Lake Superior Committee
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Status and Trends of Prey Fish Populations in Lake Superior, 2007[1]

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Abstract

The Great Lakes Science Center has conducted annual daytime bottom trawl surveys of the Lake Superior nearshore (15-80 m depth zone) every spring since 1978 to provide a long-term index of relative abundance and biomass of the fish community. Between April 24 and June 19, 2007, 54 stations were sampled around the perimeter of the lake with 12-m wide bottom trawls. Trawls were deployed cross-contour at median start and end depths of 17 and 56 m, respectively. The lakewide mean relative biomass estimate for the entire fish community declined 29% from 6.80 kg/ha in 2006 to 4.81 kg/ha in 2007. Most of this decline was a result of decreased biomass estimates for cisco (89%) and bloater (55%). However, rainbow smelt and lake whitefish biomass increased by 61% and 13% from 2005 to 2006, respectively. Lake whitefish represented the highest percentage of biomass for the entire community (31%), followed by rainbow smelt (27%), bloater (13%), and cisco (4%). Year-class strength for the 2006 cisco cohort (0.3 fish/ha) was well below the long-term (1977-2006) average (76 fish/ha), as was year-class strength for the 2006 bloater cohort (0.3 fish/ha) compared to the long-term average (12 fish/ha). The 2007 cisco age structure was dominated by the strong 2003 year class, which accounted for 42% of the mean relative density. Wisconsin waters continue to be the most productive (mean total community biomass of 12.60 kg/ha), followed by western Ontario (6.60 kg/ha), eastern Ontario (2.88 kg/ha), Michigan (1.98 kg/ha), and Minnesota (0.06 kg/ha).

For the first time, we examined lake trout densities from the bottom trawl series by size classes to detect population trends. Our analysis showed a strong recovery of adult lake trout in the mid-1980s preceded by increasing densities of small and intermediate size classes. Periods of increased recruitment of small (< 226 mm) and intermediate (226-400 mm) size fish followed the appearance and growth of large year classes of native prey fishes (cisco, bloater) in 1984-1989 and 1992-1999. After 2000, recruitment and growth of small and intermediate size wild lake trout declined and this is the primary reason for a declining trend in total wild lake trout biomass since 1998. Densities of large (> 400 mm) adult wild lake trout have remained relatively steady since 1986, indicative of a recovered adult spawning population for 20+ years.

As a follow-up to fall 2005 cisco spawning surveys and spring 2006 larval cisco surveys in Thunder and Black bays, we conducted additional day bottom trawls in these bays during May 2007 to characterize age-1 densities and thereby assess survival from egg to larval to age-1 life stages. Based on these surveys, we estimated survival of eggs to larvae at 0.29% and 0.46%, and larvae to age-1 at 0.16% and 0.52% in Thunder and Black bays, respectively.

In May 2007 we conducted a study of diel variation in depth distribution of the principal prey fishes. We observed that prey species have discrete habitat distributions that shift from demersal or lower pelagic during day to pelagic at night (rainbow smelt, cisco, bloater, kiyi), or shift from deeper to shallower demersal habitat from day to night (lake whitefish). These patterns reveal the potential for Lake Superior prey fishes to couple resource use in nearshore and offshore zones by movement across habitats.

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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 is intended to provide a long-term index of relative abundance and biomass of Lake Superior's fish community in nearshore waters. The survey began in 1978 in United States (U.S.) waters and included 43-53 stations and was expanded in 1989 to include Canadian waters, increasing the total sampling effort to 76-86 stations. In 2005, the number of stations sampled lake-wide was reduced to 51 after it was found that this smaller sample yielded similar estimates of relative biomass of major species (Stockwell et al. 2006a). In this report, we update the time series of relative density and biomass with data collected in 2007 from 54 stations.

Additional spring sampling was conducted to assess survival of cisco *Coregonus artedi* egg and larval life stages in Black and Thunder bays and to describe diel patterns in bathymetric and vertical distribution of Lake Superior fishes in the Apostle Islands.

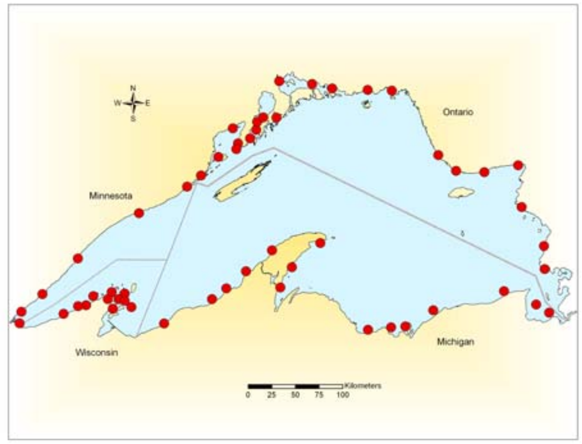

Figure 1. *Locations of 54 stations sampled during the 2007 annual spring bottom trawl survey in Lake Superior.*

Methods

Spring Survey

A total of 54 stations distributed around the perimeter of Lake Superior were sampled with bottom trawls during daylight hours between April 24 and June 19, 2007 (Fig. 1). We sampled 50 of the 51 stations that were sampled in 2005. Station 142 at Big Bay, Michigan, was not sampled because of the presence of trap nets. Four stations were added because of favorable logistics. Catch for each station was weighted for calculation of mean density and biomass (see below). Details regarding sub-sampling the 86 stations and assignment of weightings are given in Stockwell et al. (2006a).

Trawl samples were taken as a single cross-contour tow at each station. Median start and end depths for bottom trawl tows were 17 m (range 11-28 m, interquartile range 15-20 m) and 56 m (range 19-129 m, interquartile range 44-73 m), respectively. Median trawl tow duration was 22 minutes (range 6-61 minutes, interquartile range 14-35 minutes).

For each trawl tow, fish were sorted by species, counted, and weighed in aggregate by species to the nearest gram. Relative density (fish/ha) was estimated from sample counts and biomass (kg/ha) was estimated by aggregate weights expressed in kg divided by the number of hectares swept. These estimates were then modified by the station-specific weighting given in Stockwell et al. (2006). For important prey species (cisco, bloater *C. hoyi*, rainbow smelt *Osmerus mordax*, lake whitefish *C. clupeaformis*, year-class strength was estimated as the relative density (fish/ha) of age-1 fish, the first age-class that recruits to the bottom trawl in the spring. Densities of age-1 fish were estimated for rainbow smelt < 100 mm, lake whitefish < 160 mm, cisco < 140 mm, and bloater < 130 mm. 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 that sub-sampling of stations occurred) were calculated as $SD/\sqrt{n}$, where SD = the sample standard deviation and n = number of observations. Because weighted means were used after 2004, 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 of 100% indicates the standard error was equal to the estimated mean.

