Status and Trends in the Lake Superior Fish Community, 2022

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Abstract

In 2022, the Lake Superior fish community was sampled with daytime bottom and surface trawls at 71 nearshore locations in May-June and 35 offshore locations in July, and at 51 Coordinated Science and Monitoring Initiative (CSMI) locations in July-October with bottom trawls, surface trawls, mid-water trawls and acoustics that were previously sampled in 2011 and 2016. Nearshore bottom trawls collected 11,603 fish from 25 species or morphotypes. Nearshore mean biomass was 1.6 kg per ha which was one of the lowest biomass estimates over survey's 45-year history. Offshore bottom trawls collected 13,876 fish from 11 species or morphotypes. Offshore mean biomass was 5.1 kg per ha, which was less than the annual average since 2011 of 6.5 kg per ha. Recruitment, as measured by age-1 densities, was near zero for Bloater (*Coregonus hoyi*), Cisco (*C. artedi*), and Kiyi (*C. kiyi*), 2 age-1 fish per ha for Lake Whitefish (*C. clupeaformis*) and 77 age-1 fish for Rainbow Smelt (*Osmerus mordax*). All were less than the long-term averages. Sampling at the CSMI locations collected 26 species and morphotypes. The most abundant species' lakewide were Deepwater Sculpin (all years), young-of-year ciscoe (Bloater, Cisco, and Kiyi, 2022), and Rainbow Smelt (2011 and 2016). Cisco had the highest estimated lakewide biomass in

2011 and 2022 and siscowet Lake Trout had the highest estimated lakewide biomass in 2016. Native species were more abundant than invasive species by numbers (80, 65, and 92%) and biomass (94, 93, 96%) in 2011, 2016, and 2022, respectively.

Total lakewide benthic fish biomass declined from 47 thousand metric tons in 2011 to 29 thousand metric tons in 2016 and increased to 33 thousand metric tons in 2022. Total lakewide pelagic fish biomass declined from 61 thousand metric tons in 2011 to 25 thousand metric tons in 2016 and increased to 54 thousand metric tons in 2022. The most unexpected result from our sampling in 2022 was the 2 billion age-0 ciscoe estimate from the mid-water trawl and acoustic sampling in August-October. These fish were broadly distributed across the lake, being collected at 53 of the 54 locations, and their population estimates were highest in the depths >100 m. The factors underlying the survival of these ciscoes into late summer in 2022 as compared to previous years have not been identified, but our annual population surveys of larval ciscoes suggests that lake conditions in June and July may have differed from previous years and enhanced survival. In 2022, ciscoe larval densities in May were lower than average (likely due to a cold winter and spring that delayed hatching), June densities were similar to previous years, and July density estimates were more than double that of any previous year's estimate.

The data associated with this report are currently under review and will be publicly available in 2023. Previous versions of the data may be accessed at U.S. Geological Survey, Great Lakes Science Center, 2019, Great Lakes Research Vessel Operations 1958-2018. (ver. 3.0, April 2019): U.S. Geological Survey data release, https://doi.org/10.5066/F75M63X0. Please direct questions to our Data Management Librarian, Sofia Dabrowski, at sdabrowski@usgs.gov.

Introduction

The U.S. Geological Survey (hereafter USGS), Great Lakes Science Center (hereafter GLSC), Lake Superior Biological Station , based in Ashland, Wisconsin conducts two recurring lakewide fish community surveys: 1) annual daytime surface and bottom trawl sampling in nearshore (~15-80 m depths) and offshore (~80-300 m depths) waters and 2) quinquennial surface, benthic, and pelagic fish trawling and hydroacoustic sampling based on a spatially-balanced random probability study design that enables depth zone and lakewide mass estimates to be made for major chemical constituents, biological taxa, and trophic levels. Both surveys provide data for assessing trends in species occurrence, relative abundance, and biomass for principal fishes.

The nearshore bottom trawl survey has been conducted annually since 1978 in USA waters, and since 1989 in USA and Canadian waters. In 2020 only nearshore locations in Management Unit WI-2 (the Apostle Islands) were sampled and in 2021 only nearshore locations in USA waters were sampled due to COVID restrictions. The primary purpose of the nearshore bottom trawl survey is to report on population biomass estimates for all sizes of common fish species and age-1 density estimates for selected commercial and recreational fish species (Cisco, Bloater, Kiyi, Lake Whitefish, Rainbow Smelt; scientific names are provided in Table 1) as indices of year-class strength. The offshore bottom trawl survey has been conducted annually since 2011 in USA and Canadian waters with the purpose of assessing fish populations in waters >80 m. Deepwater Sculpin, Kiyi, and siscowet Lake Trout are the primary species encountered in offshore habitats. Offshore sampling locations are quinquennial sampling locations with a bathymetric depth >~80 m. Surface trawling has occurred annually during the nearshore and offshore surveys since 2014, except for 2020 and 2021 due to COVID restrictions. The purpose of surface trawling is to collect larval *Coregonus* fishes as a measure of species occurrence and relative abundance in support of evaluating factors influencing their survival to age-1. Larval *Coregonus* fishes have been identified using genomics since 2019 (Ackiss et al. 2020).

The quinquennial benthic and pelagic fish surveys began in 2011 as part of the Laurentian Great Lakes Cooperative Science and Monitoring Initiative (CSMI) that emphasizes work on each of the Great Lakes on an annual rotation (https://www.epa.gov/great-lakes-monitoring/cooperative-science-and-monitoring-initiative-csmi). In Lake Superior, the U.S. Geological Survey has focused their CSMI efforts on addressing two Lake Superior Partnership priorities: 1) the Great Lakes Fishery Commission's Fish Community Objective for prey fish, a "self-sustaining assemblage of prey dominated by indigenous species at population levels capable of supporting desirable populations of predators and a managed commercial fishery" (Horns et al. 2003) and 2) what are the trophic relationships among species (Pratt et al. 2016). The U.S. Environmental Protection Agency (EPA) and the USGS collaborated on the design of the study and shared data collection, analyses, and reporting efforts. The EPA is responsible for reporting on lower trophic level attributes, including, nutrients, zooplankton, *Mysis*, and benthic invertebrates, and the USGS is responsible for reporting on the fish community. This report is structured in two parts: 1) an annual overview of benthic prey fish populations from nearshore and offshore surveys and 2) a comparison of benthic and pelagic fish population metrics from CSMI surveys conducted in 2011, 2016, and 2022.

Annual surveys

Methods

Nearshore bottom trawl fish collections

Nearshore locations are located around the perimeter of the lake (Figure 1). Locations were established in the USA in 1978 and in Canada in 1989. Locations may be sampled with slight annual variations due to commercial fishing operations, mechanical issues, or weather. In 2022, 71 locations were sampled between May 18 and June 16. At each location, a single bottom trawl tow was conducted using a 12-m Yankee bottom trawl with either a chain or 6-inch rubber roller foot rope. The roller foot rope was used at locations with steeper, rockier bottoms to reduce snagging. The median start and end depths for bottom trawl tows were 17 m (range 11-29 m) and 55 m (range 8-133 m), respectively. The median distance trawled was 1.6 km (range 0.4-4.0 km) at a speed of ~4.0 km per h. Bottom trawl fishing area was calculated based on a fixed trawl wing spread of 7.8 m and the distance the trawl was on the lake bottom as determined using a Marport trawl mensuration system (Marport.com) and the Research Vessel Kiyi's global positioning system.

Offshore bottom trawl fish collections

Offshore locations are a subset of CSMI locations where bathymetric depths were >~80 m (Figure 1). Locations were selected in 2011 and have been sampled annually thereafter, except for 2020 and 2021. In 2022, 35 locations were sampled during daylight hours from July 6-29. A single bottom trawl tow was conducted at each location using a 12-m Yankee bottom trawl with a chain foot rope. All tows were made on-contour for 20 minutes. Station depths ranged from 75 to 297 m. The median trawl distance was 1.3 km (range 1.1-1.4 km) at a speed of ~4.0 km per h. Bottom trawl fishing area was calculated based on a fixed trawl wing spread of 7.8 m and the distance the trawl was on the bottom as determined using a Marport trawl mensuration system (Marport.com) and the Research Vessel Kiyi's global positioning system.

Surface trawl fish collections

Surface trawling was conducted at all nearshore and offshore bottom trawl locations using a paired one-square-meter 500-micron mesh neuston net (model 9550, Sea-Gear Corporation, Melbourne, Florida). The bottom of the net frame was fished ~0.5 m below the lake surface for 10 minutes at ~4.0 km per h for ~0.7 km as determined from the Research Vessel Kiyi's global positioning system.

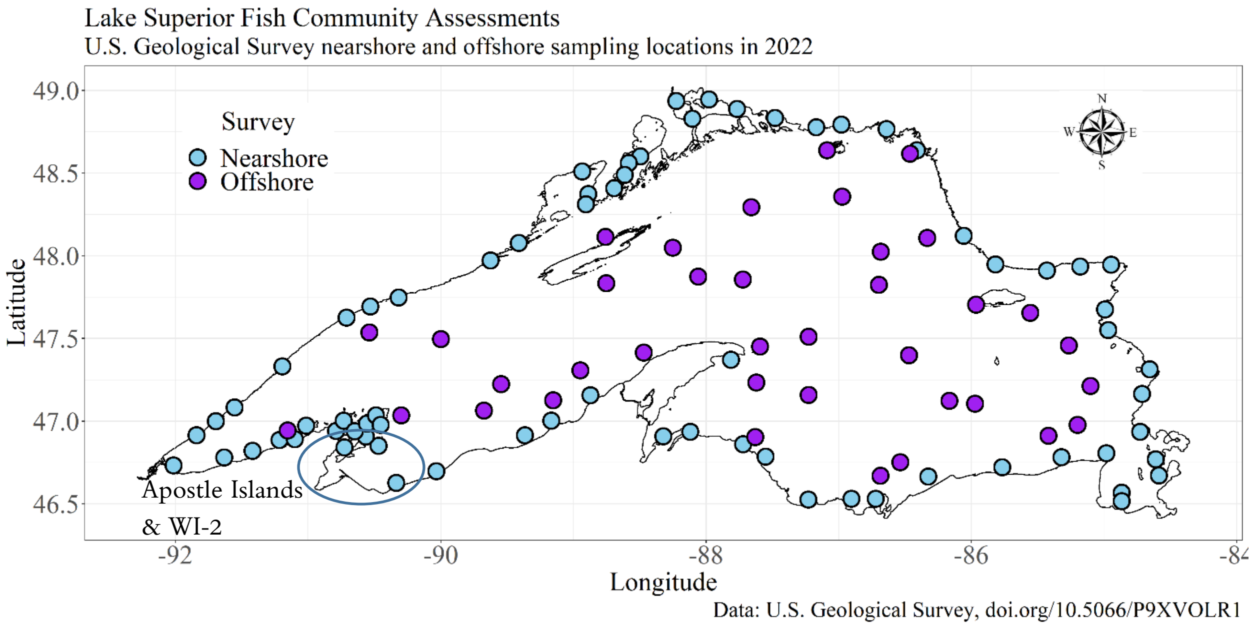

Figure 1. Location of 71 nearshore (bathymetric depths ~<80 m) and 35 offshore (bathymetric depths ~>80 m) Lake Superior sampling locations sampled in 2022. Fish collections at nearshore and offshore sampling stations included bottom trawls for benthic fish and surface trawls for larval fish. Further location details provided in Appendix 1.

Catch processing

Fish collected in bottom trawls were sorted by species, counted, and weighed in aggregate to the nearest gram. Total length was measured for a maximum of 50 individuals per species per trawl. Lengths from these individuals were extrapolated to the entire catch when more than 50 individuals were collected. Relative density (fish per ha) and biomass (kg per ha) were estimated by dividing sample counts and aggregate weights by the area swept by each trawl tow (ha). For annual nearshore bottom trawl collections, biomass estimates are reported for all species combined and individually for Bloater, Cisco, Lake Whitefish, and Rainbow Smelt, and combined for Sculpin species (Slimy-, Spoonhead-, and Deepwater Sculpin). A composite estimate is also reported for less-common (species collected in low numbers) species. For offshore bottom trawl collections, biomass estimates are reported for all species combined and individually for Deepwater Sculpin, Kiyi, and siscowet Lake Trout. Age-1 year-class strength was estimated as the mean nearshore lakewide density of age-1 fish as determined by total length; Cisco <140 mm (Dryer and Beil 1964), Bloater <130 mm (Dryer and Beil 1968), Lake Whitefish <160 mm, and Rainbow Smelt <100 mm, and for offshore collected Kiyi <130 mm (Lepak et al. 2017). These age-total length cutoffs were based on past published and unpublished age estimates, are approximate, and are known to vary among years.

Larval fish collected in surface trawls were immediately removed from the nets and identified as *Coregonus*, Deepwater Sculpin, Rainbow Smelt, or Pacific Salmon based on morphological characters (Hinrichs 1979; Auer 1982). *Coregonus* larvae were counted and stored in 20 ml polyethylene scintillation vials filled with 90% ethanol. Other larval species were noted as being present and discarded. Larval total length was measured to the nearest 0.1 mm for up to 25 individuals from each sample in the USGS laboratory several months later. Larval fish densities were calculated based on the width of the sampling nets and the distance towed. Data are not reported for 2020 and 2021 as fewer locations were sampled due to COVID restrictions.

Results

Nearshore Fish Collections

A total of 11,603 individual fish from 25 species or morphotypes were collected across 71 locations (Table 1). The number of species collected at each location ranged from zero to 11, with a median of 4 species. Estimated fish biomass at individual locations ranged from zero to 20.5 kg per ha (Figure 2). Individual locations with the highest biomass in 2022 were 86-Basswood Island, 2-Stockton Island, and 151-Bark Point located in the Apostle Islands in Wisconsin and locations 406-George's Point and 408-Northeast Black Bay which are near Thunder Bay, Ontario (Figure 2, Appendix 1). Average lakewide fish biomass across all locations was 1.6 kg per ha, which was one of the lowest lakewide biomass estimates over the survey's 45-year history (Figure 3). Average lakewide biomass in 2022 was highest for Lake Whitefish (0.4 kg per ha), Rainbow Smelt (0.3 kg per ha), and Bloater (0.2 kg per ha), which were all less than the long-term averages for these species (Table 2).

Other species collected in nearshore bottom trawl tows in 2022 (number collected) included Ninespine Stickleback (1,092), Trout-perch (736), Pygmy Whitefish (243), Slimy Sculpin (156), Deepwater Sculpin (89), Spoonhead Sculpin (38), lean Lake Trout (36), Cisco (28), Longnose Sucker (22), Ruffe (17), Splake (14), siscowet Lake Trout (8), Kiyi (4), Johnny Darter (2), Burbot (2), Threespine Stickleback (2), and one each of Lake Sturgeon, Brown Trout, Yellow Perch, Central Mudminnow, and Pink Salmon. Scientific names and collection summaries are provided for all species in Table 1.

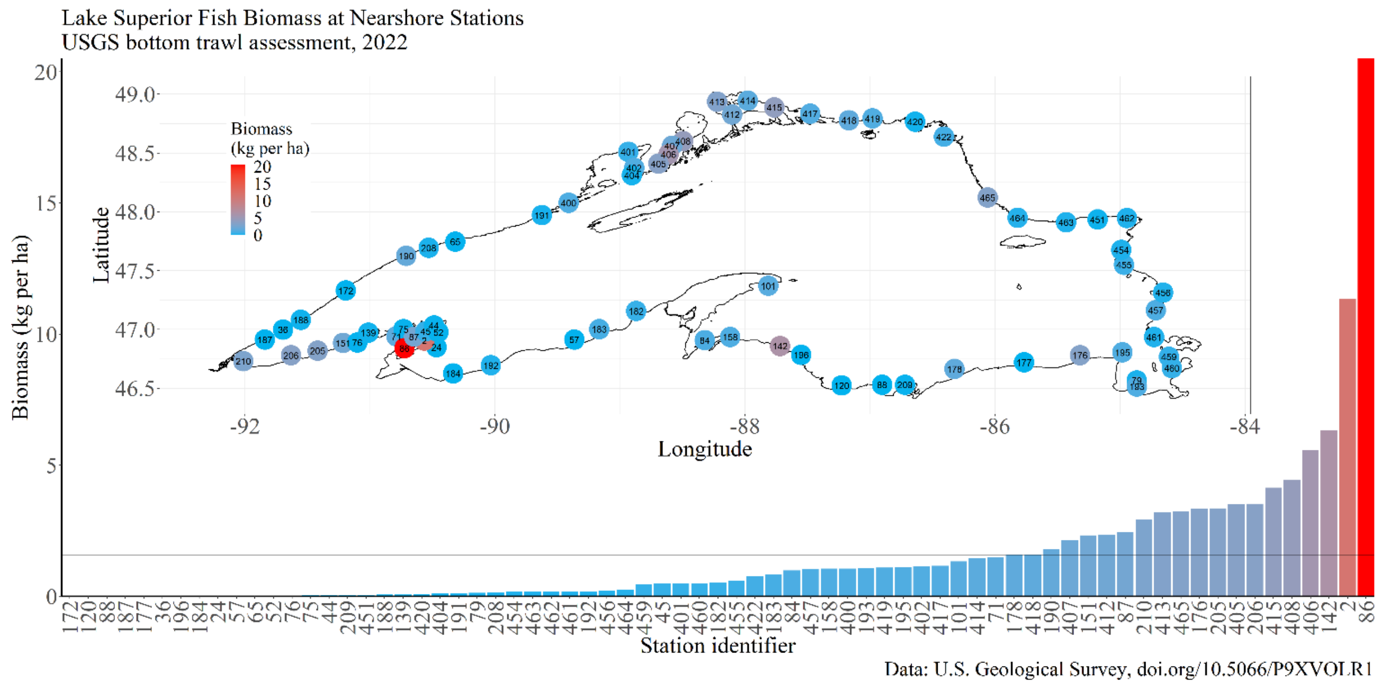

Figure 2. Estimated total fish biomass (kg per ha) at 71 sampling locations in nearshore (bathymetric depths ~<80 m) USA and Canada waters of Lake Superior in 2022 (Appendix 1). The horizontal line is the 2022 average biomass across all locations (1.6 kg per ha). The inset figure shows sampling locations and their estimated biomass (kg per ha) in 2022.

