Status and Trends in the Lake Superior Fish Community, 2021

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As was the case for all Great Lakes fisheries management and research agencies, the impacts of the COVID-19 pandemic on the U.S. Geological Survey (USGS) Great Lakes Science Center's deepwater science work were significant. The most severe impacts were related to deepwater science cruises scheduled in the spring/early summer, and those requiring extended overnight stays on vessels. In addition, USGS vessels could not get clearance to cross into Canadian waters as a result of the pandemic, which reduced the spatial scope of data normally collected. Because of these limitations, reporting for 2021 deepwater science surveys will be limited in scope, and in some cases, limited in the ability to make meaningful comparisons to data from previous years. All USGS personnel involved in deepwater science cruises are looking forward to the return of a more normal sampling schedule in 2022, pandemic conditions permitting.

The data associated with this report have not received final approval by the U.S. Geological Survey (USGS) and are currently under review. The Great Lakes Science Center is committed to complying with the Office of Management and Budget data release requirements and providing the public with high quality scientific data. We plan to release all USGS research vessel data collected between 1958 and 2021 and make those publicly available. Please direct questions to our Information Technology Specialist, Scott Nelson, at snelson@usgs.gov.

Abstract

The Lake Superior nearshore fish community was sampled in May-June 2021 with daytime bottom trawl tows at 45 stations located in USA waters. The 45 locations sampled were long-term monitoring sites that had been annually sampled since 1978. All comparisons to 2021 results were limited to past collections from USA waters, as compared to previous years, where comparisons included USA and Canadian sites. In 2021, the number of species collected at each site ranged from 0 to 15, with a median of 5 species. Average fish biomass was 6.3 kg/ha, which was higher than the average observed over the past 10 years (4.7 kg/ha), similar to the average observed from 2001-10 (6.7 kg/ha), and less than the averages observed in 1991-2000 (14.8 kg/ha), and 1981-1990 (11.9 kg/ha), but higher than the average from 1978-1980 (5.2 kg/ha). Average biomass in 2021 was highest for Lake Whitefish (*Coregonus clupeaformis*, 3.2 kg/ha), Bloater (C. hoyi, 1.4 kg/ha), Rainbow Smelt (*Osmerus mordax*, 0.5 kg/ha), and Cisco (*C. artedi*, 0.3 kg/ha). *Coregonus* spp. year-class strength, as measured by densities of age-1 fish, was 8 fish/ha for Bloater, 11 fish/ha for Cisco, and 41 fish/ha for Lake Whitefish. The age-1 Bloater estimate was in the range observed for the 2014, 2015, and 2016 year-classes (7-9 age-1 fish/ha) and greater than that observed in other years over the past decade (<1 age-1 fish/ha). The age-1 Cisco estimate was the highest estimate since the 2009 year-class. Average Lake Whitefish age-1 density was the second highest estimate observed over the past 44-years. Cisco survival to age-1 has been low since 2009 and near zero since the 2014- and 2015-year classes. This lack of survival has yet to be adequately explained and continues to be a major concern of fishery managers due to Cisco's importance in ecosystem dynamics and value to the commercial fishery.

Introduction

The U.S. Geological Survey Great Lakes Science Center, Lake Superior Biological Station, based in Ashland, Wisconsin conducts annual daytime bottom trawl fish surveys in nearshore (~15-80 m depths) and offshore (~100-300 m depths) waters of Lake Superior. These surveys provide data for assessment of trends in species occurrence, relative abundance, and biomass for principally demersal fish. These data have historically been considered population indices rather than absolute abundance and biomass estimates. The nearshore survey has been conducted annually since 1978 in USA waters, and since 1989 in Canadian waters. The offshore survey has been conducted annually since 2011 in both USA and Canadian waters, minus the 2020 pandemic year. The primary goal of the surveys is to report on population biomass estimates for all sizes of common species and age-1 density estimates for selected commercial and recreational species (Cisco, Bloater, Kiyi, Lake Whitefish, Rainbow Smelt, scientific names are provided in Table 1) as indices of year-class strength. Aging structures and stomach contents are collected for selected species. Fish population data in this report are based solely on bottom trawl sampling. Fishing gear bias should be considered when interpreting the results, particularly for species with lower vulnerability to daytime bottom trawl tows, such as adult Cisco and adult Lake Trout (Yule, et al. 2008). At each fish sampling station, zooplankton are sampled by a whole water column (up to 100 m) vertical zooplankton tow, and an electronic water profiler is deployed that collects data on depth, water temperature, specific conductance, pH, dissolved oxygen, chlorophyll a, photosynthetic active radiation (PAR), and beam transmission. Herein we report on fish collected during the 2021 survey and compare these collections to previous annual collections made since 1978 in USA waters. Due to the COVID-19 pandemic, sampling in 2021 was limited to locations in the USA.

Methods

In 2021, 45 sampling sites were sampled from May 18 to June 3, 2021 using the Research Vessel ARCTICUS (Figure 1). At each location, a single bottom trawl tow was conducted with a 12-m Yankee bottom trawl with a chain foot rope. The median start and end depths for bottom trawl tows were 20 m (range 12-51 m) and 58 m (range 22-144 m), respectively. The median distance trawled was 1.9 km (range 0.5-3.8 km). A trawl wingspread of 7.8 m was used to calculate area swept for all trawl tows. Fish collected in trawls were sorted by species, counted, and weighed in aggregate to the nearest gram. Total length was measured on a maximum of 50 individuals per species per trawl. Lengths for these individuals were extrapolated to the entire catch when more than 50 individuals were collected. Relative density (fish/ha) and biomass (kg/ha) were estimated by dividing sample counts and aggregate weights by the area (ha) of the lake bottom swept by each trawl tow. Biomass estimates are reported for all species combined and individually for Bloater, Cisco, Lake Whitefish, Rainbow Smelt, and Sculpin species (Slimy-, Spoonhead-, and Deepwater-Sculpin). Scientific names are provided in Table 1. A composite estimate is also reported for less-common species (Other species as listed in Table 1 caption). Age-1 year-class strength was estimated as the mean density of age-1 fish as determined by total length; Cisco ≤140 mm, Bloater ≤130 mm, Lake Whitefish ≤160 mm, and Rainbow Smelt ≤100 mm, across all sites. These age-size cutoffs were based on past unpublished age estimates and are approximate and are known to vary among years. In 2020, the COVID-19 pandemic limited our sampling to 11 locations within the Apostle Islands, this is much fewer samples than the 40-50 sites sampled in most other years. In all years, fish population biomass is typically higher in the 11 nearshore sites sampled in 2020 in the Apostle Islands than most of the other ~30 nearshore sites sampled in USA waters in a typical year (Figure 1). This should be considered when comparing population estimates from 2020 to other years.

