Lake Superior Committee
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Status and Trends of Prey Fish Populations in Lake Superior in 2003[1]

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Abstract–The Lake Superior Biological Station has conducted lake-wide surveys of the fish community of Lake Superior every spring since 1978 in U.S. waters and every spring since 1989 in Canadian waters. Annual assessments were performed by research vessels systematically sampling coastal habitats around the entire lake with 12-m bottom trawls towed cross-contour starting at depths <15 m at nearshore to 100 m at the offshore terminus of the tow. In 2003, sampling was conducted at 87 stations to assess year-class strengths of lake herring, rainbow smelt, bloater, and lake whitefish populations, and biomass of lake herring, rainbow smelt, bloater, lake whitefish, trout-perch, ninespine stickleback, and slimy sculpin populations. Predominant prey fish in 2003 included (in order of dominance by biomass) lake whitefish, lake herring, bloater, and rainbow smelt. These four species represented 58.4% of the total fish community biomass compared to 69.8% in 2002. Prey fish biomass has continued to decline since the 1990 peak and is now near the low levels observed in 1978-1979. Reasons for the decline can be linked to weak recruitment of age-1 lake herring, bloater, and smelt, as indicated by low densities of these species. Of the less important prey fish, slimy sculpin and ninespine stickleback have continued a long-term decline while trout perch continued to fluctuate at levels above those observed in 1978-1983. Sharp differences in biomass of prey fish populations exist among jurisdictions. The greatest biomass of lake herring, bloater, smelt and lake whitefish was observed in Wisconsin waters. Prior to 2001, the greatest biomass of bloater was in Michigan waters, however, sharp declines in Michigan bloater populations coupled with increases in Wisconsin waters has shifted the area of biomass concentration to Wisconsin waters. Biomass of prey fishes in Minnesota waters continues to be the lowest among U.S. jurisdictions. Trends in prey fish biomass in Canadian waters followed patterns and levels for U.S. waters. Biomass of important prey species (lake herring, bloater, lake whitefish, rainbow smelt) was substantially greater in western Ontario waters compared to eastern Canadian waters where biomass continues to remain at near record low levels in 2003. Overall, the trend in Lake Superior prey fish populations is one of continuing decline since the mid-1990s. The 1998 cohorts of lake herring and bloater produced moderate year classes in 2002. If another moderate year-class is produced in 2003, prey fish biomass may increase in subsequent years over the present relatively low levels.

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INTRODUCTION

The U.S. Geological Survey's Lake Superior Biological Station has conducted lake-wide surveys of the fish community of Lake Superior every spring (early-May to mid-June) since 1978 in U.S. waters and every spring since 1989 in Canadian waters. Annual lake-wide assessments were performed by research vessels systematically sampling coastal habitats with12-m bottom trawls towed cross-contour starting at depths <15 m at nearshore to 100 m at the offshore terminus of the tow. In 2003, sampling was conducted at 87 stations (*Figure 1)* to assess year-class strengths of lake herring, rainbow smelt, bloater, and lake whitefish populations, and biomass of lake herring, rainbow smelt, bloater, lake whitefish, trout-perch, ninespine stickleback, and slimy sculpin populations. Note that a new Canadian station was established near Heron Bay south of Marathon, Ontario. Estimates of year-class strengths were based on geometric mean abundance of yearling fishes in the area swept by the trawl (number/ha). Species-specific biomass (kg/ha) was calculated as the geometric mean weight of the catches in the area swept by the trawl.

RESULTS

Lake herring

Strengths of lake herring year classes in Lake Superior fluctuated by a factor of 4379 over the monitoring period (*Figure 2*). During the 26 years of monitoring, strong year-classes occurred during only three intervals, 1984, 1988-1990, and 1998, and age-1 abundance for those cohorts ranged from 5 to 70 fish/ha. The 1988-1990 interval produced three consecutive strong year classes and included the strongest year class to date (1989). Most of the adult population present in the lake is the result of recruitment and subsequent growth of the 1998 year-class. Our analysis of cohorts has shown that the 1984 year class was produced from the 1980 year class, the 1988-1990 year classes were produced by the 1984 year class, and the 1998 year class was produced by the 1988-1990 year classes. The new, moderate 2002 year class was produced by the 1998 cohort. The minimum interval between year classes was 4 years, which occurs when herring spawn at 3.5 years of age, the age of reproductive maturity in lake herring (Dryer and Beil 1964). During the protracted 7 year interval between the 1988-1990 and the 1998 year classes, small year classes were produced in each year. Given the past history of cohorts, the first year that a moderate year class could be produced by the 1998 cohort was in 2002, which did occur as demonstrated by the results of our 2003 trawl assessment.

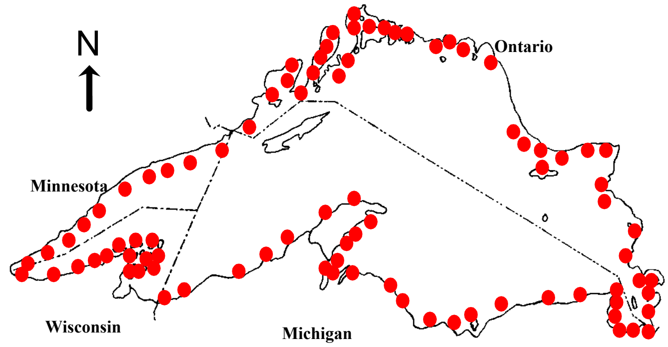


Figure 1. **Locations of stations sampled to assess Lake Superior fish communities, May-June 2001-2003**

Lake herring mean biomass in U.S. waters during 1978-2002 (0.72 kg/ha) was higher than any other species captured, accounting for 21.6% of the total community biomass. Trends in biomass of lake herring appear to be linked to recruitment of strong year classes and reproductive failures (*Figure 3*) and ranged from a low of 0.01