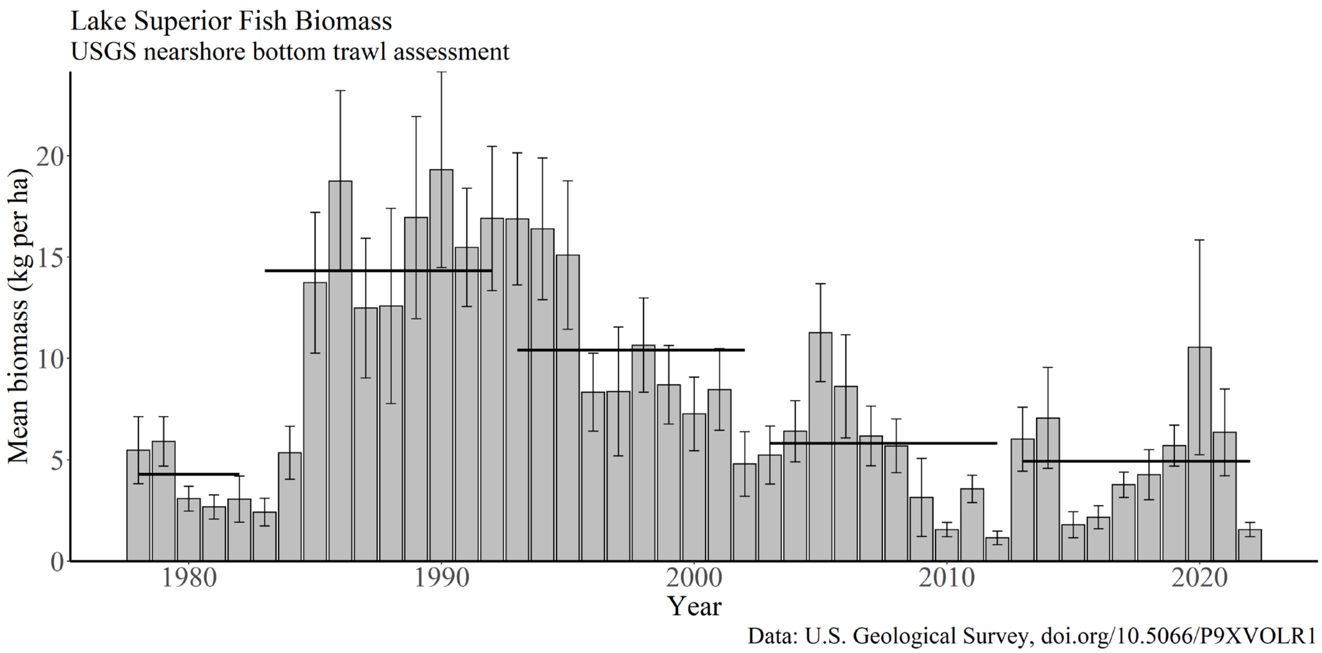

Figure 3. Lake Superior annual (mean ± standard error) total fish biomass estimates for all fish species collected in bottom trawl tows from 1978-2022. Horizontal lines are 10-year averages across different periods. In 2020 only 11 locations were sampled in WI-2 in the Apostle Islands (Figure 1, Appendix 1) and in 2021 only USA waters were sampled, due to COVID restrictions. The number of locations sampled in each year is presented in Table 2.

Year-Class Strength

The number of age-1 fish per ha has been used historically as a measure of year-class strength. Few age-1 Bloater, Cisco, and Lake Whitefish were caught in 2022. Age-1 Bloater were caught at 5 locations, Cisco at 3 locations, and Lake Whitefish at 8 Locations (Figure 4). Age-1 abundance estimates for Bloater and Cisco were near zero, Lake Whitefish was 2 age-1 fish per ha, and age-1 Rainbow Smelt densities were 78 age-1 fish per ha (Table 3).

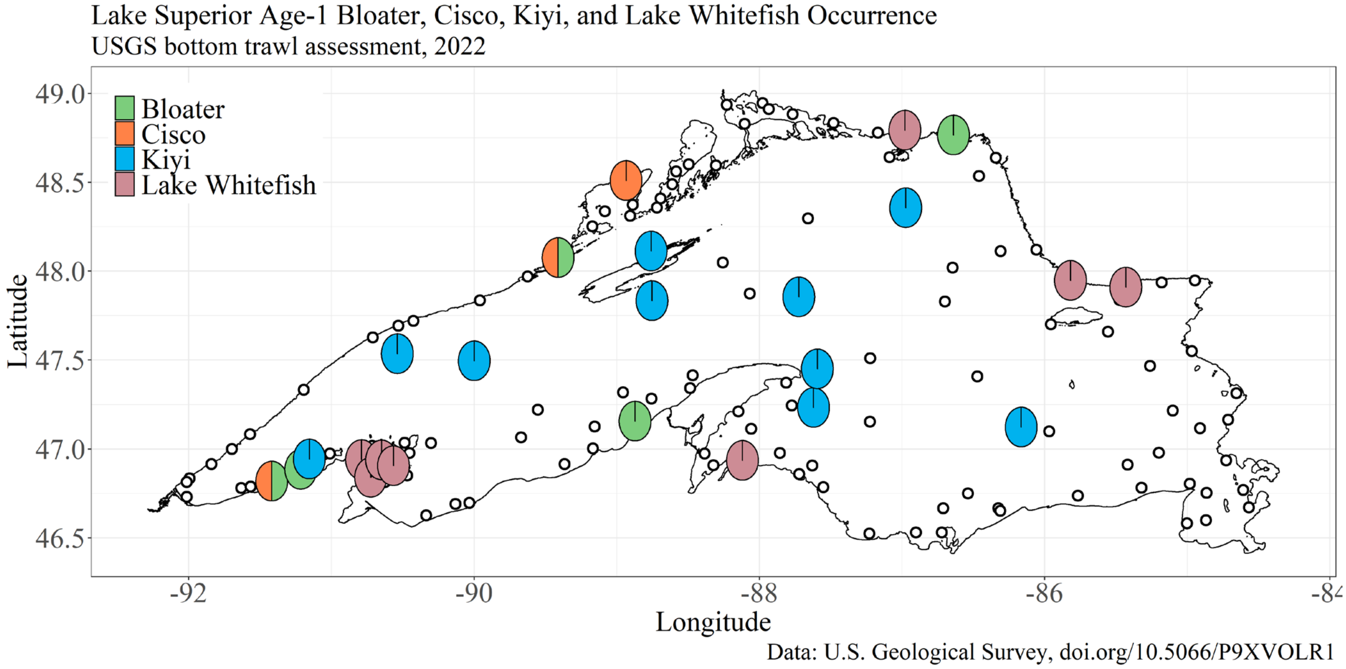

Figure 4. Occurrence of age-1 Bloater, Cisco, Kiyi, and Lake Whitefish at individual nearshore (bathymetric depths ~<80 m) and offshore (bathymetric depths ~>80 m) sampling locations in Lake Superior in 2022. Open circles are locations where no age-1 Bloater, Cisco, Kiyi, or Lake Whitefish were collected.

Annual Offshore Fish Collections

Thirty-five offshore locations were sampled in 2022 from which 13,876 fish from 11 species or morphotypes were collected (Table 1). Estimated fish biomass at individual locations ranged from 0.6 to 18.8 kg per ha (Figure 5). Individual locations with the highest biomass in 2022 were locations 2139, a 175 m deep location near the Slate Islands, Canada, 2114, a 120 m deep location near the northeast tip of the Keweenaw Peninsula, and 2040, a 90 m deep location near Bark Point, Wisconsin (Figure 5, Appendix 1). Average lakewide fish biomass across all locations was 5.1 kg per ha, which was less than the long-term average of 6.5 kg per ha.

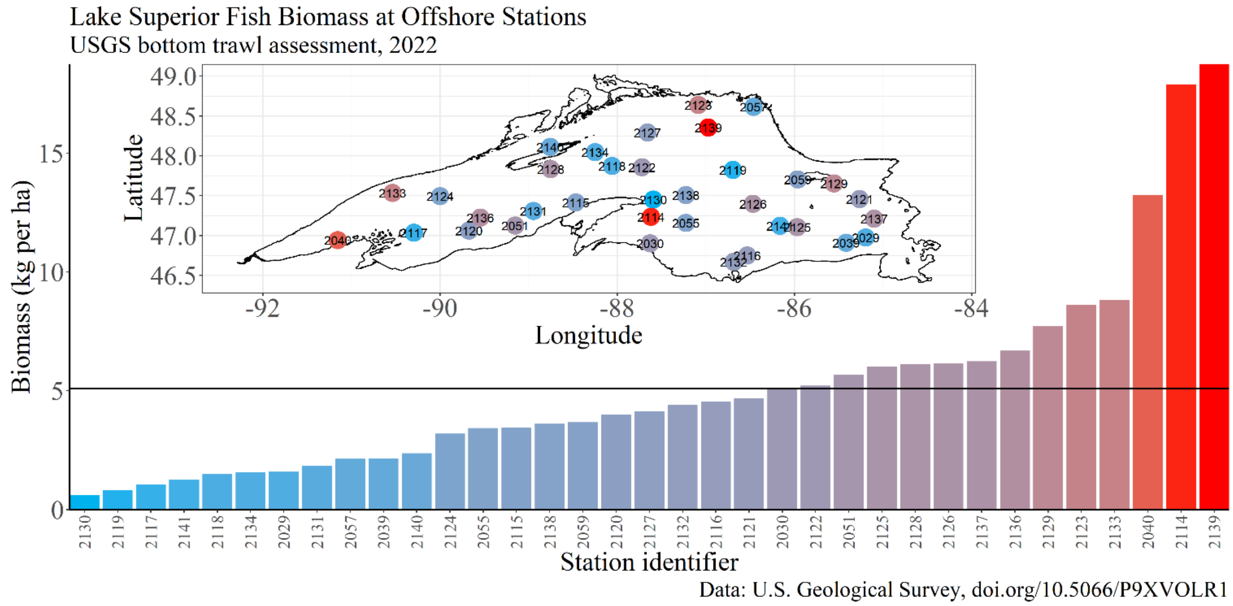

Figure 5. Estimated biomass (kg per ha) at individual offshore locations in Lake Superior in 2022. The horizontal line is the 2022 lakewide offshore average biomass (5.1 kg per ha). The inset figure shows sampling locations and their estimated biomass (kg per ha) in 2022. See Appendix 1 for location details.

Deepwater Sculpin, Kiyi, and siscowet Lake Trout made up 98% of the total number of individuals and 91% of the biomass collected in offshore waters (Table 1). Bloater and Pygmy Whitefish were the most common other species collected (Table 1), but these species were limited to depths <100 m. Deepwater Sculpin offshore biomass averaged 1.7 kg per ha in 2022, which was similar to that observed in the last complete offshore survey in 2019 and similar to the 2011-2019 average of 1.9 kg per ha (Figure 6). Kiyi offshore biomass averaged 0.5 kg per ha in 2022, which was the lowest estimate of the time series (Figure 6). Age-1 Kiyi were collected at 10 of 35 locations. Lakewide age-1 density at offshore sites was 0.3 fish per ha in 2022 which was less than the 2011-2019 average of 5 fish per ha (Table 3). Siscowet Lake Trout biomass averaged 2.3 kg per ha in 2022, which was less than the 2011-2019 average of 3 kg per ha (Figure 6).

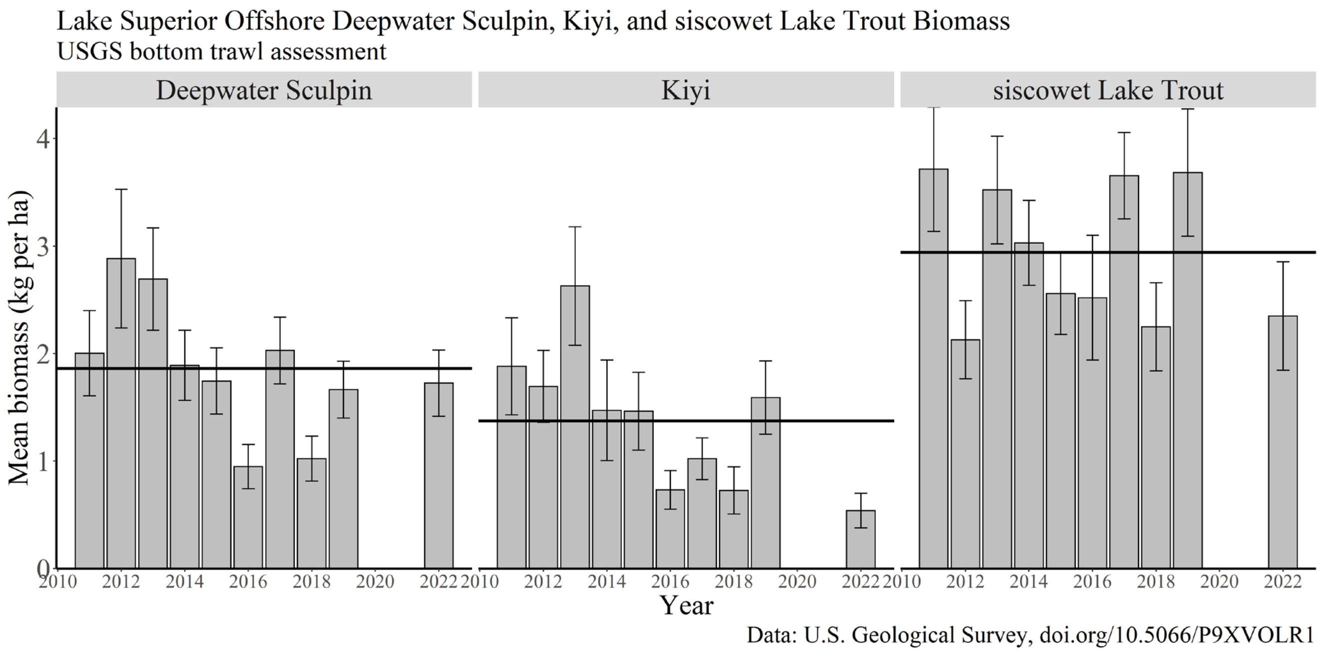

Figure 6. Annual Lake Superior offshore (bathymetric depths ~>80 m) biomass estimates (mean lakewide kg per ha ± standard error) for Deepwater Sculpin, Kiyi and siscowet Lake Trout from 2011-2022. Annual offshore sampling locations were not sampled in 2020 and 2021, due to COVID restrictions. Mean biomass of the time series shown as a solid horizontal line.

Surface trawl fish collections

A total of 11,295 larval *Coregonus* individuals were collected from May-July 2022. In 2022, nearshore mean larval *Coregonus* densities were 892 fish per ha in May and 704 fish per ha in June and offshore densities were 505 fish per ha in July (Figure 7). Average 2022 larval *Coregonus* densities were less in May and similar in June to previous estimates, and July density estimates were more than double that of any previous year's estimate (range 41-230 fish per ha).

