Status and Trends in the Fish Community of Lake Superior, 2012[1]

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Abstract

The Great Lakes Science Center has conducted daytime nearshore bottom trawl surveys of Lake Superior (15-80 m bathymetric depth zone) each spring since 1978 and an offshore survey (>80 m) since 2011 to provide long-term trends of relative abundance and biomass of the fish community. In 2012, 72 nearshore and 34 offshore stations were sampled with a 12-m Yankee bottom trawl.

The 2012 estimate of lake-wide nearshore fish community biomass was 1.14 kg/ha, second lowest in the 35-year survey history, down from 3.63 kg/ha observed in the 2011 survey. Dominant species in the catch, in order of relative biomass, were bloater, rainbow smelt, lake whitefish, pygmy whitefish, and shortjaw cisco. Compared to 2011 levels, biomass of all species decreased. Year-class strengths for the 2011 cisco and bloater cohorts were well below average and ranked as the second weakest year-classes in the past 35 years. Year-class strength of rainbow smelt was the weakest in the survey record, continuing a decline that began in 2008. As in 2011, densities of hatchery lake trout remained near zero in 2012, while densities of wild (lean) lake trout and siscowet lake trout decreased. Proportions of total lake trout density in 2012 that were hatchery, wild, and siscowet were 5, 74, and 21%, respectively.

The 2012 estimate of lake-wide offshore fish community biomass was 6.9 kg/ha, down from 9.0 kg/ha in 2011. Deepwater sculpin, kiyi, and siscowet lake trout represented 98% of the fish caught in terms of both density and biomass. Community composition, number of species collected and densities and biomass for most species were similar to that observed in 2011.

Due to ship mechanical failures, nearshore sampling was delayed from mid-May to mid-June to mid-June to late August. The shift to summer sampling when the lake was stratified may have affected our estimates, thus our estimates of status and trends for the nearshore fish community in 2012 are tentative, pending results of future surveys. However, the results of the 2012 survey are comparable with those during 2009 and 2010 when lake-wide fish biomass declined to < 1.40 kg/ha. Declines in prey fish biomass since the late 1990s can be attributed to a combination of increased predation by recovered lake trout populations and infrequent and weak recruitment by the principal prey fishes, cisco and bloater. In turn declines in lake trout biomass since the mid-2000s are likely linked to declines in prey fish biomass. If lean and siscowet lake trout populations in nearshore waters continue to remain at current levels, predation mortality will likely maintain the relatively low prey fish biomass observed in recent years. Alternatively, if lake trout populations show a substantial decline in abundance in upcoming years, prey fish populations may rebound in a fashion reminiscent to what occurred in the late 1970s to mid-1980s. However, this scenario depends on substantial increases in harvest of lake trout, which seems unlikely given that levels of lake trout harvest have been flat or declining in many regions of Lake Superior since 2000.

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I. Status and trends in the nearshore fish community of Lake Superior

Introduction

The Great Lakes Science Center's Lake Superior Biological Station conducts an annual daytime bottom trawl survey each spring in the nearshore waters (~15-80 m depth) of Lake Superior. The survey is intended to provide data for assessment of long-term trends of relative abundance and biomass of the nearshore fish community. Beginning in 1978, the survey included 43-53 stations in the United States (U.S.). Stations were added in Canadian waters in 1989, raising the sampling effort to 76-86 stations. During 2005-2010, the number of stations was reduced to 52-64 sites.

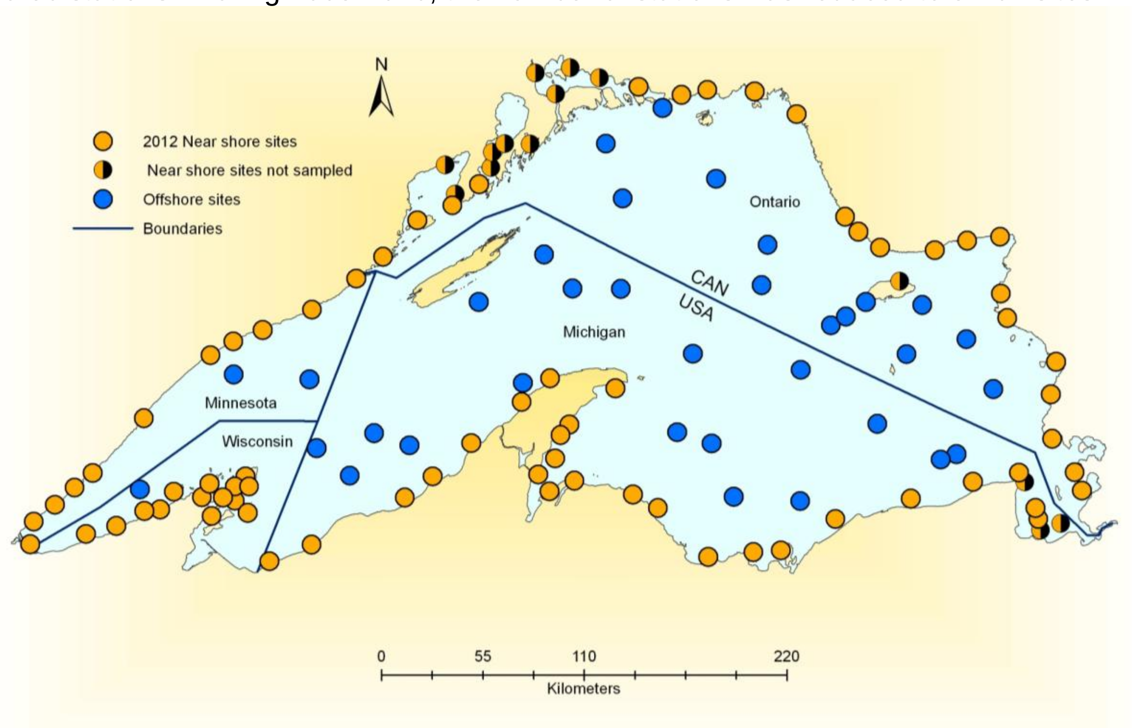


Figure 1. *Locations of 86 nearshore and 34 offshore bottom trawl stations established for sampling the Lake Superior fish community. Of the 86 nearshore stations, 72 were sampled in 2012.*

Methods

Nearshore Survey

A total of 72 of the 86 long-term nearshore sites distributed around the lake perimeter were sampled with bottom trawls during daylight hours between 19 June and 25 August 2012 (Fig. 1). A single sample was taken at each station with a 12-m Yankee bottom trawl towed cross-contour. The median start and end depths for bottom trawl tows were 16 m (range 10-31 m, interquartile range 14-20 m) and 59 m (range 21-143 m, interquartile range 48-76 m), respectively. Median trawl tow duration was 25 minutes (range 7-55 minutes, interquartile range 14-35 minutes). Fish were sorted by species, counted, and weighed in aggregate to the nearest gram. Relative density (fish/ha) and biomass (kg/ha) were estimated by dividing sample counts and aggregate weights by the area of the bottom swept by each trawl (ha).