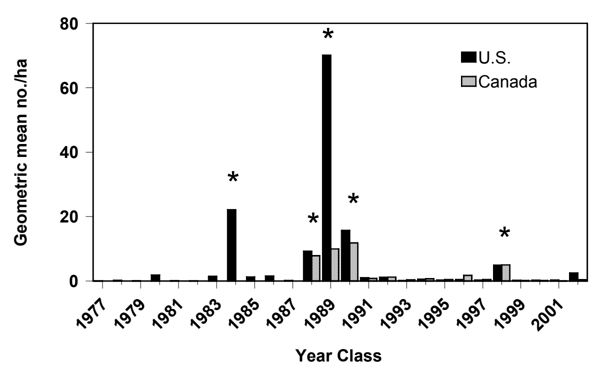


Figure 2. Year class strengths for lake herring in U.S. and Canadian waters of Lake Superior, 1977-2002.
**** indicates strong year class.***

kg/ha in 1978 to a high of 3.26 kg/ha in 1990, which represented 0.5% and 40.4% of the total community biomass, respectively. Lake herring biomass was low during 1978-1984, but increased sharply in 1985 as the result of recruitment of the large 1984 year class. Biomass peaked in 1990 as a result of recruitment of the 1988-1990 year classes but then declined over a 7-year period of poor reproduction to 0.28 kg/ha in 1997. The 1998 year class resulted in an increase in biomass to 1.03 kg/ha in 2000 but subsequently declined to 0.33 kg/ha in 2003.

Population trends for lake herring in Canadian waters have been similar to those in U.S. waters (*Figure 3*). Except in 1996, lake herring biomass in Canadian waters has been lower than in U.S. waters, ranging from a high of 1.31 kg/ha in 1991 to a low of 0.16 kg/ha in 1998. The sharp drop to 0.04 kg/ha in 2002 represents a departure from the trend but it did recover to 0.15 kg/ha in 2003.

Trends in lake herring biomass were similar across U.S. jurisdictions with increases in biomass following appearance of major cohorts in 1984, 1988-1990, and 1998 (*Figures 4-6*). However, there was great disparity in the biomass of herring among jurisdictions. Over the 26-year monitoring period, Minnesota accounted for only 2% of the total biomass in U.S. waters (0= 0.067 kg/ha), Michigan accounted for 20.1% (0= 0.68 kg/ha) and Wisconsin accounted for 77.9% (0= 2.62 kg/ha).

Trends in lake herring biomass in western and eastern Ontario waters varied over the 1989-2003 monitoring period (*Figure 7*). Differences in these trends are likely to be the result of sampling different lake herring populations in distinct lake habitats: most of the biomass data from western Ontario comes from Thunder, Black, and Nipigon bays, while data from eastern Ontario is from open nearshore habitat of Lake Superior. Although the timing of peaks and troughs differed, lake herring biomass in

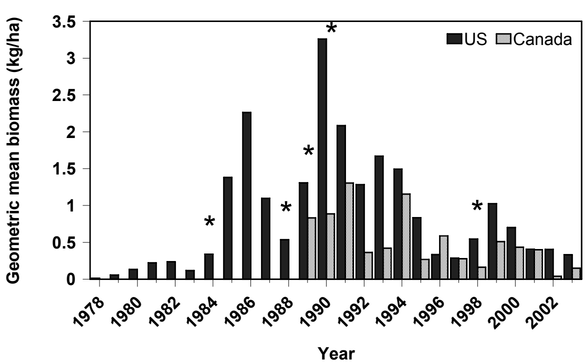


Figure 3. Biomass of lake herring in Lake Superior, 1978-2003. * indicates strong year class.

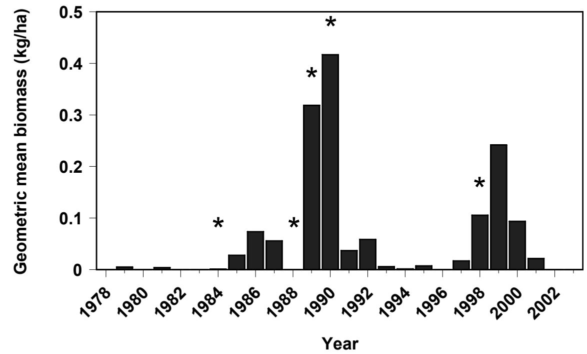


Figure 4. Biomass of lake herring in Minnesota waters of Lake Superior, 1978-2003. * indicates strong year class.

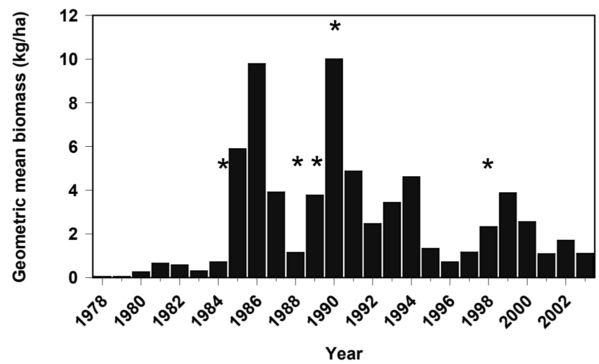


Figure 5. Biomass of lake herring in Wisconsin waters of Lake Superior, 1978-2003. * indicates strong year class.