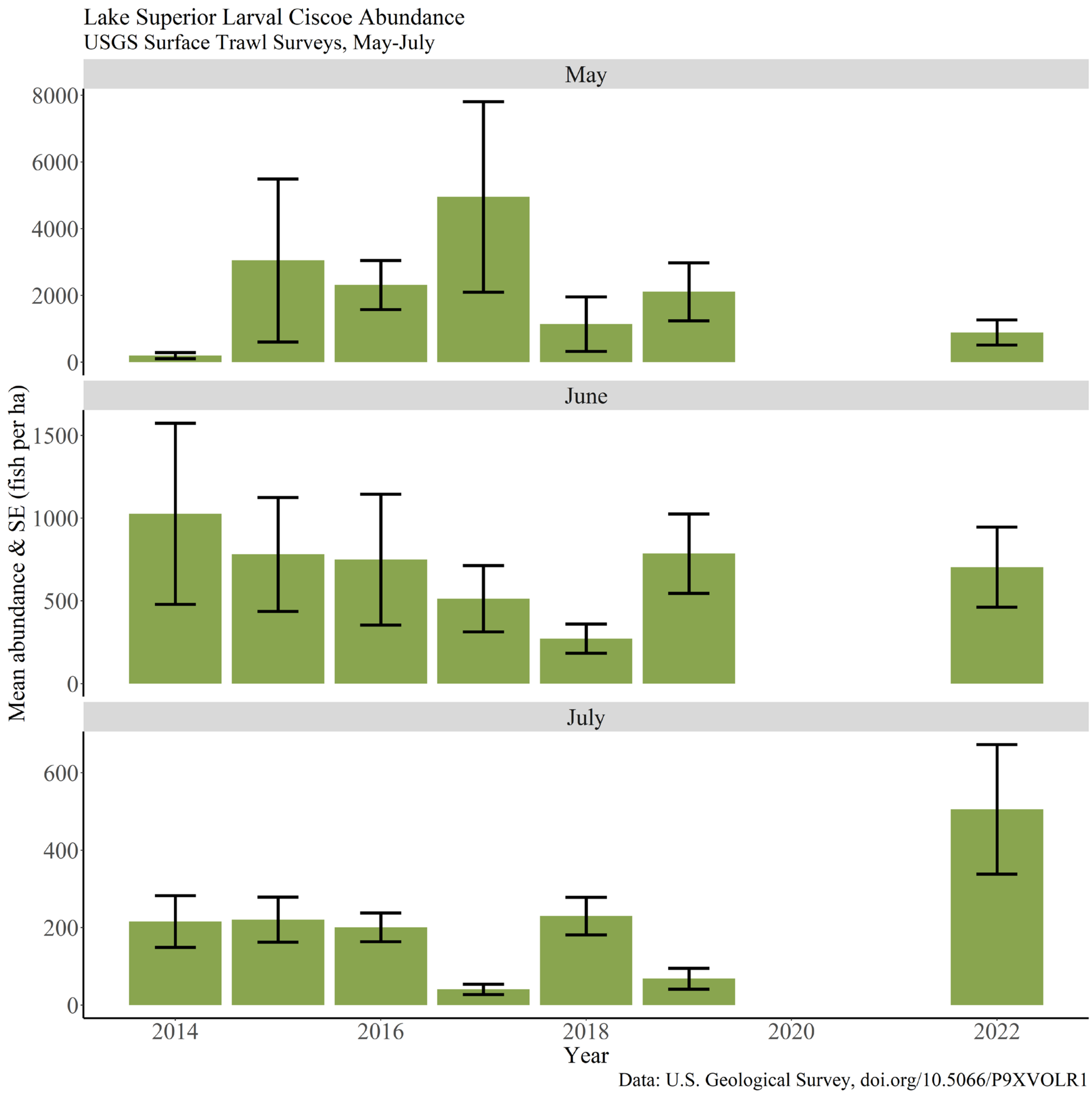

Figure 7. Larval Coregonus density estimates (fish per ha ± standard error) for May, June, and July in Lake Superior from 2014-2022, sans 2020 and 2021, due to COVID restrictions. ND = no data. Sampling locations in May and June were from the nearshore (bathymetric depths ~<80 m) and from the offshore (bathymetric depths ~>80 m) survey in July. Sampling locations are shown in Figure 1 and location details are provided in Appendix 1. Note different y-axis scales.

Summary

Over the 45-year history of the USGS Lake Superior nearshore fish community surveys, total estimated biomass of benthic 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 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, total prey fish biomass estimates over the past two decades were similar or 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. Coregonine survival is monitored 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. 2014). The combination of our near- and offshore bottom and surface trawl surveys provide a lakewide picture of the status and trends of the Lake Superior fish community susceptible to these trawls, particularly with respect to describing larval and age-1 *Coregonus* species population metrics and offshore Deepwater Sculpin, Kiyi, and siscowet Lake Trout populations. Our plan is to continue these surveys into the future and adapt them as needed to address emerging issues.

Table 1. *Summary of Lake Superior 2022 nearshore and offshore fish collections. Shown are the species collected, the number of locations collected at, the number of individuals collected, and the average estimated density (fish per ha) and biomass (kg per ha) from 71 nearshore and 35 offshore locations in Lake Superior in 2022. Sampling locations are shown in Figure 1.*

		Nearshore survey				Offshore survey			
Common name	Scientific name	Locations caught	Number caught	Density number per ha	Biomass kg per ha	Locations caught	Number caught	Density number per ha	Biomass kg per ha
Rainbow Smelt	*Osmerus mordax*	64	8421	110.2	0.3	1	1	0.0	0.0
Ninespine Stickleback	*Pungitius pungitius*	50	1092	12.5	0.0	6	7	0.2	0.0
Trout-Perch	*Percopsis omiscomaycus*	39	736	7.5	0.0	0	0	0.0	0.0
Lake Whitefish	*Coregonus clupeaformis*	18	365	3.5	0.4	0	0	0.0	0.0
Bloater	*Coregonus hoyi*	12	321	2.7	0.2	10	149	4.0	0.4
Pygmy Whitefish	*Prosopium coulteri*	25	243	2.7	0.0	7	38	1.1	0.0
Slimy Sculpin	*Cottus cognatus*	32	156	1.7	0.0	8	13	0.4	0.0
Deepwater Sculpin	*Myoxocephalus thompsoni*	11	89	1.0	0.0	33	13033	362.3	1.7
Spoonhead Sculpin	*Cottus ricei*	8	38	0.5	0.0	6	9	0.3	0.0
lean Lake Trout	*Salvelinus namaycush*	21	36	0.4	0.3	2	31	0.9	0.1
Cisco	*Coregonus artedii*	6	28	0.3	0.0	0	0	0.0	0.0
Longnose Sucker	*Catostomus catostomus*	12	22	0.4	0.2	0	0	0.0	0.0
Ruffe	*Gymnocephalus cernuus*	6	17	0.2	0.0	0	0	0.0	0.0
Splake	*Salvelinus fontinalis x namaycush*	2	14	0.1	0.0	0	0	0.0	0.0
siscowet Lake Trout	*Salvelinus namaycush siscowet*	3	8	0.0	0.0	31	198	5.5	2.3
Kiyi	*Coregonus kiyi*	2	4	0.0	0.0	24	395	10.9	0.5
Johnny Darter	*Etheostoma nigrum*	2	3	0.0	0.0	0	0	0.0	0.0
Burbot	*Lota lota*	2	2	0.0	0.0	2	2	0.1	0.0
Threespine Stickleback	*Gasterosteus aculeatus*	2	2	0.0	0.0	0	0	0.0	0.0
Lake Sturgeon	*Acipenser fulvescens*	1	1	0.0	0.0	0	0	0.0	0.0
Unidentified Coregonid	*Coregonus*	1	1	0.0	0.0	0	0	0.0	0.0
Brown Trout	*Salmo trutta*	1	1	0.0	0.0	0	0	0.0	0.0
Yellow Perch	*Perca flavescens*	1	1	0.0	0.0	0	0	0.0	0.0
Central Mudminnow	*Umbra limi*	1	1	0.0	0.0	0	0	0.0	0.0
Pink Salmon	*Oncorhynchus gorbuscha*	1	1	0.0	0.0	0	0	0.0	0.0

Table 2. *Annual lakewide bottom trawl biomass (kg per ha) estimates for all species and for a few common prey fishes collected in the nearshore (bathymetric depths ~<80 m) bottom trawl survey of Lake Superior, 1978-2022. 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 locations are the number of locations where no fish were collected.*

Year	Sampling locations	Zero fish locations	Total species	Total mean biomass	Total median biomass	Bloater	Cisco	Lake Whitefish	Rainbow Smelt	Sculpins	Other fishes
1978	43	0	17	5.5	0.7	0.1	0.0	0.7	3.7	0.12	0.8
1979	49	0	17	5.9	2.3	0.4	0.1	1.3	2.0	0.18	2.0
1980	48	0	16	3.1	1.1	0.3	0.3	0.6	0.8	0.16	1.0
1981	46	0	19	2.7	0.4	0.4	0.4	0.7	0.2	0.16	0.8
1982	32	0	18	3.1	0.3	0.4	0.3	0.8	0.2	0.03	1.2
1983	50	0	19	2.4	0.5	0.4	0.2	0.2	0.9	0.05	0.7
1984	53	0	21	5.3	1.4	1.5	0.6	1.2	0.7	0.05	1.2
1985	53	0	19	13.7	3.5	2.3	6.4	1.9	1.2	0.07	1.8
1986	51	0	19	18.8	4.0	3.4	8.6	2.7	2.8	0.06	1.3
1987	53	0	16	12.5	1.2	2.3	5.3	1.9	1.7	0.06	1.1
1988	53	0	19	12.6	0.8	5.1	2.9	2.3	1.1	0.04	1.1
1989	76	0	21	17.0	3.2	1.6	5.9	5.4	2.0	0.07	1.9
1990	81	0	22	19.3	5.0	4.1	9.1	2.3	1.9	0.08	1.9
1991	83	0	22	15.5	3.5	0.7	9.1	2.7	1.1	0.09	1.7
1992	85	0	24	16.9	3.2	7.3	3.1	3.6	0.9	0.07	2.0
1993	86	0	23	16.9	5.1	3.7	4.6	3.6	2.1	0.08	2.9
1994	87	0	23	16.4	3.6	0.4	6.5	5.3	1.8	0.08	2.2
1995	87	0	27	15.1	2.5	0.5	3.4	5.8	2.1	0.09	3.2
1996	87	0	26	8.3	2.4	2.8	0.9	1.5	1.2	0.10	1.8
1997	84	0	30	8.4	2.2	0.8	1.4	2.8	1.3	0.05	2.1
1998	87	0	22	10.7	1.7	3.9	1.1	2.2	1.4	0.06	2.0
1999	78	0	23	8.7	1.7	2.8	2.4	1.1	1.0	0.03	1.3
2000	81	0	25	7.3	1.3	1.0	2.5	1.7	0.9	0.04	1.1
2001	82	0	32	8.5	1.7	1.2	1.2	2.8	1.5	0.05	1.7
2002	82	0	26	4.8	0.6	0.6	1.5	1.7	0.2	0.02	0.8
2003	78	0	26	5.2	1.7	1.0	0.7	2.0	0.3	0.02	1.2
2004	74	0	25	6.4	2.0	1.2	1.8	1.9	0.3	0.03	1.2
2005	52	0	27	11.3	4.4	1.6	2.2	4.4	1.0	0.01	2.0
2006	53	0	24	8.6	1.8	1.9	2.3	1.8	1.0	0.03	1.7
2007	56	0	31	6.2	1.0	0.9	0.3	1.9	1.8	0.02	1.3

2008	56	0	23	5.7	1.7	0.2	0.4	2.5	1.0	0.02	1.6
2009	64	6	20	3.1	0.1	1.2	0.3	0.1	0.4	0.02	1.1
2010	75	10	24	1.6	0.2	0.2	0.3	0.3	0.2	0.05	0.5
2011	82	6	21	3.6	1.3	0.6	0.4	0.9	0.6	0.05	1.0
2012	72	16	25	1.1	0.3	0.4	0.0	0.2	0.2	0.03	0.4
2013	79	3	27	6.0	1.2	0.5	0.5	3.0	0.5	0.02	1.5
2014	73	3	28	7.1	1.9	0.5	0.4	4.3	0.4	0.02	1.5
2015	76	4	21	1.8	0.2	0.4	0.2	0.5	0.2	0.02	0.4
2016	76	5	23	2.2	0.2	0.4	0.2	0.5	0.4	0.02	0.6
2017	76	4	27	3.8	1.8	0.5	0.2	1.1	0.9	0.01	1.1
2018	77	10	24	4.3	0.3	0.1	0.4	1.5	1.2	0.02	1.0
2019	76	8	25	5.7	1.4	0.7	0.1	2.5	1.0	0.02	1.4
2020	11	1	17	10.5	3.3	6.2	0.9	2.3	0.3	0.01	0.8
2021	45	6	23	6.4	0.8	1.5	0.3	3.2	0.5	0.02	0.8
2022	71	1	25	1.6	0.5	0.2	0.0	0.4	0.3	0.01	0.6
Mean	67	1.8	23	8.0	1.8	1.5	2.0	2.0	1.0	0.05	1.4
Median	75	0	23	6.4	1.7	0.8	0.7	1.9	1.0	0.04	1.2

Table 3. Age-1 Bloater, Cisco, Lake Whitefish, and Rainbow Smelt densities (fish per ha) in an annually conducted nearshore (bathymetric depths ~<80 m) bottom trawl survey and age-1 Kiyi densities from an offshore (bathymetric depths ~>80 m) survey of Lake Superior, 1978-2022. Age-1 fish were defined by species-specific lengths: Cisco <140 mm, Bloater <130 mm, Kiyi <130 mm, Lake Whitefish <160 mm, and Rainbow Smelt <100 mm. ND = no data.

Sampling year	Year class	Sampling locations Nearshore / offshore	Cisco	Bloater	Kiyi	Lake Whitefish	Rainbow Smelt
1978	1977	43/0	0.0	0.7	ND	2.6	83.9
1979	1978	49/0	6.3	27.2	ND	3.9	216.1
1980	1979	48/0	0.1	1.4	ND	1.9	89.2
1981	1980	46/0	14.1	7.1	ND	17.1	110.5
1982	1981	32/0	0.2	0.8	ND	4.2	63.8
1983	1982	50/0	0.1	0.8	ND	0.5	96.8
1984	1983	53/0	18.5	4.4	ND	7.9	211.0
1985	1984	53/0	743.4	42.0	ND	2.3	145.1
1986	1985	51/0	71.0	27.6	ND	3.6	142.5
1987	1986	53/0	5.1	3.8	ND	11.9	253.0
1988	1987	53/0	0.4	5.8	ND	6.1	149.0
1989	1988	76/0	222.4	36.1	ND	36.1	260.7
1990	1989	81/0	400.2	48.2	ND	8.3	250.7
1991	1990	83/0	215.8	11.3	ND	16.3	151.9
1992	1991	85/0	8.3	9.8	ND	11.7	158.8
1993	1992	86/0	3.4	0.2	ND	7.7	154.2
1994	1993	87/0	0.8	0.1	ND	4.9	192.6
1995	1994	87/0	1.4	0.0	ND	13.5	386.2
1996	1995	87/0	0.9	0.1	ND	6.2	159.8
1997	1996	84/0	11.2	0.2	ND	8.9	245.6
1998	1997	87/0	1.2	0.1	ND	7.7	141.2
1999	1998	78/0	80.7	0.4	ND	8.2	192.5
2000	1999	81/0	4.0	0.5	ND	0.8	61.3
2001	2000	82/0	0.9	0.1	ND	2.4	260.5
2002	2001	82/0	0.5	0.1	ND	14.0	58.2
2003	2002	78/0	36.6	0.7	ND	8.6	85.9

2004	2003	74/0	177.7	27.6	ND	6.5	71.2
2005	2004	52/0	8.2	12.1	ND	3.0	110.4
2006	2005	53/0	19.3	14.1	ND	5.6	258.9
2007	2006	56/0	0.4	0.3	ND	19.7	366.5
2008	2007	56/0	0.2	0.3	ND	0.7	294.7
2009	2008	64/0	0.3	0.6	ND	3.0	71.6
2010	2009	75/0	14.2	2.5	ND	6.7	46.0
2011	2010	82/35	0.3	0.8	10.7	4.0	74.0
2012	2011	72/34	0.0	0.1	0.6	1.9	10.9
2013	2012	79/35	0.2	0.2	0.2	5.5	142.9
2014	2013	73/30	0.0	0.1	0.1	2.3	68.5
2015	2014	76/33	14.3	8.6	16.7	1.0	30.7
2016	2015	76/35	5.0	9.7	16.4	1.6	83.0
2017	2016	76/36	1.4	5.8	7.1	1.4	147.0
2018	2017	77/35	0.0	0.1	1.1	1.1	161.4
2019	2018	76/35	0.3	3.8	0.9	6.7	137.1
2020	2019	11/0	0.1	0.9	ND	12.5	5.1
2021	2020	45/0	10.6	7.6	ND	41.3	140.5
2022	2021	71/35	0.1	0.0	0.3	2.0	77.8
Mean		67/34	46.7	7.2	5.0	7.6	147.1
Median		75/35	1.4	0.8	0.9	5.6	142.5

Coordinated Science and Monitoring Initiative Surveys

Cooperative Science and Monitoring Initiative (CSMI) fishery surveys were conducted on Lake Superior in 2011, 2016, and 2022. In addition to the standardized data collected by these surveys to assess the status and trends of the fish community and support fisheries management agencies, different survey years have emphasized different aspects of the fish community. A primary product of the 2011 effort was development and testing of an acoustic target strength to fish length relationship for the Lake Superior pelagic fish community (Yule et al. 2013). Work in 2016 focused on describing niche parameters and niche overlap among Bloater, Cisco, Kiyi, and Rainbow Smelt (Rosinski et al. 2020). For 2022, in this report, we compare benthic and pelagic fish population metrics across the three survey years.