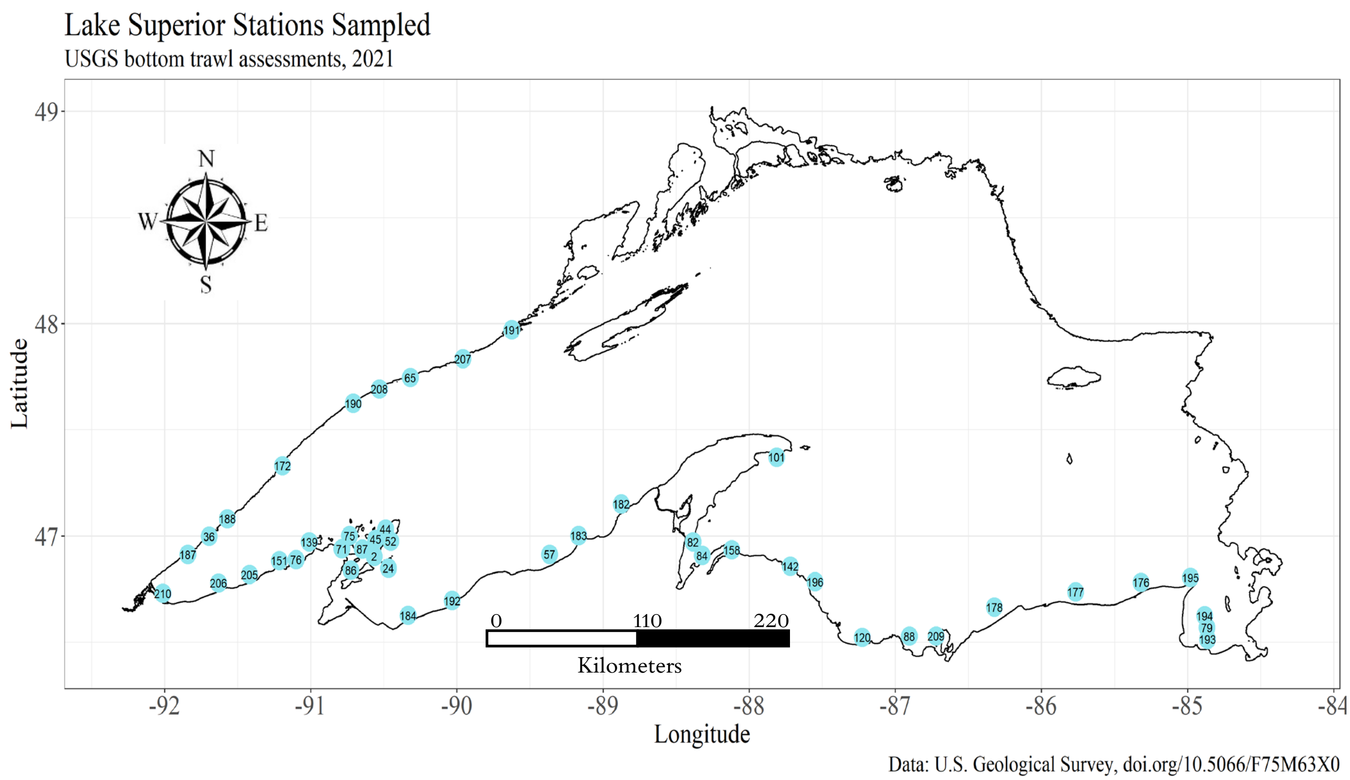


Figure 1. Location of 45 stations sampled from 18 May-3 June 2021. Numbers are the station identifier. Samples collected at each location included a bottom trawl tow for demersal fish, a whole water column zooplankton collection, and a water profile that electronically collected data on depth, temperature, specific conductance, pH, dissolved oxygen, chlorophyll a, photosynthetic active radiation, and beam transmission.

Results

Population Biomass

A total of 23,058 individual fish from 23 species or morphotypes were collected from 45 locations (Table 1). The number of species collected at each station ranged from zero to 15, with a median of 5 species. Estimated fish biomass at individual stations ranged from zero to 77.3 kg/ha (Figure 2). Individual stations with the highest biomass were 2-Stockton Island, 86-Basswood Island, and 151-Bark Point which are all located in western Lake Superior (Figure 2) in Wisconsin. Average fish biomass across all stations was 6.3 kg/ha, which was higher than the average observed over the past 10 years in USA waters (4.7 kg/ha), similar to the average observed from 2001-10 (6.7 kg/ha), and less than the averages observed in 1991-2000 (14.8 kg/ha), and 1981-1990 (11.9 kg/ha), but higher than the average from 1978-1980 (5.2 kg/ha, Figure 3). Average biomass in 2021 was highest for Lake Whitefish (3.2 kg/ha), Bloater (1.4 kg/ha), Rainbow Smelt (0.5 kg/ha), and Cisco (0.3 kg/ha).

