52% of the mean relative density (Fig. 7). The 2003 and 2002 cohorts accounted for 24 and 14% of the mean relative density, respectively. Older cohorts (≥ age-5) represented 8% of the mean relative density (Fig. 7).



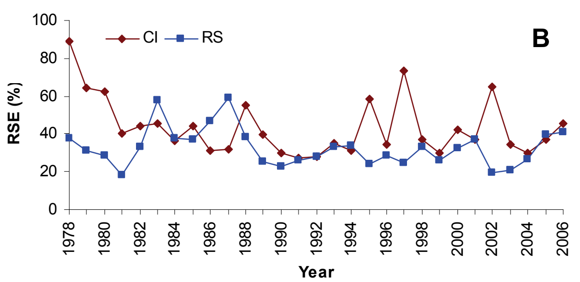


Figure 4. ***(A)*** *Mean relative biomass (kg/ha) of age-1 and older cisco (CI) and rainbow smelt (RS) for all nearshore sampling stations in Lake Superior, 1978-2006. Note Canadian waters were not sampled until 1989.* ***(B)*** *RSE (relative standard error) of mean biomass in (A).*

Rainbow Smelt

Year-class strength of rainbow smelt increased from 107 fish/ha for the 2004 cohort to 209 fish/ha for the 2005 cohort (Fig. 3A). Year-class strength for the 2005 cohort is slightly greater (109%) than the average over the entire survey period (191 fish/ha). RSE has remained fairly constant over the entire survey period at 24% with the 2000 year-class being the only exception at 60% (Fig. 3B). RSE for the 2005 year-class was 27% (Fig. 3B). The 2005 year-class was stronger in Ontario waters (302 fish/ha) than in U.S. waters (151 fish/ha).

Mean relative biomass for age-1 and older rainbow smelt decreased by 27% from 2005 (1.09 kg/ha) to 2006 (0.80 kg/ha; Fig. 4A). This decrease in 2006 followed a 3x increase from 2004 to 2005, which ended a three-year period of low biomass that was similar to the low estimates in 1981 and 1982 (Fig. 4A). RSE has fluctuated between 20 and 59% over the survey period, with the RSE in 2006 at 41% (Fig. 4B).

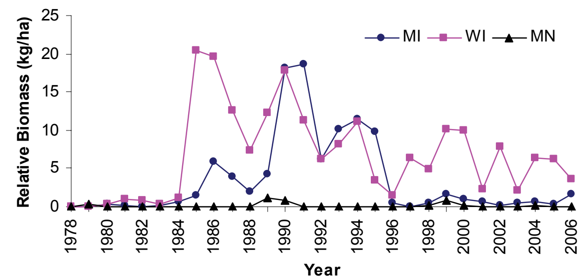


Figure 5. *Mean relative biomass (kg/ha) of age-1 and older cisco in Michigan (MI), Wisconsin (WI), and Minnesota (MN) nearshore waters of Lake Superior, 1978-2006.*

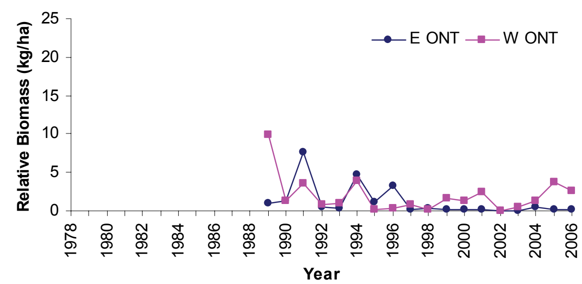


Figure 6. *Mean relative biomass (kg/ha) of age-1 and older cisco in eastern and western Ontario nearshore waters of Lake Superior, 1989-2006. Eastern and western Ontario waters are divided in the northeast corner of Lake Superior near Marathon, Ontario. Axes are identical to Figure 4 to facilitate comparisons across jurisdictions.*

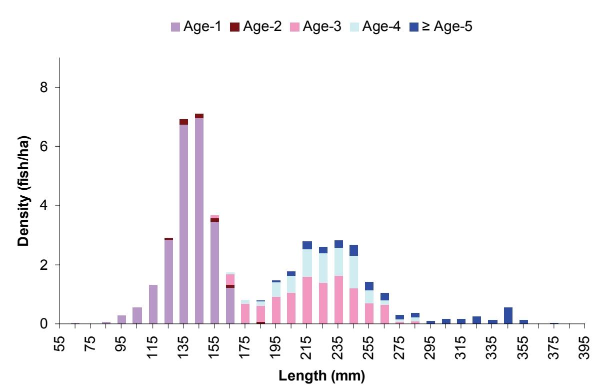


Figure 7. *Mean relative density (fish/ha) as a function of length and age for cisco caught at all nearshore*

sampling stations in Lake Superior in 2006. A total of 666 cisco were aged, and an age-length key was applied to density data for each length bin. The oldest age was 13 years.