Survey design

Sampling locations were selected in 2011 based on a spatially-balanced random probability study design that would enable depth zone and lakewide mass estimates to be made for major chemical constituents, biological taxa, and trophic levels. Fifty-six locations were allocated across 4 depth zones: 0-30, 30-100, 100-200, and >200 m (Figure 8). Fifty-six locations were thought to be the number that could be sampled for all attributes in a single summer and provide sufficient replication to produce robust lakewide estimates. Individual location depths ranged from 5 to 315 m. Sampling occurs on a 5-year interval, except for a 1-year delay that pushed the 2021 sampling schedule to 2022 due to COVID restrictions. Data and samples collected at each location includes, bottom trawls for benthic fish, surface trawls for larval fish, mid-water trawls and acoustics for pelagic fish, whole water column (up to 100 m) zooplankton collections, *Mysis* collections, benthic invertebrate collections, major dissolved chemical constituents, and a water column profile that electronically collects data on depth, temperature, specific conductance, pH, dissolved oxygen, chlorophyll a, photosynthetic active radiation, and beam transmission. Each location is sampled once for each attribute each year.

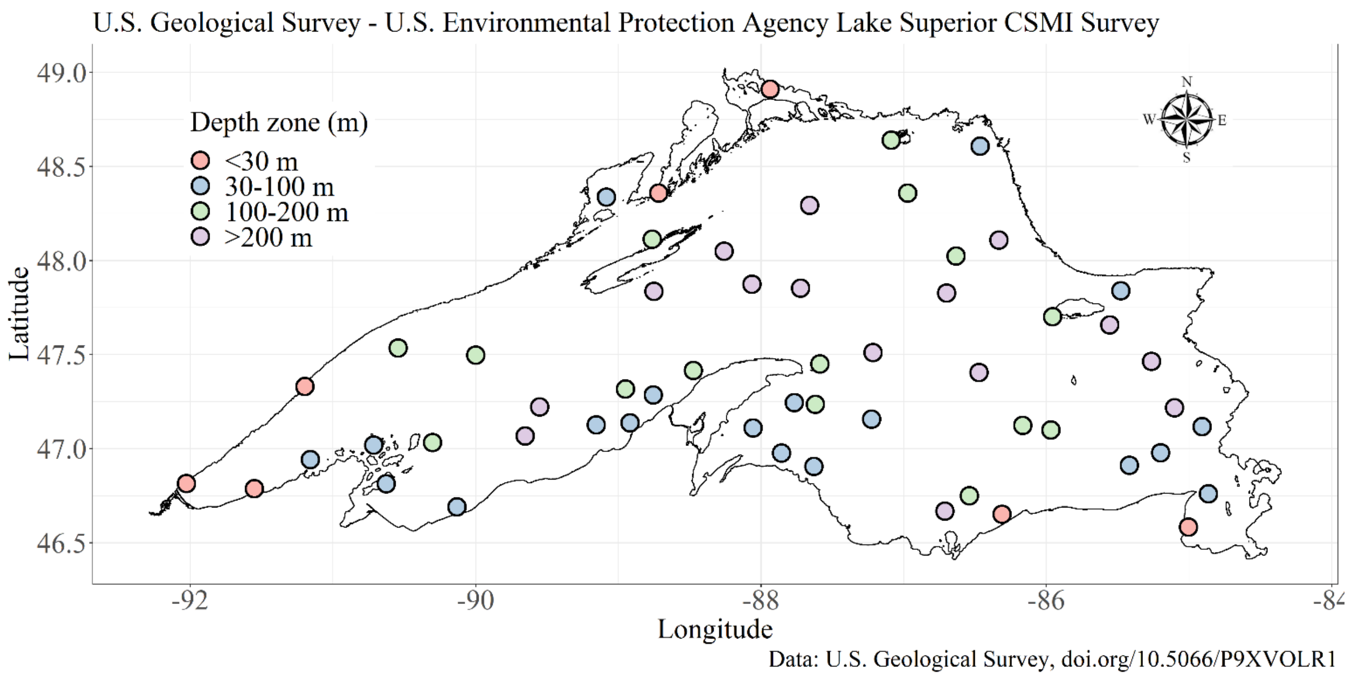

Figure 8. Coordinated Science and Monitoring Initiative (CSMI) sampling locations in Lake Superior showing depth zone designation. Sites were sampled in 2011, 2016, and 2022.

Benthic fish collections

Benthic fish were collected using bottom trawls. Trawling occurred from June 23 to July 26 in 2011, June 27 to July 25 in 2016, and July 6-29 in 2022. Bottom trawling was successfully completed at 54 locations in 2011, 54 locations in 2016, and 51 locations in 2022. Differences in sampling locations among years were due to weather and fishing gear issues. A single bottom trawl tow was conducted at each site during the day using a Yankee bottom trawl with a 11.9 m head rope, 15.5 m foot rope, and 2.2 m wing height with stretch meshes of 89 mm at the mouth, 64 mm for the trammel, and 13 mm at the cod-end. Trawl foot ropes were equipped with six-inch rubber rollers (roller trawl) in 2011 and 2016 and with chain in 2022 (conventional bottom trawl) as no roller trawls were available. Trawl tows were made at ~4 km per h for 20 minutes for 1-1.8 km (mean and median = 1.4 km). Bottom trawl fishing area was calculated based on a fixed trawl wing spread of 7.8 m and the distance the trawl was on the bottom as determined using trawl mensuration systems (NetMind (2011 and 2016) or Marport (2022)) and the Research Vessel Kiyi's global positioning system.

Surface fish collections

Surface trawling was done from June 27 to July 27 in 2011 and June 27 to July 25 in 2016 during the bottom trawl surveys. In 2022 surface trawling was done at all locations during both the bottom trawl (July 6-29) and the mid-water trawl – acoustic surveys (August 18 – October 4). In all years, samples were collected using a paired one-square-meter 500-micron mesh neuston net (model 9550, Sea-Gear Corporation, Melbourne, Florida). The bottom of the net frame was fished ~0.5 m below the lake surface for 10 minutes at ~4.0 km per h for ~0.7 km as determined from the Research Vessel Kiyi's global positioning system.

Pelagic fish collections

Surveys of pelagic fish occurred from August 3 to September 28 in 2011, August 17 to September 27 in 2016, and August 18 to October 4 in 2022. Fish were sampled with mid-water trawls at 52 locations in 2011 and 2022, and at 53 locations in 2016. The same locations were not sampled in all years due to weather. One or two midwater trawl tows were made at each location depending on site depth and acoustic targets identified prior to trawl deployment. At shallow locations, a single midwater trawl was performed that targeted the depth at which the most fish occurred based on acoustic information. At deeper locations one to two trawls were performed. If two trawl tows were made, one was at a shallow depth (0-20 m headrope depth) and one was at a greater depth (20-80 m headrope depth). The midwater trawl net had 15.2 m headrope and footrope lines and 13.7 m breast lines. The mesh graduated from a stretch measure of 15.2 cm at the mouth to 1.3 cm at the cod end. Average trawl fishing depths ranged from 0 (surface) to 71 m in all years. Trawl tows were made at ~4 km per h for 20-30 minutes for 0.7-1.6 km (median = 0.9 km).

Pelagic fish hydroacoustic data collection

Acoustic data were collected per the Great Lakes acoustic data collection and processing standard operating procedure (hereafter GL-SOP; Parker-Stetter et al. 2009; Rudstam et al. 2009). A BioSonics DTX echosounder (Seattle, WA, USA) equipped with 6-7° beam angles split-beam 120-kHz transducer was deployed through a tube through the hull of the vessel. An average of 2.9 km of acoustic data was collected at a speed of ~4 km per h at each location. Acoustic sampling was done at 51 locations in 2011, 53, locations in 2016, and 54 locations in 2022.

Catch processing

Fish collected in bottom and mid-water trawls were sorted by species, counted, and weighed in aggregate to the nearest gram. Total length was measured for a maximum of 50 individuals per species per trawl. Lengths from these individuals were extrapolated to the entire catch when more than 50 individuals were collected. Relative density (fish per ha) and biomass (kg per ha) were estimated by dividing sample counts and aggregate weights by the area swept by each trawl tow (ha). Lakewide densities were then calculated using estimates of the total area of each depth zone in the lake based on publicly available geographic information system data. Areas were 0-30 m, 387,700 ha; 30-100 m, 1,647,200 ha; 100-200 m, 3,726,900 ha; and >200 m, 2,287,600 ha (Yule et al. 2013). Bottom trawls were used to estimate Bloater, Burbot, Deepwater Sculpin, hatchery Lake Trout, Johnny Darter, Lake Whitefish, lean Lake Trout, Longnose Sucker, Ninespine Stickleback, Pygmy Whitefish, Ruffe, Sea Lamprey, Shortjaw Cisco, siscowet Lake Trout, Slimy Sculpin, Spoonhead Sculpin, and Trout-Perch. Mid-water trawl and hydroacoustic data were used to estimate Chinook Salmon, Cisco, young-of-year ciscoe, Coho Salmon, Kiyi, Rainbow Smelt, Threespine Stickleback, and Walleye. Gear determinations were based on previous work on Lake Superior that assessed individual species vulnerability to different gear (Yule et al. 2007, 2008). Based on 2022 fish collections, eight species had estimated total lakewide abundances of more than ten-million fish. These included, from most to least, Deepwater Sculpin, young-of-year ciscoe, Rainbow Smelt, Kiyi, siscowet Lake Trout, Bloater, and Pygmy Whitefish. Data for these species are presented individually, and data for the other 18 species are presented collectively as other fish (Table 5).

All larval fish were removed from the nets and identified as *Coregonus*, Deepwater Sculpin, Rainbow Smelt, or Pacific Salmon based on morphological characters (Hinrichs 1979; Auer 1982). *Coregonus* larvae were counted and stored in 20 ml polyethylene scintillation vials filled with 90% ethanol. Other larval species were noted as being present and discarded. Several months later, in the laboratory, larval total length was measured to the nearest 0.1 mm for up to 25 individuals from each sample in 2011 and 2016 and for all individuals in 2022. Larval fish densities were calculated based on the width of the sampling nets and the distance towed.

Pelagic fish hydroacoustic data processing

Acoustic data were processed using hydroacoustic data processing software (Echoview software version 12.1.64 (Myriax Pty Ltd., Tasmania, Australia)). Total fish abundance (fish per ha) of layers along each transect were calculated using the echo integration method per the GL-SOP. Depth layers were 10 m high. Acoustic transects were assigned an average bottom depth by exporting the bottom line from hydroacoustic software for each transect. Acoustic layers were then assigned to one of the four bathymetric depth zones, <30, 30-100, 100-200, and >200 m. Mid-water trawl catches were used to develop Categorical and Regression Tree (CART) models for the four depth zones (Yule et al. 2013). Single echo detections (SEDs) were sized using target strength-to-length models. SEDs having target strengths ≤-40 decibels (dB) at bathymetric depths ≤100 m were sized with the Rudstam et al. (2003) model for Rainbow Smelt because this species is the predominant small-bodied pelagic fish in these waters (Yule et al. 2013). SEDs having target strengths ≤-40 dB at bathymetric depths >100 m were sized with the Fleischer et al. (1997) model for Bloater, because Kiyi is most abundant in these waters (Yule et al. 2013). SEDs >-40 dB at all bathymetric depths were sized with Love (1971), which works well for predicting length of large-bodied species such as Cisco and Lake Trout. SEDs were then assigned a species based on the CART model developed for each stratum. After assigning each SED to a species, average predicted weights of each SED were calculated using length-to-weight models (Yule et al. 2013). The density of each species in each layer (fish per ha) was calculated by multiplying the estimated total fish density by the respective species proportions. The biomass density (kg per ha) of a species was then calculated by multiplying the species layer density estimate by the average mass of SEDs assigned to that species in that layer. Each transect had multiple 10-m-high layers. Species density (fish per ha) and biomass density (kg per ha) were summed over all layers along each transect to come up with species specific abundance and biomass estimates on a per hectare basis at each location.

Results

Across the three survey years a total of 25 species and morphotypes were collected (Table 4). Of these, 19 species or morphotypes were native, four were invasive, Rainbow Smelt, Ruffe, Sea Lamprey, and Threespine Stickleback, and three were introduced sports fish, Coho Salmon, Chinook Salmon, and hatchery Lake Trout. The most abundant species' lakewide were Deepwater Sculpin (all years), young-of-year ciscoe (2022), and Rainbow Smelt (2011 and 2016, Table 5). By biomass, Cisco had the highest estimated lakewide biomass in 2011 and 2022 and siscowet Lake Trout had the highest estimated lakewide biomass in 2016 (Table 5). Native species were more abundant than invasive species by numbers (80, 65, and 92%) and biomass (94, 93, 96%) in 2011, 2016, and 2022, respectively (Table 5).

Benthic fish

Total lakewide benthic fish biomass declined from 47 thousand metric tons in 2011 to 29 thousand metric tons in 2016 and increased to 33 thousand metric tons in 2022 (Figure 9). This decline from 2011 to 2016 was due to declines in Deepwater Sculpin and siscowet Lake Trout and the increase in biomass from 2016 to 2022 was primarily due to an increase in Deepwater Sculpin. Siscowet Lake Trout lakewide biomass was 27 thousand, 19 thousand, and 16 thousand metric tons in 2011, 2016, and 2022, respectively (Table 5). Deepwater Sculpin were the most numerically abundant benthic fish lakewide in 2011 (2.2 billion), 2016 (1.4 billion), and 2022 (2.9 billion). Deepwater Sculpin, averaged 244, 140, and 264 fish per ha and 1.5, 0.7 and 1.3 kg per ha in in 2011, 2016, and 2022, respectively. Mean siscowet Lake Trout biomass was 2.9, 2.0, and 1.7 kg per ha in 2011, 2016, and 2022, respectively. Bloater and Pygmy Whitefish were the other two most common benthic species. Bloater mean abundance decreased from 13.7 to 9.0 to 3.0 fish per ha from 2011 to 2016 to 2022 (Figure 9). Pygmy Whitefish mean abundance decreased from 9.2 to 5.2 to 2.2 fish per ha from 2011 to 2016 to 2022. Across the three survey years, "other" fish accounted for 1% of total fish abundance and 4% of total fish biomass. Lean Lake Trout, Lake Whitefish, and Burbot had the highest biomass of "other" fish and Ninespine Stickleback, Slimy Sculpin, and Lake Whitefish were the most abundant "other" fish across the three surveys.

Table 4. Summary of Coordinated Science and Monitoring Initiative (CSMI) fish collections in Lake Superior in 2011, 2016, and 2022. Locations refers to the number of locations collected at (MWT or BT) or estimated (AC) at. Sampling gear abbreviations are AC = acoustics, BT = bottom trawl, MWT = mid-water trawl. YOY ciscoe refers to young-of-year Bloater, Cisco, and Kiyi.