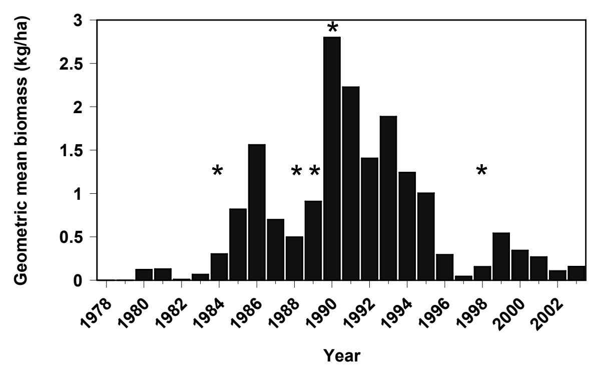


Figure 6. Biomass of lake herring in Michigan waters of Lake Superior, 1978-2003. * indicates strong year class.

both western and eastern Ontario waters showed similar patterns of fluctuation between 1989 and 1996. Between 1999 and 2001, lake herring biomass continued to decline in eastern Ontario waters, in contrast to the sharp increase in western Ontario waters. In 2002, biomass in both regions dipped to the lowest levels recorded in the 14 -year monitoring period. However, the increased biomass recorded in the 2003 assessment for western Ontario represents a change from the declining trend. Like those in U.S. waters, cycles of increases in biomass followed the appearance of strong year classes. Sequential strong year classes appeared in both regions in 1988-1990, but only in western Ontario in 1998 (*Figures 2 and 7*). The lack of a strong year class in eastern Ontario in 1998 resulted in a continuous decline in biomass since 1996.

Lake herring populations in Lake Superior have undergone large population fluctuations over the past 25 years. These cycles appear to be driven by large variance in recruitment dynamics coupled with a rapid loss of adults in the population following maturation of large year classes (3-4 years). In essence, lake herring populations appear to be cohort-driven, i.e., the dominant feature of lake herring populations is the presence of a single, dominant cohort that replaces itself sequentially over time. While the minimum time interval between cohorts is constrained by age of sexual maturity (3-4 years), conditions that promote high recruitment of age-0 fish are not predictable or reliable, but appear to be synchronized over large portions of Lake Superior. We observed large year classes produced by large cohorts upon reaching sexual maturity in 1984 and 1988. However, the large cohort derived from the strong year classes of 1988, 1989, and 1990 were not successful in producing a strong year class until 1998, which underscores the vagary of conditions that allow recruitment of large year classes. In the 7 year interval following the production of the large 1988-1990 cohort, biomass of adults declined to levels approaching those observed in the early 1980s. After just 4 years, the 1998 cohort produced a moderate year class in 2002, but most of that reproductive success was limited to Wisconsin waters, the area of the highest concentration of lake herring. To increase the likelihood that large year classes are produced in every year where conditions are conducive to high recruitment, a sufficiently large population of adults must be present and allowed to allocate the maximum number of gametes toward reproduction. Thus, achieving recovery and long-term persistence of lake herring populations will require preserving sufficient numbers of reproductive adults in the population to ensure future reproductive success.

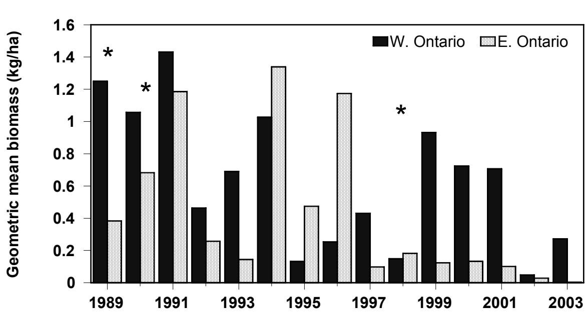


Figure 7. Biomass of lake herring in Ontario waters of Lake Superior, 1989-2003. * indicates strong year class.

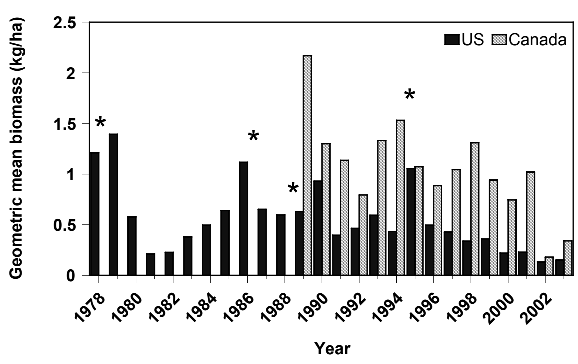


Figure 8. Biomass of rainbow smelt in Lake Superior, 1978-2003. * indicates strong year class.

Rainbow smelt

Mean rainbow smelt biomass in U.S. waters during 1978-2003 (0.55 kg/ha) ranked second behind lake herring and accounted for 19.8% of the total community biomass. In 1978-1979 smelt was the dominant prey fish in Lake Superior, representing 40.2-53.7% of the total community biomass. Prior to the monitoring period, smelt populations were at record levels in Lake Superior. In 1978-1979, the beginning of the monitoring period, smelt biomass in U.S. waters peaked at 1.39 kg/ha but subsequently dropped by more than 85% to 0.21 kg/ha by 1981 (*Figure 8*). During 1982-1986, biomass gradually increased to 1.12 kg/ha. Between 1986 and 1995, biomass fluctuated and then declined steadily after 1995, reaching record low levels in 2002 and 2003 (0.13 and 0.15 kg/ha, respectively). Unlike lake herring, strong year classes of smelt did not fluctuate so widely (a factor of 13 in smelt vs. 4379 in herring, *Figures 2, 9*), and did not appear to have a strong effect on trends in population biomass (*Figure 8*). For example, the appearance of a strong year class in 1978 did not prevent a sharp decline in 1980-1981, the 1986 and 1988 year classes did not result in incremental and sustained increases in population biomass, and the 1994 year class did not reverse a sustained decline after 1995. Estimates of total mortality show that loss of adult fish >3 yr of age increased sharply after 1978. Mortality rates have remained high ever since, such that fish 4 years and older have represented <1.3% of the total population since 1981.