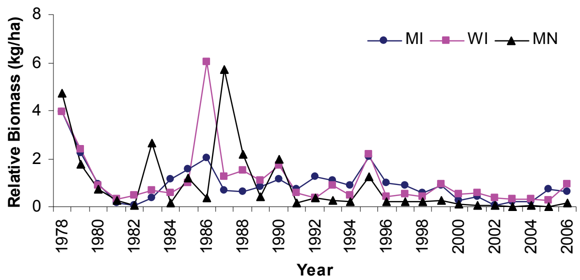


Figure 8. *Mean relative biomass (kg/ha) of age-1 and older rainbow smelt in Michigan, Wisconsin, and Minnesota nearshore waters of Lake Superior, 1978-2006.*

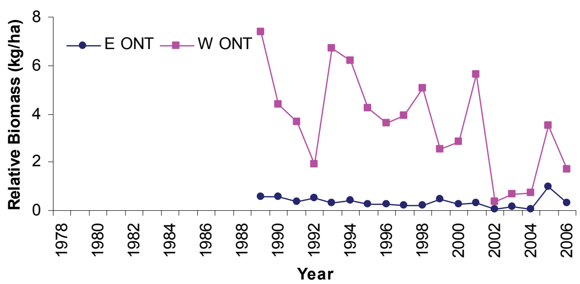


Figure 9. *Mean relative biomass (kg/ha) of age-1 and older rainbow smelt in eastern and western Ontario nearshore waters of Lake Superior, 1989-2006. Axes are similar to Figure 7 to facilitate comparisons across jurisdictions.*

Relative biomass of rainbow smelt remained relatively constant from 2005 (0.73 kg/ha) to 2006 (0.63 kg/ha) in Michigan waters, but increased substantially in Wisconsin (0.28 to 0.93 kg/ha) and Minnesota (0.02 to 0.14 kg/ha) waters (Fig. 8). Rainbow smelt relative biomass in Ontario waters decreased from 2.33 kg/ha in 2005 to 1.09 kg/ha in 2006. Decreases were evident in both eastern and western portions of Ontario (Fig. 9).

Bloater

Year-class strength for the 2005 cohort was 16 fish/ha, compared to < 1 fish/ha for the 2004 cohort (Fig. 10A). Year-class strength was much greater in U.S. waters (25 fish/ha) than in Canada (1 fish/ha). RSE has fluctuated between 20 and 60% over the survey period (Fig. 10B).

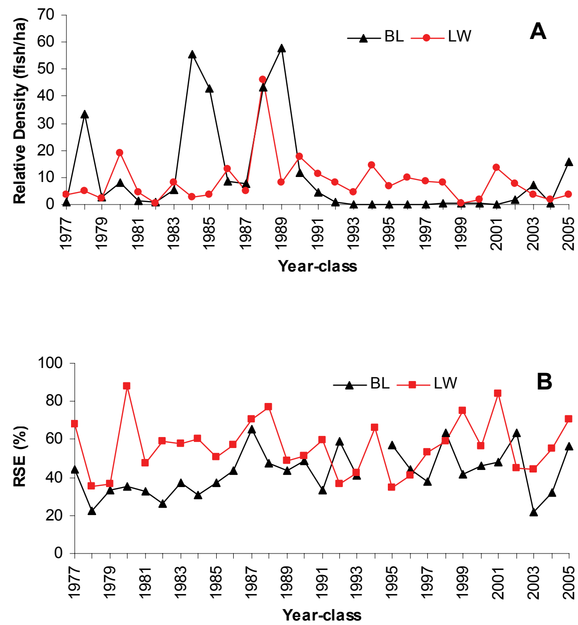


Figure 10. ***(A)*** *Year-class strength (number of age-1 fish/ha) for bloater (BL) and lake whitefish (LW) for all nearshore sampling stations in Lake Superior for cohorts produced from 1977 to 2005. Note only U.S. waters were sampled for the 1977-1988 year-classes. Also note that X-axis reflects the 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).*

Mean relative biomass of age-1 and older bloater was similar in 2006 (1.36 kg/ha) and 2005 (1.28 kg/ha; Fig. 11A). The 2006 mean biomass still remains well below the 1978-2006 average of 2.03 kg/ha. Decreases from 2005 to 2006 were evident in Wisconsin (4.37 to 3.66 kg/ha; Fig. 12) and Ontario (1.16 to 0.26 kg/ha; Fig. 13) waters. Mean relative biomass did not change in Minnesota waters (no bloaters captured in either year; Fig. 12) and increased in Michigan waters (0.55 to 1.90 kg/ha; Fig. 12).