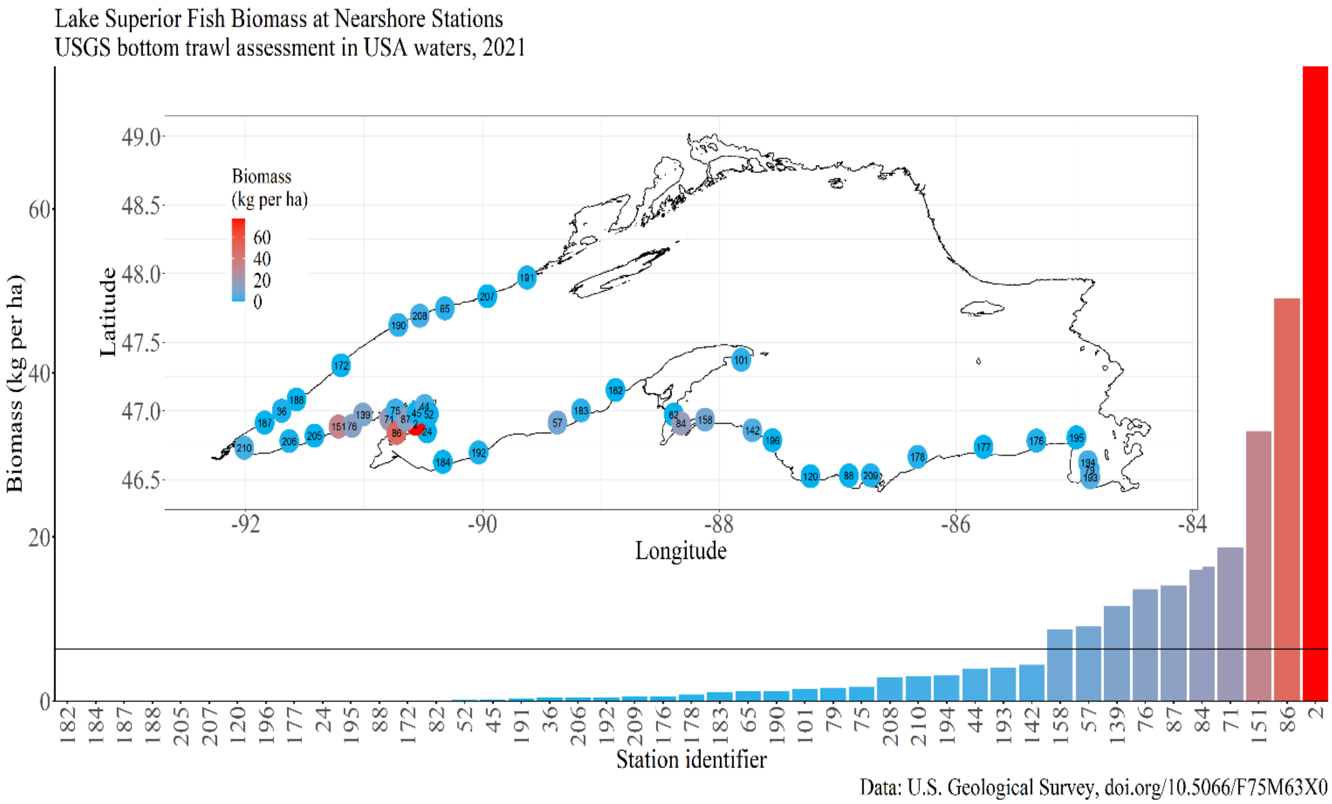


Figure 2. Estimated total fish biomass (kg/ha) at 45 sampling stations in nearshore USA waters of Lake Superior in 2021. The horizontal line is the 2021 average biomass across all stations (6.3 kg/ha). The inset figure shows the spatial distribution of total fish biomass (kg/ha) at individual sampling stations in 2021.

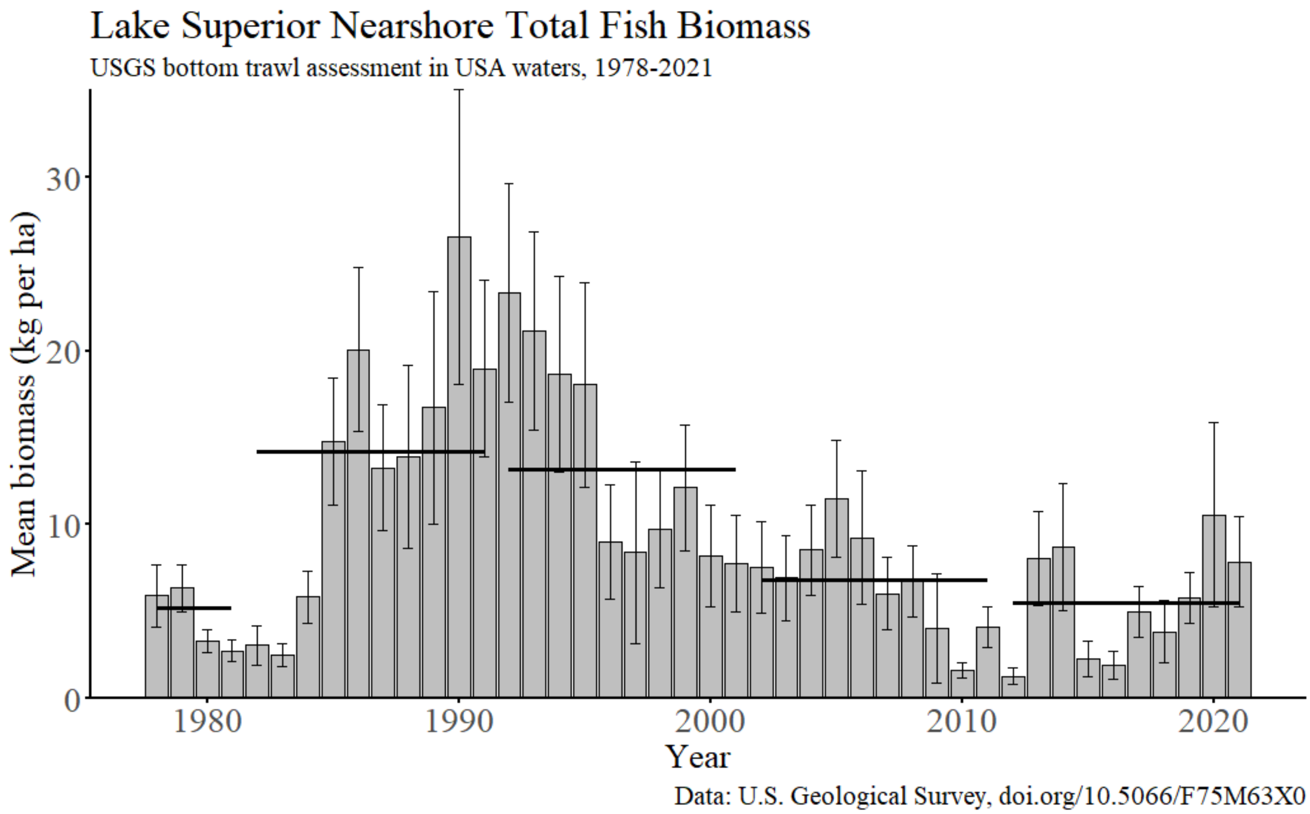


Figure 3. Annual (mean ± standard error) total fish biomass estimates for all fish species collected in bottom trawl tows from 1978-2021 in nearshore USA waters of Lake Superior. Horizontal lines are 10-year averages across different periods. In 2020 only 11 sites were sampled in the Apostle Islands because of the COVID-19 pandemic. The number of sites sampled in each year is presented in Table 2.

Bloater biomass averaged 1.4 kg/ha in 2021. This biomass estimate was greater than estimates since 2009 if 2020 is excluded due to the limited number of sites sampled that year (Figure 4, Table 2).

Cisco biomass averaged 0.3 kg/ha in 2021. This biomass estimate was similar to the previous 10-year average (0.4 kg/ha), and much less than that estimated from 1986-2006 when biomass typically exceeded 2 kg/ha (Figure 4, Table 2).

Whitefish biomass averaged 3.2 kg/ha in 2021. This was greater than the previous 10-year average of 2.1 kg/ha and the previous 44-year average of 2.6 kg/ha (Figure 4, Table 2).