Trends in rainbow smelt biomass were similar among jurisdictions in U.S. waters, where biomass declined sharply between 1979 and 1982 and then increased during the mid-1980s and in 1995 (*Figure 10*). After

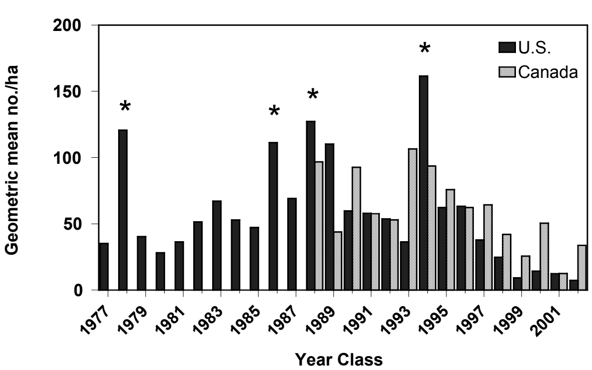


Figure 9. Year class strengths for rainbow smelt in U.S. and Canadian waters of Lake Superior, 1977-2002.
**** indicates strong year class.***

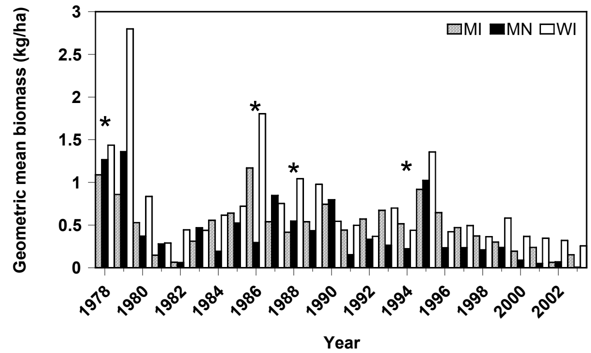


Figure 10. Biomass of rainbow smelt in U.S. waters of Lake Superior, 1978-2003. * indicates strong year class.

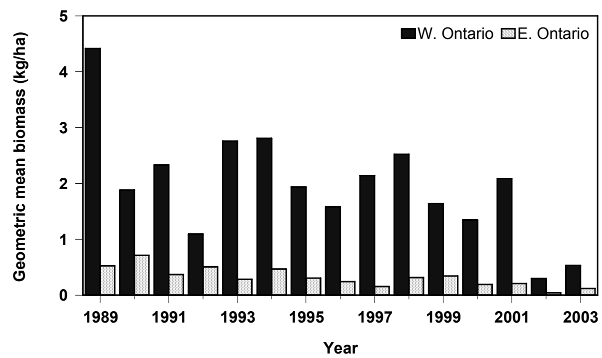


Figure 11. Biomass of rainbow smelt in the Ontario waters of Lake Superior, 1989-2003.

1995, biomass declined in all jurisdictions, and by 2002-2003 matched the low levels observed during 1981-82 (~0.06 - 0.29 kg/ha). Among U.S. jurisdictions, Wisconsin accounted for 44.7% of the total smelt biomass, Michigan 30.6% and Minnesota 24.6%. The largest peaks in smelt biomass were observed in Wisconsin waters during 1979, 1986 and 1995, (2.80, 1.80, 1.36 kg/ha, respectively) while the lowest levels were observed in Michigan and Minnesota waters in 1982 and 2002 (0.06-0.07 kg/ha). The lowest mean biomass in Wisconsin waters was recorded in 1981 (0.29 kg/ha).

During the 1989-2003 monitoring period, trends in rainbow smelt biomass in Canadian waters shared features with those in U.S. waters, but biomass levels were consistently much higher in Canadian waters until 2001 (Figure 8). Mean biomass for smelt in Canadian waters was nearly twice that in U.S. waters (1.05 kg/ha vs. 0.55 kg/ha).

During 1989-1995, trends in biomass were similar in both jurisdictions, however, biomass declined in U.S. waters after 1995. In 2002, smelt biomass in Canadian waters plummeted to 0.18 kg/ha, similar to the low levels observed in U.S. waters. There were strong differences in smelt biomass between western and eastern Ontario; 86% of the smelt biomass was concentrated in western Ontario, which includes Thunder, Black and Nipigon bays (*Figure 11*), and was reflected in mean biomass estimates; 1.96 kg/ha vs. 0.32 kg/ha for western and eastern Ontario waters, respectively. Open lake habitats of eastern Ontario contributed little to smelt biomass in Canadian waters of Lake Superior.

Bloater

Mean bloater biomass in U.S. waters during 1978-2003 (0.55 kg/ha) ranked fourth behind lake herring, rainbow smelt, and lake whitefish, and accounted for 11.9% of the total community biomass. In U.S. waters, bloater biomass was low during 1978-1983 (0.11-0.32 kg/ha), more than doubled in 1984-1986 (0.44-0.74 kg/ha), and remained relatively high through 1993 *(Figure 12)*. After the peak of 1.37 kg/ha in 1992, biomass declined to low levels (0.14-0.20 kg/ha) in 1994-1995, but recovered partially by 1998, achieving 0.68 kg/ha. In the 1998-2003 interval, biomass declined gradually to 0.27 kg/ha in 2002 and rebounded slightly to 0.35 kg/ha in 2003.

Like lake herring, trends in biomass in bloater populations were driven by recruitment of strong year classes, and also like lake herring, bloater showed a wide range in year class strengths, varying by more than 227 between the weakest and strongest year classes (*Figures 12, 13)*. The strong year class of 1978 gave rise to the 1984 and 1985 year classes which in turn gave rise to the 1988 and 1989 year classes, which in turn gave rise to the 1998 year class. The intervals between these year classes were 5, 3, and 8 years, respectively. Like lake herring, the 1998 bloater cohort may have produced a moderate year class in 2002, but because of the difficulty in identifying yearlings, we will not be able to verify this until the cohort reaches age2. Our cohort analysis showed that, like lake herring, bloater starts to reproduce at 3 years of age, which concurs with the findings of Dryer and Beil (1968). Most of the strong year classes of bloater occurred at the same time strong year classes appeared in lake herring populations. The exceptions include the 1978 and 1985 year classes for boater and the 1980 and 1990 year classes in lake herring. The four strong year classes that appeared between 1984 and 1990 resulted in a increase in biomass that peaked in 1992 at 1.37 kg/ha. With the exception of 1996, biomass declined from 1993 through 1997. In 1998, when a new strong year class was produced, biomass increased to 0.68 kg/ha and subsequently decreased to a low of 0.27 kg/ha in 2002.

