Lake Superior Committee
20 March 2012

Status and Trends of the Nearshore Fish Community of Lake Superior, 2011[1]

Owen T. Gorman, Lori M. Evrard, Gary A. Cholwek, Daniel L. Yule and Mark R. Vinson

U.S. Geological Survey
Great Lakes Science Center
Lake Superior Biological Station
2800 Lakeshore Drive East
Ashland, Wisconsin 54806

Abstract

The Great Lakes Science Center has conducted daytime nearshore bottom trawl surveys of Lake Superior (15-80 m bathymetric depth zone) each spring since 1978 to provide long-term trends of relative abundance and biomass of the fish community. Between 19 May and 20 June 2011, 82 stations distributed around the perimeter of the lake were sampled with a 12-m Yankee bottom trawl towed cross-contour. The 2011 estimate of fish community biomass was 3.63 kg/ha, seventh lowest in the 34-year survey history, but up from 1.37 kg/ha observed in the 2010 survey. The distribution of biomass across jurisdictions was uneven; mean biomass in Canada East, Canada West, Michigan, Minnesota and Wisconsin waters were 2.23, 3.64, 2.07, 0.01, and 7.73 kg/ha, respectively. Dominant species in the catch, in order of relative biomass, were lake whitefish, rainbow smelt, bloater, cisco, and longnose sucker. Compared to 2010 levels, biomass of cisco, bloater, shortjaw cisco, lake whitefish, rainbow smelt, and lean and siscowet lake trout increased. Year-class strengths for the 2010 cisco and bloater cohorts were well below average and ranked as the ninth and twelfth weakest year-classes, respectively, in the past 34 years. The 2011 cisco age structure was dominated by age-2 fish (2009 year-class), which accounted for 91% of the ciscoes captured. Remaining ciscoes captured were composed mostly of adults from the 2005, 2003 and 1998 year-classes. Year-class strength of rainbow smelt was the fifth weakest in the survey record, continuing a decline that began in 2008.

As in 2010, densities of small, intermediate and large hatchery lake trout remained near zero in 2011. Densities of small and intermediate wild (lean) lake trout increased in 2011 while density of large wild lake trout decreased. Density of all sizes of siscowet lake trout declined in 2011. Proportions of total lake trout density in 2011 that were hatchery, wild, and siscowet were 2, 66, and 32%, respectively.

Declines in prey fish biomass since the late 1990s can be attributed to predation by recovered lake trout populations. In turn, recent declines in lake trout biomass 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 is unlikely given present management strategies.

---

[1]Presented to: Great Lakes Fishery Commission, Lake Superior Committee Meeting, Windsor, Ontario, 20 March 2012

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. In 2011, 82 sites were included in the annual survey.

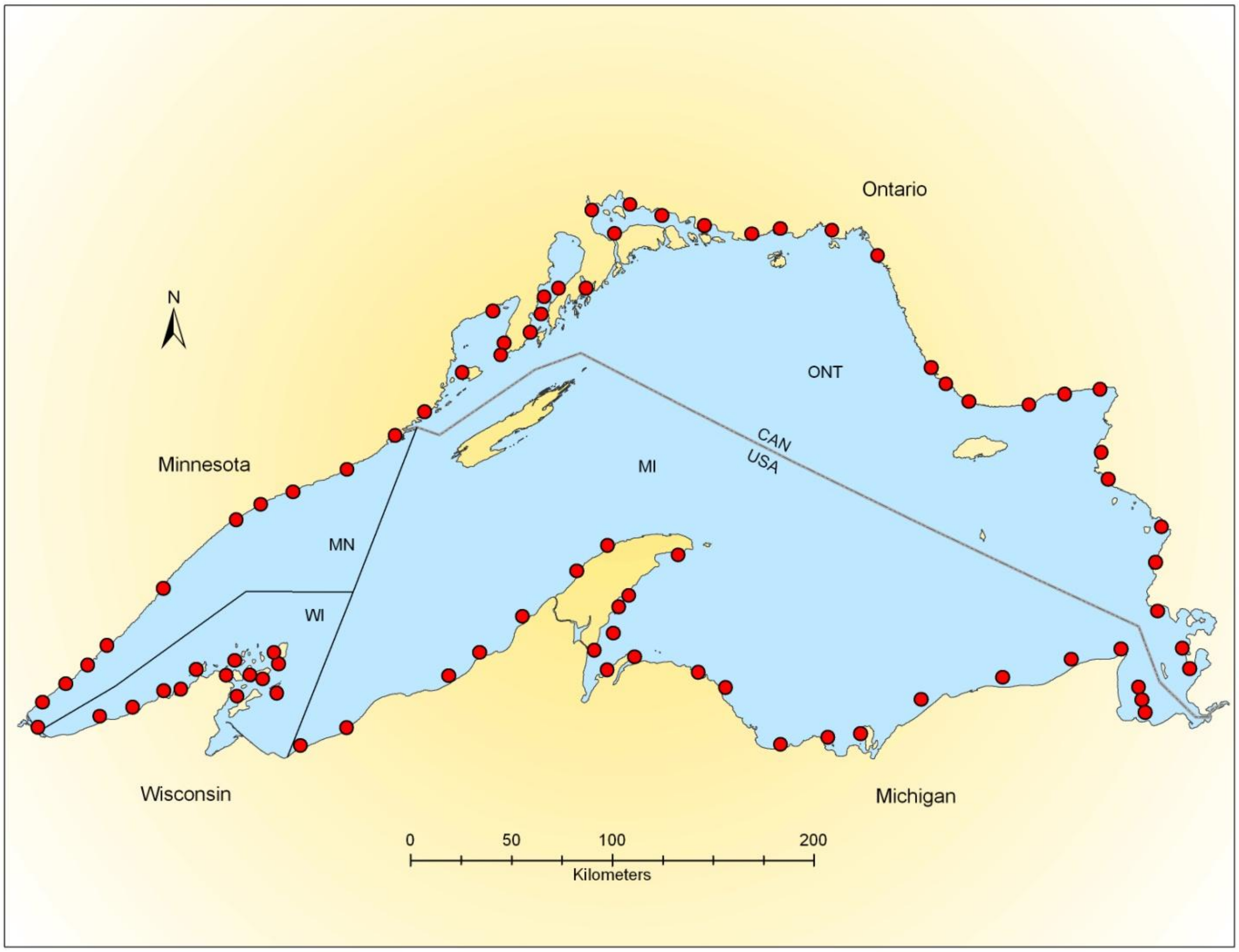

Figure 1. *Locations of 82 stations (red dots) sampled during the 2011 annual spring bottom trawl survey of Lake Superior.*

Methods

Spring Survey

A total of 82 of the 86 long-term sites distributed around the perimeter of Lake Superior were sampled with bottom trawls during daylight hours between 19 May and 20 June 2011 (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 17 m (range 10-28 m, interquartile range 15-21 m) and 54 m (range 19-144 m, interquartile range 44-73 m), respectively. Median trawl tow duration was 23 minutes (range 7-57 minutes, interquartile range 14-34 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).