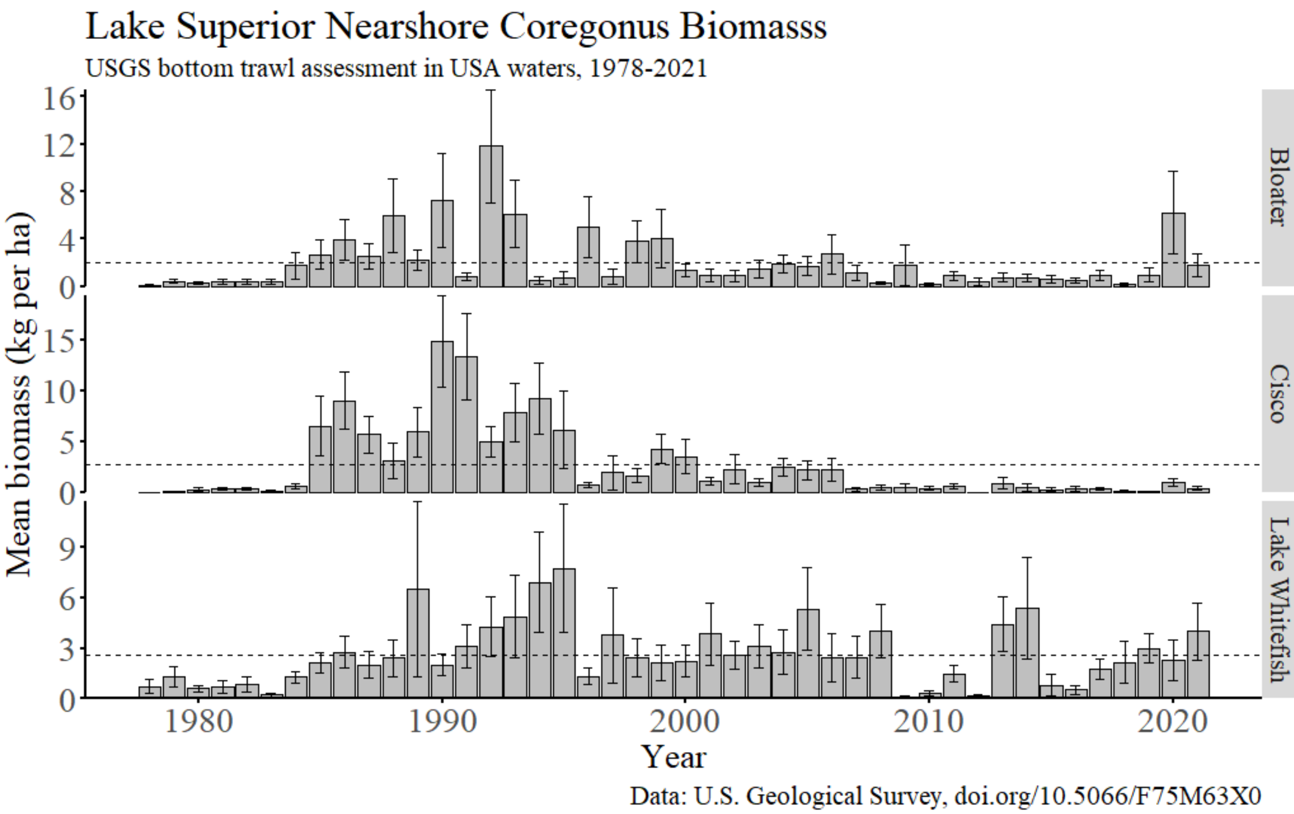


Figure 4. Mean annual biomass estimates (kg/ha ± standard error) for Bloater, Cisco, and Lake Whitefish collected in bottom trawl tows from 1978-2021 in nearshore USA waters of Lake Superior. The horizontal line is the 44-year period-of-record mean. In 2020 only 11 sites were sampled in the Apostle Islands because of the COVID-19 pandemic. The number of sites sampled in each year is presented in Table 2.

Two non-native species, Rainbow Smelt and Eurasian Ruffe, were collected in 2021. Rainbow Smelt biomass averaged 0.5 kg/ha in 2021. This biomass was greater than the previous 10-year average of 0.3 kg/ha and less than previous 44-year average of 0.8 kg/ha (Table 2). Seven Eurasian Ruffe were collected at four locations in Wisconsin (sites 2, 86, 87, and 210).

Other species collected in bottom trawl tows in 2021 (number collected) included Ninespine Stickleback (1,110), Trout-perch (1,008), Pygmy Whitefish (502), Slimy Sculpin (230), Deepwater Sculpin (145), lean Lake Trout (76), siscowet Lake Trout (53), Spoonhead Sculpin (31), Longnose Sucker (20), Kiyi (17), Round Whitefish (5), Burbot (3), Shortjaw Cisco (3), hatchery Lake Trout (3), Blackfin Cisco (2), Johnny Darter (2), Lake Sturgeon (1), and Shortnose Cisco (1). Scientific names and collection summaries are provided for all species in Table 1. The combined average biomass of these other species was 0.8 kg/ha (Table 2).

Year-Class Strength

Density of age-1 prey fish (age-1 fish/ha) was used as a measure of year-class strength. The 2021 age-1 Bloater estimate was eight age-1 fish/ha. Age-1 Bloater were collected at 12 of the 45 nearshore stations sampled (Figure 5). This density estimate was in the range observed for the 2014, 2015, and 2016 year-classes (5-9 age-1 fish/ha) and greater than that estimated in other years over the past decade (<1 age-1 fish/ha, Figure 6, Table 3). Age-1 Bloater density has exceeded five age-1 fish/ha in seven of the past twenty years (Table 3).

The 2021 age-1 Cisco estimate was 11 age-1 fish/ha. Age-1 Cisco were collected at 13 of the 45 nearshore stations sampled (Figure 5). This was the highest age-1 Cisco density estimate since the 2009 year-class (Figure 6, Table 3). Age-1 Cisco density has been estimated at less than one age-1 fish/ha in seven of the past 10-years (Figure 6, Table 3).

Lake Whitefish age-1 density averaged 41 fish/ha, which was the second highest estimate observed over the past 44-years. Age-1 Lake Whitefish were collected at 15 of the 45 nearshore stations sampled (Figure 5). Lake Whitefish density has exceeded 10 age-1 fish/ha the past three years (Table 3).

Length-frequency distributions for Cisco, Bloater and Lake Whitefish from 1978-2021 for collections in USA waters are provided to help visualize how recruitment events have shaped these populations over time (Appendix A). The Cisco population in this region has been characterized by high recruitment variation, with clear evidence that sporadic catches of age-1 Cisco persist and can be seen growing larger in subsequent years. That same general pattern is evident for Bloater, but with strong year-classes occurring at a lower frequency. Recruitment of Lake Whitefish has shown far less variation compared to Cisco and Bloater. It is interesting to note that large Lake Whitefish (> 300 mm) are not always caught (e.g., 2019 and 2020) when prior-year catches would suggest those fish should have been present in the area. This may point to interannual variation in large Lake Whitefish spatial distributions such that large individuals may not be present at our fixed stations each year and these larger fish may be less susceptible to our bottom trawl gear.

Rainbow Smelt age-1 density was 141 age-1 fish/ha in 2021 which was the highest estimate since the 2005 year-class. Age-1 Rainbow Smelt density averaged 42 age-1 fish/ha over the past 10-years and 74 age-1 fish/ha from 2001-2010 (Table 3).