Trends in biomass in U.S. and Canadian jurisdictions between 1989-2001 were very similar, however, biomass tended to be slightly higher in U.S. waters (*Figure 12*).

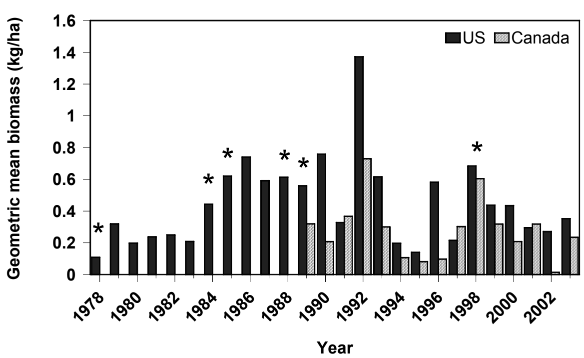


Figure 12. Biomass of bloater in Lake Superior, 1978-2003. * indicates strong year class.

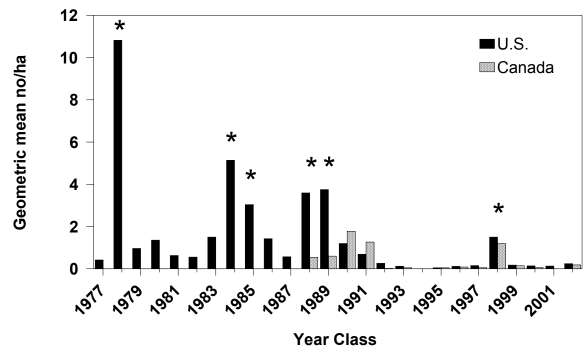


Figure 13. Year class strengths for bloater in U.S. and Canadian waters of Lake Superior, 1977-2002. * indicates strong year class.

Strong year classes in Ontario during 1990-1991 and 1998 resulted in subsequent increases in biomass (*Figures 12 and 13*). The sharp drop in bloater biomass to 0.01 kg/ha in Ontario in 2002 was countered in 2003 by a value more in line with mean biomass in U.S. waters (0.235 vs. 0.352 kg/ha).

Among U.S. jurisdictions, bloater biomass was extremely low in Minnesota waters, averaging <0.01 kg/ha over the 25 year monitoring period and accounted for only 0.9% of total biomass (*Figure 14*). As a result, biomass in Minnesota waters was too low annually to describe meaningful trends. Most bloater biomass in U.S. waters was concentrated in Michigan waters which averaged 0.47 kg/ha and accounted for 58.2% of the total biomass while Wisconsin averaged 0.33 kg/ha and represented 40.9% of the total biomass. Trends in bloater biomass in Michigan and Wisconsin waters showed relatively low biomass between 1978 and 1983 (0.04-0.25 kg/ha), increasing biomass between 1984 and 1993 (0.20-1.68 kg/ha), and a period of variable decline in 1994-1997. In 1998 both areas showed an increase in biomass, reaching 0.44 - 0.55 kg/ha. Subsequently, biomass declined steadily in Michigan to 0.09 kg/ha in 2002, while biomass increased steadily in Wisconsin waters, reaching 1.0 kg/ha in 2003. Like U.S. waters as a whole, trends in biomass in Michigan and Wisconsin waters were strongly affected by the appearance and recruitment of strong year classes (*Figures 12-14*).

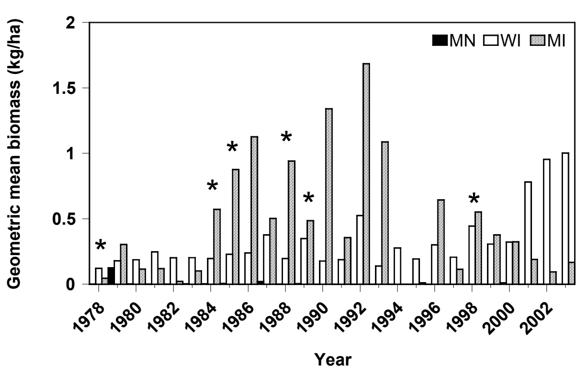


*Figure 14. Biomass of bloater in U.S. waters of Lake Superior, 1978-2003. * indicates strong year class.*

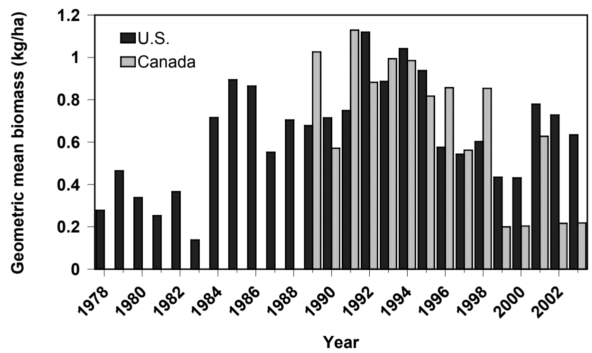


Figure 15. Biomass of lake whitefish in Lake Superior, 1978-2003.

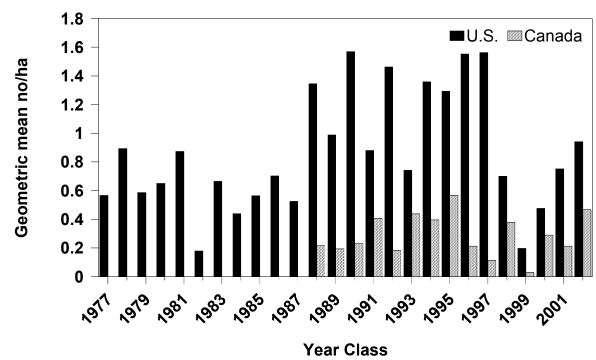


Figure 16. Year class strengths for lake whitefish in U.S. and Canadian waters of Lake Superior, 1977-2002.