To determine the age structure of Lake Superior cisco in 2007, we used a length-age key to estimate relative density of each age-class as a function of length. To stratify sampling of fish for age determination, we divided Lake Superior into nine regions, and took a maximum of 10 cisco per 10-mm length bin for each region (50-400 mm range). Ages for all cisco were estimated from scales by a single trained reader; age estimates from otoliths were not available in 2007.

During 2000-2006 we used a combination of methods to determine cisco length-at-age. In general, scales were used for fish < 250 mm and otoliths were used for fish ≥ 250 mm because scales become less reliable as coregonids mature (Aass 1972; Mills and Beamish 1980; Yule et al. 2008). We used the crack and burn method to estimate ages from otoliths (Schreiner and Schram 2001). Because we were limited to application of scale age data in 2007, we developed a statistical age key similar to one developed for rainbow smelt (Gorman 2007) to estimate age composition of cisco as follows: Age data based on scales and otoliths from the 2000-2006 were used to generate size-at-age distributions. A default age key based on a composite catch curve and size-at-age distributions was then modified by weighting age classes by the relative abundance of their age-1 abundance. This weighted statistical age key was then applied to 2007 length-frequency distribution to estimate size-age specific density distributions.

Results

Cisco

Year-class strength for the 2006 cisco cohort was estimated at 0.3 fish/ha. This value was the sixth weakest recorded year-class strength over the 30-year survey and one of five year classes of ≤ 1 fish/ha since 1999. Year-class strength for the 2006 cohort was similar in U.S. (0.3 fish/ha) and in Canadian (0.2 fish/ha) waters. For comparison, the density of the strong 2003 year class was estimated at 182.2 fish/ha and moderate 2002 and 2005 year classes at 35.1 and 24.7 fish/ha, respectively (Fig. 3A). We previously under-reported the strength of the 2003 year-class at 24.7 fish/ha; in reality the 2003 year-class is the 5th strongest in the 30-yr survey and stronger than the most recent strong 1998 year-class (139.0 fish/ha). Relative standard error (RSE) fluctuated between 20 and 100% over the survey period, with the estimate for the 2006 year-class (56 %) 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.

Mean relative biomass of age-1 and older cisco (0.20 kg/ha) in 2007 was much lower than in 2006 (1.79 kg/ha) and 2005 (1.88 kg/ha; Fig. 4A), and is well below the 1978-2006 average of 3.08 kg/ha. RSE was 44% in 2006, matching the survey average of 44% (Fig. 4B).

Relative cisco biomass decreased substantially in all jurisdictions from 2006 to 2007: 1.68 to 0.25 kg/ha in Michigan waters (85% reduction), 3.64 to 0.37 kg/ha in Wisconsin waters (90% reduction), 2.65 to 0.14 kg/ha in W. Ontario waters (95% reduction), and 0.16 to 00.12 kg/ha in E. Ontario waters (25% reduction), respectively (Figs. 5 and 6). Relative biomass estimates as a percent of long-term means were low in all jurisdictions: Michigan (7%), Wisconsin (6%), W. Ontario (7%), and E. Ontario (10%). Cisco were not captured in Minnesota waters during the 2007 spring survey.

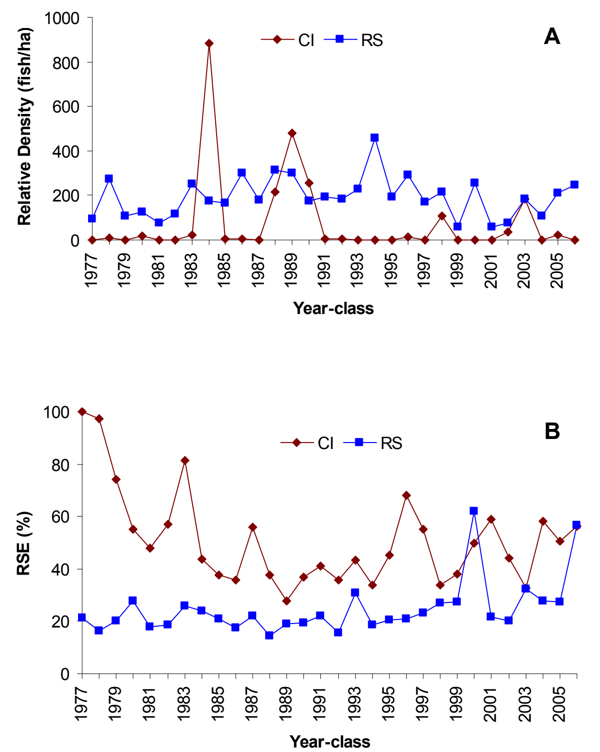

Figure 3. ***(A)*** *Year-class strength (number of age-1 fish/ha) for cisco (CI) and rainbow smelt (RS) for all nearshore sampling stations in Lake Superior for cohorts produced from 1977 to 2006. Only U.S. waters were sampled for the 1977-1988 year classes.* ***(B)*** *RSE (relative standard error) of year-class strengths in (A).*

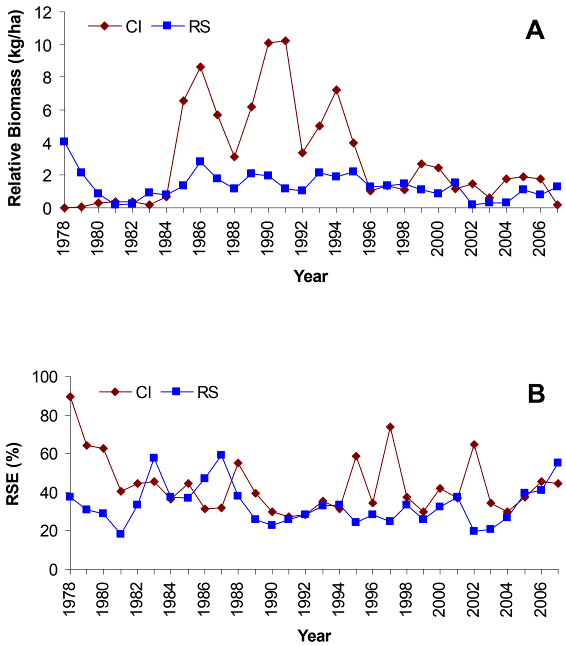

Figure 4. ***(A)*** *Mean relative biomass (kg/ha) of age-1 and older cisco (CI) and rainbow smelt (RS) for all nearshore sampling stations in Lake Superior, 1978-2007. Canadian waters were not sampled until 1989.* ***(B)*** *RSE (relative standard error) of mean biomass in (A).*