To estimate the age structure of Lake Superior cisco in 2011, we applied a statistical age key based on age data derived from scales and otoliths collected in 2000-2006, similar to the approach used by Gorman (2007) for rainbow smelt and Gorman et al. (2008) for cisco. Because scales become less reliable for age determination as coregonids mature (Aass 1972; Mills and Beamish 1980; Yule et al. 2008), we used scales for aging fish < 250 mm and otoliths for aging fish ≥ 250 mm. Age estimates from otoliths were acquired by the crack and burn method (Schreiner and Schram 2001). Using this 2000-2006 age data, we generated size-at-age distributions for age classes 1 to 9 and ≥ 10 years. 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 2011 length-frequency distribution to estimate size-age specific density distributions.

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), we summarized our lake trout data 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 2010 cisco cohort was estimated at 0.30 fish/ha, the ninth weakest year-class observed over the 34-year survey (Fig. 2A). The 2010 cohort was 0.4% of the 34-year survey mean density of 67.41 fish/ha, and 10.0% of the survey median density of 3.07 fish/ha. Year-class strength for the 2010 cohort in U.S. waters was 0.12 fish/ha and 0.58 fish/ha in Canadian waters. RSE estimated for the 2010 year-class was 38%, which is lower than the series average of 49% (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.

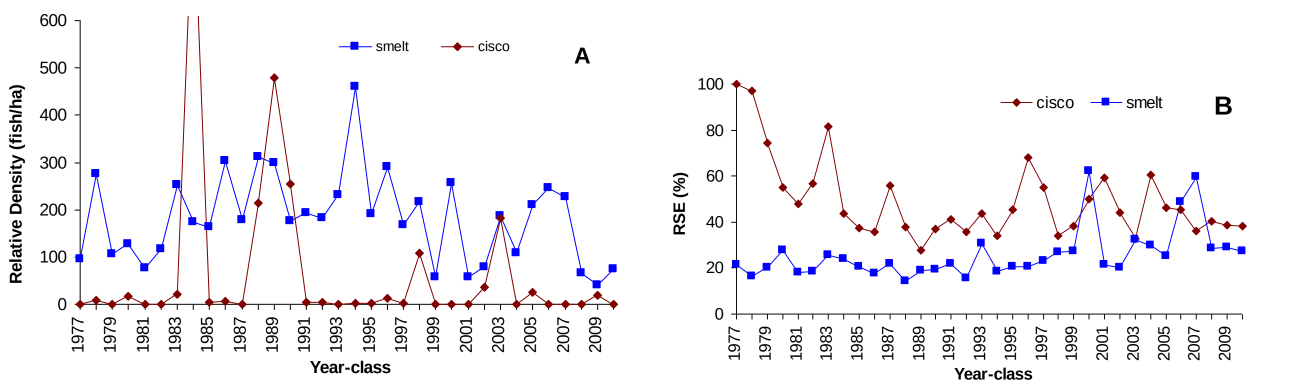

Figure 2. ***(A)*** *Year-class strength (number of age-1 fish/ha) for cisco and rainbow smelt for all nearshore sampling stations in Lake Superior for cohorts produced from 1977 to 2010. Only U.S. waters were sampled for the 1977-1988 year-classes. Off-chart value for age-1 cisco density in 1984 was 885.62 fish/ha.* ***(B)*** *RSE (relative standard error) of year-class strengths.*

Mean relative biomass of age-1 and older cisco increased from 0.30 kg/ha in 2010 to 0.41 kg/ha in 2011 due largely to growth of the small 2009 year-class, which dominated the catch in 2011 (Figs. 3A, 5). The small increase in biomass resulted in the highest level since 2007 but did not reverse the recent trend of low population biomass after 2004-2006, when biomass averaged ≈ 1.80 kg/ha and was well below the long-term 1978-2006 average of 2.90 kg/ha. The RSE of age-1 and older cisco estimated biomass was 40% in 2011, which was lower than the survey average of 44% (Fig. 3B).

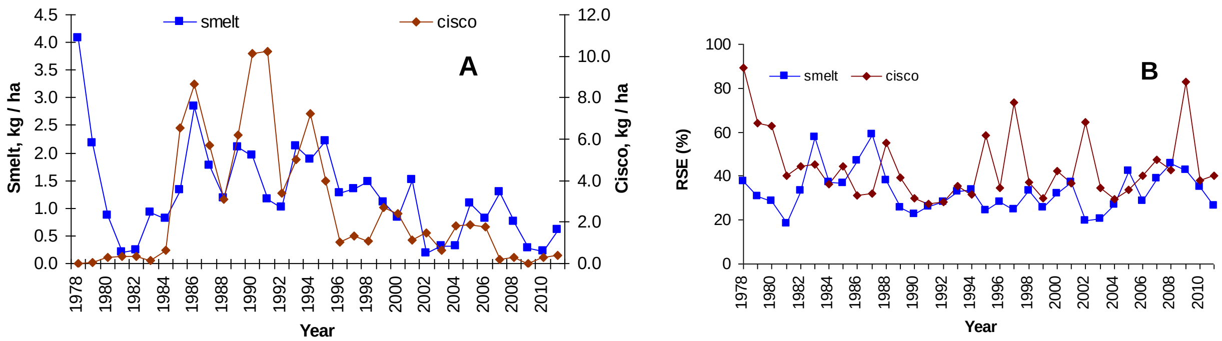

Figure 3. ***(A)*** *Mean relative biomass (kg/ha) of age-1 and older cisco and rainbow smelt for all nearshore sampling stations in Lake Superior, 1978-2011. Canadian waters were not sampled until 1989.* ***(B)*** *RSE (relative standard error) of mean biomass.*