Lake whitefish

Mean lake whitefish biomass in U.S. waters during 1978-2003 (0.63 kg/ha) was second only to lake herring and accounted for 18.7% of the total community biomass. During 1978-1983, biomass of lake whitefish was low in U.S. waters (0.14-0.46 kg/ha), then increased to more than 0.80 kg/ha during 1984-1986 and then fluctuated between 0.43 and 1.12 kg/ha to the present time (*Figure 15*). Year class strength in U.S. waters varied by a factor of 9 over the 25 year monitoring period, which was much less than that for other coregonids (*Figure 16*). As a result, there were numerous moderate to strong year classes, especially after 1987 when population levels and biomass had fully recovered. Unlike lake herring and bloater, year class strength appears to have little effect on subsequent population biomass. Year class strengths tended to decline after 1997 but population biomass continued to remain high (0.71 kg/ha for the period 2001-2003; *Figures 15, 16*). Trends

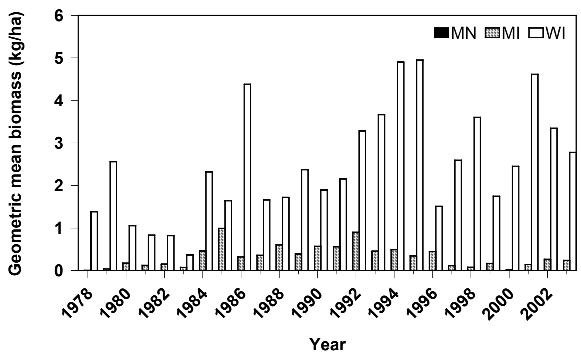


Figure 17. Biomass of lake whitefish in U.S. waters of Lake Superior, 1978-2003.

in lake whitefish biomass in Canadian waters were similar to those in U.S. waters during 1989-2003, but dropped to record lows (0.22 kg/ha) in 1999-2003 (*Figure 15*).

Lake whitefish mean biomass differed greatly among U.S. jurisdictions (*Figure 17*). Biomass was extremely low in Minnesota (<0.01 kg/ha annually) and accounted for <0.1% of the total biomass in U.S waters. In Michigan, the mean biomass was higher (0.33 kg/ha) and accounted for 11.6% of the total biomass. Biomass of whitefish in Wisconsin was relatively high (2.49 kg/ha) and represented 88.4% of the total biomass. Trends in lake whitefish biomass differed among jurisdictions. Biomass in Minnesota waters was too low annually to describe meaningful trends. In Michigan waters, lake whitefish biomass was very low in 1978-1983 (<0.2 kg/ha) but then increased rapidly to 0.46 kg/ha in 1985 and continued to fluctuate between 0.33 and 0.99 kg/ha during 1984-1996. Subsequently, biomass declined and fluctuated between 0.08 and 0.27 kg/ha. Like Michigan, lake whitefish biomass in Wisconsin waters was relatively low before 1984 and increased rapidly and fluctuated at higher levels after 1983. However, biomass levels in Wisconsin between 1984-1996 were substantially higher, ranging from 1.51 to 4.94 kg/ha, and have remained high in 1997-2003 (1.75-4.62 kg/ha).

Ninespine stickleback

Ninespine stickleback was a relatively minor species in U.S. waters during 1978-2003; mean biomass was 0.08 kg/ha and accounted for 2.4% of the total community biomass. Biomass in the first two years of the monitoring period was much higher than in the following 1980-1999 interval (0.16-0.27 vs. 0.02-0.15 kg/ha; *Figure 18*). Since 1999, biomass declined to 0.01-0.06 kg/ha and dipped to record lows in the 2000-2003 interval. In Canadian waters, biomass averaged 0.09 kg/ha between 1989 and 2003 and trends were similar to those in the U.S. with the exception of a large spike in biomass that occurred in 1995-1997 (*Figure 18*).

Among U.S. jurisdictions, biomass of ninespine stickleback was very low in Minnesota waters (<0.01 kg/ha annually) and accounted for 2% of the total biomass in U.S. waters. Biomass of ninespine stickleback was higher in Michigan waters (0.07 kg/ha) and accounted for 34.6% of the total biomass. Wisconsin waters held the highest fraction of stickleback (63.3%) and had the

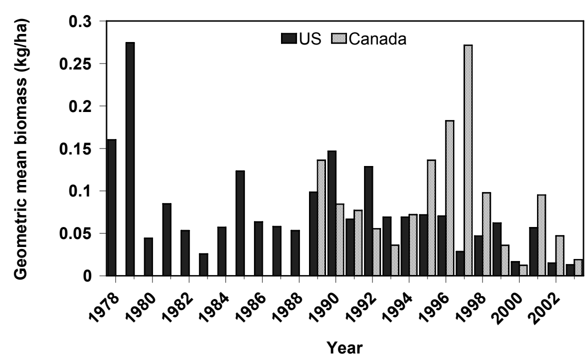


Figure 18. Biomass of ninespine stickleback in Lake Superior, 1978-2003.

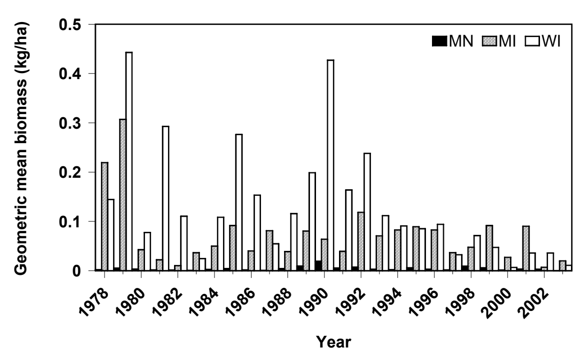


Figure 19. Biomass of ninespine stickleback in U.S. waters of Lake Superior, 1978-2003.

highest mean biomass for the 25 year monitoring period (0.13 kg/ha). Trends in biomass among the jurisdictions differed over the monitoring period (*Figure 19*). In both Michigan and Wisconsin waters, stickleback biomass was relatively high in 1978-1979, but afterwards biomass in Michigan dropped and remained low and fluctuated through 2001 (0.01-0.12 kg/ha). Stickleback biomass in Wisconsin waters remained relatively high and fluctuated between 1978 and 1992 (0.05-0.44 kg/ha) and afterwards declined to levels comparable to Michigan waters (0.01-0.07 kg/ha). During the 2000-2003 interval, stickleback biomass in Wisconsin and Michigan reached a nadir of 0.007 kg/ha.