For principal prey species (cisco *Coregonus artedi*, 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. Densities of age-1 fish were estimated from densities of 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). Standard errors (SE) were calculated as SD/√n, where SD = the sample standard deviation and n = number of observations. For sample years 2005-2010 when weighted means were calculated, SE was calculated from the unweighted data. The SE was standardized by the mean to generate relative standard error (RSE = SE/mean*100).

For other species (sculpins, ninespine stickleback, and lake trout), we provide plots showing trends in biomass. Because our bottom trawls capture a broad spectrum of lake trout *Salvelinus namaycush* sizes and life stages, biomass estimates are sensitive to variable capture of large adult fish (Stockwell et al. 2007). Therefore, as in previous reports (Gorman et al. 2008, 2009, 2010, 2011, 2012), we included a summary of lake trout data expressed as density by size bins: small, < 226 mm (ca., ≤ age-3), intermediate, 226-400 mm (ca., age 4-8), and large, > 400 mm (ca., > age-8). We used moving averages to dampen inter-annual variation in density estimates for each size class of lake trout. Moving averages of two years for hatchery and wild (lean) lake trout and three years for siscowet lake trout were sufficient in reducing the standard deviation of inter-annual density estimates to <90% of the long-term mean density.

Results

Cisco

Year-class strength for the 2011 cisco cohort was estimated at 0.03 fish/ha, the second weakest year-class observed over the 35-year survey (Fig. 2A). The 2011 cohort was 0.05% of the 35-year survey mean density of 65.48 fish/ha, and 1.9% of the survey median density of 1.71 fish/ha. Year-class strength for the 2011 cohort in U.S. waters was 0.05 fish/ha and 0.00 fish/ha in Canadian waters. RSE estimated for the 2011 year-class was 100%, which is higher than the series average of 51% (Fig. 2B). The RSE for cisco year-class strength (Fig. 2B) exceeded the level of precision (no greater than ± 30% of the mean) recommended by Walters and Ludwig (1981) for stock-recruit data sets.

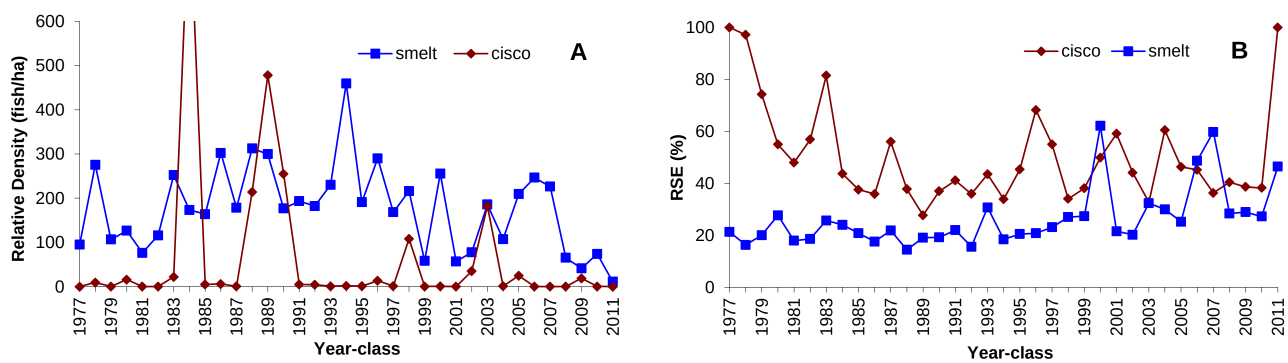


Figure 2. ***(A)*** *Year-class strength (number of age-1 fish/ha) for cisco and rainbow smelt for all nearshore sampling stations in Lake Superior for cohorts produced from 1977 to 2011. Only U.S. waters were sampled for the 1977-1988 year-classes. Off-chart value for age-1 cisco density in 1984 was 885.62 fish/ha.* ***(B)*** *RSE (relative standard error) of year-class strengths.*

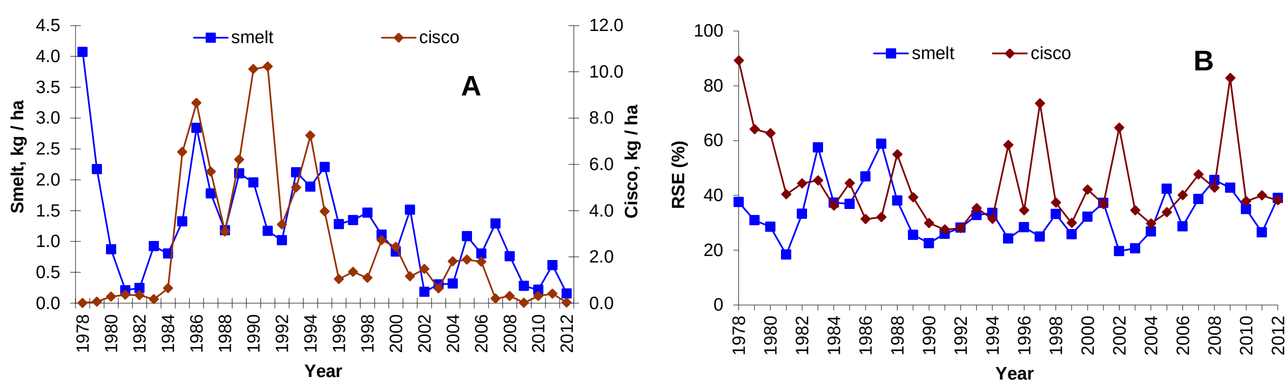


Figure 3. ***(A)*** *Mean relative biomass (kg/ha) of age-1 and older cisco and rainbow smelt for all nearshore sampling stations in Lake Superior, 1978-2012. Canadian waters were not sampled until 1989.* ***(B)*** *RSE (relative standard error) of mean biomass.*

In 2012, cisco biomass was near zero in all jurisdictions (Fig. 4). The low biomass recorded in Minnesota, Michigan and Canadian waters continues a trend of low levels since 2007. The decline in biomass in Wisconsin waters from 1.67 kg/ha in 2011 to 0.05 kg/ha in 2012 ends a 4-year trend of higher biomass (1.20-1.68 kg/ha) sustained by recruitment from a weak 2009 year class (Figs. 2A, 4A). The 2012 relative biomass estimates as a percent of long-term means was very low in US jurisdictions (Wisconsin, 0.8%; Michigan, 0.1%; Minnesota, 0.2%) and low in Canadian jurisdictions (E. Ontario, 3.1%; W. Ontario, 1.9%). This pattern is consistent with low cisco recruitment since 2003.