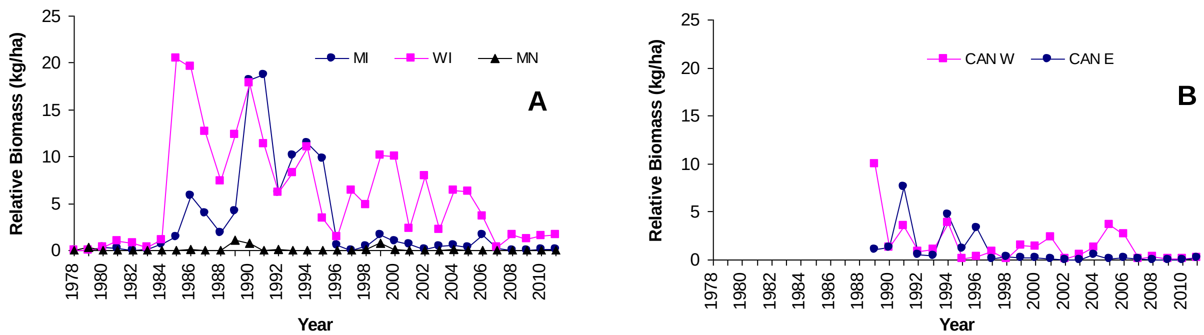

Figure 4. *Mean relative biomass (kg/ha) of age-1 and older cisco in nearshore waters of Lake Superior: (**A**) Michigan (MI), Wisconsin (WI), and Minnesota (MN), 1978-2011. (**B**) eastern and western Ontario, 1989-2011. Eastern and Western Ontario waters are divided in the northeast corner of Lake Superior near Marathon, Ontario.*

The level of cisco biomass in Wisconsin waters was sustained by growth of a moderate 2009 cohort present there (Fig. 4A). The weak showing of the 2009 cohort in Michigan, Minnesota and Ontario waters contributed to a continuation of low biomass in those jurisdictions (Fig 4). The 2011 relative biomass estimates as a percent of long-term means was low in Wisconsin (28%) and E. Ontario (23%), very low in W. Ontario (11%) and Michigan (5%), and extremely low in Minnesota (0%). This pattern is consistent with low cisco recruitment since 2003.

The 2011 cisco age structure was dominated by the 2009 year-class and accounted for 91% of the mean relative density (Fig. 5) and the remaining 9% were adults age 3 and older. The moderate-to-large 2003 and 2005 cohorts accounted for 57% and 23% of the mean relative density, respectively, of adult cisco age 5 and older.

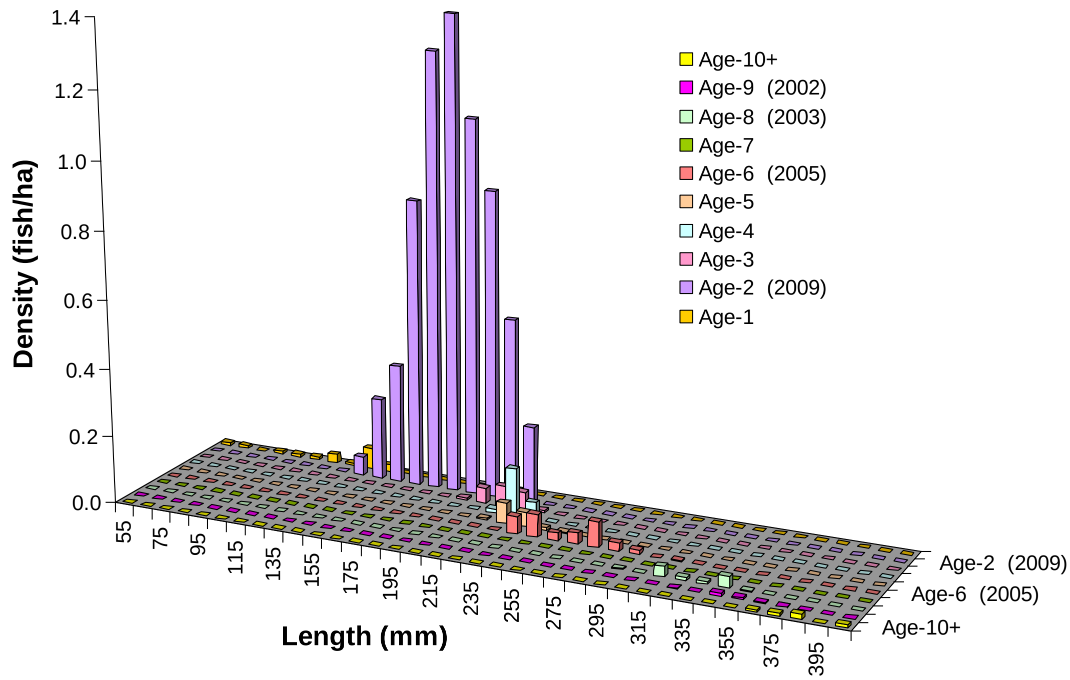

Figure 5. *Estimated age-length distribution of cisco in Lake Superior in 2011. Year labels attached to age classes represent notable year-classes; 2003, 2005 (strong), 2002 (moderate), 2009 (weak).*

Rainbow Smelt

Rainbow smelt year-class strength increased from a record low 41.03 fish/ha for the 2009 cohort to 73.98 fish/ha for the 2010 cohort. This modest increase continues a trend of weak year-classes following the last peak of 246.58 fish/ha for the 2006 cohort (Fig. 2A). The 2010 cohort was 40.6% of the 34-year survey mean density of 182.01 fish/ha, and 41.1% of the survey median density of 180.11 fish/ha. RSE was relatively low (27.2%, Fig. 2B) and similar to the 34-yr average (25.7%), due to a pattern of low catches across most jurisdictions. The 2010 year-class was stronger in Canadian waters (139.89 fish/ha) compared to U.S. waters (31.80 fish/ha).

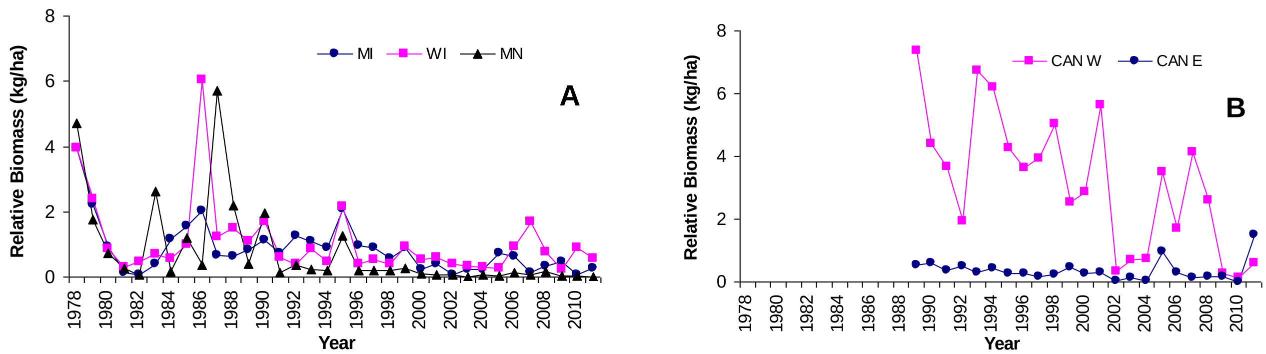

Figure 6. *Mean relative biomass (kg/ha) of age-1 and older rainbow smelt in nearshore waters of Lake Superior: (**A**) Michigan, Wisconsin, and Minnesota, 1978-2011. (**B**) Eastern and Western Ontario, 1989-2011.*