		Native, invasive, or introduced	Locations 2011			Locations 2016			Locations 2022			Total catch 2011		Total catch 2016		Total catch 2022	
Common name	Scientific name		AC	MWT	BT	AC	MWT	BT	AC	MWT	BT	MWT	BT	MWT	BT	MWT	BT
Bloater	*Coregonus hoyi*	Native	34	8	13	35	10	12	31	4	13	23	708	41	475	10	153
Burbot	*Lota lota*	Native	0	0	5	0	0	5	3	1	3	0	5	0	5	1	3
Chinook Salmon	*Oncorhynchus tshawytscha*	Introduced	0	0	0	10	2	0	0	0	0	0	0	2	0	0	0
Cisco	*Coregonus artedii*	Native	51	55	7	49	48	5	54	29	0	610	27	414	233	118	0
Coho Salmon	*Oncorhynchus kisutch*	Introduced	0	0	0	0	0	0	10	1	0	0	0	0	0	2	0
Deepwater Sculpin	*Myoxocephalus thompsoni*	Native	1	1	39	1	16	35	0	16	37	1	12082	33	7067	35	13042
hatchery Lake Trout	*Salvelinus namaycush*	Introduced	0	0	0	0	0	1	6	0	0	0	0	0	1	0	0
Johnny Darter	*Etheostoma nigrum*	Native	0	0	0	0	0	0	0	0	1	0	0	0	0	0	5
Kiyi	*Coregonus kiyi*	Native	42	54	27	48	46	29	35	19	24	447	1859	993	1029	146	395
Lake Whitefish	*Coregonus clupeaformis*	Native	5	1	4	12	1	4	33	4	2	1	10	1	115	7	8
lean Lake Trout	*Salvelinus namaycush*	Native	15	3	5	21	5	6	18	1	8	3	8	5	23	1	50
Longnose Sucker	*Catostomus catostomus*	Native	3	1	0	0	0	0	0	0	0	1	0	0	0	0	0
Ninespine Stickleback	*Pungitius pungitius*	Native	22	8	14	12	4	9	22	13	12	100	46	7	128	31	116
Pygmy Whitefish	*Prosopium coulteri*	Native	0	0	15	8	1	11	0	0	10	0	448	4	267	0	108
Rainbow Smelt	*Osmerus mordax*	Invasive	48	33	13	48	39	13	50	37	11	3733	3875	9517	693	4943	2724
Ruffe	*Gymnocephalus cernuus*	Invasive	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0
Sea Lamprey	*Petromyzon marinus*	Invasive	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
Shortjaw Cisco	*Coregonus zenithicus*	Native	12	1	10	24	4	3	0	0	0	1	48	4	5	0	0
siscowet Lake Trout	*Salvelinus namaycush siscowet*	Native	43	6	35	45	11	32	37	3	32	7	368	15	277	3	199
Slimy Sculpin	*Cottus cognatus*	Native	0	0	13	0	0	9	0	0	13	0	50	0	36	0	42
Spoonhead Sculpin	*Cottus ricei*	Native	25	6	6	3	1	10	0	3	8	18	6	1	16	4	12
Threespine Stickleback	*Gasterosteus aculeatus*	Invasive	22	6	0	1	1	0	5	3	0	8	0	1	0	4	0
Trout-Perch	*Percopsis omiscomaycus*	Native	1	1	2	0	0	3	0	0	2	1	3	0	9	0	14
Unidentified Coregonid	*Coregonus*	Native	5	0	1	19	2	3	4	1	0	0	2	3	5	1	0
Walleye	*Sander vitreus*	Native	6	1	0	5	1	0	0	0	0	1	0	1	0	0	0
YOY ciscoe	*Coregonus*	Native	0	0	0	0	0	0	53	52	0	0	0	0	0	4654	0

Table 5. Total lakewide abundance and biomass estimates for fish collected in Lake Superior Coordinated Science and Monitoring assessments in 2011, 2016, 2022. Grouping indicates if the species was grouped into the 'Other' composite category. Gear refers to the fishing gear used in the population estimate, either bottom trawl (BT) or acoustics (AC). YOY ciscoe refers to young-of-year Bloater, Cisco, and Kiyi.

			Mean number of fish per ha			Mean biomass, kg per ha			Total lakewide abundance			Total lakewide biomass, metric tons		
Common name	Grouping	Gear	2011	2016	2022	2011	2016	2022	2011	2016	2022	2011	2016	2022
Bloater	Bloater	BT	13.65	9.01	2.97	0.78	0.22	0.26	101,526,483	53,981,685	15,520,086	5,131	1,817	1,346
Burbot	Other	BT	0.10	0.10	0.06	0.02	0.02	0.01	923,537	886,486	532,361	208	246	114
Chinook Salmon	Other	AC	0.00	0.04	0.00	0.00	0.00	0.00	0	590,433	0	0	12	0
Cisco	Cisco	AC	47.22	17.23	9.60	7.03	2.29	2.42	223,808,636	90,309,665	62,664,343	43,386	15,255	19,702
Coho Salmon	Other	AC	0.00	0.00	0.24	0.00	0.00	0.05	0	0	1,068,189	0	0	201
Deepwater Sculpin	Deepwater Sculpin	BT	244.00	139.59	264.36	1.49	0.71	1.26	2,198,111,492	1,346,445,290	2,920,356,021	13,132	6,771	13,917
hatchery Lake Trout	Other	BT	0.00	0.02	0.00	0.00	0.00	0.00	0	81,450	0	0	4	0
Johnny Darter	Other	BT	0.00	0.00	0.10	0.00	0.00	0.00	0	0	368,466	0	0	0
Kiyi	Kiyi	AC	38.10	20.26	34.58	0.95	0.46	1.64	382,480,176	214,037,868	388,937,613	9,614	4,945	16,598
Lake Whitefish	Other	BT	0.20	2.18	0.16	0.05	0.08	0.09	1,020,497	11,340,886	749,228	234	462	427
lean Lake Trout	Other	BT	0.16	0.43	1.02	0.08	0.06	0.19	824,745	2,341,008	4,717,689	395	293	896
Longnose Sucker	Other	BT	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0	0	0
Ninespine Stickleback	Other	BT	0.92	2.20	2.31	0.00	0.00	0.00	5,571,819	11,041,917	8,949,951	4	11	14
Pygmy Whitefish	Pygmy Whitefish	BT	9.21	5.25	2.20	0.06	0.05	0.02	50,065,158	29,396,240	10,221,694	312	290	97
Rainbow Smelt	Rainbow Smelt	AC	184.00	231.58	108.36	1.51	0.93	0.61	707,732,801	984,370,343	486,659,337	6,042	3,982	3,125
Ruffe	Other	BT	0.02	0.00	0.00	0.00	0.00	0.00	244,718	0	0	1	0	0
Sea Lamprey	Other	BT	0.00	0.02	0.00	0.00	0.00	0.00	0	181,504	0	0	17	0
Shortjaw Cisco	Other	BT	0.92	0.10	0.00	0.07	0.01	0.00	7,244,870	802,785	0	519	105	0
siscowet Lake Trout	siscowet Lake Trout	BT	7.35	5.44	4.06	2.92	2.04	1.71	68,942,930	46,912,595	35,730,598	27,023	19,138	16,407
Slimy Sculpin	Other	BT	1.01	0.68	0.84	0.00	0.00	0.00	8,640,988	4,379,676	4,858,019	29	13	13

Spoonhead Sculpin	Other	BT	0.12	0.31	0.25	0.00	0.00	0.00	1,139,071	2,237,159	1,806,279	2	3	3
Threespine Stickleback	Other	AC	3.75	0.01	0.15	0.00	0.00	0.00	15,816,610	23,649	674,824	14	0	1
Trout-Perch	Other	BT	0.06	0.14	0.28	0.00	0.00	0.00	297,472	665,324	1,037,921	2	1	4
Unidentified Coregonid	Other	BT	0.04	0.10	0.00	0.00	0.01	0.00	303,913	1,049,386	0	20	96	0
Walleye	Other	AC	0.47	0.64	0.00	0.68	0.31	0.00	1,648,581	2,626,085	0	2,404	1,273	0
YOY ciscoe	YOY ciscoe	AC	0.00	0.00	248.25	0.00	0.00	1.55	0	0	2,096,465,232	0	0	14,895

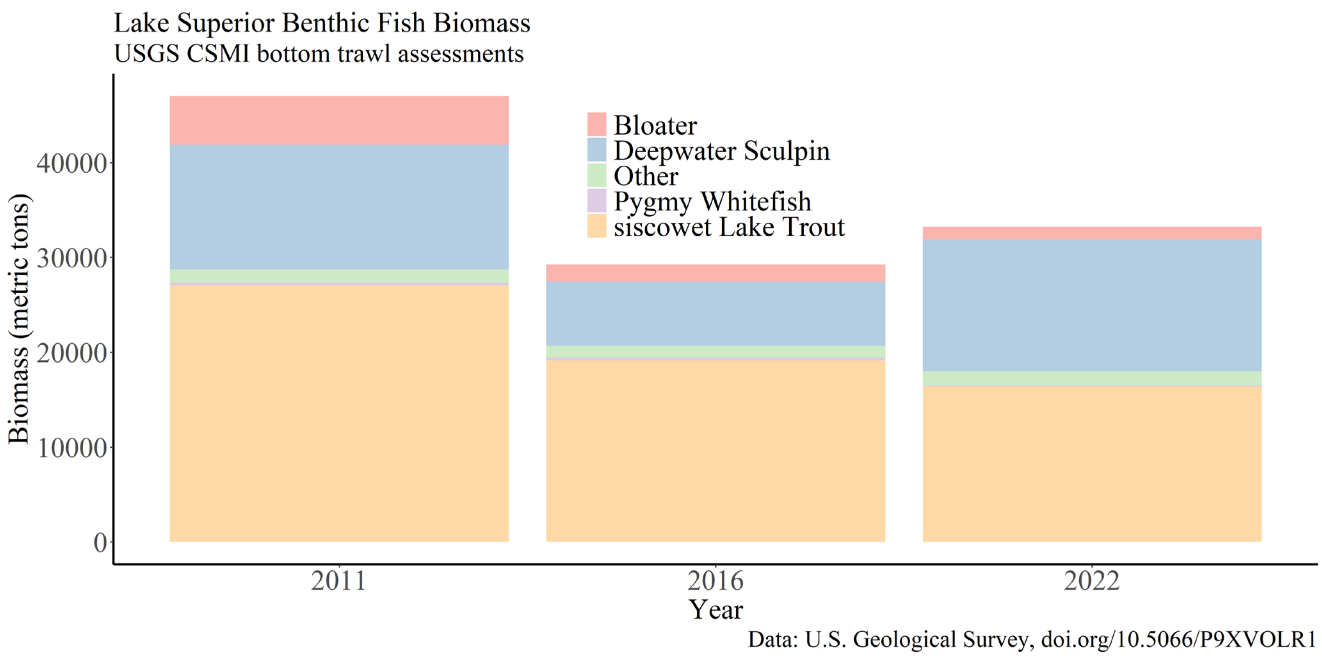

Figure 9. Lakewide Lake Superior total biomass (metric tons) of benthic fish in Lake Superior in 2011, 2016, and 2022. Other fish are identified in Table 5.

Abundance of Lake Superior benthic fish varied strongly with depth. Across the three sampling years, mean benthic fish abundance was 3-29 fish per ha in shallow, <30 m deep habitats, 28-73 fish ha in 30-100 m habitats, 168-474 fish per ha in 100-200 m habitats, and 337-595 fish per ha in >200 m deep habitats (Figure 10). At depths <30 m deep, Ninespine Stickleback, Slimy Sculpin, and Trout-Perch were most abundant. Fish abundance at depths <30 m increased from 3 to 13 to 29 fish per ha in 2011, 2016, and 2022, respectively (Figure 10). At 30-100 m deep locations, Bloater, Pygmy Whitefish, and Slimy, Spoonhead, and Deepwater Sculpin were most abundant. Total abundance at 30-100 m deep locations decreased from 73 to 67 to 29 fish per ha in 2011, 2016, and 2022, respectively. At locations >100 m deep, Deepwater Sculpin and siscowet Lake Trout were the dominant benthic species and total abundances ranged from 168-595 fish per ha. Abundances were highest in 2022 in 100-200 m deep habitats and highest in 2011 in waters >200 m deep.

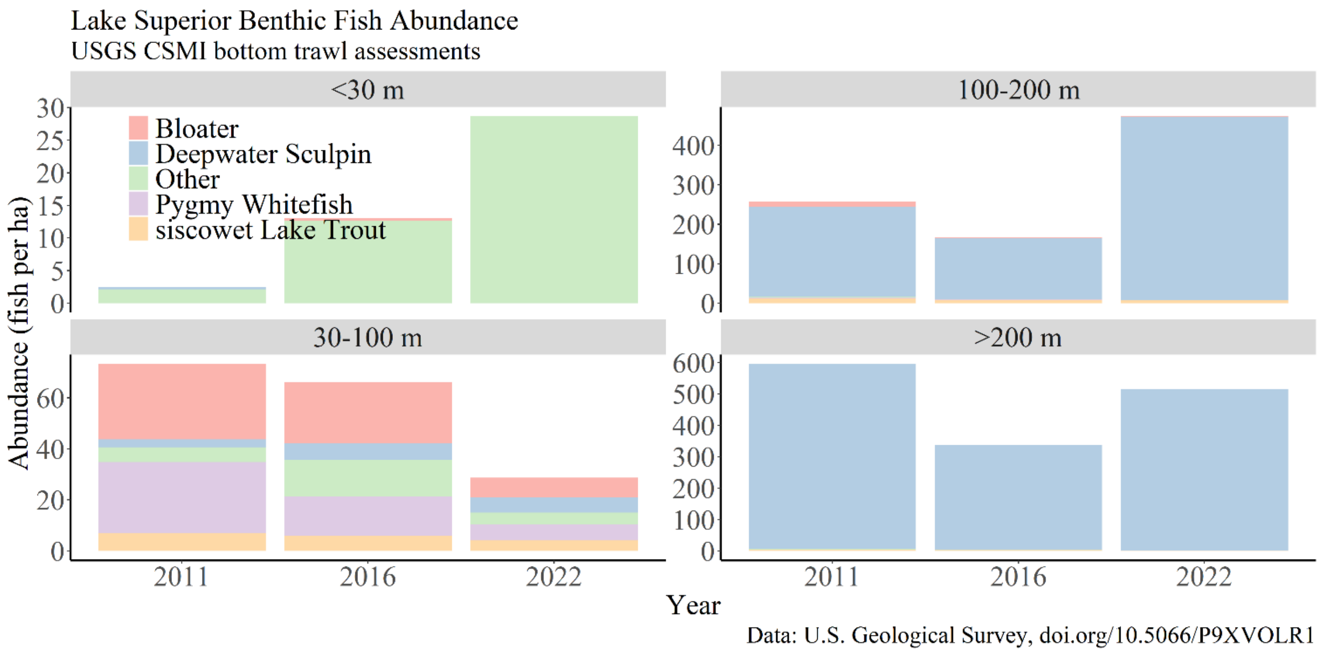

Figure 10. Mean abundance (fish per ha) of benthic fish in Lake Superior in 2011, 2016, and 2022 at four depth zones, <30, 30-100, 100-200, and >200 m. Other fish are identified in Table 5. Note different y-axis scales among depth zones.

Benthic fish biomass showed a similar trend as fish abundance as biomass was highest in waters >100 m (Figure 11). Across the three sampling periods, biomass was near zero (0.004-0.1 kg per ha) in waters <30 m, 2-4.6 kg per ha in 30-100 m deep habitats, 4.3-6 kg per ha in 100-200 m deep habitats, and 3.6-7.4 kg per ha in waters >200 m deep. In the <30 m depth zone, biomass increased, albeit a small increase (~0.1 kg per ha) in 2022, due to a high abundance of Ninespine Stickleback at a few locations. In the 30-100 and 100-200 m depth zones, biomass declined from 2011 to 2016 and then increased slightly in 2022. In the 100-200 m depth zone, due to a mix of fish in the 30-100 m zone and Deepwater Sculpin in the 100-200 m depth zone. In the >200 m depth zone, total biomass declined from 2011-

2022 due primarily to a decline in siscowet Lake Trout. Deepwater sculpin biomass in the >200 m depth zone increased from 2016 to 2022.