Lake Whitefish

Lake whitefish year-class strength for the 2005 cohort was 4 fish/ha and ended a three-year decline in year-class strength (Fig. 10A). RSE for lake whitefish year-class strength has fluctuated between 40 and 80% over the survey period (Fig. 10B). The 2005 year-class was stronger in U.S. (5 fish/ha) than in Canadian waters (1 fish/ha). Average year-class strength for lake whitefish over the survey period is 8 fish/ha.

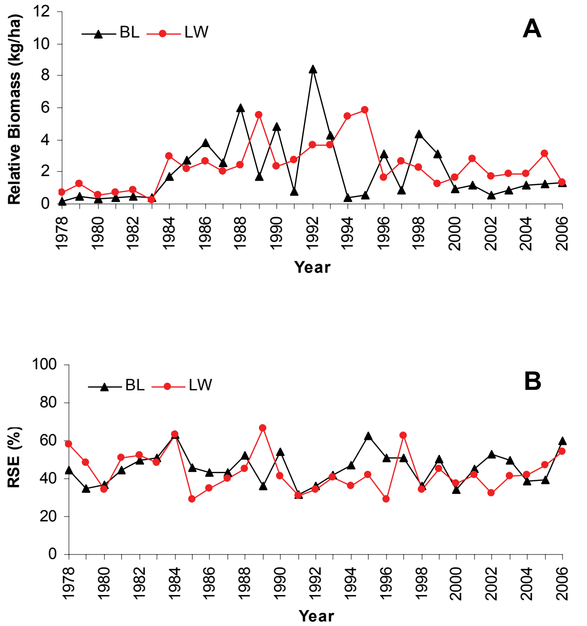


Figure 11. ***(A)*** *Mean relative biomass (kg/ha) of age-1 and older bloater (BL) and lake whitefish (LW) for all nearshore sampling stations in Lake Superior, 1978-2006. Note Canadian waters were not sampled until 1989.* ***(B)*** *RSE (relative standard error) of mean biomass in (A). Y-axis is identical to Figure 4 to facilitate comparisons across major prey species.*

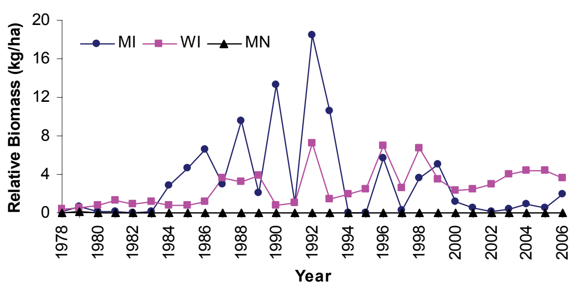


Figure 12. *Mean relative biomass (kg/ha) of age-1 and older bloater in Michigan, Wisconsin, and Minnesota nearshore waters of Lake Superior, 1978-2006.*

Despite the moderate increase in recruitment of age-1 fish to the bottom trawl, the mean relative biomass for age-1 and older lake whitefish in all waters decreased from 2005 (3.14 kg/ha) to 2006 (1.33 kg/ha; Fig. 11A). Mean relative biomass has remained steady since 1996, averaging 2.01 kg/ha over this period. RSE for lake whitefish biomass has also 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 (Fig. 14) despite the major decrease in these waters from 15.89 kg/ha in 2005 to 4.16 kg/ha in 2006. Relative biomass increased by over an order of magnitude in Michigan waters from 0.05 kg/ha in 2005 to 1.14 kg/ha in 2006 (Fig. 14). Biomass of lake whitefish in western Ontario waters decreased from 2005 to 2006 (2.56 to 0.71 kg/ha, respectively) while biomass in eastern Ontario waters increased from 0.12 to 0.48 kg/ha over the same time period (Fig. 15).

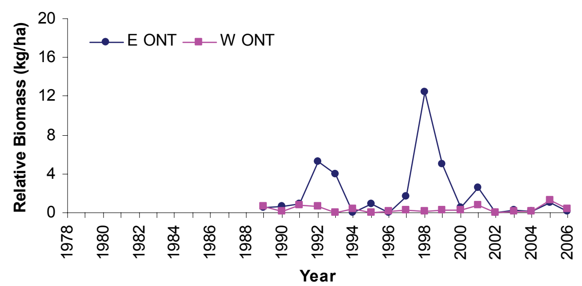


Figure 13. *Mean relative biomass (kg/ha) of age-1 and older bloater in eastern and western Ontario nearshore waters of Lake Superior, 1989-2006. Axes are identical to Figure 12 to facilitate comparisons across jurisdictions.*