The mean relative density of all cisco, as measured by the day bottom trawl survey, decreased from 45 fish/ha in 2006 to 3 fish/ha in 2007. Age structure of cisco in 2007, expressed as the relative density of each age-class by length, is shown based on scale ages and a weighted statistical age-length key (Fig. 7). We found differences in the two distributions to be the result of error in estimating ages from scales, e.g., too many age-4 fish were classified as age-3, the 2004 cohort, which was estimated to be 331 times weaker than the 2003 year class. Thus, we judged the distribution based on the weighted statistical age key to be more reliable for interpreting the 2007 cisco age structure (Fig 7B). The 2007 cisco age structure was dominated by the 2003 year class, which accounted for 42% of the mean relative density (Fig. 7B). The 2002, 2004, 2005 and the most recent 2006 cohorts accounted for 15, 2, 27, and 11% of the mean relative density, respectively. Older cohorts (≥ age-6) represented 3% of the mean relative density (Fig. 7B).

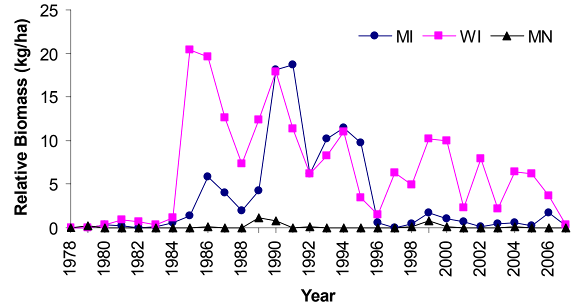

Figure 5. *Mean relative biomass (kg/ha) of age-1 and older cisco in Michigan (MI), Wisconsin (WI), and Minnesota (MN) nearshore waters of Lake Superior, 1978-2007.*

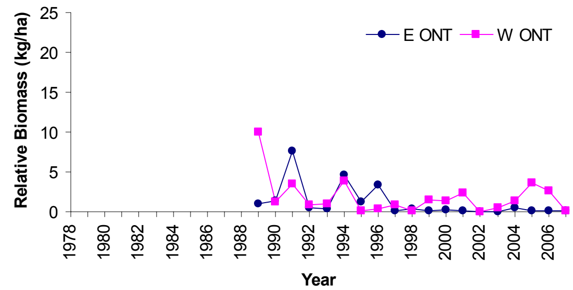

Figure 6. *Mean relative biomass (kg/ha) of age-1 and older cisco in eastern and western Ontario nearshore waters of Lake Superior, 1989-2007. Eastern and western Ontario waters are divided in the northeast corner of Lake Superior near Marathon, Ontario.*

Rainbow Smelt

Year-class strength of rainbow smelt increased from 206 fish/ha for the 2005 cohort to 246 fish/ha for the 2006 cohort (Fig. 3A). Year-class strength for the 2006 cohort is greater (128%) than the average over the 30-yr survey period (193 fish/ha). RSE was relatively high (57%) relative to the 30-yr average (25%), likely caused by high variation in catches among jurisdictions (Fig. 3B). The 2006 year-class was stronger in Ontario waters (530 fish/ha) than in U.S. waters (67 fish/ha).

Mean relative biomass for age-1 and older rainbow smelt increased by 61% from 2006 (0.80 kg/ha) to 2007 (1.29 kg/ha; Fig. 4A) and was 96% of the 30-year mean of 1.35 kg/ha. This increase is consistent with a recent trend in greater biomass in 2005-2007 and contrasts with a period of low biomass in 2002-2004. RSE for 2007 samples was a relatively high 55% in comparison to the 30-year range of 20 to 59% (Fig. 4B).

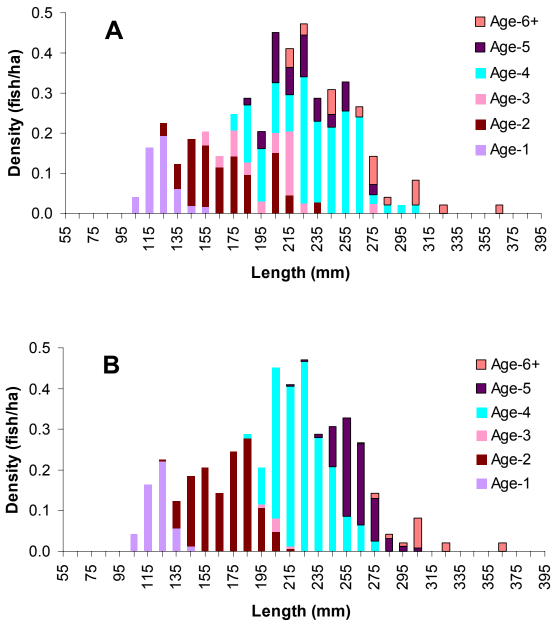

Figure 7. *Age-length distribution of cisco caught at all nearshore sampling stations in Lake Superior in 2007. Panel **A** shows the distribution based on a scale age key and panel **B** shows the distribution based on a weighted statistical age key.*

Relative biomass of rainbow smelt declined in Michigan and Minnesota waters from 0.63 and 0.14 kg/ha) in 2006 to 0.12 and 0.06 kg/ha in 2007, respectively. In contrast, biomass increased from 0.93 to 1.70 kg/ha in Wisconsin waters (Fig. 8). Rainbow smelt biomass in W. Ontario waters increased from 1.69 kg/ha in 2006 to 4.14 kg/ha in 2007 while biomass in E. Ontario waters continued a three-year decline from 0.29 kg/ha in 2006 to 0.12 kg/ha in 2007 (Fig. 9).

Bloater

Bloater year-class strength declined sharply from 15.8 fish/ha for the 2005 cohort to 0.3 fish/ha for the 2006 cohort (Fig. 10A). Year-class strength was greater in U.S. waters (0.4 fish/ha) compared to Ontario waters (0.1 fish/ha). We revised the strength of the 1998 year-class from 0.6 fish/ha to 31.5 fish/ha, following a correction in our database. RSE of bloater yearling density has fluctuated between 20 and 60% over the survey period (Fig. 10B).