Trout-perch

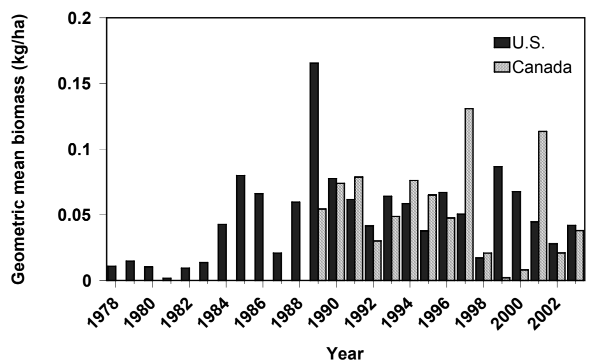
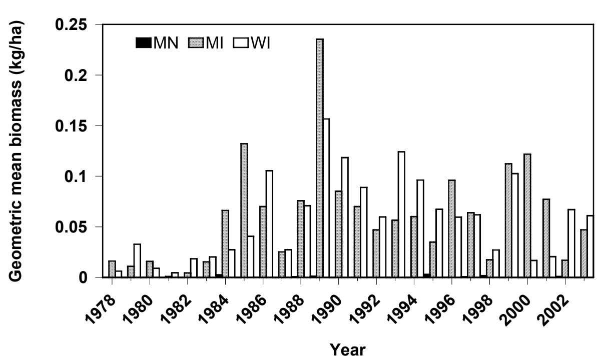


Figure 20. Biomass of trout-perch in Lake Superior, 1978-2003.



3igure 21. Biomass of trout-perch in U.S. waters of Lake Superior, 1978-2003.

Trout-perch was another relatively minor species in U.S. waters during 1978-2003; mean biomass was 0.05 kg/ha and accounted for 1.4% of the total community biomass. Biomass during the 1978-1983 period was relatively low ($\leq$0.01 kg/ha) and subsequently increased to levels that fluctuated about 0.05 kg/ha through 2002 (*Figure 20*). Trout-perch biomass and trends in Canadian waters between 1989 and 2002 were similar to those in U.S. waters with the exception of the 1997-2001 period where trout-perch biomass underwent large fluctuations (*Figure 20*). The lowest values for trout-perch biomass in U.S. and Canadian waters (0.002 kg/ha) occurred in 1981 and 1999, respectively.

Among U.S. jurisdictions, trout-perch biomass was lowest in Minnesota waters (<0.001 kg/ha annually), and accounted for only 0.4% of the total biomass in U.S. waters. Mean biomass was higher in Michigan and Wisconsin (~0.06 kg/ha) and accounted for 51.2% and 48.4% of the total biomass, respectively. Trends in trout-perch were too low in Minnesota waters to describe meaningful trends (*Figure 21*). Trends in Michigan and Wisconsin waters were similar and followed trends for U.S. waters overall.

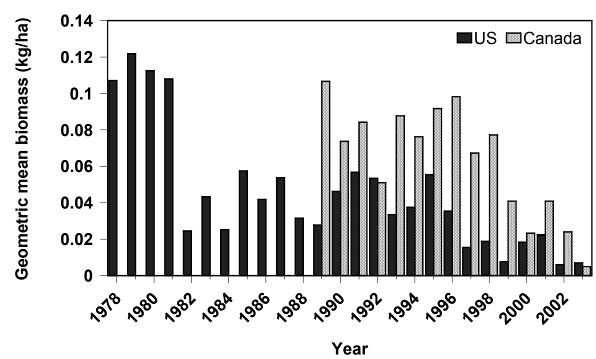


Figure 22. Biomass of slimy sculpin in Lake Superior, 1978-2003.

Slimy sculpin

Slimy sculpin, another minor species, was the most abundant sculpin species in U.S. waters during 1978-2003; mean biomass was 0.04 kg/ha and accounted for

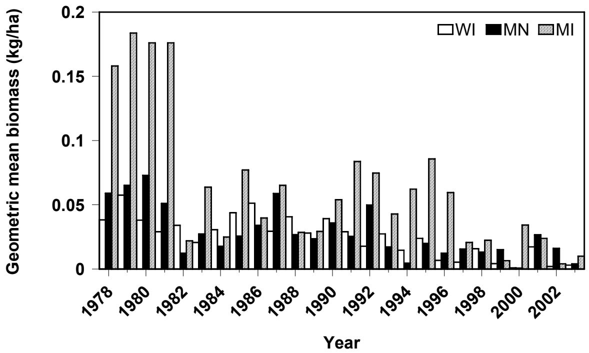


Figure 23. Biomass of slimy sculpin in U.S. waters of Lake Superior, 1978-2003.

1.5% of the total community biomass. Biomass of slimy sculpin during the early portion of the monitoring period (1978-1981) was relatively high (0.11-0.12 kg/ha) and then declined and fluctuated about 0.04 kg/ha between 1982 and 1996. In the final period (1997-2003), biomass declined to the lowest levels in the time series (~0.01-0.02 kg/ha; *Figure 22*). This pattern of biomass change in slimy sculpin over the 26-year monitoring period is similar to that for nine-spine stickleback (*Figure 18*). In Canadian waters, slimy sculpin biomass has tended to be higher (0.07 kg/ha) than in U.S. waters, but the trends for the 1989-2002 period were similar (*Figure 22*). Like that in U.S. waters, slimy sculpin biomass in Canadian waters declined to the lowest levels in the time series during the 2000-2002 interval.