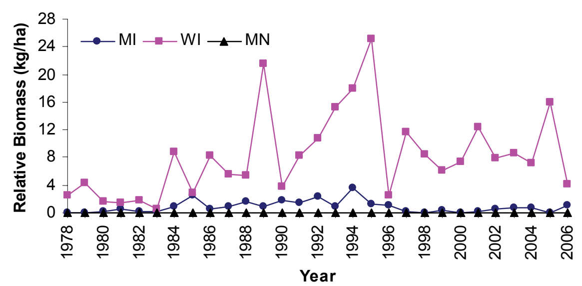


Figure 14. *Mean relative biomass (kg/ha) of age-1 and older lake whitefish in Michigan, Wisconsin, and Minnesota nearshore waters of Lake Superior, 1978-2006.*

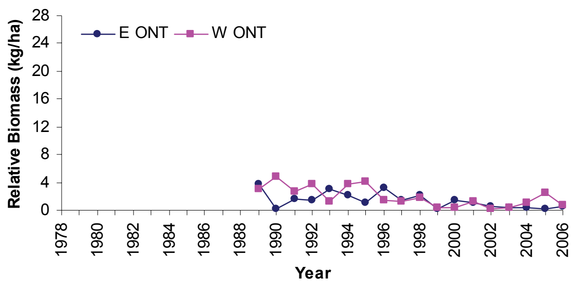


Figure 15. *Mean relative biomass (kg/ha) of age-1 and older lake whitefish in eastern and western Ontario nearshore waters of Lake Superior, 1989-2006. Axes are identical to Figure 14 to facilitate comparisons across jurisdictions.*

Other Species

Ninespine stickleback – Mean relative biomass for ninespine sticklebacks (*Pungitius pungitius*) increased from 2005 (0.01 kg/ha) to 2006 (0.04 kg/ha; Fig. 16). Mean relative biomass for all waters since 1997 was 0.04 kg/ha whereas mean biomass between 1978 and 1996 was 0.21 kg/ha.

Sculpins – Mean relative biomass for all three sculpin species combined (spoonhead *Cottus ricei*, deepwater *Myoxocephalus thompsoni*, and slimy *C. cognatus*) has followed a trajectory similar to ninespine sticklebacks since 1993 (Fig. 16). Relative biomass increased from 2005 (0.01 kg/ha) to 2006 (0.04 kg/ha). Deepwater sculpins were 74% of total sculpin biomass in 2006, followed by slimy (23%) and spoonhead (3%) sculpins. Deepwater sculpins were 55% of the sculpin biomass in 1984, and never exceeded 33% in the remaining 27 years of the survey. Slimy sculpins averaged 64% of the total sculpin biomass across all years, but represented a higher percentage in the earlier years (81% from 1978 to 1983 compared to 59% from 1984 to 2006).

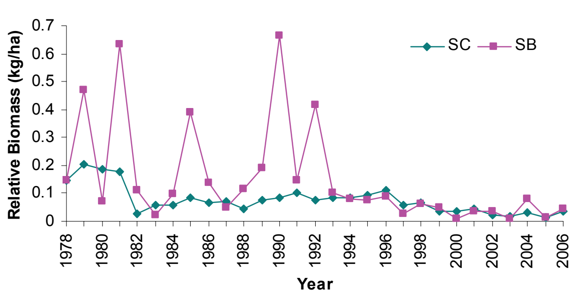


Figure 16. *Mean relative biomass (kg/ha) of age-1 and older sculpins (slimy, spoonhead, and deepwater combined; SC) and ninespine sticklebacks (SB) for all nearshore sampling stations in Lake Superior, 1978-2006. Note Canadian waters were not sampled until 1989.*

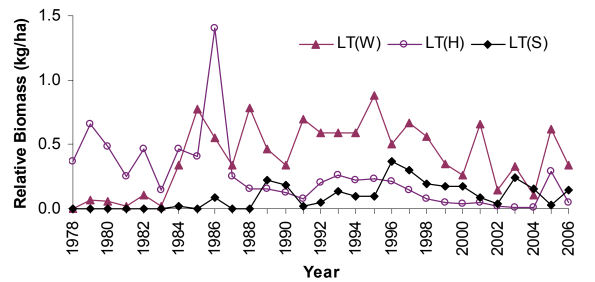


Figure 17. *Mean relative biomass (kg/ha) of age-1 and older wild lake trout (LT(W)), hatchery lake trout (LT(H)), and siscowet (LT(S)) for all nearshore sampling stations in Lake Superior, 1978-2006. Note Canadian waters were not sampled until 1989.*

Lake Trout – Mean relative biomass of siscowet lake trout (*Salvelinus namaycush*) increased 5-fold from 2005 to 2006 (0.03 to 0.15 kg/ha) but decreased by 45% for wild lean lake trout (*S. namaycush*) (0.61 to 0.34 kg/ha; Fig. 17). Mean relative biomass of hatchery lake trout decreased by 83% from 2005 to 2006 (0.29 to 0.05 kg/ha; Fig. 17). Stockwell et al. (2006a) attributed the large increases in biomass of hatchery and wild lean lake trout from 2004 to 2005 to three stations with at least one fish > 500 mm for hatchery fish, and increased catches of both large (> 500 mm) and total numbers of wild fish. Year-to-year differences in lake trout biomass from the bottom trawl survey should be interpreted cautiously.