Mean relative lake-wide biomass of age-1 and older bloater declined from 1.36 kg/ha in 2006 to 0.61 kg/ha in 2007 (Fig. 11A). Declines between 2006 and 2007 were evident in Michigan (1.90 to 0.68 kg/ha), Wisconsin (3.66 to 1.55 kg/ha; Fig. 12), and W. Ontario (0.33 to 0.11 kg/ha; Fig. 13). Only E. Ontario showed and increase from 0.18 kg/ha in 2006 to 0.68 kg/ha in 2007 (Fig. 13). No bloaters were captured in Minnesota in 2006 or 2007 (Fig. 12).

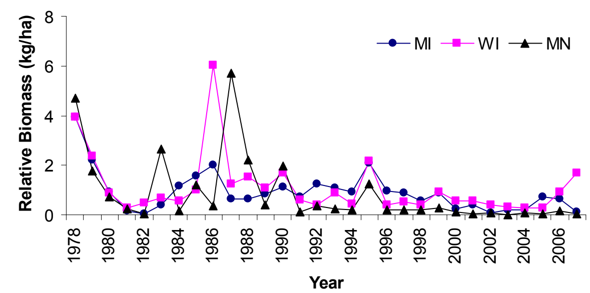

Figure 8. *Mean relative biomass (kg/ha) of age-1 and older rainbow smelt in Michigan, Wisconsin, and Minnesota nearshore waters of Lake Superior, 1978-2007.*

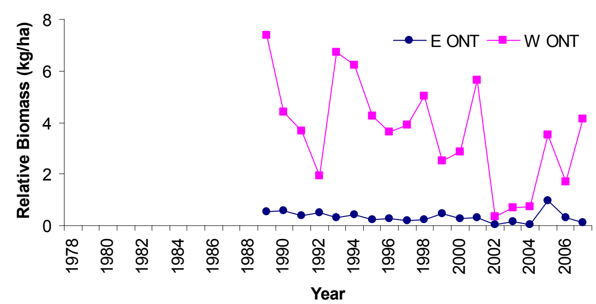

Figure 9. *Mean relative biomass (kg/ha) of age-1 and older rainbow smelt in eastern and western Ontario nearshore waters of Lake Superior, 1989-2007.*

Lake Whitefish

Lake whitefish year-class strength increased from 3.8 fish/ha for 2005 cohort to 12.3 fish/ha for the 2006 cohort (Fig. 10A). RSE for lake whitefish year-class strength was a record high 98% (Fig. 10B). The 2006 year-class was much stronger in U.S. (19.9 fish/ha) than in Canadian waters (0.2 fish/ha). Average year-class strength for lake whitefish over the 30-year survey period is 8.5 fish/ha.

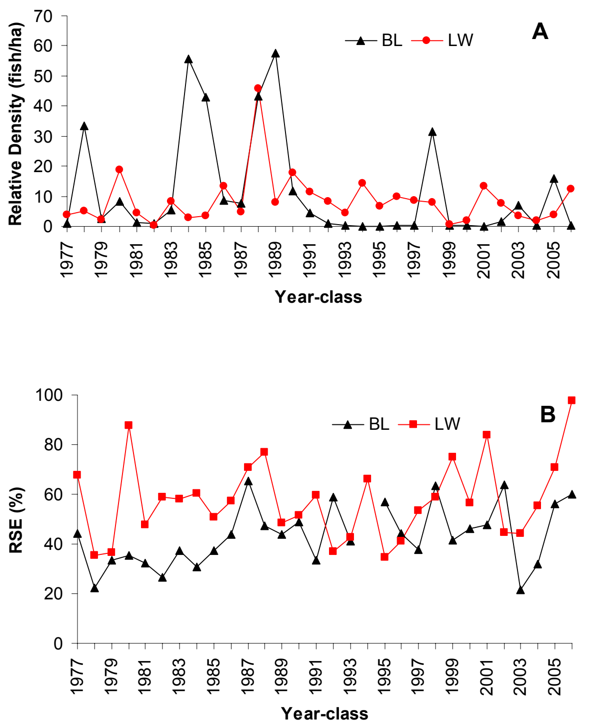

Figure 10. ***(A)*** *Year-class strength (number of age-1 fish/ha) for bloater (BL) and lake whitefish (LW) for all nearshore sampling stations in Lake Superior for cohorts produced from 1977 to 2006. Only U.S. waters were sampled for the 1977-1988 year-classes.* ***(B)*** *RSE (relative standard error) of year-class strengths in (A).*

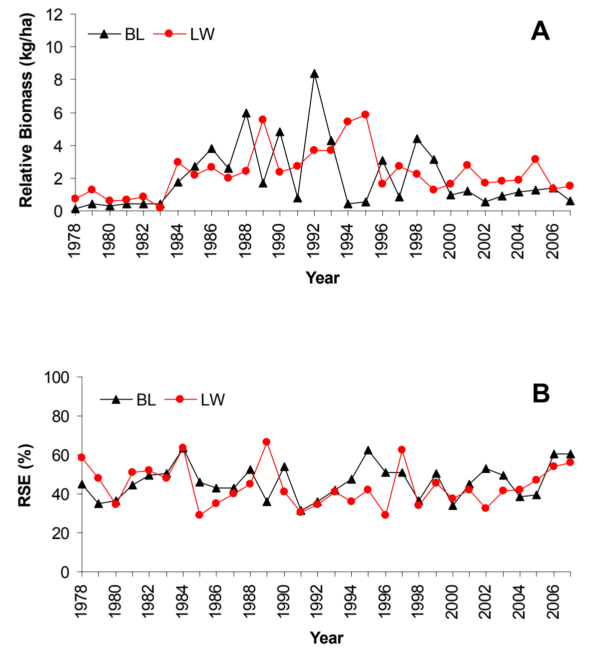

Figure 11. ***(A)*** *Mean relative biomass (kg/ha) of age-1 and older bloater (BL) and lake whitefish (LW) for all nearshore sampling stations in Lake Superior, 1978-2007. Canadian waters were not sampled until 1989.* ***(B)*** *RSE (relative standard error) of mean biomass in (A).*