Mean relative biomass for age-1 and older rainbow smelt was 0.62 kg/ha, continuing a declining trend following the most recent maximum of 1.29 kg/ha in 2007 (Fig. 3A). The 2011 biomass estimate was 50% and 41% of the 34-year mean of 1.24 kg/ha. RSE of the 2011 biomass estimate was 26.5%, which is lower than the 34-year survey mean of 33.3% (Fig. 3B). Compared to 2010, estimated biomass of rainbow smelt in 2011 declined in Wisconsin and Minnesota waters but increased in Michigan and Ontario waters (Fig. 6). In E. Ontario waters, the relative biomass estimate was more than four times the long-term average. Relative biomass in all other jurisdictions was lower than the long-term average: 53%, 30%, 19%, and < 1% in Wisconsin, Michigan, W. Ontario, and Minnesota waters, respectively.

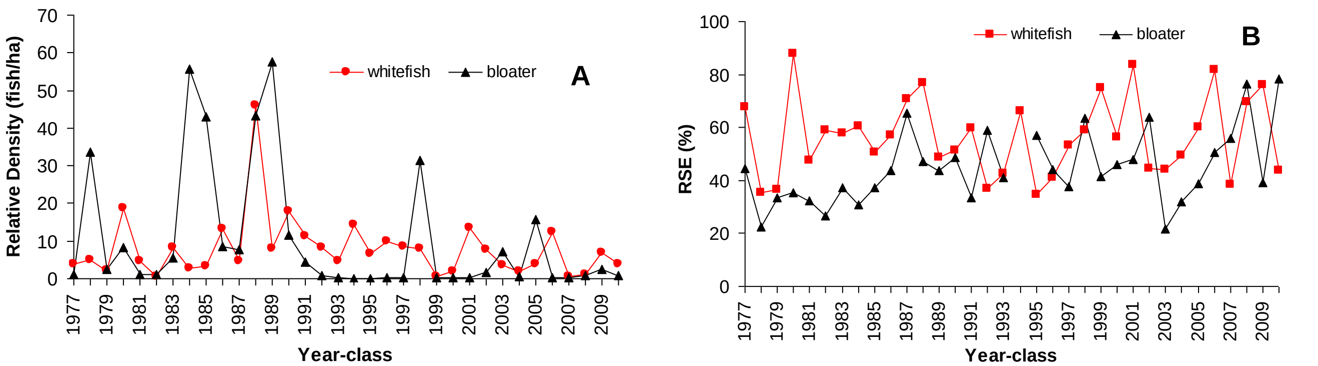

Figure 7. ***(A)*** *Year-class strength (number of age-1 fish/ha) for bloater and lake whitefish for all nearshore sampling stations in Lake Superior for cohorts produced from 1977 to 2010. Only U.S. waters were sampled for the 1977-1988 year-classes.* ***(B)*** *RSE (relative standard error) of year-class strengths.*

Bloater

The 2010 bloater year-class strength (Fig. 7A) was weak (0.75 fish/ha), weaker than the 2009 year-class (2.45 fish/ha), and well below the 34-year average and median densities of 10.24 and 1.43 fish/ha, respectively. Year-class strength was greater in Canadian waters (1.51 fish/ha) compared to U.S. waters (0.26 fish/ha). RSE of bloater yearling density was 78%, well above the 34-year survey average of 45% (Fig. 7B).

Mean relative lake-wide biomass of age-1 and older bloater increased modestly from 0.19 kg/ha in 2010 to 0.56 kg/ha in 2011, but the overall trend has been low since 2006 when lake-wide biomass was 1.36 kg/ha (Fig. 8A). The modest increase in biomass in 2011 follows the two lowest biomass estimates in the 34-year survey in 2009 and 2010 . RSE for the 2011 biomass estimate was 46%, which is within the 34-year survey range of 32-64% (Fig. 8B).

In 2011, bloater biomass increased to 90% of the long-term average in Wisconsin waters but remained well below long-term averages in all other jurisdictions: 18% in Michigan, 0% in Minnesota, 23% in W. Ontario, and 5% in E. Ontario waters (Fig. 9).

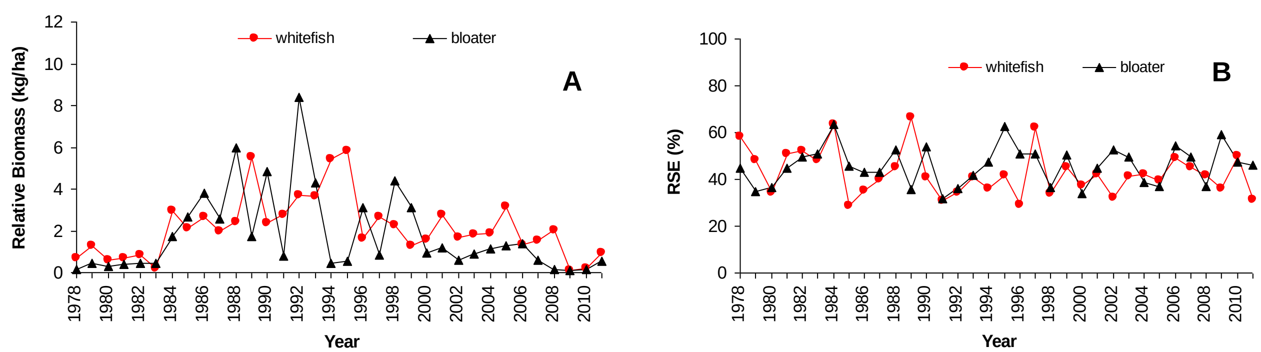

Figure 8. ***(A)*** *Mean relative biomass (kg/ha) of age-1 and older bloater and lake whitefish for all nearshore sampling stations in Lake Superior, 1978-2011. Canadian waters were not sampled until 1989.* ***(B)*** *RSE (relative standard error) of mean biomass.*

Lake Whitefish

Lake whitefish year-class strength decreased from 6.89 fish/ha for the 2009 cohort to 3.98 fish/ha for the 2010 cohort (Fig. 7A). For comparison, the average and median lake-wide year-class strengths for the 34-year survey period were 7.89 and 5.85 fish/ha, respectively. RSE for lake whitefish year-class strength was 44%, which is within the 34-year survey range of 35-88% (Fig. 7B). The 2010 year-class was stronger in U.S. (4.33 fish/ha) than in Canadian waters (3.42 fish/ha).