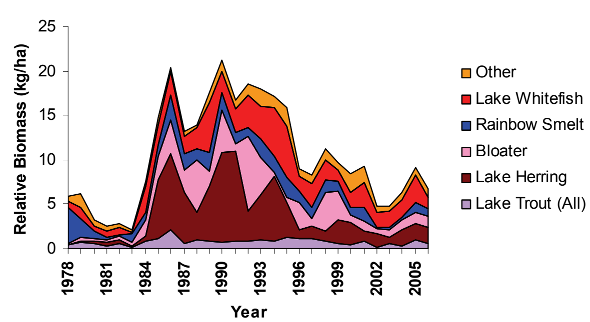


Figure 18. *Cumulative area plot of mean relative biomass (kg/ha) of the fish community caught in bottom trawls at all nearshore sampling stations in Lake Superior, 1978-2006. Note Canadian waters were not sampled until 1989. Other category consists of: kiyi (*C.

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 during the spring bottom trawl survey decreased 26% from 9.13 kg/ha in 2005 to 6.80 kg/ha in 2006 (Fig. 18). The decrease in community biomass from 2005 to 2006 follows two consecutive years of increased biomass (34% increase from 2003 to 2004 and 45% increase from 2004 to 2005). Decreased biomass in 2006 was a result declines in estimated biomass of lake whitefish and lake trout. Cisco, rainbow smelt, bloater, and lake whitefish represented 78% of the mean relative biomass for all nearshore waters of Lake Superior in 2006. Cisco made up the highest percentage of biomass for any species (26%), followed by bloater (20%), lake whitefish (20%), and rainbow smelt (12%). In 2005, lake whitefish represented 34% of the average lakewide biomass, followed by cisco at 21%, bloater at 14%, and rainbow smelt at 12%.

Gear Comparison in Thunder and Black Bays

A total of 5,986 fish were caught in the 4 day bottom trawl samples collected from Black Bay (trawls 5-8 in Figure 2), with rainbow smelt (72.7% by number) and cisco (17.4%) the most frequently caught species. Rainbow smelt were also predominant in night midwater trawl catches from Black Bay (n = 7 trawl tows), representing 95.4% of the 4,701 fish captured. Cisco represented 3.5% of the total catch in midwater trawls from Black Bay. Cisco captured in bottom and midwater trawls from Black Bay were consistently larger than rainbow smelt (Figs. 19A and 19B). The acoustic target strength distribution from the midwater trawl paths (Fig. 19C) also reflected the two distinct sizes of rainbow smelt and cisco in Black Bay seen in the day bottom trawl samples (Fig. 19A) but not the night midwater trawl samples (Fig. 19B).

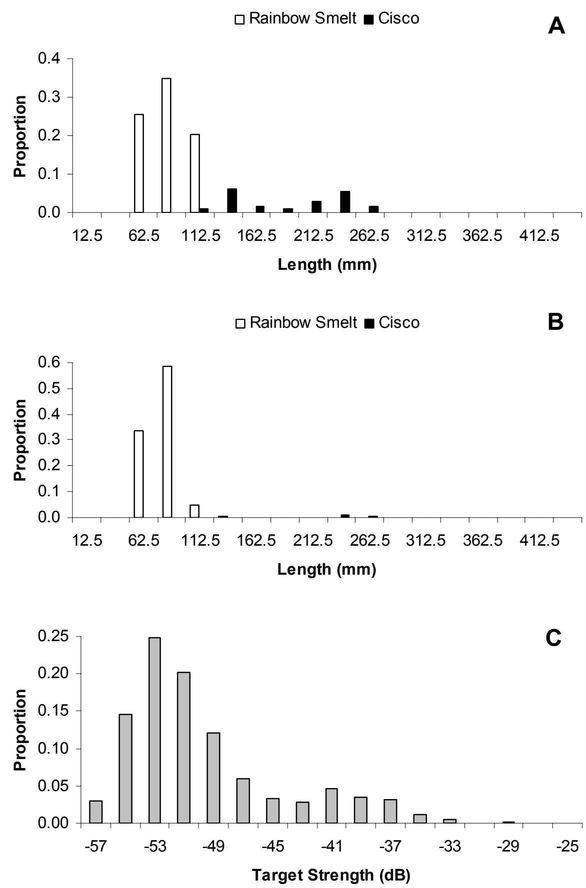


Figure 19. *Length frequency distributions of rainbow smelt and cisco captured with **(A)** day bottom trawls and **(B)** night midwater trawls in Black Bay. Note that proportions in each of **(A)** and **(B)** sum to one. The night acoustic target strength distribution (n = 2,043 targets) from all midwater trawl paths in Black Bay is shown in panel **(C)**.*