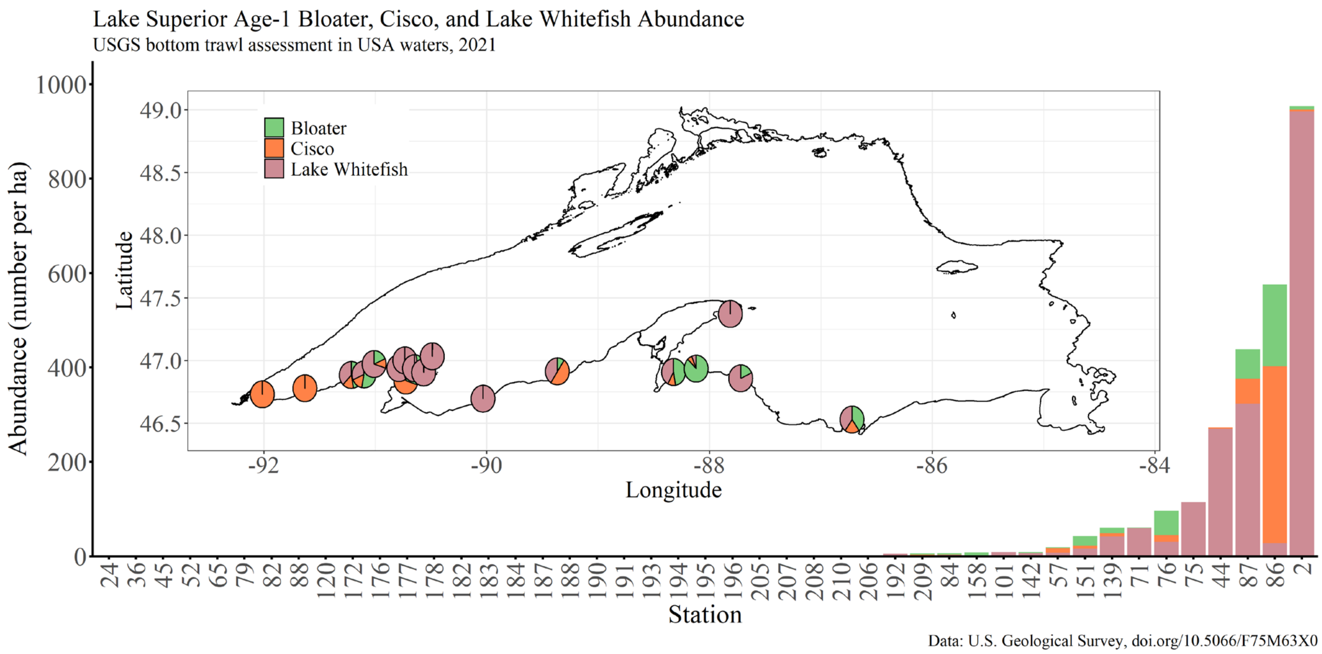
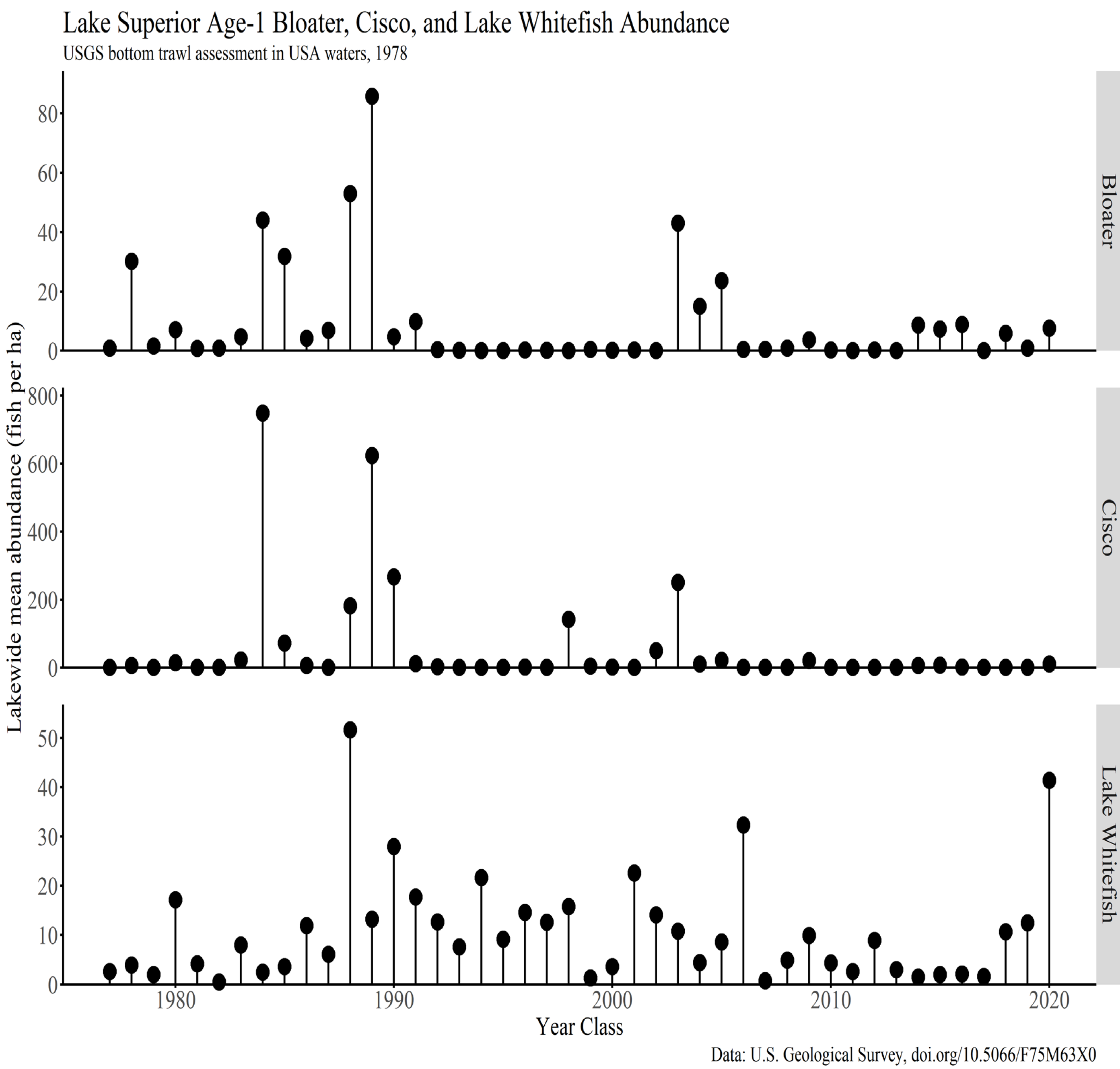


Figure 5. Estimated abundance (number/ha) of age-1 Bloater, Cisco, and Lake Whitefish at individual nearshore sampling stations in USA waters of Lake Superior in 2021. The inset map shows sampling station locations.

Figure 6. Estimated annual average cohort abundance (age-1 fish/ha) of Bloater, Cisco, and Lake Whitefish from 1978-2021 in nearshore USA waters of Lake Superior. Y-axis scales differ among species. The year-class is plotted by the year it hatched.