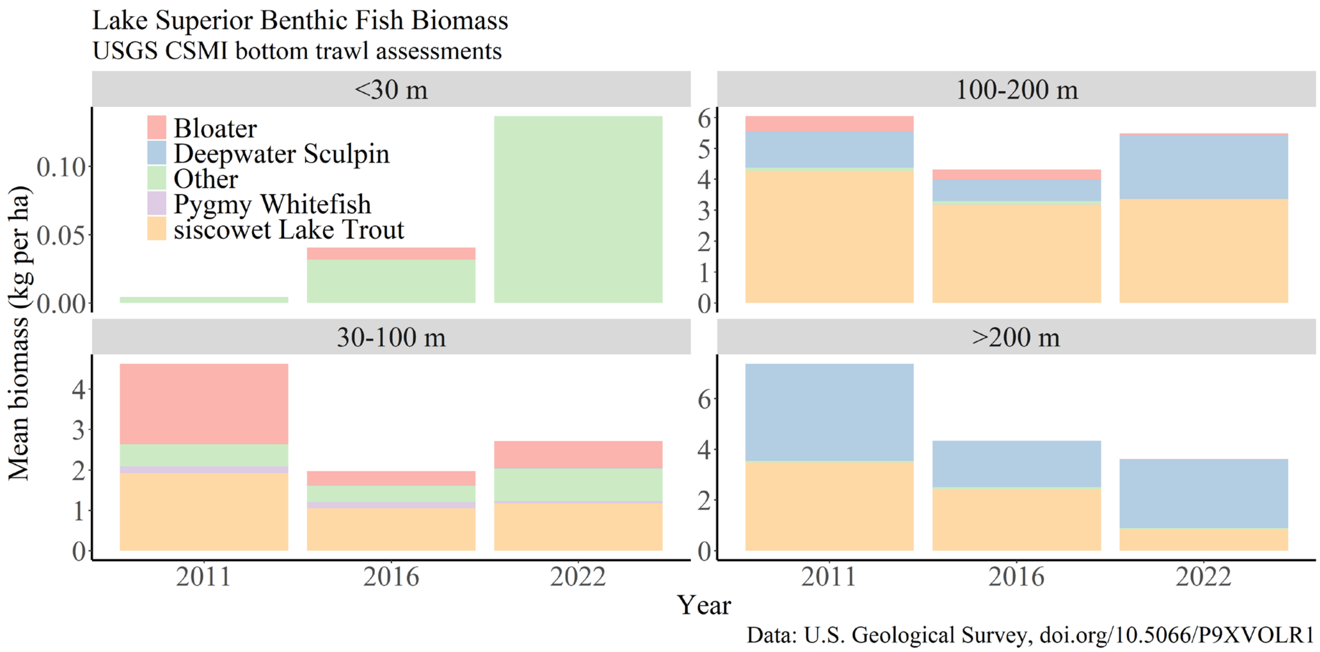

Figure 11. Mean biomass (kg per ha) of benthic fish in Lake Superior in 2011, 2016, and 2022 at four depth zones, <30, 30-100, 100-200, and >200 m. Other fish are identified in Table 5. Note different y-axis scales among depth zones.

Pelagic fish

Rainbow Smelt was the most abundant pelagic fish lakewide in 2011 (707 million) and 2016 (984 million) and young-of-year ciscoes (Bloater, Kiyi, and Cisco) were the most abundant pelagic fish in 2022 (2.1 billion). Cisco had the highest lakewide pelagic biomass in 2011 (43 thousand metric tons), 2016 (15 thousand metric tons), and 2022 (20 thousand metric tons, Table 5). Total lakewide pelagic fish biomass declined from 61 thousand metric tons in 2011 to 25 thousand metric tons in 2016 and increased to 54 thousand metrics in 2022 (Figure 12). Adult Cisco and Kiyi increased their lakewide biomass, and for adult Kiyi their abundance increased as well, from 2016 to 2022. In contrast to these species, Rainbow Smelt lakewide abundance declined from 984 million to 486 million and biomass declined from near four thousand to near three thousand metric tons from 2016 to 2022. The most prevalent other pelagic species' were Threespine Stickleback, Walleye, and Pacific Salmon. These fish were mostly observed in waters <30 m deep.

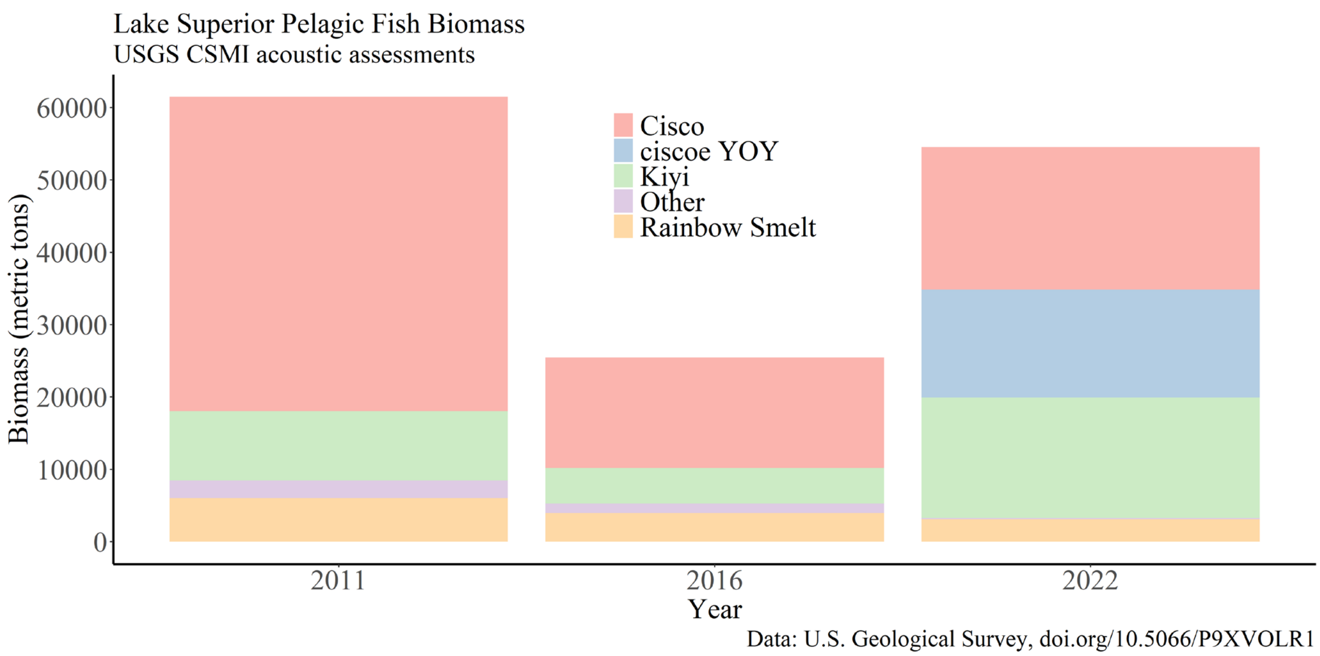

Figure 12. Lakewide Lake Superior total biomass (metric tons) of pelagic fish in Lake Superior in 2011, 2016, and 2022. Other fish are identified in Table 5.

Contrary to that observed for benthic fish abundance, pelagic fish abundance decreased with depth. Across the three sampling years, mean pelagic fish abundance was 589-1900 fish per ha in shallow, <30 m deep habitats, 198-387 fish per ha in 30-100 m habitats, 43-315 fish per ha in 100-200 m habitats, and 30-434 fish per ha in >200 m deep habitats (Figure 13). This variation was most pronounced in 2011 and 2016. In 2022, high abundance of young-of-year ciscoe at depths >30 m (262, 226, and 354 fish per ha in 30-100, 100-200, and >200 depth zones) increased total fish abundance at deeper depths. Few (26 fish per ha) young-of-year ciscoe were observed at depths <30 m deep. Rainbow Smelt was the predominant species observed in waters <30 m deep in all years. Cisco were most abundant at locations <100 m deep. Kiyi were most abundant at locations >100 m deep.

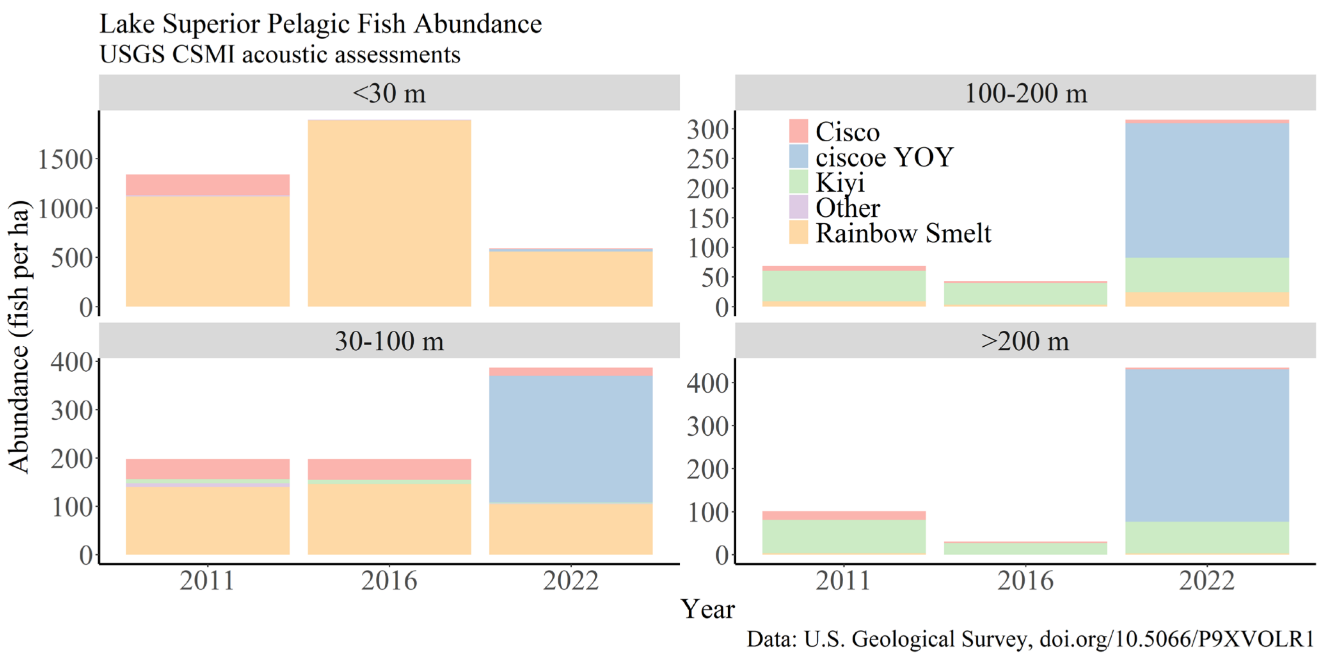

Figure 13. Mean abundance (fish per ha) of pelagic fish in Lake Superior in 2011, 2016, and 2022 at four depth zones, <30, 30-100, 100-200, and >200 m. Other fish are identified in Table 5. Note different y-axis scales among depth zones.

Pelagic fish biomass showed a similar trend as fish abundance as biomass was highest in waters <30 and uniformly declined at deeper depth zones, except in 2022, where mean biomass levels were more similar at the three depth zones <200 m deep (4.8 kg per ha in <30 m, 3.6 in 30-100 m, 4.6 in 100-200 m) and were highest at depths >200 m (12.9 kg per ha) due to young-of-year ciscoes and yearling and older Kiyi (Figure 14). In 2022, mean Kiyi biomass at depths >200 m deep was 5.3 kg per ha as compared to 1.8 and 0.7 kg per ha in 2011 and 2016 respectively. Ciscoe young-of-year biomass increased with depth. It was 0.1 kg per ha in waters <30 m deep, 0.8 kg per ha in 30-100 m habitats, 1.6 kg per ha in 100-200 m habitats, and 3.3 kg per ha in >200 m deep habitats. Cisco biomass declined in all years at depths <100 m and declined from 2011 to 2016 and increased from 2016 to 2022 at depths >100 m. Overall, Cisco biomass decreased from a lakewide average of 7.4 kg per ha in 2011 to 2.3 and 2.4 kg per ha in 2016 and 2022, respectively. Rainbow Smelt biomass was highest in waters <30 m deep and biomass within this depth zone declined from 8.3 to 7.6 to 2.7 kg per ha from 2011 to 2016 to 2022, respectively.

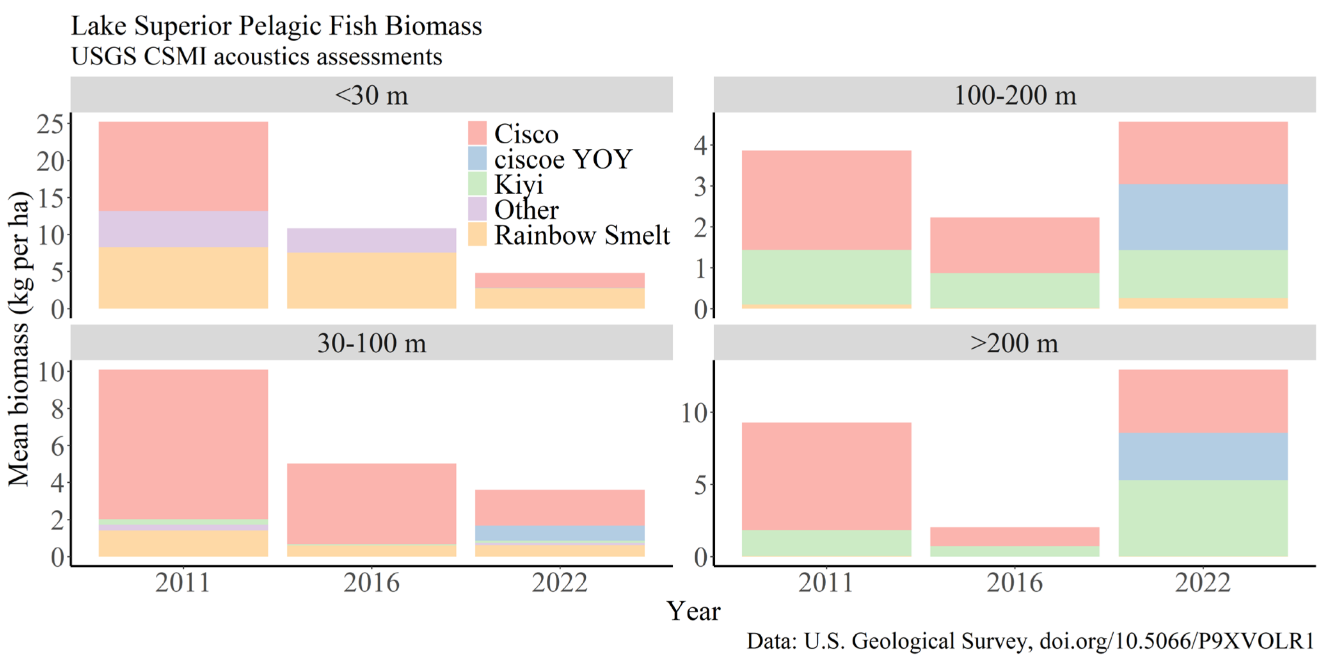

Figure 14. Mean biomass (kg per ha) of pelagic fish in Lake Superior in 2011, 2016, and 2022 at four depth zones, <30, 30-100, 100-200, and >200 m. Other fish are identified in Table 5. Note different y-axis scales among depth zones.

Summary

The 2022 Lake Superior CSMI fish community survey had some expected and unexpected findings. A decrease in adult Cisco populations was expected due to the sporadic and anemic Cisco year-class strength over the past 20-years as measured by survival to age-1 (Figure 15). Adult Cisco population estimates in 2011 were 223 million fish and 43 thousand metric tons. In 2022, adult Cisco populations were estimated to be 62 million and 20 thousand metric tons. Bloater and Kiyi have also had similar poor survival to age-1 over the same time. This was reflected in a decrease in Bloater from 101 million in 2011 to 15 million in 2022. Unexpectedly, the Kiyi population estimate of 389 million in 2022 was similar to the 2011 estimate of 382 million fish. The reason for this is not well understood and was not reflected in the offshore bottom trawl survey, but is likely a combination of the small, but measurable, 2018 year-class, and a decrease in predation by siscowet Lake Trout. Siscowet Lake Trout declined from an estimated 69 million in 2011 to 47 million in 2016, to 36 million in 2022. Decline of Rainbow Smelt to perhaps their lowest abundance in sixty-years was also unexpected. Between 2016 and 2022, Rainbow Smelt lakewide abundance declined from almost 1 billion to 486 million fish. This decline was also observed in the spring nearshore bottom trawl survey over the past several years (Table 2).