A total of 3,846 fish were caught in the 4 day bottom trawl samples collected from Thunder Bay (trawls 1-4 in Fig. 2), with rainbow smelt (94.7%) the predominant species. Only 5 cisco (0.14%) were captured using day bottom trawls. Cisco were predominant in night midwater trawls (n = 14 tows; Fig. 2) representing 57.3% of the catch (2,156 fish), followed by rainbow smelt (30.9%). Similar to Black Bay, cisco captured in bottom and midwater trawls from Thunder Bay were consistently larger than rainbow smelt (Figs. 20A and 20B). The target strength distribution from the midwater trawl paths in Thunder Bay (Fig. 20C) reflected a more continuous and uniform distribution than Black Bay (Fig. 19C), but was similar to the length frequency distributions from the Thunder Bay midwater trawl samples (Fig. 20B).

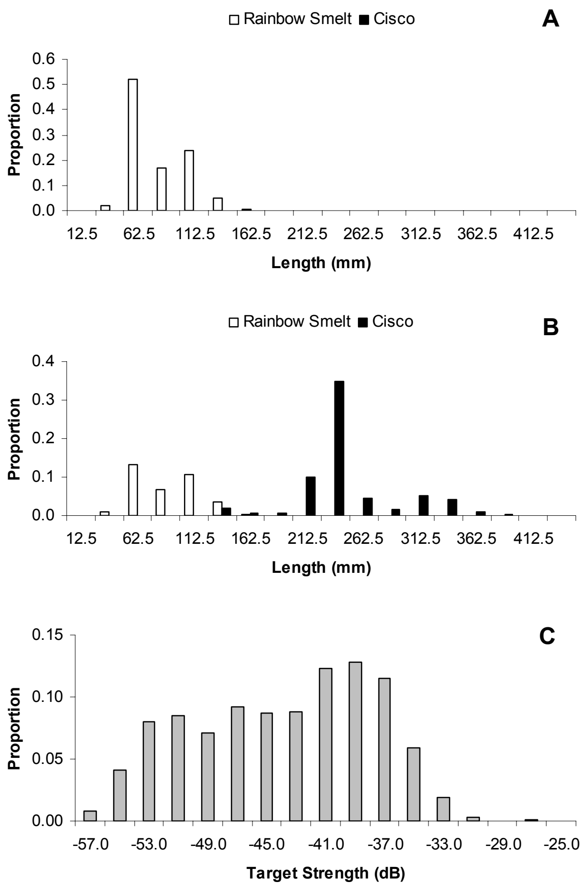


Figure 20. *Length frequency distributions of rainbow smelt and cisco captured with **(A)** day bottom trawls and **(B)** night midwater trawls in Thunder Bay. Note that proportions in each of **(A)** and **(B)** sum to one. The night acoustic target strength distribution (n = 7,194 targets) from all midwater trawl paths in Thunder Bay is shown in panel **(C)**.*

A total of 220 and 96 km were acoustically sampled in Thunder and Black Bays, respectively (Fig. 2). When apportioning acoustic fish density estimates to species we assumed all targets smaller than -44.59 dB, regardless of depth, were rainbow smelt. This cutoff value (-44.59 dB) was based on comparisons of TS distributions with concurrently collected midwater trawl tows that consisted of "pure" cisco or "pure" rainbow smelt catches (Fig. 2; D. Yule, unpublished data). Cisco represented 99.8% of the coregonids caught above 30 m in Thunder Bay at night so we assumed targets above 30 m that were greater than -44.59 dB were cisco. We apportioned targets larger than -44.59 dB detected below 30 m depth in Thunder Bay to species based the average proportions of cisco (62.5%), bloaters (18.5%) and kiyi (19%) caught in deep midwater trawl tows deployed at depths > 30 m. Because both night midwater trawl samples and day bottom trawl samples suggested that bloater and kiyi were rare in Black Bay, we assumed all targets deeper than 30 m in Black Bay that exceeded -44.59 dB were cisco.

Acoustically-derived estimates of rainbow smelt density throughout Black Bay were generally high with the greatest values in the southwest and central east portions of the bay (Fig. 21). The estimated mean density of rainbow smelt in Black Bay using night acoustics was 3,435 fish/ha while CPUE from midwater trawls was 47.1 fish/min. The mean density estimate for Black Bay using the 4 day bottom trawl tows was 1,181 fish/ha. In Thunder Bay, rainbow smelt acoustic density estimates were lower throughout the bay compared to Black Bay (Fig. 21). The estimated mean density of rainbow smelt in Thunder Bay using night acoustics was 530 fish/ha while the CPUE from midwater trawls was 2.3 fish/min. The mean density estimate for Thunder Bay using the 4 day bottom trawl tows was 983 fish/ha.