Summary

Over the 44-year history of the U.S. Geological Survey's Lake Superior nearshore fish community surveys in USA waters, total estimated biomass of demersal fish has reflected the survival of Bloater, Cisco, and Lake Whitefish populations to age-1+ as well as survival of Rainbow Smelt to age-3 or older. The lack of significant survival of Bloater and Cisco to age-1 over the past twenty years has resulted in lower adult prey fish biomass estimates than were observed during 1985-2000, when several large year-classes of Bloater and Cisco were present. Conversely, fish biomass estimates over the past two decades are larger than observed during the first seven years of this survey prior to the large 1984 Cisco year-class. Coregonine populations worldwide have experienced declines due to highly variable and low survival to age-1 (Lepak et al., 2017 (Lake Superior); Nyberg et al., 2001 (Sweden); Parks and Rypel, 2018 (northern Wisconsin) which have been associated with climate-induced changes in early-life stage environments (Nyberg et al., 2001). However, an underlying mechanism between changing lake environments and coregonine year-class strength has yet to be established. Low coregonine survival is disconcerting to fishery managers as coregonine fishes support valuable commercial fisheries, are native prey for a rehabilitated Lake Trout population, and play an important role in energy transfer throughout the lake (Stockwell et al. 2009; 2014).

Note: All GLSC sampling and handling of fish during research are carried out in accordance with guidelines for the care and use of fishes by the American Fisheries Society (https://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf).

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Table 1. *Fish species collected, native or non-native status for Lake Superior, the number of sites collected at, the number of individuals collected, and the average estimated density (fish/ha) and biomass (kg/ha) from a nearshore bottom trawl survey at 45 locations in USA waters of Lake Superior in 2021. Sampling locations shown in Figure 1.*

Common name	Scientific name	Native or exotic	Sites collected at	Individuals collected	Average density (fish/ha)	Average biomass (kg/ha)
Rainbow Smelt	*Osmerus mordax*	non-native	38	13063	203.6	0.5
Lake Whitefish	*Coregonus clupeaformis*	native	19	4475	67.5	3.2
Bloater	*Coregonus hoyi*	native	13	1597	24.8	1.5
Ninespine Stickleback	*Pungitius pungitius*	native	28	1110	15.4	0.0
Trout-Perch	*Percopsis omiscomaycus*	native	23	1008	13.7	0.0
Cisco	*Coregonus artedii*	native	14	717	13.8	0.3
Pygmy Whitefish	*Prosopium coulteri*	native	24	502	9.7	0.0
Slimy Sculpin	*Cottus cognatus*	native	26	230	4.7	0.0
Deepwater Sculpin	*Myoxocephalus thompsoni*	native	14	145	1.9	0.0
lean Lake Trout	*Salvelinus namaycush*	native	17	76	1.5	0.3
siscowet Lake Trout	*Salvelinus namaycush siscowet*	native	6	53	0.4	0.2
Spoonhead Sculpin	*Cottus ricei*	native	11	31	0.4	0.0
Longnose Sucker	*Catostomus catostomus*	native	3	20	0.2	0.2
Kiyi	*Coregonus kiyi*	native	2	17	0.2	0.0
Eurasian Ruffe	*Gymnocephalus cernuus*	non-native	4	7	0.1	0.0
Round Whitefish	*Prosopium cylindraceum*	native	1	5	0.1	0.0
Burbot	*Lota lota*	native	3	3	0.1	0.0
Shortjaw Cisco	*Coregonus zenithicus*	native	3	3	0.0	0.0
hatchery Lake Trout	*Salvelinus namaycush*	native	2	3	0.0	0.0
Blackfin Cisco	*Coregonus nigripinnis*	native	2	2	0.0	0.0
Johnny Darter	*Etheostoma nigrum*	native	1	2	0.0	0.0
Lake Sturgeon	*Acipenser fulvescens*	native	1	1	0.0	0.0
Shortnose Cisco	*Coregonus reighardi*	native	1	1	0.0	0.0

Table 2. *Average bottom trawl biomass (kg/ha) estimates for all species and for a few common prey fishes collected in an annually conducted nearshore bottom trawl survey in USA waters of Lake Superior, 1978-2021. Sculpin includes Slimy, Spoonhead, and Deepwater Sculpin. Mean and median total biomass includes all species. Other species includes Ninespine Stickleback, Trout-perch, Kiyi, Shortjaw Cisco, Pygmy Whitefish, Round Whitefish, Longnose Sucker, and lean, siscowet, and hatchery Lake Trout. Zero fish sites are the number of sites where no fish were collected.*

Year	Sites sampled	Zero fish sites	Species	Mean biomass	Median biomass	Bloater	Cisco	Lake Whitefish	Rainbow Smelt	Sculpin	Other species
1978	43	0	17	5.9	0.8	0.1	0.0	0.7	4.1	0.1	1.0
1979	49	0	17	6.3	2.3	0.4	0.1	1.3	2.2	0.2	2.4
1980	48	0	16	3.3	1.1	0.3	0.3	0.6	0.9	0.2	1.3
1981	46	0	19	2.7	0.4	0.4	0.4	0.7	0.2	0.2	1.0
1982	32	0	18	3.1	0.3	0.4	0.3	0.8	0.2	0.0	1.2
1983	50	0	19	2.5	0.5	0.4	0.2	0.2	0.9	0.1	0.8
1984	53	0	21	5.8	1.7	1.7	0.6	1.3	0.8	0.1	1.4
1985	53	0	19	14.8	3.5	2.7	6.5	2.1	1.3	0.1	2.1
1986	51	0	19	20.1	4.2	3.9	9.0	2.8	3.0	0.1	1.4
1987	53	0	16	13.3	1.4	2.6	5.7	2.0	1.8	0.1	1.2
1988	53	0	19	13.9	0.9	6.0	3.1	2.4	1.2	0.0	1.2
1989	53	0	18	16.7	1.8	2.2	5.9	6.5	0.8	0.1	1.3
1990	53	0	20	26.6	3.5	7.2	14.8	2.0	1.5	0.1	1.1
1991	52	0	19	19.0	1.8	0.8	13.3	3.1	0.6	0.1	1.1
1992	53	0	23	23.3	2.5	11.8	5.0	4.3	0.9	0.1	1.3
1993	52	0	20	21.1	2.9	6.1	7.8	4.9	0.9	0.1	1.4
1994	53	0	20	18.7	1.3	0.5	9.2	6.9	0.6	0.1	1.4
1995	53	0	23	18.1	2.2	0.7	6.1	7.8	2.0	0.1	1.5
1996	53	0	24	9.0	1.1	5.0	0.7	1.3	0.7	0.1	1.3
1997	50	0	24	8.4	0.8	0.9	1.9	3.8	0.7	0.0	1.1
1998	53	0	21	9.7	0.8	3.8	1.6	2.4	0.4	0.0	1.4
1999	46	0	21	12.1	1.1	4.0	4.3	2.1	0.9	0.0	0.8
2000	49	0	22	8.1	0.6	1.4	3.6	2.2	0.3	0.0	0.5
2001	50	0	25	7.2	0.7	1.0	1.0	3.8	0.4	0.0	0.8
2002	50	0	24	6.9	0.3	0.9	2.5	2.6	0.2	0.0	0.7
2003	45	0	22	6.6	0.8	1.5	1.0	3.3	0.2	0.0	0.5
2004	42	0	23	8.2	1.6	1.9	2.5	2.8	0.2	0.0	0.8
2005	34	0	20	11.2	2.1	1.7	2.3	5.6	0.4	0.0	1.1
2006	31	0	19	9.1	0.7	2.9	2.4	2.5	0.6	0.0	0.6
2007	34	0	23	5.9	0.4	1.2	0.3	2.7	0.7	0.0	0.9
2008	33	0	21	5.9	0.7	0.2	0.5	4.0	0.3	0.0	0.9
2009	39	5	18	4.0	0.1	1.8	0.5	0.1	0.4	0.0	1.2