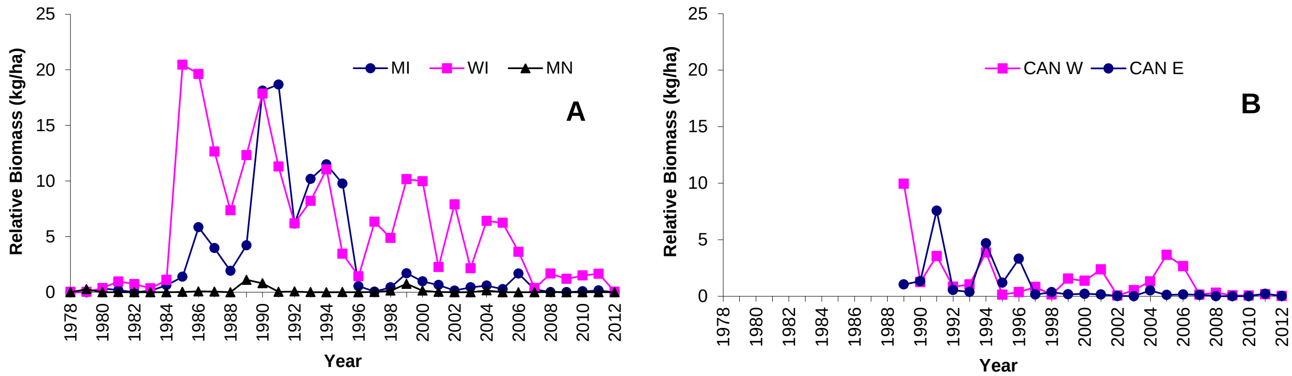


Figure 4. *Mean relative biomass (kg/ha) of age-1 and older cisco in nearshore waters of Lake Superior: (**A**) Michigan (MI), Wisconsin (WI), and Minnesota (MN), 1978-2012. (**B**) Eastern and western Ontario, 1989-2012. Eastern and western Ontario waters are divided in the northeast corner of Lake Superior near Marathon, Ontario.*

Rainbow Smelt

Rainbow smelt year-class strength decreased to a record low 11.05 fish/ha in 2012, much lower than the previous a record low 41.03 fish/ha set in 2009 (Fig. 2A). This decline continues a trend of weak year-classes following the 246.58 fish/ha peak set by the 2006 cohort (Fig. 2A). The 2011 cohort was 6.2% of the 35-year survey mean density of 177.13 fish/ha, and 6.2% of the survey median density of 178.1 fish/ha. RSE was 46.4%, above the 34-yr average of 26.3% (Fig. 2B). The 2011 year-class strength was similar in Canadian waters (10.53 fish/ha) and U.S. waters (11.05 fish/ha).

Mean relative biomass for age-1 and older rainbow smelt declined to record low 0.16 kg/ha, continuing a declining trend following the most recent maximum of 1.29 kg/ha in 2007 (Fig. 3A). The 2012 biomass estimate was 13% of the 35-year mean of 1.21 kg/ha. RSE of the 2011 biomass estimate was 39.1%, which is higher than the 35-year survey mean of 33.3% (Fig. 3B). Compared to 2011, estimated biomass of rainbow smelt in 2012 declined sharply in Wisconsin and Ontario waters but increased slightly in Michigan and Minnesota waters (Fig. 5). Relative biomass was lower than the long-term average in all jurisdictions: 45.9%, 33.3%, 7.1%, 6.9%, and 3.5% in E. Ontario, Michigan, Wisconsin, Minnesota, and W. Ontario waters, respectively.

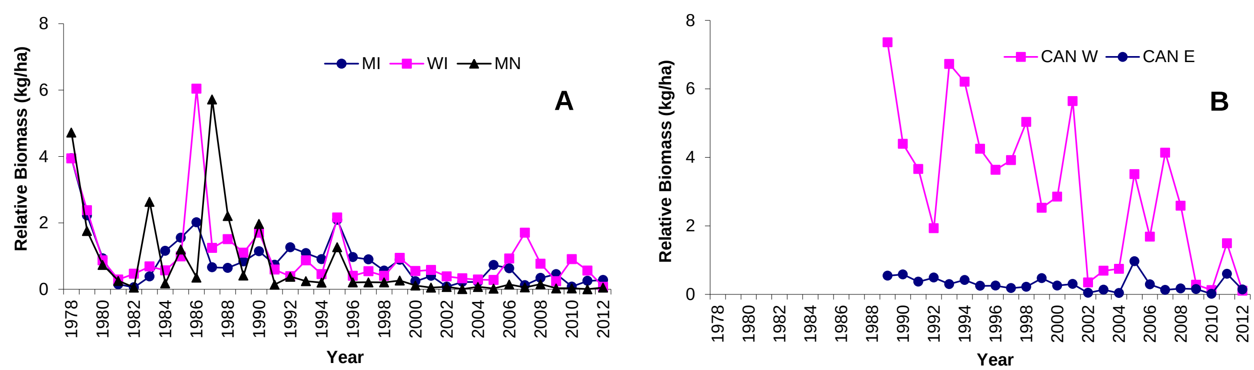


Figure 5. *Mean relative biomass (kg/ha) of age-1 and older rainbow smelt in nearshore waters of Lake Superior: (**A**) Michigan, Wisconsin, and Minnesota, 1978-2012. (**B**) Eastern and western Ontario, 1989-2012.*

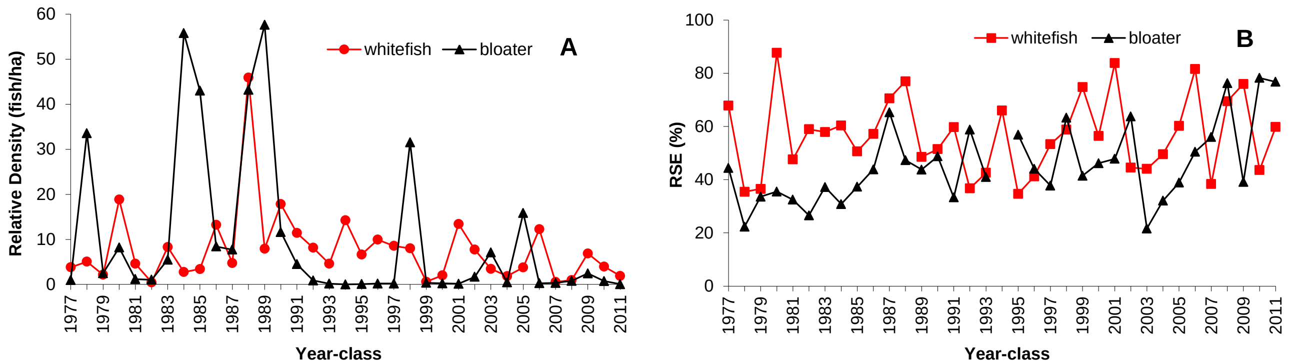


Figure 6. ***(A)*** *Year-class strength (number of age-1 fish/ha) for bloater and lake whitefish for all nearshore sampling stations in Lake Superior for cohorts produced from 1977 to 2011. Only U.S. waters were sampled for the 1977-1988 year-classes.* ***(B)*** *RSE (relative standard error) of year-class strengths.*

Bloater

The 2011 bloater year-class strength (Fig. 6A) was the second weakest on record (0.05 fish/ha), only surpassed by record of 0.00 fish/ha set in 1994, and that value was the result of incorrectly identifying yearling bloater as cisco in the annual survey. The 2011 year-class was 0.5% and 0.4% of the 35-year average and median densities of 9.95 and 1.18 fish/ha, respectively. Year-class strength was greater in US waters (0.42 fish/ha) compared to Canadian waters (0.12 fish/ha). RSE of bloater yearling density was 77%, well above the 35-year survey average of 46% (Fig. 6B).