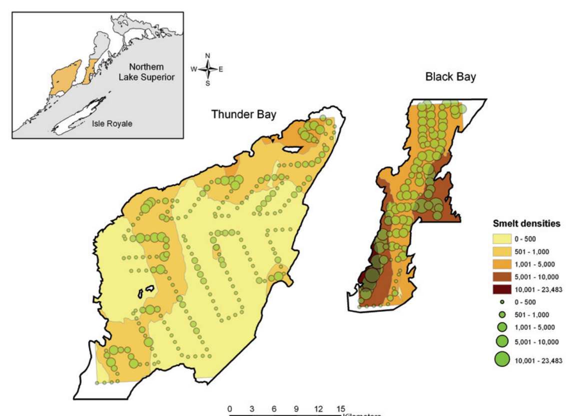


Figure 21. *Map of rainbow smelt densities (fish/ha) in Thunder Bay and Black Bay, Ontario measured with acoustic techniques between May 17-22, 2006. The interpolated surfaces were created using ordinary kriging.*

Cisco densities throughout Black Bay were generally higher in the middle and northwest portion of the bay (Fig. 22). The estimated mean density of cisco in Black Bay using night acoustics was 287 fish/ha while the CPUE from midwater trawls was 1.8 fish/min. The mean density estimate for Black Bay using the 4 day bottom trawl tows was 316 fish/ha. In Thunder Bay, cisco acoustic density estimates appeared to be patchier compared to Black Bay (Fig. 22). Greater concentrations were found in the southwest, central, and east central portions of the bay (Fig. 22). The estimated mean density of cisco in Thunder Bay using night acoustics was 327 fish/ha while the CPUE from midwater trawls was 4.2 fish/min. The mean density estimate for Thunder Bay using the 4 day bottom trawl tows was 1 fish/ha.

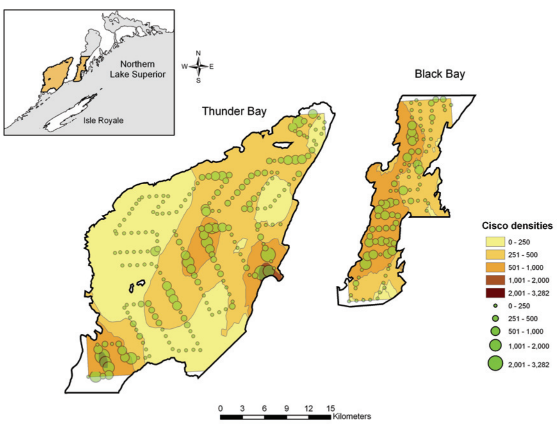


Figure 22. *Map of cisco densities (fish/ha) in Thunder Bay and Black Bay, Ontario measured with acoustic techniques between May 17-22, 2006. The interpolated surfaces were created using ordinary kriging.*

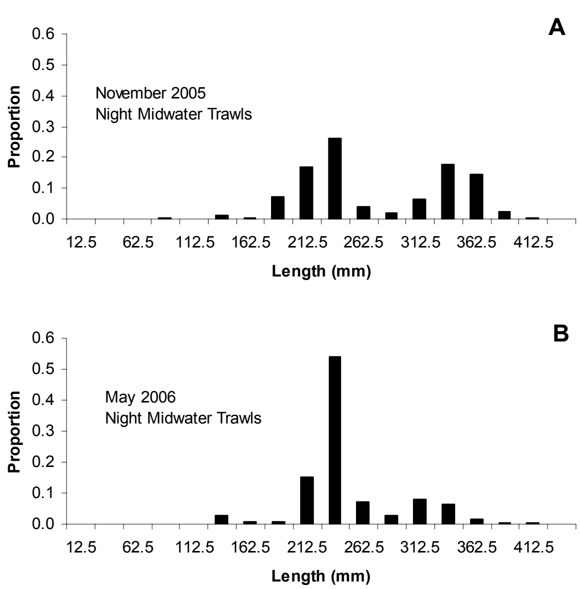
If we relied solely on the spring bottom trawl survey to make inferences about relative densities between Thunder and Black Bays, we would conclude that rainbow smelt densities were similar between the two bays and that cisco densities were much greater (> 2 orders of magnitude) in Black Bay than in Thunder Bay (Table 1). However, our inferences changed dramatically when comparing density and CPUE estimates from comprehensive acoustic coverage of each bay at night and midwater trawls. Based on these sampling strategies, rainbow smelt densities were 6- to 20-fold greater in Black Bay than in Thunder Bay and cisco estimates were similar or slightly greater in Thunder Bay compared to Black Bay (Table 1). Given that night sampling with acoustics and midwater trawls appears to be a better strategy for sampling pelagic species such as cisco and rainbow smelt (Mason et al. 2005, Stockwell et al. 2006, Yule et al. 2007) and our spatial coverage of each bay using these methods was much more representative of each bay compared to the day bottom trawl survey, we conclude that the density estimates based on the acoustics and midwater trawls are more accurate and thus better represent the cisco and rainbow smelt populations in each bay. Additional day bottom trawl stations would improve spatial coverage for the spring survey and may help improve population estimates for age-1 cisco and age-1 and older rainbow smelt because these species/life-stages appear to be associated with the bottom during day. However, gains in spatial coverage for the day bottom trawl survey will still be offset by 1) limitations to bottom trawling based on substrate, 2) decreased availability of cisco to the bottom trawl as they grow (Stockwell et al. 2006b), and 3) influence of environmental variability (e.g., turbidity) on the vertical distribution of fish during daylight hours (Stockwell et al. In press). We strongly urge skepticism even when making qualitative inferences about population dynamics of cisco and to a lesser extent rainbow smelt based on spring bottom trawl survey data.