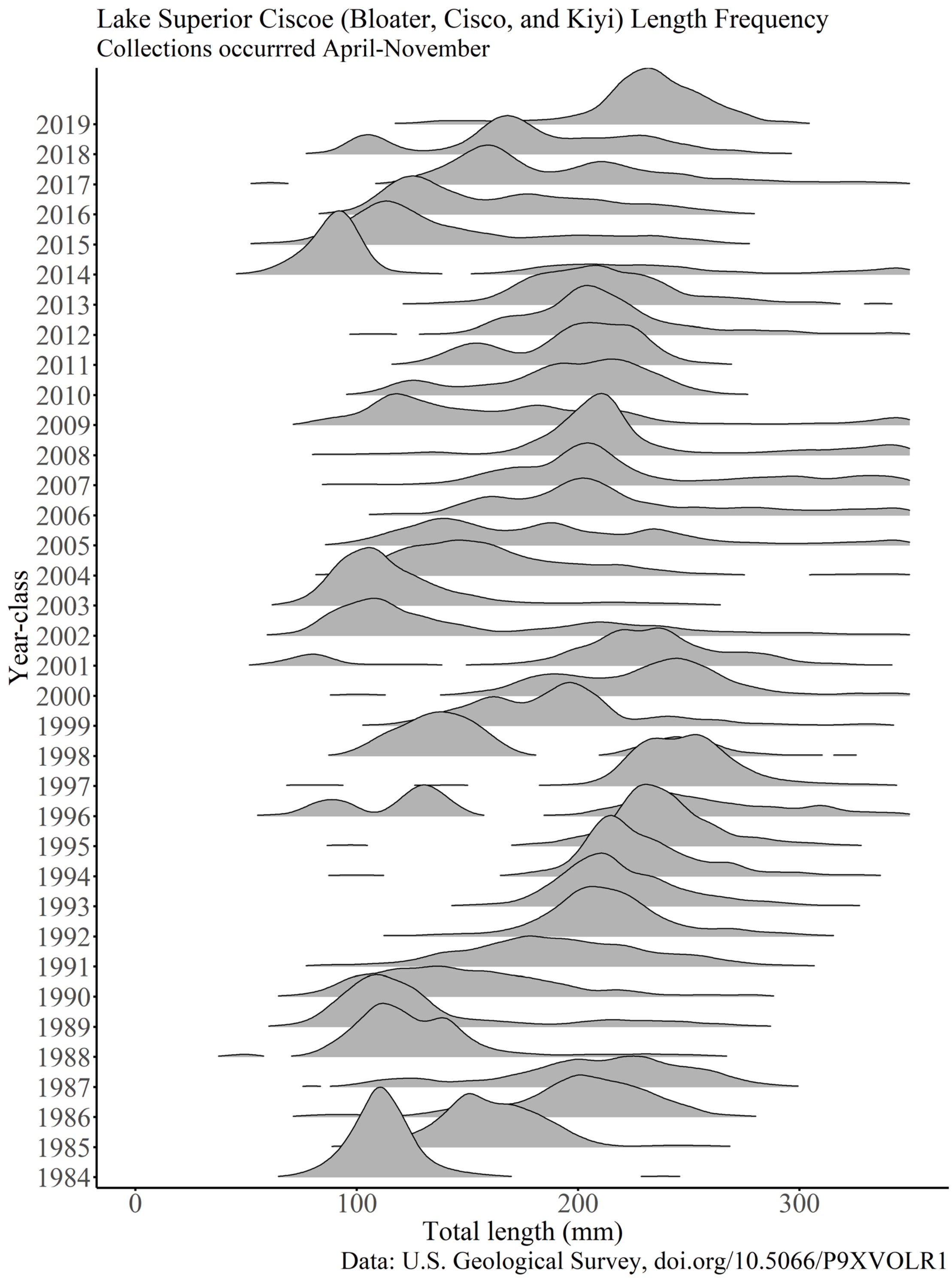

Figure 15. Annual Lake Superior Bloater, Cisco, and Kiyi length frequency distributions showing the sporadic and limited number of years for which age-1 fish (~<150 mm) were present in the population.

The most unexpected result from our sampling in 2022 was the 2 billion age-0 ciscoe estimate from the mid-water trawl and acoustic sampling in August-October. These fish were broadly distributed across the lake, 53 of the 54 locations, and their population estimates were highest in the deepest depth zones (Figure 13). No age-0 ciscoes were collected in 2011 and the 2011 year-class strength indexes were near zero for all three ciscoe species (Table 3). In 2016, a few age-0 fish were collected in late summer mid-water trawls and the year-class strength index numbers for the 2016 year-class were 6 for Bloater, 1 for Cisco, and 7 for Kiyi (Figure 16, Table 3). The strength of the 2022 year-class won't be determined until spring 2023 during the nearshore bottom trawl survey, but these previous findings suggest it could be robust if the age-0 fish survive the 2023 winter. Preliminary genomics analyses of ~1,600 2022 age-0 fish, indicates the cohort to be a mix of Bloater (6%), Cisco (28%), and Kiyi (67%), which is similar to their 2022 adult population proportions, 3, 13, and 83%, respectively. The factors underlying the survival of these ciscoes into late summer in 2022 as compared to previous years have not been identified, but our annual population surveys of larval ciscoes suggest that lake conditions in June and July may have differed from previous years and enhanced survival. In 2022, ciscoe larval densities in May were lower than average (likely due to a cold winter and spring that delayed hatching), June densities were similar to previous years, and July density estimates were more than double that of any previous year's estimate (Figure 7). A comparison of Lake Superior thermal conditions during the three CSMI years (Figure 17) show 2022 was cooler during winter and spring than 2011 and 2016 and similar in temperature during these seasons to 2003, 2009, and 2014, the last three years with moderate to high ciscoe year-class index numbers (Table 3, Figure 15). Late summer temperatures were similar between 2022 and 2003 and warmer than that observed in 2009 and 2014. The role of temperature in influencing ciscoe year-class strength has been previously speculated, with colder winters hypothesized to enhance larval ciscoe survival (Stewart et al., 2021, 2022), but this has not been demonstrated in the Great Lakes. Identifying recruitment bottlenecks is a globally recognized multifaceted problem to solve, but one worthy of continued investigation. There may be no truer representation of this than Lake Superior, where ciscoe play such an important role in ecosystem dynamics and commercial fisheries, and where a single year with high year-class survival can support these ecosystem functions for a decade or longer.

Lake Superior CSMI ecosystem surveys have provided valuable information for managing the lake's dynamic fisheries (Matthias et al. 2021). A significant feature of these surveys has been their evolving nature to address current management issues and utilize new technology. Our plan is to continue these surveys into the future and adapt them as needed to address emerging issues.

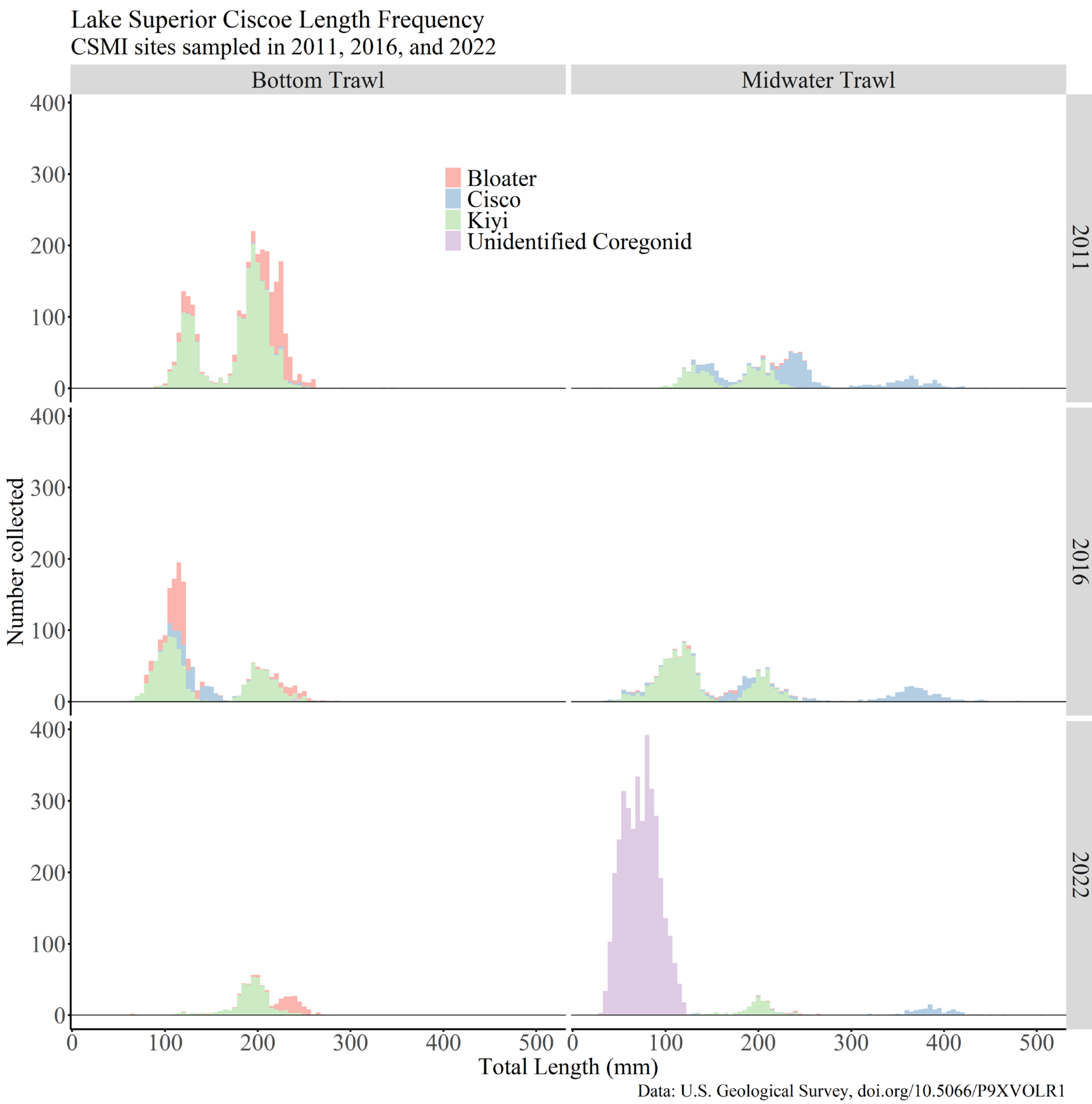

Figure 16. Bloater, Cisco, and Kiyi length frequency distributions from July bottom trawl and August-October mid-water trawl collections in Lake Superior in 2011, 2016, and 2022. Bin width is 5-mm.

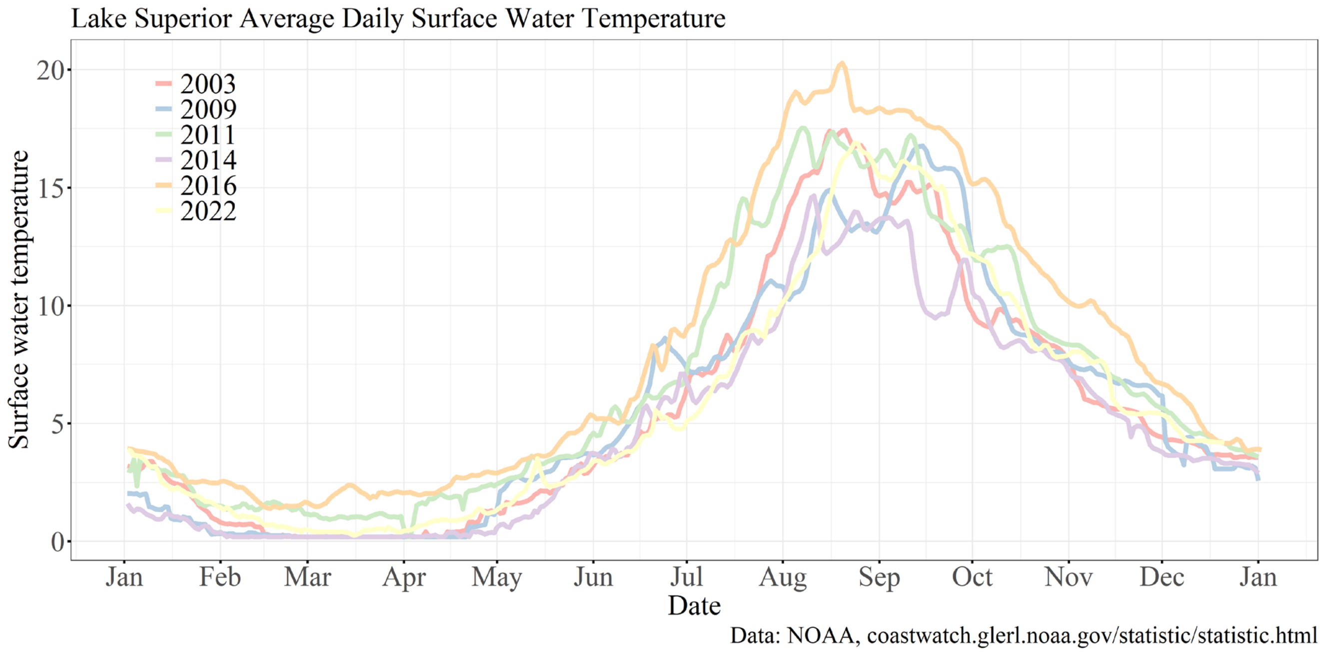

Figure 17. Lake Superior average daily surface water temperatures in the three CSMI years, 2011, 2016, and 2022 and for 2003, 2009, and 2014 the last three years with moderate to high ciscoe year-class index values (Table 3, Figure 15). Data from coastwatch.glerl.noaa.gov.

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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Appendix 1. Trawl station location information.

Survey	Date	Time	Location	Management unit	Mid latitude	Mid longitude	Begin depth m	End Depth m	Surface temperature C	Bottom temperature C
nearshore	18-May-22	1303	71	WI2	46.940	-90.789	19	37	6.3	4.4
nearshore	18-May-22	1457	75	WI2	47.002	-90.732	38	48	4.3	3.9
nearshore	18-May-22	1705	86	WI2	46.841	-90.725	22.5	54	6	4.1
nearshore	19-May-22	919	24	WI2	46.850	-90.468	14	63	3	3.7
nearshore	19-May-22	1057	2	WI2	46.906	-90.566	28	100	4.4	3.8
nearshore	19-May-22	1314	87	WI2	46.938	-90.649	15	60	4.4	3.8
nearshore	20-May-22	916	45	WI2	46.985	-90.556	12	66	4.2	3.4
nearshore	20-May-22	1052	44	WI2	47.035	-90.488	10	55	4.3	3.7
nearshore	20-May-22	1217	52	WI2	46.977	-90.453	16	100	3.6	3.8
nearshore	21-May-22	1216	190	MN2	47.626	-90.711	25.3	58	2.7	2.1
nearshore	21-May-22	1429	208	MN3	47.694	-90.531	16.5	69	2.8	2
nearshore	21-May-22	1636	65	MN3	47.747	-90.318	11	63	2.7	1.7
nearshore	22-May-22	1140	172	MN2	47.331	-91.194	18	41	2.7	2
nearshore	22-May-22	1452	188	MN1	47.082	-91.554	21	27	3.3	2.1
nearshore	22-May-22	1638	36	MN1	46.999	-91.697	20	33.5	3.2	2
nearshore	23-May-22	746	210	WI1	46.731	-92.014	14	22.5	7.5	4.2
nearshore	23-May-22	1022	206	WI1	46.780	-91.632	21	46.5	7	2.5
nearshore	23-May-22	1234	205	WI1	46.819	-91.419	21	52	4.1	2.8
nearshore	23-May-22	1545	187	MN1	46.914	-91.841	17	36	3	2.2
nearshore	24-May-22	1048	151	WI1	46.885	-91.215	11	68	3.1	2.8
nearshore	24-May-22	1230	76	WI2	46.890	-91.101	13.5	37	3.5	3
nearshore	24-May-22	1418	139	WI2	46.973	-91.014	24	47.5	4.3	2.5
nearshore	1-Jun-22	1019	184	MI2	46.627	-90.335	16.5	36.5	9.1	4.9
nearshore	1-Jun-22	1255	192	MI2	46.696	-90.033	14	37.5	7.7	4
nearshore	1-Jun-22	1657	57	MI2	46.914	-89.366	19	45.5	5.9	3.7
nearshore	2-Jun-22	831	183	MI2	47.002	-89.166	15	45	7.5	3.9
nearshore	2-Jun-22	1147	182	MI3	47.157	-88.872	27	49	7.1	3.9
nearshore	3-Jun-22	1145	84	MI4	46.908	-88.323	15	133	8.2	3.7
nearshore	3-Jun-22	1750	101	MI4	47.371	-87.813	26	55	4.6	3.6
nearshore	4-Jun-22	1011	158	MI4	46.936	-88.119	16.5	51	7.4	5.6
nearshore	4-Jun-22	1323	142	MI5	46.860	-87.720	18	66	7.4	5.2
nearshore	4-Jun-22	1515	196	MI5	46.785	-87.551	27	77	6.4	3.7
nearshore	5-Jun-22	758	120	MI5	46.524	-87.228	19.5	56	7.3	3.7
nearshore	5-Jun-22	1050	88	MI6	46.530	-86.904	28.5	80	6.8	3.5
nearshore	5-Jun-22	1307	209	MI6	46.530	-86.721	21	88	8.2	3.8
nearshore	5-Jun-22	1606	178	MI6	46.664	-86.325	27.5	88	4.8	3.6
nearshore	6-Jun-22	820	177	MI7	46.721	-85.768	19	61	4.2	3.4
nearshore	6-Jun-22	1148	176	MI7	46.782	-85.322	19	46.5	9.3	3.9
nearshore	6-Jun-22	1413	195	MI8	46.805	-84.982	10	62	7.3	4.1