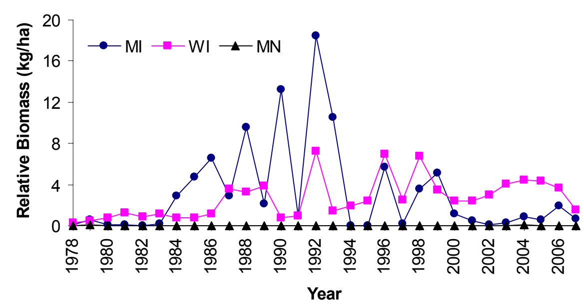

Figure 12. *Mean relative biomass (kg/ha) of age-1 and older bloater in Michigan, Wisconsin, and Minnesota nearshore waters of Lake Superior, 1978-2007.*

Mean relative biomass for age-1 and older lake whitefish in all waters increased slightly from 1.33kg/ha in 2006 to 1.51 kg/ha in 2007 (Fig. 11A). Overall, this estimate is consistent with a pattern of relatively steady biomass since 1996. RSE for 2007 was 56%, which is within the 30-year survey range of 29-66% (Fig. 11B).

Among jurisdictions, whitefish biomass increased in Wisconsin from 4.16 kg/ha in 2006 to 6.90 kg/ha in 2007 but declined in Michigan (1.14 to 0.38 kg/ha), W. Ontario (0.71 to 0.49 kg/ha), and E. Ontario (0.48 to 0.34 kg/ha; Figs. 14, 15). Lake whitefish have only been caught once in Minnesota waters (1995) over the entire time series.

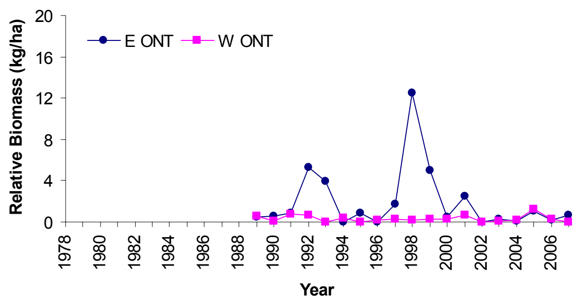

Figure 13. *Mean relative biomass (kg/ha) of age-1 and older bloater in eastern and western Ontario nearshore waters of Lake Superior, 1989-2007.*

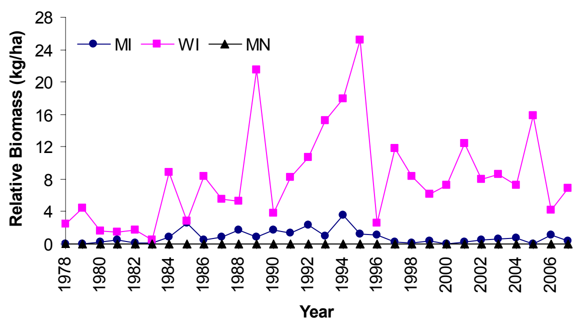

Figure 14. *Mean relative biomass (kg/ha) of age-1 and older lake whitefish in Michigan, Wisconsin, and Minnesota nearshore waters of Lake Superior, 1978-2007.*

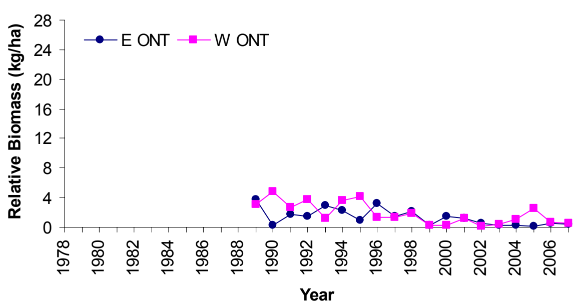

Figure 15. *Mean relative biomass (kg/ha) of age-1 and older lake whitefish in eastern and western Ontario nearshore waters of Lake Superior, 1989-2007.*

Other Species

Ninespine stickleback – Estimates of mean relative biomass for ninespine stickleback *Pungitius pungitius* in 2006 and 2007 were similar (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*, slimy *C. cognatus*, and deepwater *Myoxocephalus thompson*) has followed a declining trajectory similar to ninespine sticklebacks since 1993 (Fig. 16). Estimates of relative biomass in 2006 and 2007 were similar (0.04 kg/ha). Deepwater sculpins were 86% of total sculpin biomass in 2007, followed by slimy (12%) and spoonhead (2%) sculpins. Although deepwater sculpins strongly dominated the assemblage in 2006-2007, slimy sculpins were the dominant species in the group from 1978-2005, with the exception of 1984 when deepwater sculpins represented 55% of the biomass. Slimy sculpins averaged >68% of the total sculpin biomass across all years, but represented a higher percentage from 1978 to 1983 (81%) compared to 1984 to 2001 (64%) and 2002-2007 (35%).

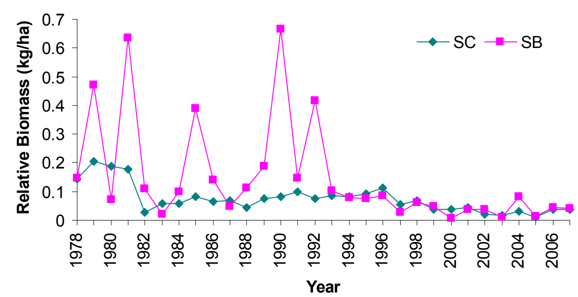

Figure 16. *Mean relative biomass (kg/ha) of age-1 and older sculpins (slimy, spoonhead, and deepwater combined; SC) and ninespine sticklebacks (SB) for all nearshore sampling stations in Lake Superior, 1978-2007. Canadian waters were not sampled until 1989.*

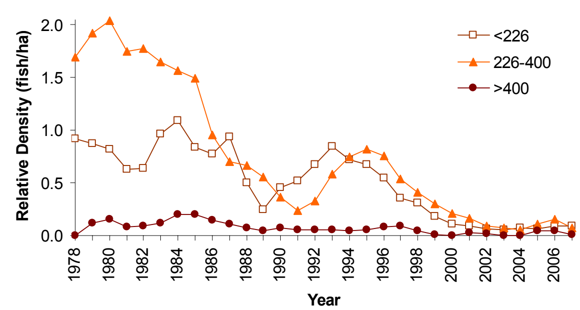

Figure 17. *Mean relative density (fish/ha) of age-1 and older hatchery lake trout for all nearshore sampling stations in Lake Superior, 1978-2007. Canadian waters were not sampled until 1989. Densities are shown for three length bins: <226 mm, 226-400 mm, and >400 mm TL.*