Mean relative biomass for age-1 and older lake whitefish in all waters increased from 0.19 kg/ha in 2010 to 0.94 kg/ha in 2011 (Fig. 8A). Although the increase reverses a decline from survey record lows in 2009 and 2010, the 2011 biomass levels are well below the recent peak of 2.04 kg/ha in 2008 and the long-term average of 2.14 kg/ha (Fig. 8A). RSE for 2011 was 31%, which is at the low end of 33-year survey range of 29-66% (Fig. 8B).

Whitefish biomass estimates increased across all U.S. and Canadian jurisdictions with the exception of Minnesota where biomass estimates remained at zero (Fig. 10). In Michigan waters, the 2011 biomass estimate (0.88 kg/ha) exceeded the long-term average (0.80 kg/ha). In all other jurisdictions, the 2011 biomass estimates were a fraction of the long-term averages: 32% in Wisconsin, 0% in Minnesota, 48 % in W. Ontario, and 35% in E. Ontario waters.

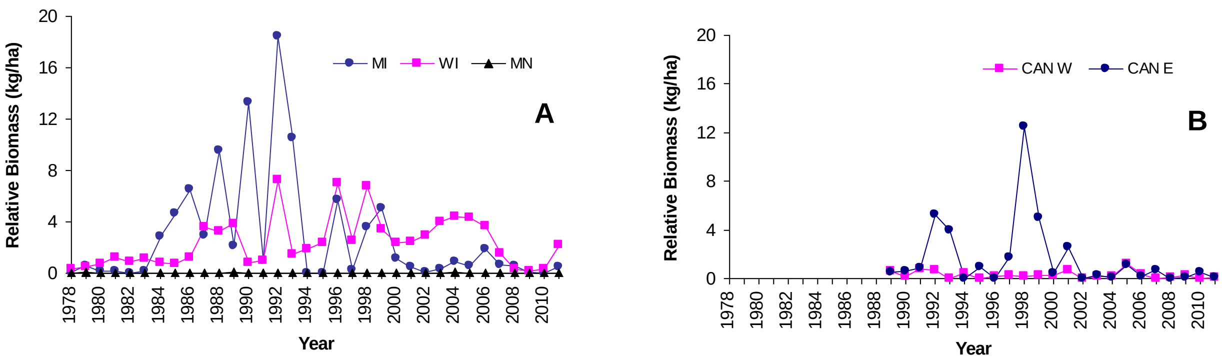

Figure 9. *Mean relative biomass (kg/ha) of age-1 and older bloater in nearshore waters of Lake Superior: (**A**) Michigan, Wisconsin, and Minnesota, 1978-2011. (**B**) Eastern and Western Ontario, 1989-2011.*

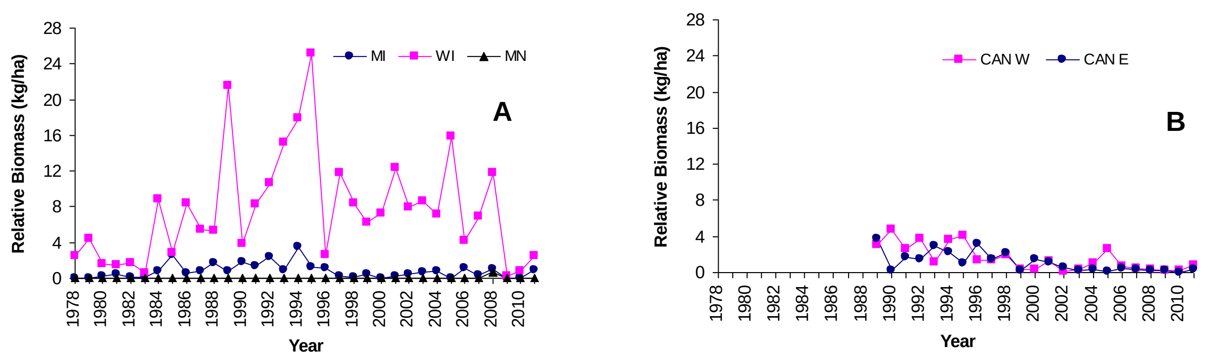

Figure 10. *Mean relative biomass (kg/ha) of age-1 and older lake whitefish in nearshore waters of Lake Superior: (**A**) Michigan, Wisconsin, and Minnesota, 1978-2011. (**B**) Eastern and Western Ontario, 1989-2011.*

Other Species

Ninespine stickleback – The lake-wide estimate of mean relative biomass for ninespine stickleback *Pungitius pungitius* remained low, increasing from 0.01 kg/ha in 2010 and to 0.02 kg/ha in 2011 (Fig. 11A). The low 2011 estimate continues a trend of declining biomass since the late 1990s; biomass averaged 0.04 kg/ha for 2000-2011 compared to 0.14 kg/ha for 1978-1999 (Fig. 11A).

Sculpins – Mean relative biomass for all three sculpin species combined (spoonhead *Cottus ricei*, slimy *C. cognatus*, and deepwater *Myoxocephalus thompsonii*) decreased slightly in 2011, down to 0.05 kg/ha from 0.07

kg/ha in 2010 (Fig. 11A). The 2011 decrease was caused by a 51% decline in abundance of slimy sculpin, which represented 50% of sculpin biomass. Deepwater sculpins represented 22% and spoonhead sculpins represented 28% of the estimated biomass. The dominance of slimy sculpins in 2010 and 2011 reverses the dominance of deepwater sculpins that occurred in 2006-2009. Prior to 2006, slimy sculpins were the dominant species in the group, 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 2002-2011 (48%).