Mean relative lake-wide biomass of age-1 and older bloater decreased from 0.56 kg/ha in 2011 to 0.33 kg/ha in 2012, continuing a recent declining trend that began 2006 when lake-wide biomass was 1.36 kg/ha (Fig. 7A). The RSE for the 2011 biomass estimate was 68%, which is above the 35-year survey average of 46% (Fig. 7B).

In 2011, bloater biomass was well below the long-term average in all jurisdictions: 56% in Wisconsin, 13% 18% in E. Ontario, 3% in W. Ontario, 2% in Michigan, and 0% in Minnesota waters (Fig. 8).

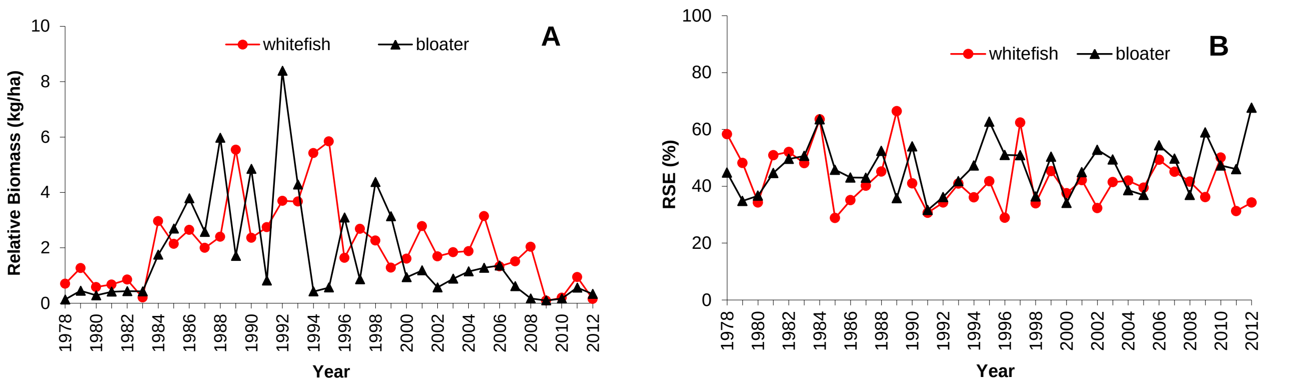


Figure 7. ***(A)*** *Mean relative biomass (kg/ha) of age-1 and older bloater and lake whitefish for all nearshore sampling stations in Lake Superior, 1978-2012. Canadian waters were not sampled until 1989.* ***(B)*** *RSE (relative standard error) of mean biomass.*

Lake Whitefish

Lake whitefish year-class strength decreased from 3.98 fish/ha for the 2010 cohort to 1.90 fish/ha for the 2011 cohort (Fig. 6A). For comparison, the average and median lake-wide year-class strengths for the 35-year survey period were 7.72 and 5.05 fish/ha, respectively. RSE for lake whitefish year-class strength was 60%, slightly greater than the 35-year survey average of 57% (Fig. 6B). The 2011 year-class was stronger in U.S. (2.58 fish/ha) than in Canadian waters (0.33 fish/ha).

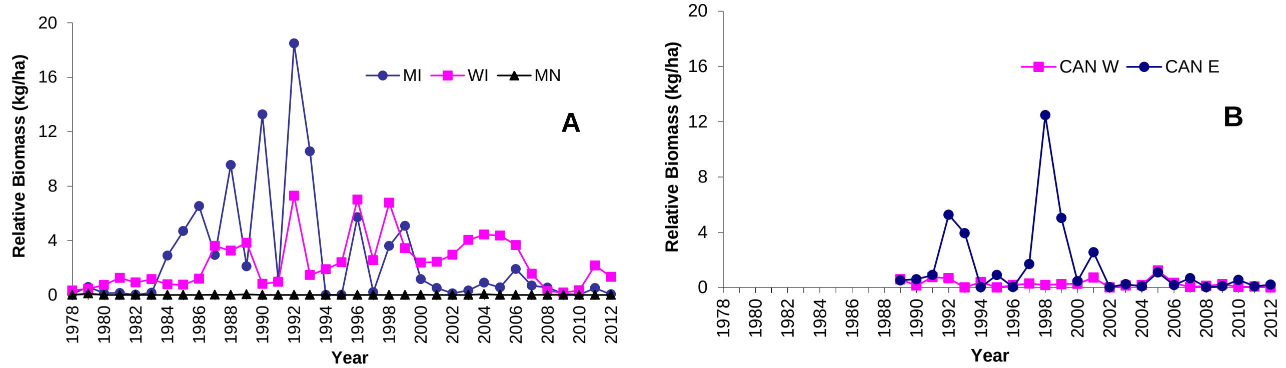


Figure 8. *Mean relative biomass (kg/ha) of age-1 and older bloater in nearshore waters of Lake Superior: (**A**) Michigan, Wisconsin, and Minnesota, 1978-2012. (**B**) Eastern and western Ontario, 1989-2012.*

Mean relative biomass for age-1 and older lake whitefish in all waters decreased from 0. 94 kg/ha in 2011 to 0.15 kg/ha in 2012, resuming a trend of decline that began after the last high of 2.04 kg/ha in 2008 (Fig. 7A). RSE for the 2012 biomass estimate was 34%, which is below the 33-year average of 43% (Fig. 7B).

Whitefish biomass estimates decreased across all U.S. and Canadian jurisdictions with the exception of Minnesota where biomass estimates remained at zero (Fig. 9). The 2012 biomass estimates were a fraction of the long-term jurisdictional averages: 10% in Michigan, 9% in E. Ontario, 7% in Wisconsin, 0% in Minnesota, 0% in W. Ontario waters.