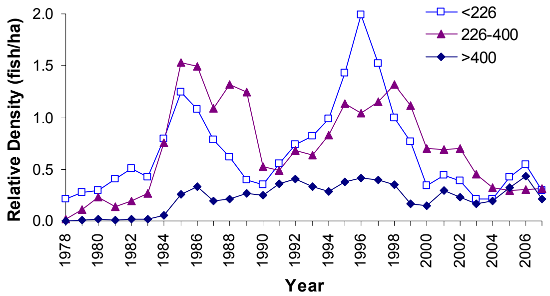

Figure 18. *Mean relative density (fish/ha) of age-1 and older wild lake trout for all nearshore sampling stations in Lake Superior, 1978-2007. Canadian waters were not sampled until 1989. Densities are shown for three length bins: <226 mm, 226-400 mm, and >400 mm TL.*

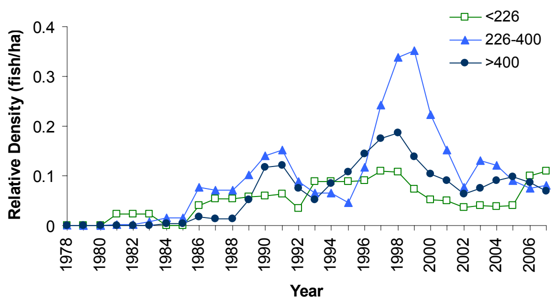

Figure 19. *Mean relative density (fish/ha) of age-1 and older siscowet lake trout for all nearshore sampling stations in Lake Superior, 1978-2007. Canadian waters were not sampled until 1989. Densities are shown for three length bins: <226, 226-400, and >400 mm TL.*

Lake Trout – Because our bottom trawls capture a broad spectrum of lake trout *Salvelinus namaycush* sizes and life stages, previously reported biomass indices were sensitive to variable capture of large adult fish (Stockwell et al. 2007a). Therefore, in this report we summarized our lake trout data as density by size bins: small, < 226 mm (≤ age-3), intermediate, 226-400 mm (age 4-8), and large, > 400 mm (> age-8). To reduce inter-annual variation in our density estimates, we expressed annual density using 2-year moving averages for hatchery and wild lake trout, and 3-year moving averages for siscowet lake trout.

Hatchery lake trout dominated the trout assemblage in the early portion of the survey (1978-1985), while wild lake trout dominated in the later portion of the survey (1985-2007; Figs. 17-18). Our data suggest that survival of hatchery lake trout beyond age 4-8 was poor and agrees with the assessments of Hansen et al. (1994a, 1994b, 1995) Bronte et al. (2003), Sitar and He (2006), and Sitar et. al. (2007). Moreover, persistence of hatchery lake trout appeared to be dependent on continued stocking and as stocking declined after 2000 (Sitar et al. *in review*), population density of all size classes declined to near zero by 2003 (Fig. 17). Small upturns in density of hatchery fish after 2004 were due to stocking in Canadian waters.

Recovery of wild lake trout, evidenced by a sharp rise in density of large fish in 1984-1986, was preceded by increasing densities of small and intermediate size fish during 1978-1983 (Fig. 18). Two periods of strong recruitment and growth in small and intermediate size classes of wild lake trout were evident; 1984-1989 and 1992-1999 (Fig 18). These periods overlap with the appearance and growth of the very large 1984, and 1988-1990 cisco year- classes (Fig. 4A). After 2000, recruitment and growth of small and intermediate sized wild lake trout declined to levels observed at the beginning of the survey period (1978-1983) and this is the primary reason for a declining trend in total wild lake trout biomass since 1998 (Stockwell et al 2007a). Densities of large adult wild lake trout have remained relatively steady since 1986, suggesting persistence of a recovered adult spawning population for 20+ years. The pattern of recovery observed from trawl data is generally congruent with results of lake-wide large-mesh gillnet assessments, e.g., Bronte et al. (2003) and Sitar and He's (2006) overview of lake trout recovery in Michigan waters of Lake Superior.

Small and intermediate-sized siscowet lake trout began to appear regularly in our nearshore trawl tows by 1986 and large individuals by 1990, but at much lower densities than lean lake trout. Over the time series siscowet densities show a variable but increasing trend (Fig. 19). This pattern suggests to us that recovery of siscowet populations was synchronous with wild lake trout and sharp increases in siscowet abundance reported from commercial gill-net fishery after 1980 (Bronte et al. 2003) supports our interpretation. In contrast to wild lake trout, most of the siscowet lake trout in our samples were intermediate and large fish, which suggests that larger siscowets move from deep offshore habitats into nearshore waters (Bronte et al. 2003).

Lake Superior Fish Community

In 2007, cisco, rainbow smelt, bloater, and lake whitefish represented 75% of the mean relative

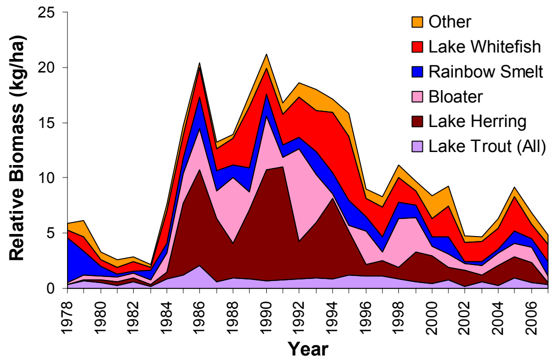

Figure 20. *Cumulative area plot of mean relative biomass (kg/ha) of the fish community caught in bottom trawls at all nearshore sampling stations in Lake Superior, 1978-2007. Canadian waters were not sampled until 1989.*

biomass for all nearshore waters of Lake Superior. Since 2005, mean biomass of all fish species caught during the spring bottom trawl survey declined 47%; from 9.13 kg/ha in 2005 to 6.80 kg/ha in 2006 and to 4.81 kg/ha in 2007 (Fig. 20). This decline follows two consecutive years of increased biomass (34% increase from 2003 to 2004 and 45% increase from 2004 to 2005). Similarly, community biomass increased in 2000-2001 and then declined sharply in 2002-2003. A common factor in this pattern was a sharp decline in cisco biomass. Decreased biomass in 2006-2007 was a result of declines in estimated biomass of cisco, bloater, lake whitefish and lake trout. In 2007, lake whitefish represented the highest percentage of biomass for the entire community (31%), followed by rainbow smelt (27%), bloater (13%), and cisco (4%). This structure contrasts with 2006 when cisco represented the highest percentage of biomass for any species (26%), followed by bloater (20%), lake whitefish (20%), and rainbow smelt (12%).