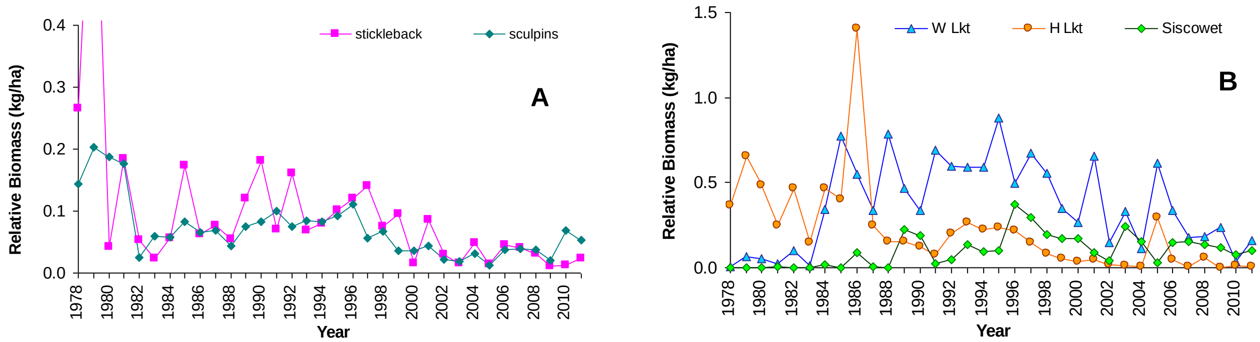

Figure 11. *Mean relative biomass (kg/ha) of age-1 and older (**A**) ninespine stickleback and sculpins (slimy, spoonhead, and deepwater combined), and (**B**) lake trout (wild-lean, hatchery, and siscowet) for all nearshore sampling stations in Lake Superior, 1978-2011. Lake trout data are not smoothed as in Fig. 12. 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 2011 remained unchanged from 2010 (0.01 kg/ha), slightly above the near-zero record observed in 2009 (Fig. 11B). Between 2010 and 2011, biomass of wild (lean) lake trout increased from 0.04 to 0.16 kg/ha (Fig. 11B). Biomass of siscowet lake trout increased slightly in 2011, up from 0.08 kg/ha in 2010 to 0.10 kg/ha, punctuating a declining trend beginning in 2007 (Fig. 11B).

Densities of small, intermediate and large hatchery lake trout in Lake Superior remained at near zero between 2010 and 2011 (Fig. 12A), 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 2011, densities of small and intermediate wild (lean) lake trout increased from 0.05 and 0.07 fish/ha, to 0.22 and 0.15 fish/ha, respectively (Fig. 12B). Density of large wild lake trout decreased from 0.10 fish/ha in 2010 to 0.04 fish/ha in 2011. The overall small increase in wild lake trout density punctuated a declining trend that started in 1996-1998 (Fig. 12B). Between 2010 and 2011, density of small and intermediate siscowet lake trout declined from 0.07 and 0.11 fish/ha to 0.04 and 0.07 fish/ha, respectively (Fig. 12C). Density of large siscowet declined slightly, from 0.10 fish/ha in 2010 to 0.09 fish/ha in 2011. 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. 12C). In 2011, the proportions of total lake trout density that were hatchery, wild, and siscowet were 2, 66, and 32%, respectively.

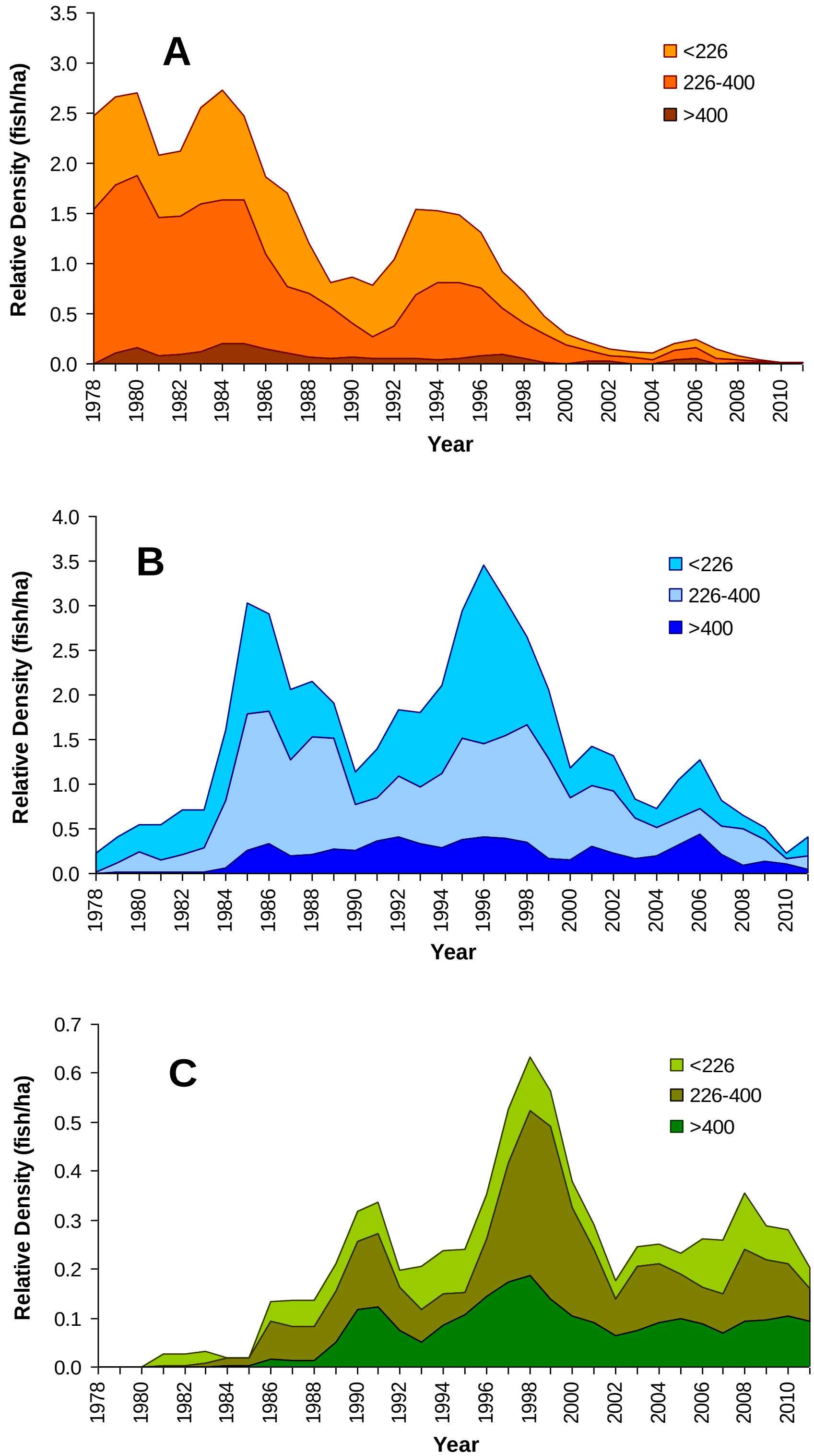

Figure 12. *Mean relative density (fish/ha) of age-1 and older lake trout for all nearshore sampling stations in Lake Superior, 1978-2011. Canadian waters were not sampled until 1989. Densities for hatchery and wild (lean) lake trout are 2-year running averages and densities for siscowet lake trout are 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.*