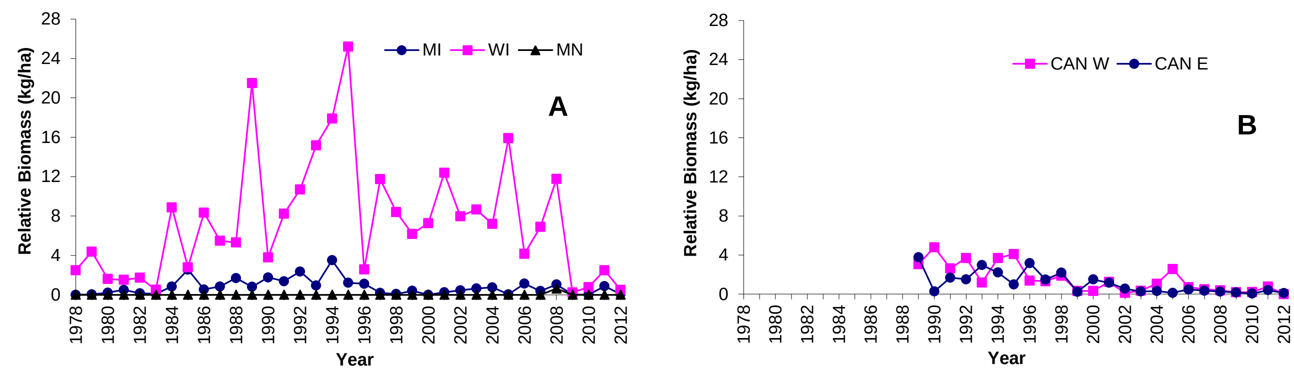
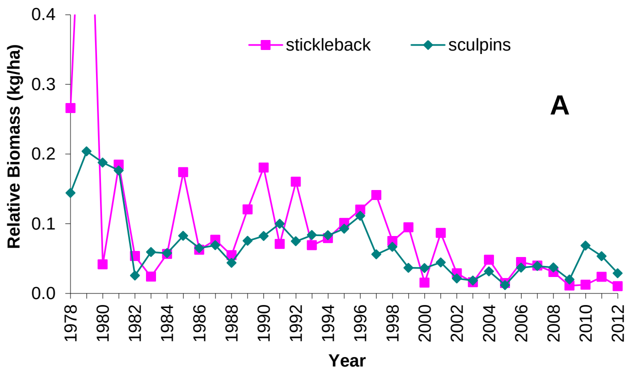


Figure 9. *Mean relative biomass (kg/ha) of age-1 and older lake whitefish in nearshore waters of Lake Superior: (**A**) Michigan, Wisconsin, and Minnesota, 1978-2012. (**B**) Eastern and western Ontario, 1989-2012.*

Other Species

Ninespine stickleback – The 2012 lake-wide estimate of mean relative biomass for ninespine stickleback *Pungitius pungitius* declined to the lowest level in the survey record (0.01 kg/ha), only slightly lower than the previously lowest values recorded in 2009 and 2010. The record low 2012 estimate continues a trend of declining biomass since the late 1990s; biomass averaged 0.03 kg/ha for 2000-2012 compared to 0.14 kg/ha for 1978-1999 (Fig. 10A).

Sculpins – Mean relative biomass for the three sculpin species (spoonhead *Cottus ricei*, slimy *C. cognatus*, and deepwater *Myoxocephalus thompsonii*) decreased in 2012, down to 0.03 kg/ha from 0.05 kg/ha in 2011 (Fig. 10A). The 2012 decrease was caused by a decline in abundance of all sculpin species and continues a recent trend of decline after the recent peak of 0.07 kg/ha in 2010.



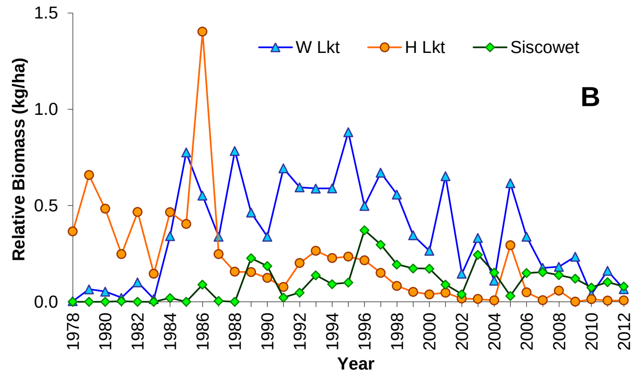


Figure 10. *Mean relative biomass (kg/ha) of age-1 and older (**A**) ninespine stickleback and sculpins (slimy, spoonhead, and deepwater combined), and (**B**) lake trout (wild-lean, hatchery, and siscowet) for all nearshore sampling stations in Lake Superior, 1978-2012. Lake trout data are not smoothed as in Fig. 11. Canadian waters were not sampled until 1989. Off-chart value for 1979 ninespine stickleback biomass is 0.77 kg/ha.*

Lake Trout – Biomass of hatchery lake trout in 2012 remained unchanged from 2011 (0.01 kg/ha), slightly above the near-zero record observed in 2009 (Fig. 10B). Between 2011 and 2012, biomass of wild (lean) lake trout decreased from 0.16 to 0.07 kg/ha, continuing a declining trend following the 2005 high of 0.62 kg/ha (Fig. 10B). Biomass of siscowet lake trout decreased from 0.10 kg/ha in 2011 to 0.08 kg/ha in 2012, continuing a declining trend that began after reaching 0.15 kg/ha in 2006 and 2007 (Fig. 10B).

Densities of small, intermediate and large hatchery lake trout in Lake Superior remained very low in 2012 (Fig. 11A), consistent with the decline beginning in the mid-1990s that followed a decline in stocking after 1995 (Sitar and He 2006; Linton et al. 2007; Gorman 2012). Between 2010 and 2012, densities of small and intermediate wild (lean) lake trout increased from 0.05 and 0.07 fish/ha, to 0.42 and 0.23 fish/ha, respectively (Fig. 11B). Density of large wild lake trout decreased from 0.10 fish/ha in 2010 to 0.04 fish/ha in 2012. The overall increase in wild lake trout density in 2011-2012 punctuates a declining trend that started in 1996-1998 (Fig. 11B). Between 2010 and 2012, density of small and intermediate siscowet lake trout declined from 0.07 and 0.11 fish/ha to 0.05 and 0.07 fish/ha, respectively (Fig. 11C). Density of large siscowet remained relatively constant at ~ 0.10 fish/ha between 2010 and 2012. Overall densities of siscowet lake trout have declined from peak levels in 1997-2000 to lower levels, and since 2008, densities have exhibited a declining trend (Fig. 11C). In 2012, the proportions of total lake trout density that were hatchery, wild, and siscowet were 5, 74, and 21%, respectively.