Changes in community structure and biomass over the 30-year times series is tied largely to changes in composition and abundance of major prey species (Gorman and Hoff 2008). Principal factors in changing community structure have been recovery of lake trout, increased mortality of rainbow smelt, and recruitment of large year classes of cisco. Variation in biomass of prey species since 1984 is tied to recruitment variation in cisco, bloater and lake whitefish. With the presence of recovered lake trout populations, we expect future prey fish biomass to continue to fluctuate as a result of recruitment variation but in dampened cycles because of predation mortality.

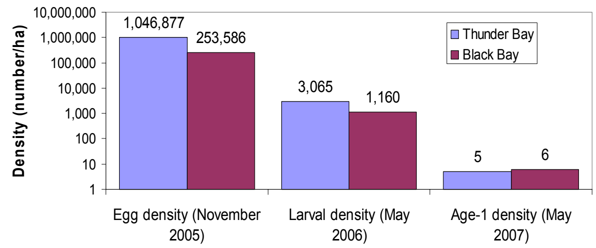

Figure 21. *Density estimates of eggs deposited by spawning females during November 2005, larval densities in May 2006 and age-1 densities measured during May 2007 gathered from Thunder and Black bays of Lake Superior.*

Survival of Early Life Stages of Cisco in Thunder and Black bays

Understanding the ecology of age-0 cisco is a high research priority of the Lake Superior fishery managers. Estimates of densities of different life stages (egg, larvae, and age-1) provide a means of assessing survival from life stage to life stage. During November 2005, LSBS and the Ontario Ministry of Natural Resources - Upper Great Lakes Management Unit collaborated on a project to estimate spawning cisco numbers in Black and Thunder bays of Ontario (Yule et al. 2006). During May 2006, larval densities were assessed using methods described by Myers et al. (2008). To better characterize age-1 densities during May 2007, we collected 4 additional bottom trawl samples in Thunder Bay and 3 in Black Bay, bringing the total effort to 8 samples in Thunder Bay and 7 samples in Black Bay.

Based upon our November 2005 surveys we estimated that 2.9 million adult female cisco were present in Thunder Bay (43 females/ha) and that these females carried 69.7 billion eggs (24,300/ female). Too few adult fish were caught in Black Bay to characterize the spawning stock, but adult spawner densities were estimated at 19.3/ha with acoustic methods. Assuming that the average female carried similar numbers of eggs in both bays, and that the female to male ratio was identical in both bays (55:45), we estimated that 134,000 females carried 3.2 billion eggs in the southern half of Black Bay where spawning was known to occur. Two synoptic larval surveys were conducted in both bays (2-7 May and 21-25 May 2006), and yielded larval density estimates of 3,065/ha and 1,160/ha for Thunder and Black bays, respectively (J. Myers, Michigan State University, unpublished data). Average age-1 cisco densities in Thunder Bay and

Black Bays were estimated at 5/ha and 6/ha, respectively during May 2007. Based on the three surveys in Thunder Bay, we estimated survival of eggs to larvae at 0.29% and larvae to age-1 at 0.16% (Fig. 21). In Black Bay, egg to larvae survival was estimated at 0.46%, while larval to age-1 survival was estimated at 0.52%.

At the close of 2007, a multi-agency proposal to study the ecology of early life history of cisco in lakes Superior, Michigan and Huron was funded by the Great Lakes Fish Restoration Act under the administration of the U.S. Fish and Wildlife Service. In future years, the LSBS will contribute to this joint effort by measuring spawner densities at nine Lake Superior locations each fall from 2008 to 2010. Each spring between 2009 and 2011 we will incorporate night sampling into our annual spring day bottom trawl assessment to characterize rainbow smelt densities and their food habits. Each May between 2009 and 2011, larval densities will be assessed by partner agencies using small vessels in nearshore waters. From this study we expect to 1) determine consistency and synchronicity of larval recruitment patterns, 2) compare larval densities with spawner densities to determine whether survival bottlenecks occur prior to or after the larval stage, and 3) examine the influence of spring growing conditions on larval cisco and rainbow smelt predation to determine which is the dominant factor governing recruitment variability.

Diel Variation in Depth Distribution of Prey Fishes

In late May 2007 we conducted a series of day and night bottom trawl tows in the Apostle Islands region of Lake Superior in conjunction with night mid-water trawl tows and acoustic data collection (Fig. 22). Our objective was to examine changes in day and night distributions of important prey fishes (rainbow smelt, cisco, bloater, kiyi *C. kiyi*, lake whitefish) and to characterize the potential for habitat coupling between nearshore (15-80 m depth) and offshore (>80 m depth) zones (Gorman et al. 2007). Day bottom trawl samples indicated that the different prey fishes studied had relatively discrete depth distributions (Fig. 23A). Large (> 300 mm) lake whitefish were found most often at depths >90 m, medium (200-300 mm) lake whitefish at depths of 60-90 m and small (< 200 mm) lake whitefish at depths of 30-60 m. Rainbow smelt were concentrated in the 30-60 m depth range, cisco and bloater were concentrated in the 60-90 m depth bin and kiyi were found only at depths >90 m. At night, densities of rainbow smelt, cisco, bloater, and kiyi in bottom trawl samples were very low (Fig. 23B). We observed a shift in densities of lake whitefish toward shallower water at night with each size class shifting to the next shallower depth bin. Night mid-water trawl samples and acoustic sampling showed that rainbow smelt, cisco, bloater, and kiyi were distributed in the pelagic zone and dispersed over nearshore and offshore depth zones (Fig. 24). These data suggest that the principal prey species have discrete habitat distributions that shift from demersal or lower pelagic during day to pelagic at night (rainbow smelt, cisco, bloater, kiyi), or shift from deeper to shallower demersal habitat from day to night (lake whitefish) (Fig. 25). These patterns reveal the potential for Lake Superior prey fishes to couple nearshore and offshore zones by movement across habitats. Research planned for 2008 will address seasonal patterns of diel movement; ontogenetic patterns of habitat use; consumption of food resources by habitat zone; and the influence of predator avoidance on habitat use patterns (Gorman et al. 2007).