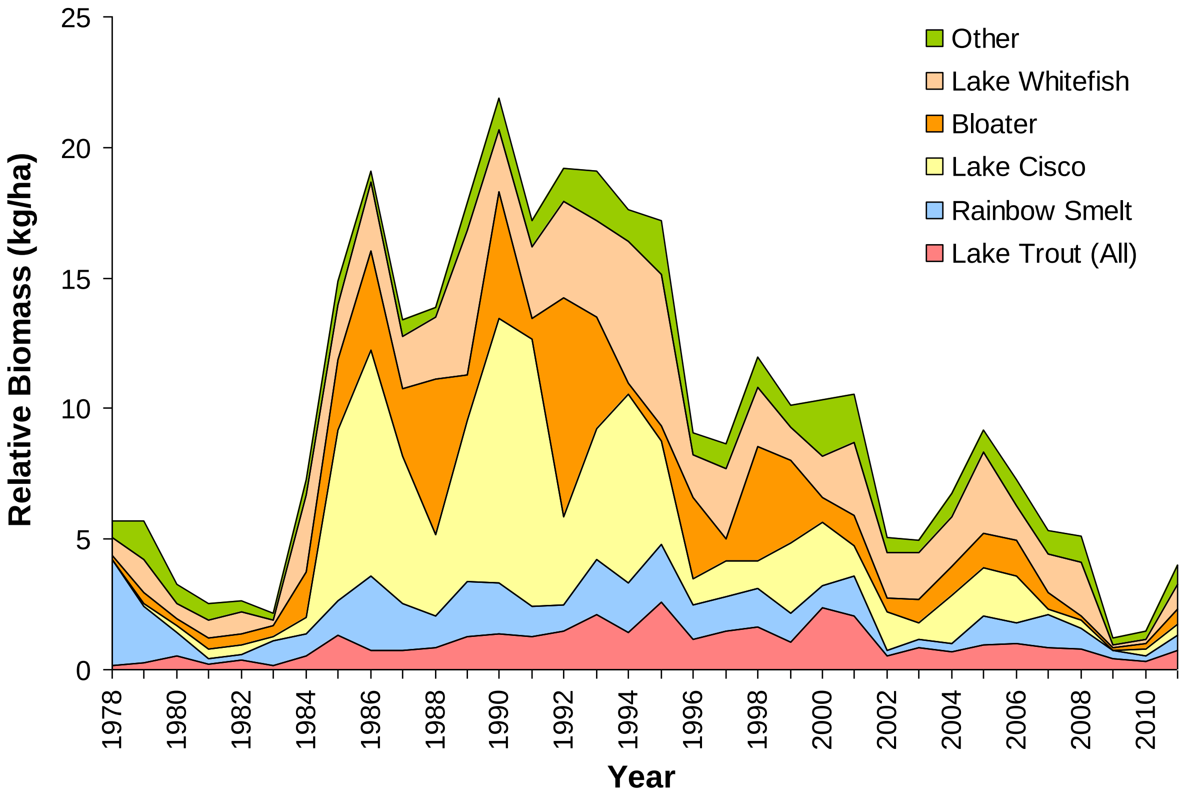

Figure 13. *Mean relative biomass (kg/ha) of the fish community caught in bottom trawls at all nearshore sampling stations in Lake Superior, 1978-2011. Canadian waters were not sampled until 1989.*

Summary and Discussion

Estimated mean biomass of all fish species caught during the spring bottom trawl survey increased 2.65-fold from 1.37 kg/ha in 2010 to 3.63 kg/ha in 2011, but was 62% lower than long-term average of 9.44 kg/ha (Fig. 13). The increased 2011 biomass estimate was not affected by the larger number of trawl samples; when the 82 stations sampled in 2011 were limited to the 62 locations sampled in 2010 and the data weighted as described in Stockwell et al. (2006), the estimated lake-wide community biomass changed by < 0.3%. The increase in total community biomass in 2011 was due in large part to increased biomass of rainbow smelt, bloater and lake whitefish. Recent declines in biomass since 2005 has been due largely to declines in estimated biomass of cisco, bloater, lake whitefish, and rainbow smelt. In 2011, principal species contributing to community biomass were: lake whitefish (26%), rainbow smelt (17%), bloater (16%), cisco (11%), longnose sucker *Catostomus catostomus* (9%), lean lake trout (5%), siscowet lake trout (5%), shortjaw cisco *C. zenithicus* (4%), and pygmy whitefish *Prosopium coulterii* (3%). The remaining 4% was composed of species that each contributed ≤ 1% to the total community biomass: slimy, spoonhead, and deepwater sculpin, hatchery lake trout, trout-perch *Percopsis omiscomaycus*, ninespine stickleback, kiyi *C. kiyi*, burbot *Lota lota*, and round whitefish *Prosopium cylindraceum*. Principal prey species (cisco, lake whitefish, bloater, rainbow smelt) represented 55% of the total community biomass in 2011. This structure 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%), rainbow smelt (13%), and together represent 83% of the total community biomass. Resumption of a full complement of trawl stations had a relatively small effect on estimated biomass and densities.

Changes in estimated community biomass over the 34-year time series have been largely the result of changes in abundance of major prey species (Fig. 13). 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 (Fig. 13). 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. Unlike previous strong year-classes of cisco that showed lake-wide synchrony, the 2009 year-class was limited largely to Wisconsin waters. In 2011, these age-2 cisco represented 72% of total cisco biomass. Since 2006, densities of adult cisco (≥ 4 yrs) in our spring bottom trawl samples have declined to levels at or below those observed prior to recovery of cisco before 1984.

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 2010, but in 2011 increased to levels similar to that observed just prior to the strong recovery of lake trout in the mid-1980s. The reduction of prey fish biomass, reduced frequency of large cisco 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 eighth by biomass in 2011. The 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 are likely to become the predominant deepwater cisco because its larger size compared to bloater provides 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 2011 over the record low levels in 2010, they remained well below levels observed before 2008 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 (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, predation mortality 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 will likely rebound and this may lead to a community response similar to what occurred in the late 1970s to mid-1980s, however, this scenario is unlikely given present management strategies.

Acknowledgments

Charles Madenjian and Donald Schreiner provided many useful comments for revising this report. Northland College students Zachariah and Zebediah Woiak and Justin Hughes provided field assistance. Laura Graf provided editorial and field assistance. The annual spring bottom trawl survey of Lake Superior is supported by funds from the U.S. Geological Survey.

References

Aass, P. 1972. Age determination and year-class fluctuation of cisco, *Coregonus albula* L., in the Mjøsa hydroelectric reservoir, Norway. Report – Institute of Fresh-water Research. Drottningholm 52:5-22.