Summary and Discussion

Estimated mean biomass of all fish species caught during the spring bottom trawl survey decreased 69% from 3.63 kg/ha in 2011 to 1.14 kg/ha in 2012 and was 88% lower than long-term average of 9.20 kg/ha (Fig. 12). The decline in community biomass might be attributable, at least in part, to a delay in the bottom trawl survey from spring (mid-May to mid-June) to summer (mid-June to late August) as a result of ship mechanical failures. Thus our estimates of status and trends for the nearshore fish community in 2012 should be viewed with caution, pending results of future surveys. However, the low yields of the 2012 survey are comparable with the 2009 and 2010 surveys when lake-wide fish biomass declined to < 1.40 kg/ha, and are consistent with a declining trend that began in 2006. Moreover, the decline in biomass across jurisdictions reflects a common pattern of declining abundances of the key prey species, cisco, bloater, rainbow smelt, and lake whitefish. Declines in prey fish biomass since the mid-1990s can be attributed to a combination of increased predation by recovered lake trout populations and infrequent and weak recruitment by the principal prey fishes, cisco and bloater. In turn, declines in lake trout biomass and adult density since the mid-2000s are likely linked to declines in prey fish biomass. If lean and siscowet lake trout populations in nearshore waters continue to remain at current levels, high predation mortality will likely limit prey fish biomass to the low levels observed since 2009.

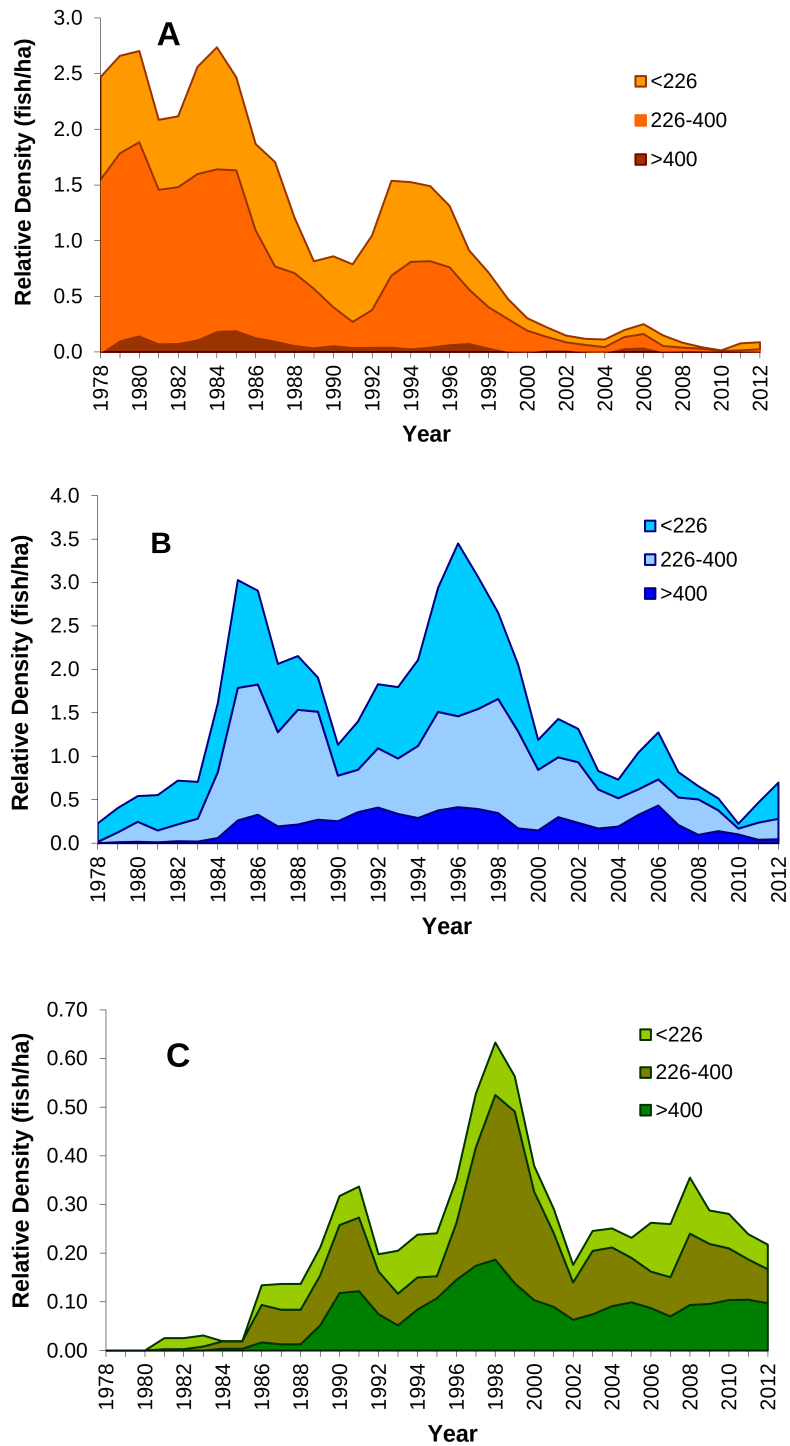


Figure 11. *Mean relative density (fish/ha) of age-1 and older lake trout for all nearshore sampling stations in Lake Superior, 1978-2012. Canadian waters were not sampled until 1989. Densities for hatchery and wild (lean) lake trout are 2-year running averages and densities for siscowet lake trout are 3-yr running averages. Densities are shown for three length bins: < 226 mm, 226-400 mm, and > 400 mm TL. (**A**) hatchery lake trout, (**B**) wild (lean) lake trout, (**C**) siscowet lake trout.*