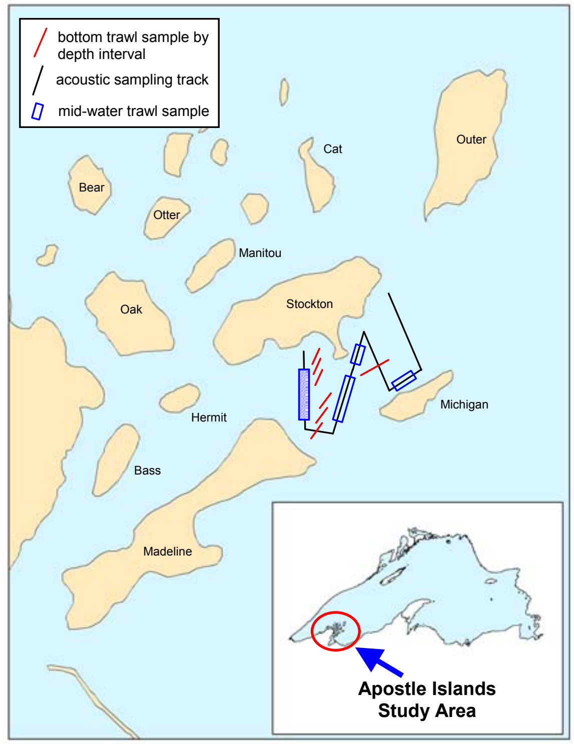

Figure 22. *Sampling design for describing diel patterns of depth distribution for principal prey fishes in the Apostle Islands region of Lake Superior, May 2007.*

We already addressed the inadequacy of our present day bottom trawl survey design to accurately assess density and biomass of the principal prey species of Lake Superior (Stockwell et al. 2006b, 2007b; Yule et al. 2007). We recommended the incorporation of night mid-water trawl and acoustic assessment into the current survey design. The early results of this new study impress upon us the need to develop annual fish community assessments that address the differential distribution of fish across habitats as defined by depth intervals and the broad range of diel vertical and horizontal movements displayed by the important prey species, e.g., cisco, rainbow smelt, bloater, and lake whitefish. We suggest that future survey designs address the distribution of fish across habitats on a diel basis to adequately assess habitat coupling across inshore, nearshore and offshore waters of Lake Superior fishes.

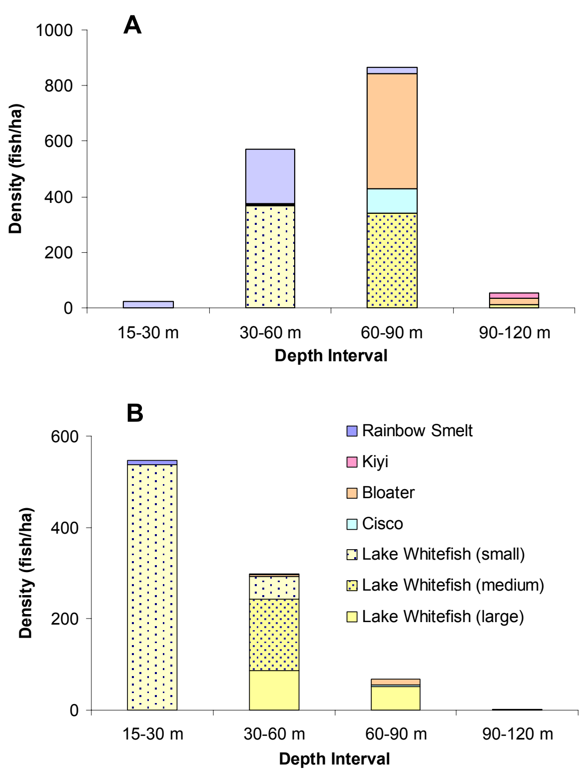

Figure 23. *Diel patterns of density of principal prey fishes by bathymetric depth in the Apostle Islands region of Lake Superior, as determined by bottom trawls in late May, 2007. Day and night densities are shown in panel A and B, respectively. Small lake whitefish are < 200 mm TL, medium are 200-300 mm TL and large are > 300 mm TL.*

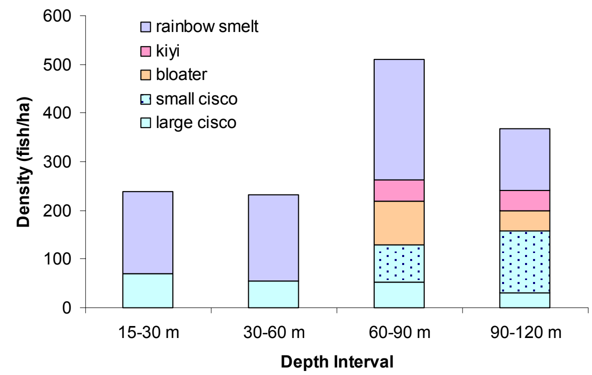

Figure 24. *Night-time densities of principal prey fishes by bathymetric depth bin in the Apostle Islands region of Lake Superior as determined by acoustics and mid-water trawl. Small cisco were fish ≤ 250 mm TL and large cisco were >250 mm TL. Sampling was conducted in May, 2007.*

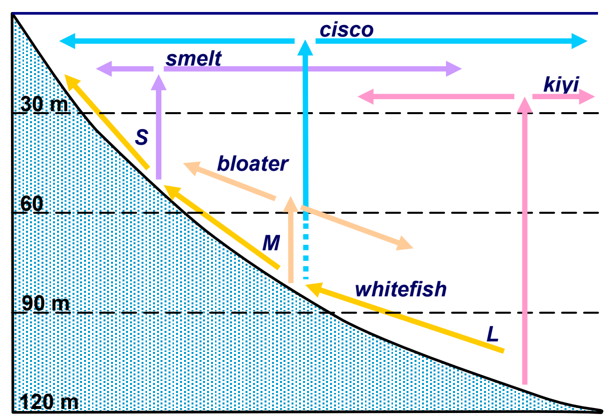

Figure 25. *Summary of diel movement of principal prey fishes in the Apostle Islands region of Lake Superior, May, 2007. Distribution of smelt, bloater, and kiyi was demersal during the day and pelagic at night, indicating upward vertical movement at night. Diel movement by cisco was similar but appeared to be less demersal during the day. These species also showed lateral dispersion over nearshore and offshore depth zones at night. Lake whitefish remained demersal both day and night but showed a pattern of up- the-bank movement into shallower depth zones at night. Lake whitefish size classes show are S – small, M – medium, L – large (see text for details).*

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