nearshore	7-Jun-22	1221	79	MI8	46.566	-84.868	21	76.5	8.9	6.4
nearshore	7-Jun-22	1434	193	MI8	46.515	-84.867	14	60	9.2	4.1
nearshore	9-Jun-22	1029	460	ONT12	46.671	-84.586	14	50.5	11.7	4
nearshore	9-Jun-22	1225	459	ONT11	46.768	-84.610	15	67.5	11.9	4.2
nearshore	9-Jun-22	1534	461	ONT11	46.936	-84.728	11.5	69	7.9	3.9
nearshore	9-Jun-22	1838	457	ONT11	47.164	-84.714	19	121	4.7	3.7
nearshore	10-Jun-22	639	456	ONT11	47.314	-84.657	21	81	5.4	3.8
nearshore	10-Jun-22	947	455	ONT11	47.550	-84.969	19	101	3.5	3
nearshore	10-Jun-22	1228	454	ONT9	47.676	-84.992	11	81	3.5	2.5
nearshore	10-Jun-22	1512	451	ONT9	47.936	-85.181	16	65	4.1	2.9
nearshore	10-Jun-22	1732	462	ONT9	47.947	-84.946	17	110	4.1	3
nearshore	11-Jun-22	926	463	ONT9	47.911	-85.431	16	75	4.3	3
nearshore	11-Jun-22	1205	464	ONT9	47.948	-85.819	12	82	4.1	3
nearshore	11-Jun-22	1508	465	ONT7	48.121	-86.059	12	98	4.2	3.2
nearshore	12-Jun-22	743	422	ONT7	48.639	-86.410	24	47	5.3	3.3
nearshore	12-Jun-22	1010	420	ONT7	48.766	-86.640	12	42	5.3	3.7
nearshore	12-Jun-22	1258	419	ONT7	48.794	-86.980	25	42.5	4.7	4.4
nearshore	12-Jun-22	1452	418	ONT4	48.778	-87.170	20	38	8.9	3.9
nearshore	12-Jun-22	1722	417	ONT4	48.834	-87.479	10	60	8	3.9
nearshore	13-Jun-22	841	415	ONT4	48.888	-87.766	12	39	10.2	4.2
nearshore	13-Jun-22	1043	414	ONT4	48.946	-87.979	13	24	11.2	4.5
nearshore	13-Jun-22	1245	413	ONT4	48.936	-88.224	17	27	11.7	6.9
nearshore	13-Jun-22	1438	412	ONT4	48.828	-88.104	16	47	14	6.9
nearshore	14-Jun-22	927	408	ONT3	48.601	-88.496	11	20	14.2	7.5
nearshore	14-Jun-22	1046	407	ONT3	48.561	-88.583	13	29	13.3	6.2
nearshore	14-Jun-22	1219	406	ONT3	48.489	-88.612	15	35	10.9	7
nearshore	14-Jun-22	1355	405	ONT3	48.409	-88.693	10	55	10.5	4
nearshore	15-Jun-22	922	401	ONT1	48.510	-88.935	13	43.5	10.7	4.1
nearshore	15-Jun-22	1059	402	ONT1	48.373	-88.887	12	45	5.7	4.3
nearshore	15-Jun-22	1308	404	ONT2	48.311	-88.905	17	56	4.7	4
nearshore	16-Jun-22	1021	400	ONT2	48.077	-89.411	8	55	5.9	3.9
nearshore	16-Jun-22	1312	191	MN3	47.971	-89.625	15	48	4.5	2.9
CSMI	19-Jul-22	1216	2050	MI8	46.583	-85.005	6	7.5	21.6	
CSMI	27-Jul-22	1232	2033	ONT3	48.358	-88.717	16	26	8.3	4.3
CSMI	3-Oct-22	2110	2037	ONT4	48.835	-87.600	18.1	40	13.1	
CSMI	7-Jul-22	920	2048	WI1	46.784	-91.569	20	23	8.6	4.5
CSMI	30-Aug-22	2251	2033	ONT3	48.354	-88.722	21.6	31.6	15.1	
CSMI	24-Jul-22	849	2037	ONT4	48.911	-87.932	23	22	20	5.1
CSMI	19-Sep-22	2213	2043	MI6	46.655	-86.310	25.8	29.5	18.4	
CSMI	23-Aug-22	2214	2032	MN1	46.815	-92.011	25.9	29.7	20.3	
CSMI	7-Jul-22	1204	2032	MN1	46.814	-92.015	26	29	16.5	5
CSMI	8-Jul-22	1157	2044	MN2	47.332	-91.193	26	34	4.8	3.6
CSMI	14-Jul-22	1427	2043	MI6	46.650	-86.312	26	30	12.5	5.7

CSMI	19-Jul-22	1630	2045	ONT11	47.117	-84.910	26		13.6	13.5
CSMI	28-Aug-22	2328	2049	ONT1	48.336	-89.087	29.5	30.6	18.4	
CSMI	27-Jul-22	1500	2049	ONT1	48.337	-89.082	30	33	16.9	5.2
CSMI	20-Aug-22	2224	2044	MN2	47.333	-91.193	30	28	16	
CSMI	5-Sep-22	2312	2054	MI3	47.124	-88.923	32	33.7	17.7	
CSMI	6-Jul-22	1059	2036	WI2	46.810	-90.627	33	34.5	12.7	11.1
CSMI	10-Jul-22	1421	2054	MI3	47.136	-88.918	33	45.5	14	4.3
CSMI	18-Aug-22	2313	2036	WI2	46.820	-90.623	33	18	20.1	
CSMI	22-Aug-22	2340	2048	WI1	46.794	-91.579	36	39.8	20	
CSMI	6-Jul-22	1609	2052	WI2	47.015	-90.715	40	45	13.5	5.1
CSMI	26-Aug-22	2223	2052	WI2	47.026	-90.709	40.3	31	18.8	
CSMI	6-Sep-22	414	2035	MI3	47.289	-88.747	42.7	80.3	17.8	
CSMI	28-Sep-22	2124	2045	ONT11	47.109	-84.903	44.9	43.9	14.7	
CSMI	13-Jul-22	1232	2058	MI4	46.976	-87.858	45	50	15.6	4.2
CSMI	24-Sep-22	2239	2050	MI8	46.637	-84.910	45.3	30	16.1	
CSMI	17-Aug-22	2245	764	WI2	46.860	-90.685	49	51	20.4	4.3
CSMI	9-Jul-22	1018	2056	MI2	46.691	-90.129	50	51.5	12.2	4.1
CSMI	8-Sep-22	2250	2056	MI2	46.693	-90.130	50.8	52.7	18.4	
CSMI	11-Jul-22	901	2035	MI3	47.284	-88.755	51	46	7.6	3.8
CSMI	24-Aug-22	26	398	MN1	46.911	-91.831	51.3	58.1	18.4	4.7
CSMI	15-Sep-22	2240	2058	MI4	46.975	-87.866	51.7	42.5	17.8	
CSMI	25-Sep-22	102	2034	MI8	46.766	-84.869	53.1	72.7	17.3	
CSMI	16-Jul-22	1337	2034	MI8	46.762	-84.865	56	59	16.5	5.9
CSMI	23-Aug-22	228	399		46.847	-91.813	62.8	60.8	19.6	4.2
CSMI	29-Aug-22	57	365	ONT1	48.370	-88.959	65	71		5.5
CSMI	18-Sep-22	2143	2030	MI5	46.911	-87.628	73.9	96.7	16.8	
CSMI	29-Sep-22	2136	2047	ONT9	47.839	-85.483	74.4	67.4	14.1	
CSMI	13-Jul-22	822	2046	MI4	47.244	-87.763	75	78.5	13.1	3.9
CSMI	20-Jul-22	1803	2059	ONT10	47.704	-85.965	75	100	5.6	3.8
CSMI	13-Jul-22	1035	2042	MI4	47.112	-88.057	77	77	15	4.1
CSMI	20-Jul-22	1231	2047	ONT9	47.838	-85.482	77	77	8.6	3.9
CSMI	16-Sep-22	403	2046	MI4	47.246	-87.754	77.7	78.9	17.1	
CSMI	16-Sep-22	111	2042	MI4	47.116	-88.062	79.2	68.5	17.6	
offshore/CSMI	13-Jul-22	1422	2030	MI5	46.903	-87.630	81	88.5	14.7	4
offshore/CSMI	22-Aug-22	248	354	WI2	46.963	-91.117	81	89	17.5	3.8
offshore/CSMI	29-Aug-22	144	365	ONT1	48.402	-88.943	83	88.5		4.3
offshore/CSMI	20-Sep-22	2226	2039	MI7	46.917	-85.426	83.9	104	18.5	
offshore/CSMI	10-Jul-22	1220	2051	MI3	47.126	-89.152	84	91.5	14.2	3.9
offshore/CSMI	16-Jul-22	836	2039	MI7	46.911	-85.419	84	88	8.5	4
offshore/CSMI	12-Jul-22	1409	2055	MI5	47.159	-87.227	86	93	7.1	3.8
offshore/CSMI	23-Jul-22	754	2057	ONT7	48.617	-86.463	86	96	8.9	3.8
offshore/CSMI	6-Jul-22	1848	2040	WI2	46.944	-91.155	89	90	10.5	3.9
offshore/CSMI	16-Jul-22	1056	2029	MI8	46.977	-85.200	89	92	9.2	3.9

offshore/CSMI	16-Sep-22	2316	2055	MI5	47.167	-87.237	89.6	54.4	15.1	
offshore/CSMI	21-Aug-22	518	2040	WI2	46.945	-91.154	90.1	91.2	16.9	
offshore/CSMI	21-Sep-22	45	2029	MI8	46.988	-85.196	90.3	81.4	15.9	
offshore/CSMI	12-Jul-22	822	2130	MI4	47.451	-87.594	92	98	9.2	3.9
offshore/CSMI	6-Sep-22	2243	2051	MI3	47.126	-89.174	92.4	97.4	19.1	
offshore/CSMI	17-Sep-22	2154	2130	MI4	47.456	-87.615	95.7	97.3	13.5	
offshore/CSMI	21-Aug-22	2329	354	WI2	46.937	-91.212	103	109	18.4	3.7
offshore/CSMI	2-Oct-22	2135	2057	ONT7	48.621	-86.433	106	114	12.4	
offshore/CSMI	18-Aug-22	148	764	WI2	46.960	-90.475	107	94.7	15.3	3.9
offshore/CSMI	11-Jul-22	1059	2131	MI3	47.307	-88.947	114	123	8.1	3.7
offshore/CSMI	6-Jul-22	1419	2117	WI2	47.035	-90.297	123	129	9.4	3.9
offshore/CSMI	12-Jul-22	1659	2114	MI4	47.234	-87.621	124	114	12.4	3.8
offshore/CSMI	19-Aug-22	230	2117	WI2	47.030	-90.299	126	129	18.8	
offshore/CSMI	6-Sep-22	149	2131	MI3	47.323	-88.971	128	128	17.6	
offshore/CSMI	27-Jul-22	928	2140	MI1	48.114	-88.759	132	144	7.6	3.8
offshore/CSMI	15-Jul-22	1142	2141	MI6	47.123	-86.165	133	136	4.6	3.7
offshore/CSMI	1-Sep-22	332	2140	MI1	48.116	-88.754	136	158	17.1	
offshore/CSMI	17-Sep-22	214	2114	MI4	47.241	-87.633	136	94.1	16.4	
offshore/CSMI	28-Jul-22	1347	2124	MN3	47.496	-89.999	144	144	10.2	3.7
offshore/CSMI	20-Aug-22	152	368	MN2	47.238	-90.859	145	148	19.5	3.8
offshore/CSMI	27-Aug-22	2230	2124	MN3	47.496	-89.998	148	147	17.4	
offshore/CSMI	29-Sep-22	14	2137	ONT10	47.222	-85.101	148	218	13.6	
offshore/CSMI	15-Jul-22	947	2125	MI7	47.105	-85.972	150	178	4.7	3.7
offshore/CSMI	27-Aug-22	2325	2124	MN3	47.522	-89.974	150	150	15.3	
offshore/CSMI	2-Oct-22	432	2139	ONT8	48.365	-87.012	150	191	12.1	
offshore/CSMI	20-Sep-22	224	2141	MI6	47.133	-86.183	152	175	15.9	
offshore/CSMI	3-Sep-22	512	2115	MI3	47.400	-88.473	158	111	16.7	
offshore/CSMI	24-Aug-22	159	398	MN1	46.941	-91.728	159	159	18.8	3.7
offshore/CSMI	29-Jul-22	735	2133	MN3	47.536	-90.538	166	172	8.3	3.7
offshore/CSMI	22-Jul-22	1319	2139	ONT8	48.358	-86.974	172	178	4.7	3.7
offshore/CSMI	11-Jul-22	1401	2115	MI3	47.413	-88.470	173	178	4.5	3.7
offshore/CSMI	27-Aug-22	259	2133	MN3	47.537	-90.537	175	172	17.1	
offshore/CSMI	14-Jul-22	1217	2116	MI6	46.751	-86.536	176	170	11.2	3.9
offshore/CSMI	23-Jul-22	1123	2123	ONT4	48.637	-87.087	177	192	5.8	3.7
offshore/CSMI	20-Jul-22	1506	2129	ONT10	47.655	-85.557	179	192	3.1	3.6
offshore/CSMI	10-Jul-22	929	2136	MI2	47.224	-89.546	188	191	4.5	3.5
offshore/CSMI	2-Oct-22	46	2135	ONT8	48.025	-86.683	188	215	11.2	
offshore/CSMI	19-Jul-22	1816	2137	ONT10	47.213	-85.103	190	197	5	3.6
offshore/CSMI	20-Aug-22	416	368	MN2	47.327	-90.959	191	200	17	3.6
offshore/CSMI	9-Jul-22	1356	2120	MI2	47.064	-89.675	193	194	6.6	3.7
offshore/CSMI	8-Sep-22	2	2136	MI2	47.215	-89.566	196	194	17.7	
offshore/CSMI	8-Sep-22	236	2120	MI2	47.067	-89.618	196	183	19.5	
offshore/CSMI	3-Oct-22	147	2123	ONT4	48.653	-87.095	202	170	12.8	

offshore/CSMI	30-Sep-22	31	2129	ONT10	47.678	-85.546	204	213	14.5	
offshore/CSMI	1-Oct-22	2206	2113	ONT7	48.107	-86.333	206	210	12.8	
offshore/CSMI	14-Jul-22	1013	2132	MI6	46.670	-86.686	207	205	7.7	3.7
offshore/CSMI	4-Oct-22	145	2127	ONT6	48.317	-87.649	214	196	10.4	
offshore/CSMI	24-Jul-22	1407	2127	ONT6	48.294	-87.660	215	216	4.6	3.6
offshore/CSMI	26-Jul-22	1049	2122	MI3	47.856	-87.724	216	212	4.9	3.6
offshore/CSMI	4-Oct-22	2202	2122	MI3	47.876	-87.734	222	258	10.5	
offshore/CSMI	25-Jul-22	1022	2128	MI1	47.834	-88.753	224	225	5.1	3.6
offshore/CSMI	26-Jul-22	1327	2118	MI1	47.874	-88.060	224	232	4.5	3.5
offshore/CSMI	1-Sep-22	2352	2128	MI1	47.840	-88.739	230	231	14.4	
offshore/CSMI	25-Jul-22	1332	2134	MI1	48.048	-88.251	237	238	4.7	3.6
offshore/CSMI	2-Sep-22	11	2118	MI1	47.871	-88.054	237	230	14.5	
offshore/CSMI	2-Sep-22	457	2134	MI1	48.052	-88.267	240	270	16.3	
offshore/CSMI	21-Jul-22	1501	2119	ONT8	47.824	-86.698	251	252	2.8	3.5
offshore/CSMI	29-Sep-22	357	2121	ONT10	47.459	-85.257	255	288	13.9	
offshore/CSMI	20-Jul-22	853	2121	ONT10	47.457	-85.266	257	260	4	3.6
offshore/CSMI	1-Oct-22	242	2119	ONT8	47.828	-86.710	258	262	10.5	
offshore/CSMI	12-Jul-22	1051	2138	MI4	47.510	-87.227	270	276	4.4	3.4
offshore/CSMI	21-Jul-22	1057	2126	MI6	47.399	-86.470	283	297	2.9	3.5
offshore/CSMI	18-Sep-22	139	2138	MI4	47.514	-87.224	289	283	15	
offshore/CSMI	30-Sep-22	2216	2126	MI6	47.399	-86.470	289	302	11.5	