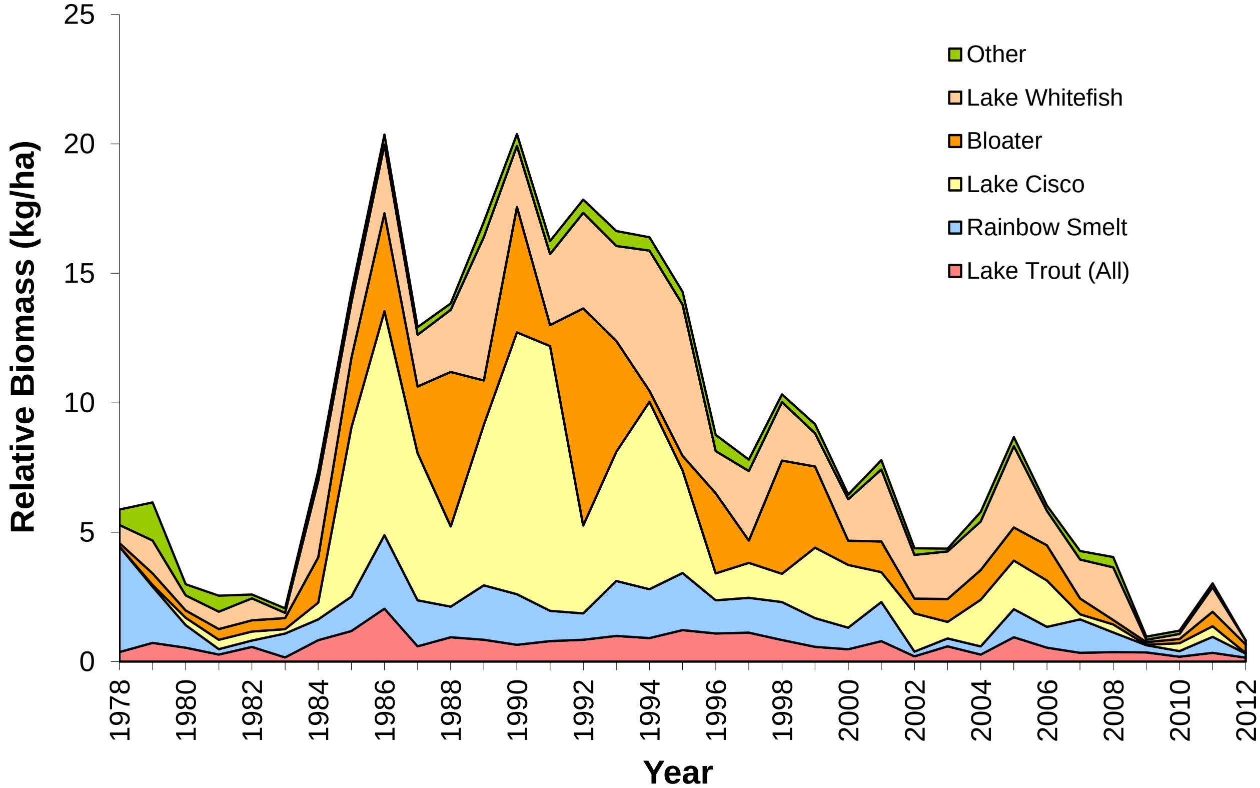


Figure 12. *Mean relative biomass (kg/ha) of the fish community caught in bottom trawls at all nearshore sampling stations in Lake Superior, 1978-2012. Canadian waters were not sampled until 1989.*

The decrease in total community biomass in 2012 was driven in large part to decreased biomass of rainbow smelt, cisco, bloater and lake whitefish, species which expressed biomass increases in 2010-2011 as a result of recruitment of weak to moderate 2009 year classes. Since the appearance of the 2009 year classes, cisco and bloater have not produced detectable year classes, and lake whitefish and rainbow smelt produced weak year classes in 2010 and 2011. Thus the 2012 survey results continue a trend of declining biomass since 2005 which was driven largely by declines in biomass of cisco, bloater, lake whitefish, and rainbow smelt. In 2012, principal species contributing to community biomass were: bloater (29%), rainbow smelt (14%), lake whitefish (13%), pygmy whitefish *Prosopium coulterii* (9%), shortjaw cisco (8%), siscowet lake trout (7%), lean lake trout (6%), and longnose sucker *Catostomus catostomus* (6%). Of the remaining 8%, cisco and burbot *Lota lota* each contributed 2% and the remaining eight species each contributed < 1% to the total community biomass: slimy, spoonhead, and deepwater sculpins, hatchery lake trout, trout-perch *Percopsis omiscomaycus*, ninespine stickleback, kiyi *C. kiyi*, and round whitefish *Prosopium cylindraceum*. The 2012 community contrasts with the long-term average community composition in which cisco represents the highest percentage of biomass for any species (28%), followed by bloater (19%), lake whitefish (23%), and rainbow smelt (13%).

Changes in estimated community biomass over the 35-year time series have been largely the result of changes in abundance of major prey species (Fig. 12). Rainbow smelt was the dominant prey fish prior to 1981 and afterwards dominance shifted to native prey species; cisco, bloater, and lake whitefish. Principal factors associated with changes in the community have been recovery of lake trout, increased mortality of rainbow smelt, sustained recruitment of lake whitefish, and variable recruitment of large year-classes of cisco and bloater (Bronte et al. 2003; Gorman and Hoff 2009; Gorman 2012). Annual variation in community biomass since 1984 has been driven largely by recruitment variation in cisco, bloater and lake whitefish. Recruitment of large year-classes of cisco in

1984, 1988-1990, and 1998 resulted in subsequent short-term increases in prey fish biomass detectable with bottom trawls (Fig. 12). Recruitment of the most recent large cisco year-class in 2003 yielded smaller and less sustained increases in biomass than previous large year-classes. Growth of cisco from the relatively weak 2009 year-class resulted in a slight increase in community biomass in 2011 but did not carry through to 2012. Since 2006, densities of adult cisco (≥ 4 yrs) in our spring bottom trawl samples declined to levels at or below those observed prior to recovery of cisco before 1984. Thus, weak recruitment of cisco has contributed considerably to the decline in prey fish biomass since the mid-1990s and especially after the mid-2000s (Fig. 12).

Recent declines in lake-wide biomass of cisco, bloater, and lake whitefish to levels near or below that observed prior to recovery of the Lake Superior fish community in the mid-1980s is consistent with a hypothesis of strong predation by recovered lake trout populations reducing prey fish populations, and in turn, resulting in food-limited lake trout populations. Total estimated community biomass reached the lowest levels in the time series in 2009 and 2012. The reduction of prey fish biomass, reduced frequency of large cisco and bloater year-classes, reduced mean sizes and younger age structure of rainbow smelt (Gorman 2007) all support the hypothesis that strong predation pressure by lake trout is resulting in a reduction of prey fish stocks (Negus et al. 2008).

Shortjaw cisco, a species of special concern in the U.S. and Canada (Gorman and Todd 2007), was ranked fifth by biomass in 2012. Some of the increase in relative importance of shortjaw cisco is due to the sharp decline in densities of cisco and bloater, however, absolute density of shortjaw cisco has increased in some regions of Lake Superior. A resurgence of shortjaw cisco since 2005 has been most evident in E. Ontario waters, where shortjaw cisco has always persisted (Gorman and Todd 2007) and in Wisconsin waters, primarily the Apostle Islands region, where a strong year-class recruited in 2003. Gorman (2012) predicted that under sustained predation pressure from recovered lake trout populations, shortjaw cisco would likely become a dominant deepwater cisco because its larger size compared to bloater affords greater protection from predation by lake trout. Thus, the recent increases in abundance of shortjaw cisco relative to bloater may be indicative that lake trout are exerting strong predation pressure on other deepwater ciscoes in Lake Superior.

Although the abundance of small and intermediate-size lean (wild) lake trout increased in 2012 over the record low levels in 2010, they remained well below levels observed before 2007 and at levels comparable to those observed before 1984, a period when wild lake trout populations were recovering (Hansen et al. 1995). The decline in abundance of small and intermediate lake trout after 2000 suggests that cannibalism of younger life stages by adult lake trout may be contributing to declining recruitment. Declines in lean lake trout lipid content reported by Paterson et al. (2009) are also consistent with declines in prey fish biomass and resulting reduced food availability in Lake Superior. Although the decline in abundance of lean lake trout we observed in our bottom trawl series since the late 1990s is consistent with a reduced prey base (this report) and slower growth (Sitar and He 2006), others have not detected a similar decline in abundance of lean lake trout based on the results of gill net surveys conducted during 2000-2005 (Sitar et al. 2010). In the future, prey fish biomass is likely to fluctuate as a result of recruitment variation. However, if lean and siscowet lake trout populations in nearshore waters continue to remain at current levels, strong predation pressure will likely dampen those fluctuations and maintain the relatively low prey fish biomass observed in recent years. Alternatively, if lake trout populations show a substantial decline in abundance in upcoming years, prey fish populations may rebound in a fashion reminiscent to what occurred in the late 1970s to mid-1980s. However, this scenario depends on substantial increases in harvest of lake trout, which seems unlikely given that levels of lake trout harvest have been flat or declining in many regions of Lake Superior since 2000 (Sitar et al. 2010).