Bronte, C.R., M. Ebener, D.R. Schreiner, D.S. DeVault, M.M. Petzold, D.A. Jensen, C. Richards, and S.J. Lozano. 2003. Fish community change in Lake Superior, 1970-2000. Canadian Journal of Fisheries and Aquatic Sciences. 60: 1552-1574.

Gorman, O.T. 2007. Changes in a population of exotic rainbow smelt in Lake Superior: boom to bust, 1974-2005. Journal of Great Lakes Research 33 (Supplement 1):75-90.

Gorman, O.T. 2012. Successional change in the Lake Superior fish community: population trends in ciscoes, rainbow smelt, and lake trout, 1958-2008. Archive für Hydrobiologie, Advances in Limnology 64: *in press*.

Gorman, O.T., and T.N. Todd. 2007. History of the shortjaw cisco (*Coregonus zenithicus*) in Lake Superior, 1895-2003. Archive für Hydrobiologie, Advances in Limnology 60:433-458.

Gorman, O.T., and M.H. Hoff. 2009. Changes in the Lake Superior fish community during 1978-2003: chronicling the recovery of a native fauna. *In* M. Munawar and I.F. Munawar (Eds.), State of Lake Superior, Aquatic Ecosystem Health and Management Society, Canada. pp. 493-532.

Gorman, O.T., L.M. Evrard, G.A. Cholwek, D.L. Yule, and J.D. Stockwell. 2008. Status and Trends of Prey Fish Populations in Lake Superior, 2007. Report to the Lake Superior Committee, Great Lakes Fishery Commission, 19 March 2008, Niagara Falls, Ontario. U.S. Geological Survey, Great Lakes Science Center, Ann Arbor, Michigan. Available online: http://www.glsc.usgs.gov/_files/reports/2007LakeSuperiorPreyfishReport.pdf

Gorman, O.T., L.M. Evrard, G.A. Cholwek, J.M. Falck, and D.L. Yule. 2009. Status and Trends of Prey Fish Populations in Lake Superior, 2008. Report to the Lake Superior Committee, Great Lakes Fishery Commission, 25 March 2009, Ypsilanti, Michigan. U.S. Geological Survey, Great Lakes Science Center, Ann Arbor, Michigan. Available online: http://www.glsc.usgs.gov/_files/reports/2008LakeSuperiorPreyfish.pdf

Gorman, O.T., L.M. Evrard, G.A. Cholwek, J.M. Falck, and M.R. Vinson. 2010. Status and Trends of Prey Fish Populations in Lake Superior, 2009. Report to the Lake Superior Committee, Great Lakes Fishery Commission, 23 March 2010, Windsor, Canada. U.S. Geological Survey, Great Lakes Science Center, Ann Arbor, Michigan. 11p. Available online: http://www.glsc.usgs.gov/_files/reports/2009LakeSuperiorPreyfish.pdf

Gorman, O.T, L.M. Evrard, G.A. Cholwek, D.L. Yule, and M.R. Vinson. 2011. Status and Trends of Prey Fish Populations in Lake Superior, 2010. U.S. Geological Survey, Great Lakes Science Center, Lake Superior Biological Station, 2800 Lake Shore Dr. E., Ashland, WI 54806. Available online: http://www.glsc.usgs.gov/_files/reports/2010LakeSuperiorPreyfish.pdf

Hansen, M.J., J.W. Peck, R.G. Schorfhaar, J.H. Selgeby, D.R. Schreiner, S.T. Schram, B.L. Swanson, W.R. MacCallum, M.K. Burnham-Curtis, G.L.Curtis, J.W. Heinrich, and R.J. Young. 1995. Lake trout (Salvelinus namaycush) populations in Lake Superior and their restoration in 1959-1993. Journal of Great Lakes Research 21(Supplement 1):152-175.

Linton, B.C., M.J. Hansen, S.T. Schram, and S.P. Sitar. 2007. Dynamics of a recovering lake trout population in eastern Wisconsin waters of Lake Superior, 1980-2001. North American Journal of Fisheries Management 27:940-954.

Mills, K.H., and R.J. Beamish. 1980. Comparison of fin-ray and scale age determinations for lake whitefish (*Coregonus clupeaformis*) and their implications for estimates of growth and annual survival. Canadian Journal of Fisheries and Aquatic Sciences 37:534–544.

Negus, M.T., D.R. Schreiner, T.N. Halpern, S.T. Schram, M.J. Seider, and D.M. Pratt. 2008. Bioenergetics evaluation of the fish community in the western arm of Lake Superior in 2004. North American Journal of Fisheries Management 28:1649-1667.

Paterson, G., D.M. Whittle, K.G. Drouillard, and G.D. Haffner. 2009. Declining lake trout (*Salvelinus namaycush*) energy density: are there too many salmonid predators in the Great Lakes? Canadian Journal of Fisheries and Aquatic Sciences 66:919-932.

Schreiner, D.R., and S.T. Schram. 2001. Lake Superior Fish Aging Manual. Great Lakes Fishery Commission, Ann Arbor, MI.

Sitar, S.P., and J.X. He. 2006. Growth and maturity of hatchery and wild lean lake trout during population recovery in Michigan waters of Lake Superior. Transactions of the American Fisheries Society 135: 915-923.

Stockwell, J.D., O.T. Gorman, D.L. Yule, L.M. Evrard, and G.A. Cholwek. 2006. Status and Trends of Prey Fish Populations in Lake Superior, 2005. Report to the Lake Superior Committee, Great Lakes Fishery Commission, Ann Arbor, MI. Available online: http://www.glsc.usgs.gov/_files/reports/2005LakeSuperiorPreyfishReport.pdf

Stockwell, J.D., D.L. Yule, L.M. Evrard, G.A. Cholwek, and O.T. Gorman. 2007. Status and Trends of Prey Fish Populations in Lake Superior, 2006. Report to the Lake Superior Committee, Great Lakes Fishery Commission, Ann Arbor, MI. Available online: http://www.glsc.usgs.gov/_files/reports/2006LakeSuperiorPreyfishReport.pdf

Walters, C.J., and D. Ludwig. 1981. Effects of measurement errors on the assessment of stock-recruitment relationships. Canadian Journal of Fisheries and Aquatic Sciences 38:704-710.

Yule, D.L., J.D. Stockwell, J.A. Black, K.I. Cullis, G.A. Cholwek, and J.T. Myers. 2008. How systematic age underestimation can impede understanding of fish population dynamics: lessons learned from a Lake Superior cisco stock. Transactions of the American Fisheries Society 137:481-495.