Table 1. *Density estimates (fish/ha) for night acoustics (AC) and day bottom trawls (BTR) and CPUE estimates (fish/min) for night midwater trawls for rainbow smelt and cisco in Black and Thunder Bays. *Inferences are based on following: "≈"= less than 2-fold difference between estimates, ">" = 2 to 10-fold difference, ">>" = 10 to 100-fold difference, and ">>>" = greater than 100-fold difference.*

Species	Gear	Black Bay	Inference*	Thunder Bay
	AC	3,435/ha	>	530/ha
Smelt	MTR	47.1/min	>>	2.3/min
	BTR	1,181/ha	≈	983/ha
	AC	287/ha	≈	327/ha
Cisco	MTR	1.8/min	<	4.2/min
	BTR	316/ha	>>>	1/ha

Evaluations of ecological interactions based on day bottom trawl estimates should be done with even greater caution (Negus 1995). For example, Selgeby et al. (1978) scaled consumption rates of rainbow smelt feeding on larval cisco to rainbow smelt density estimates from two day bottom trawl stations in Black Bay, and concluded rainbow smelt consumed negligible amounts of the larval cisco available (3 to 11%). The ratio of night:day density estimates in this study was 3:1 in Black Bay. The night estimates from this study are 10-fold greater than estimated in the Selgeby et al. (1978) study although rainbow smelt populations in the 1970s were more abundant and their size-structure was much larger (Bronte et al. 2003). Scaling predation rates by these density increases (3- to 10-fold) would drastically change the conclusions of Selgeby et al. (1978) that rainbow smelt do not have a major impact on larval cisco.

Additional work from November 2005 estimated the density of spawning-sized cisco (> 250 mm) in Thunder Bay at 78 fish/ha (Yule et al. 2006a). The density estimate of spawning-sized cisco in Thunder Bay in May 2006 (this study; using a threshold TS of -35.6 dB from Yule et al. 2005b) was 28 fish/ha. The apparent drop in density of larger cisco over the winter is also supported by a drop in the largest size-classes in midwater trawls from November 2005 (Fig. 23A) to May 2006 (Fig. 23B). Day bottom trawl density estimates for spawning-sized cisco in Thunder Bay from the spring survey stations (0 fish/ha) resulted from the absence of these size-classes in the bottom trawls (Fig. 23C). Collectively, these results indicate that 1) a large proportion of the cisco spawning stock leaves Thunder Bay after spawning, 2) estimates of the Thunder Bay spawning stock in the spring using acoustics would be inaccurate, and 3) use of spring bottom trawl survey data to make assessments of or inferences about cisco spawning stock size (e.g., Hoff 2004) is simply incorrect, and further supports conclusions by Stockwell et al. (2006b) and Yule et al. (2007).



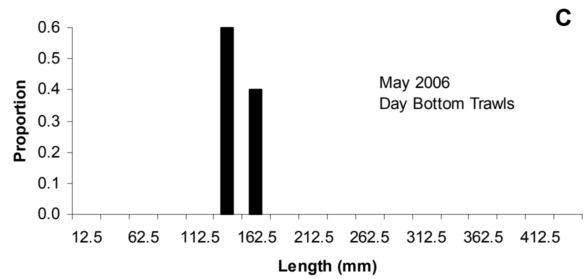


Figure 23. *Length frequency distributions of Thunder Bay cisco captured with* ***(A)*** *night midwater trawls in November 2005 (n = 12 trawls, 794 cisco),* ***(B)*** *night midwater trawls in May 2006 (n = 14 trawls, 1,236 cisco), and* ***(C)*** *day bottom trawls in May 2006 (n = 4 trawls, 5 cisco). Note that proportions in each panel sum to one.*

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