II. Status and trends in the offshore fish community of Lake Superior

In 2011, the Great Lakes Science Center's Lake Superior Biological Station established an annual daytime bottom trawl survey of the offshore waters of Lake Superior. Offshore waters (>80 m deep) make up about 77% of the lake area. The survey is intended to provide annual data for assessing long-term trends in relative biomass and density of the offshore fish community. Sampling is targeted to occur during the thermally stratified summer season. Sites were selected using a spatially-balanced, depth-weighted probabilistic sampling design (Fig. 1).

Methods

In 2012, sampling was conducted between 9 and 26 August. A single daytime bottom trawl was made at each site using a 12-m Yankee bottom trawl towed on-contour. Mean station sampling depths ranged from 89 to 311 m and the mean depth range for individual trawl tows was 6.1 m (range = 0 – 16 m). The average trawl distance was 0.9 km (range = 0.7 – 1.0 km). All fish captured were sorted to species, counted, measured to the nearest mm, and weighed in aggregate to the nearest gram. Relative density (fish/ha) and biomass (kg/ha) was estimated by dividing numbers and biomass caught by the area sampled. Area sampled was the product of average trawl wingspread and the distance the trawl was fished.

Results

In 2012, sampling at 34 locations yielded 19,912 individuals of 13 species. Collectively, deepwater sculpin, kiyi, and siscowet lake trout, represented 98% of the fish caught in terms of both density and biomass (Table 1). These results were similar to that observed in 2011 for the number of species, and both density and biomass for most species. In 2011, a total of 13 species and 15,365 individuals were collected. Lake-wide mean density and biomass estimates differed only slightly between years. Mean lake-wide density across all sites was 553.3 fish per ha in 2012 and 428.1 fish per ha in 2011. Mean lakewide biomass across all sites was 6.9 kg per ha in 2012 and 9.0 kg per hectare in 2011. Differences between years were due to more deepwater sculpin being collected in 2012 which increased mean density and fewer siscowet, kiyi, and pygmy whitefish being collected in 2012, which decreased mean biomass compared to that observed 2011.

Table 1. *The number of locations, number of individuals, mean density (number per hectare), and mean biomass (kg per hectare) of fish collected in the Lake Superior offshore survey in 2011 and 2012. The number of sites sampled was 34 in both years. In 2012, sites were sampled between 9 and 26 August. In 2011 sites were sampled between 24 June and 26 July.*

	Sites collected at		Individuals collected		Mean density		Mean biomass	
Fish	2011	2012	2011	2012	2011	2012	2011	2012
Deepwater sculpin	31	32	12066	18206	336.8	506.8	2.1	2.9
Kiyi	26	29	1860	1307	9.1	4.8	3.8	2.1
Siscowet lake trout	31	31	329	176	52.0	35.9	1.9	1.7
Slimy sculpin	12	7	40	122	1.1	3.4	0.0	0.0
Pygmy whitefish	9	4	293	48	18.5	0.2	1.1	0.0
Shortjaw cisco	8	4	44	14	8.4	1.2	0.0	0.0
Spoonhead sculpin	6	9	6	13	1.2	0.4	0.1	0.0
Rainbow smelt	5	2	12	7	0.4	0.0	0.0	0.0
Lean lake trout	0	2	0	7	0.2	0.4	0.0	0.0
Bloater	9	6	693	6	0.3	0.2	0.0	0.0
Burbot	4	3	4	3	0.1	0.1	0.0	0.0
Cisco	3	1	3	1	0.1	0.0	0.0	0.0
Ninespine stickleback	7	0	14	0	0.0	0.1	0.0	0.1
Lake whitefish	1	1	1	0	0.0	0.2	0.0	0.0
Total			15365	19912	428.1	553.3	9.0	6.9

Patterns in distribution in biomass by depth were evident for most species and were consistent between years (Fig. 13). Deepwater sculpin biomass generally increased linearly with depth throughout the range of depths sampled. Kiyi biomass had a distinct peak at 180 m. Siscowet biomass was more variable, with similar biomass peaks occurring between about 100 and 200 m. Siscowet and kiyi biomass declined at depths >200 m, whereas deepwater sculpin biomass remained high out to the deepest depths sampled.

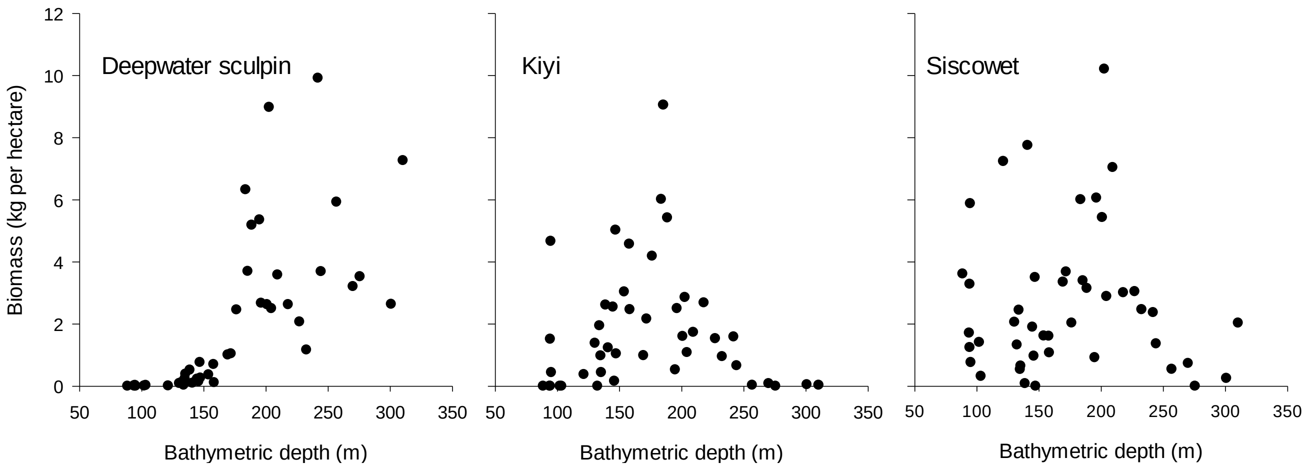


Figure 13. *Bathymetric variation in biomass (kg per hectare) for deepwater sculpin, kiyi, and siscowet for all sites sampled in 2011 and 2012.*

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