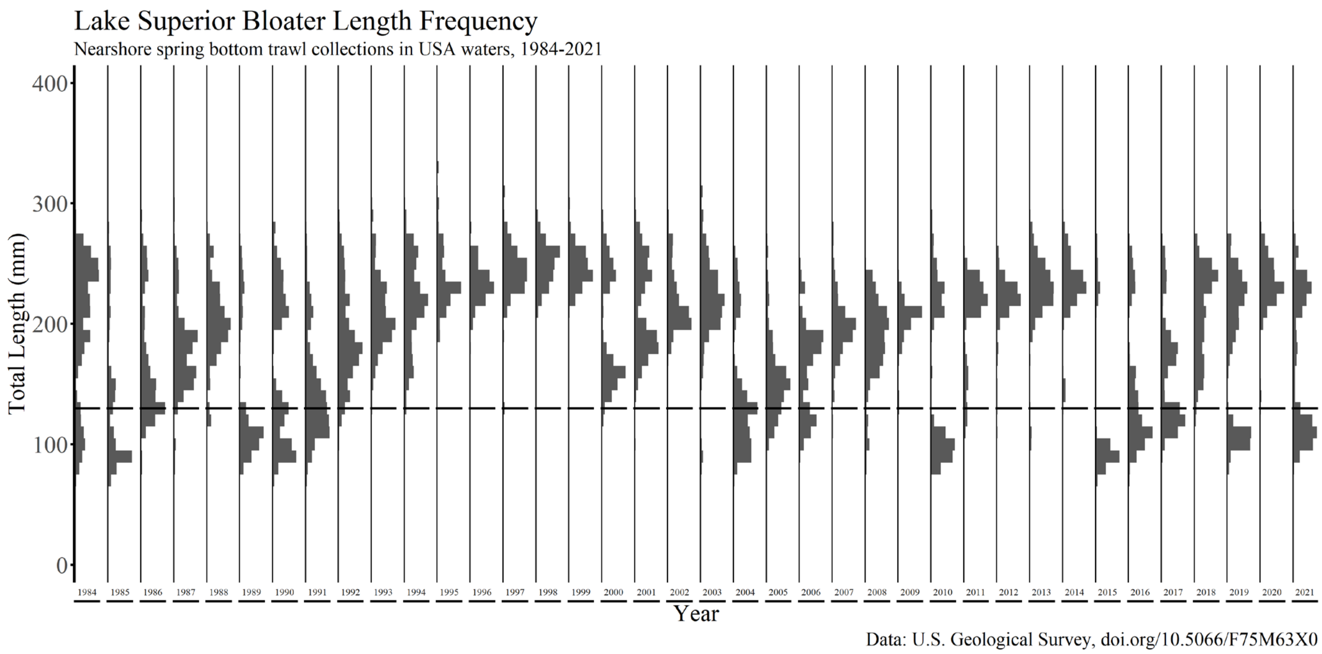
2010	51	4	21	1.6	0.2	0.2	0.4	0.3	0.3	0.0	0.3
2011	50	5	20	3.4	0.2	0.9	0.5	1.2	0.3	0.0	0.6
2012	50	14	25	1.2	0.2	0.4	0.0	0.2	0.2	0.0	0.4
2013	47	2	26	6.8	0.5	0.8	0.9	4.2	0.2	0.0	0.8
2014	49	3	24	8.0	0.8	0.7	0.5	5.6	0.3	0.0	0.9
2015	46	2	20	2.2	0.0	0.6	0.3	0.8	0.1	0.0	0.4
2016	46	4	19	1.8	0.1	0.6	0.3	0.5	0.2	0.0	0.3
2017	47	4	23	3.7	0.5	0.7	0.2	1.4	0.7	0.0	0.7
2018	47	9	20	3.8	0.1	0.2	0.2	2.2	0.6	0.0	0.5
2019	47	7	22	5.5	0.6	1.0	0.1	3.1	0.3	0.0	0.9
2020	11	1	17	10.5	3.3	6.2	0.9	2.3	0.3	0.0	0.8
2021	45	6	21	6.3	0.8	1.4	0.3	3.2	0.5	0.0	0.8

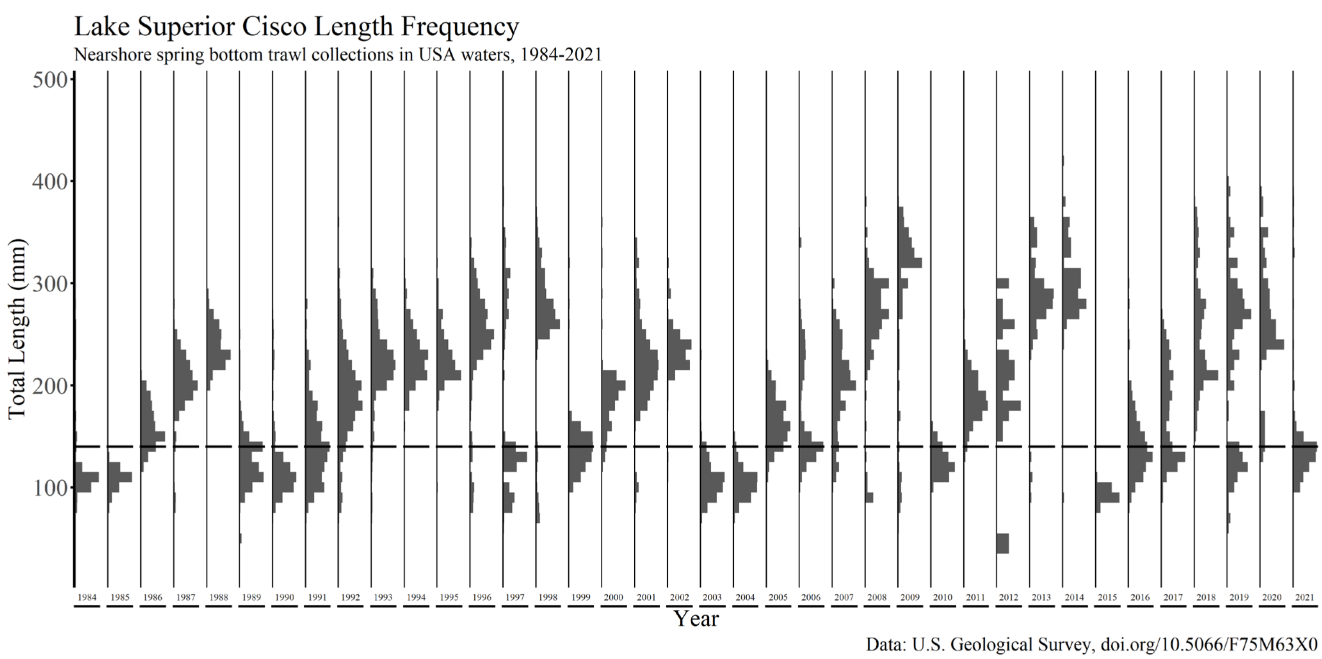
Table 3. Age-1 Bloater, Cisco, Lake Whitefish, and Rainbow Smelt densities (fish/ha) in an annually conducted nearshore bottom trawl survey in USA waters of Lake Superior. Age-1 fish were defined by species-specific lengths: Cisco <140 mm, Bloater <130 mm, Lake Whitefish <160 mm, and Rainbow Smelt <100 mm.