Among U.S. jurisdictions, mean biomass of slimy sculpin for the 26-year monitoring period was highest in Michigan waters (.06 kg/ha) and <0.03 kg/ha for both Minnesota and Wisconsin waters. Trends in biomass among the jurisdictions were similar for U.S. waters as a whole (*Figures 22, 23*). Biomass was especially high in Michigan waters in the early portion of the time series, exceeding 0.16 kg/ha annually during 1978-1981. During the 1983-1996 period, sculpin biomass in Michigan declined sharply and fluctuated about 0.05 kg/ha. Trends in sculpin biomass in Wisconsin and Minnesota waters were similar; biomass declined after 1980 and fluctuated around 0.03 kg/ha between 1981 and 1993 and afterwards declined and fluctuated about 0.01 kg/ha for the remainder of the time series. Between 1997-2003, trends in biomass were similar among the three jurisdictions and the 2000-2003 interval included the lowest biomass levels in the time series (≤ 0.004 kg/ha).

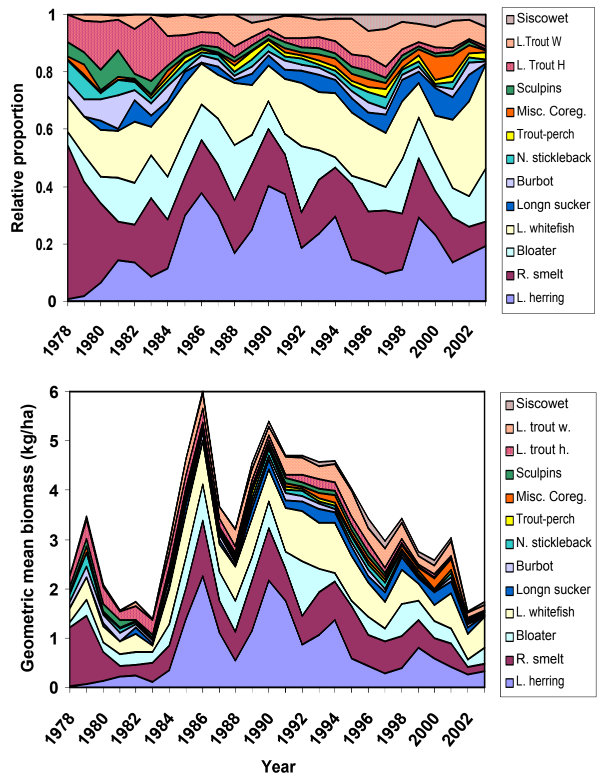


Figure 24. Composition and biomass of the Lake Superior fish community, 1978-2003.

DISCUSSION

Our comprehensive, lake-wide bottom trawl sampling provided a unique tool to evaluate the changes in the Lake Superior fish community over the past 26 years. During this period we have witnessed massive changes in the fish community composition and biomass (*Figure 24*). Principal prey species (lake herring, bloater, rainbow smelt) have represented, on average, 54% of the total community biomass. Early in the monitoring period, rainbow smelt dominated the prey fish assemblage, but by the mid-1980s to early 1990s lake herring, bloater, and lake whitefish populations rebounded. At the same time, wild lake trout populations achieved significant levels of recovery as indicated by our trawl sampling and other agency monitoring efforts (Hansen et al. 1995).

The state of the Lake Superior fish community appeared to be well on the road to recovery by the early 1990s. However, since that time we have documented declines in all key species, including lake trout. Lake herring stocks have declined to levels approaching those in the early portion of the monitoring period. Rainbow smelt biomass continued to decline and bloater remained relatively low. Biomass of benthic prey species (ninespine stickleback, trout-perch, slimy sculpin) has also declined in recent years. Only biomass of the resilient lake whitefish has tended to remain stable, thought it too has declined in many areas of Lake Superior.

Among jurisdictions, the fish community in Wisconsin waters appears to be in the best shape. Currently it has the highest biomass of principal prey species and seems to be resisting the declining trend found elsewhere in the lake. Further analysis to compare and contrast the Wisconsin fish community with others in Lake Superior is currently underway to elucidate the underlying reasons for these differences.

Historically, lake herring was a dominant species in the Lake Superior fish community. In the late 1980s-early 1990s, lake herring represented nearly 40% of the total community biomass in the lake (*Figure 24*). This resulted from successful recruitment of sequential, large year classes: one in 1984 and back-to-back year classes in 1988-1990. However, conditions that allow generation of large year classes are neither predictable nor reliable and when coupled with a rapid loss of reproductive adults in the population; large swings in biomass over time are inevitable--as occurred following the 7-year recruitment hiatus in the 1990s. Thus, long-term stability in lake herring populations is dependent on maintaining a large reserve of reproductive adults in the population. The recent 1998 lake herring cohort has now matured, and in 2002 produced its first year class, although relatively small. Perhaps the 1998 cohort will be successful in producing a larger year class in 2003, and reverse the declining trend in lake herring biomass.

Results from a recent analysis of zooplankton populations in Lake Superior for the 1989-2000 interval (Gorman, et al. 2003), suggest that zooplankton populations in the late 1990s were underutilized in many areas of the lake, a finding congruent with the decline of principal prey fishes, which are the primary planktivores in the lake. These findings suggest that Lake Superior prey fish populations are not currently food-limited. Our lake-wide trawl assessments indicate that total community biomass, including lake trout, has been in decline since the mid-1990s, which has occurred despite what appears to be an ample food base. As suggested by Kitchell et al. (2000) further increases in lake trout biomass in Lake Superior depend heavily on increasing stocks of lake herring. The key, then, to further restoration of the Lake Superior fish community is for lake herring, the principal prey species, to fully recover.

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