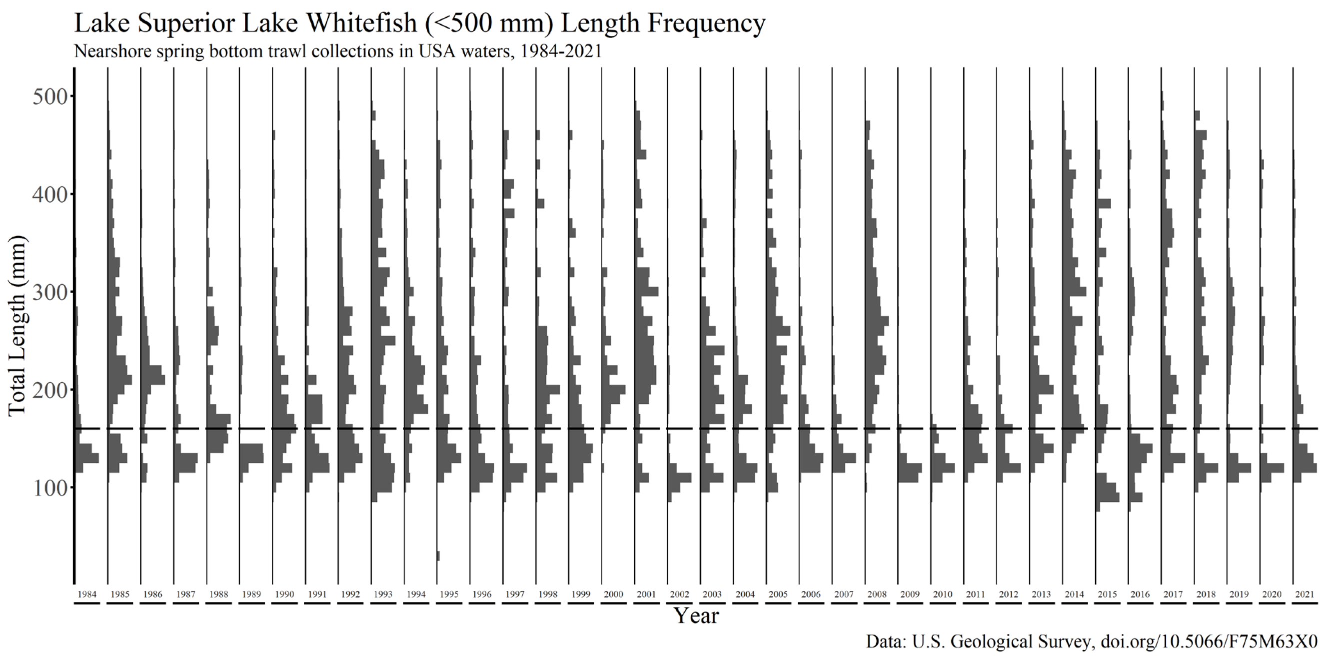
Collection year	Year-class	Sites	Bloater	Cisco	Lake Whitefish	Rainbow Smelt
1978	1977	43	0.8	0.0	2.6	95.8
1979	1978	49	30.1	6.3	3.9	234.1
1980	1979	48	1.6	0.1	2.0	96.8
1981	1980	46	7.1	14.1	17.1	110.9
1982	1981	32	0.8	0.2	4.2	63.8
1983	1982	50	0.8	0.1	0.5	103.6
1984	1983	53	4.7	21.8	8.0	223.7
1985	1984	53	44.0	748.0	2.5	149.5
1986	1985	51	31.7	71.6	3.6	156.3
1987	1986	53	4.2	5.4	11.9	273.8
1988	1987	53	6.9	0.5	6.1	155.3
1989	1988	53	53.0	181.5	51.6	278.4
1990	1989	53	85.8	622.9	13.2	329.1
1991	1990	52	4.7	267.0	27.9	143.2
1992	1991	53	9.8	11.8	17.7	192.0
1993	1992	52	0.4	1.9	12.7	153.7
1994	1993	53	0.1	0.5	7.6	104.3
1995	1994	53	0.0	0.8	21.6	435.0
1996	1995	53	0.0	0.6	9.2	125.9
1997	1996	50	0.2	1.4	14.6	216.9
1998	1997	53	0.1	0.5	12.6	84.1
1999	1998	46	0.0	141.5	15.8	208.4
2000	1999	49	0.5	3.8	1.3	39.7
2001	2000	50	0.2	1.2	3.6	56.6
2002	2001	50	0.2	0.9	22.6	58.0
2003	2002	45	0.1	49.4	14.1	44.7
2004	2003	42	43.0	250.6	10.8	52.2
2005	2004	34	15.0	10.9	4.4	44.0
2006	2005	31	23.6	21.6	8.6	183.9

2007	2006	34	0.5	0.4	32.3	78.3
2008	2007	33	0.4	0.4	0.7	60.7
2009	2008	39	0.9	0.3	4.9	106.3
2010	2009	51	3.7	20.6	9.9	60.5
2011	2010	50	0.3	0.1	4.3	31.8
2012	2011	50	0.0	0.1	2.6	10.3
2013	2012	47	0.3	0.2	8.9	49.7
2014	2013	49	0.1	0.0	3.0	22.8
2015	2014	46	8.6	5.9	1.5	33.1
2016	2015	46	7.3	7.0	2.0	60.6
2017	2016	47	8.8	1.7	2.1	81.5
2018	2017	47	0.0	0.0	1.6	67.3
2019	2018	47	5.9	0.5	10.7	59.6
2020	2019	11	0.9	0.1	12.5	5.1
2021	2020	45	7.6	10.6	41.3	140.5

Appendix A. Length-frequency distributions of Cisco, Bloater and Lake Whitefish in spring bottom trawl collections in USA waters of Lake Superior, 1984-2021. Note that Lake Whitefish data are for fish <500 mm, as Lake Whitefish >500 mm are known to be less vulnerable to our bottom trawl. The horizontal dashed lines are the estimated total length for age-1 fish in May-July; Cisco ≤140 mm, Bloater ≤130 mm, and Lake Whitefish ≤160 mm.







Lake Superior Lake Whitefish (<500 mm) Length Frequency
Nearshore spring bottom trawl collections in USA waters, 1984-2021
Total Length (mm)
500
400
300
200
100
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Year
Data: U.S. Geological Survey, doi.org/10.5066/F75M63X0