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Status of the shortjaw cisco (*Coregonus zenithicus*) in Lake Superior

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The shortjaw cisco (*Coregonus zenithicus*) was historically found in Lakes Huron, Michigan, and Superior, but has been extirpated in Lakes Huron and Michigan apparently as the result of commercial overharvest. During 1999–2001, we conducted an assessment of shortjaw cisco abundance in five areas, spanning the U.S. waters of Lake Superior, and compared our results with the abundance measured at those areas in 1921–1922. The shortjaw cisco was found at four of the five areas sampled, but abundances were so low that they were not significantly different from zero. In the four areas where shortjaw ciscoes were found, abundance declined significantly by 99% from the 1920s to the present. To increase populations of this once economically and ecologically important species in Lake Superior, an interagency rehabilitation effort is needed. Population monitoring is recommended to assess population trends and to evaluate success of rehabilitation efforts.

Introduction

The shortjaw cisco (*Coregonus zenithicus*), bloater (*C. hoyi*), and kiyi (*C. kiyi*) are the three Lake Superior species collectively referred to as deepwater ciscoes. During 1894–1950, the total commercial yield of Lake Superior deepwater ciscoes was 11-million metric tons (Fig. 1), and most of that yield was shortjaw ciscoes. The shortjaw cisco represented more than 90% of deepwater cisco commercial catches in the 1920s, when Koelz (1929) conducted surveys of their abundance across Lake Superior. By the mid-1970s, the shortjaw cisco represented 0%–31% of the deepwater cisco annual harvest in the central Michigan waters of the lake (Peck 1977). The decline of Lake Superior shortjaw cisco populations has been attributed to commercial overharvest (Lawrie 1978).

The shortjaw cisco was a Category 2 candidate species under consideration for listing by the U.S. Fish and Wildlife Service (FWS) under the Endangered Species Act of 1973 as amended. The shortjaw cisco was also listed as Threatened by the Committee On the Status of Endangered Wildlife in Canada (Houston 1988, Todd 2003), listed as Threatened by the Michigan Department of Natural Resources (MIDNR 1974), and listed as Endangered by the Wisconsin Department of Natural Resources (WDNR 1975). Although the

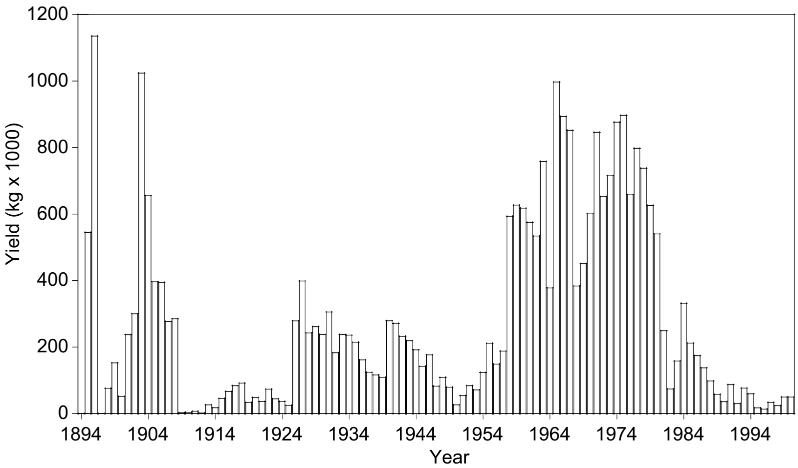

Fig. 1. Commercial yield of deepwater ciscoes from Lake Superior, 1894–2000.

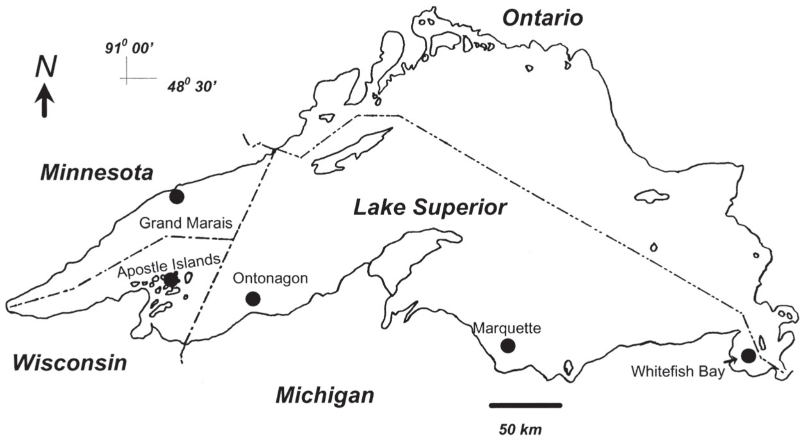

Fig. 2. Location of shortjaw cisco sampling areas in Lake Superior, 1921–1922 and 1999–2001.

range of the shortjaw cisco once included Lakes Huron, Michigan, and Superior, its present range in the United States is limited to Lake Superior. In Canada, several populations exist outside of the Great Lakes basin (Todd & Steinhilber 2002).

No prior studies have compared abundance of shortjaw cisco in the early part of the 20th century with contemporary assessments of abundance. The main objective of our study was to compare relative abundances (catch-per-unit-of-effort in standardized gill nets) of the shortjaw cisco in the historic reference period (1921–1922) and in the present (1999–2001) at five areas within the U.S. waters of the lake. Secondary objectives of our study included analysis of shortjaw cisco diet, age composition, and growth, and cisco species composition.

Sampling area and methods

Relative abundance of Lake Superior shortjaw cisco was assessed at areas near: (1) Grand Marais, Minnesota; (2) Apostle Islands, Wisconsin; (3) Ontonagon, Michigan; (4) Marquette, Michigan; and (5) Whitefish Bay, Michigan, which were areas sampled by Koelz (1929) in 1921–1922 (Fig. 2). A stratified-random design was used to assess shortjaw cisco relative abundance, and strata in the design were the lake areas. A layer of grids encompassing the depth range sampled by Koelz (1929) was placed over a navigation chart for each area. Six grids were randomly selected for sampling in the Apostle Islands and 12 grids were randomly selected for sampling in the other four areas. We assessed the relative abundance of shortjaw cisco in each grid using gill-net gangs with the same mesh sizes fished by Koelz (1929) in 1921–1922, and all netting occurred on or near the dates sampled by Koelz (1929) to ensure comparability of data collected between the two time periods (1921–1922 and 1999–2001). Our net gangs were constructed of one 92-m panel of 64-mm (stretched) nylon mesh and one 92-m panel of 70-mm mesh. Koelz (1929) did not use constant effort across all locations, and even the soak times of his net sets differed. Only data for gill nets set for the same duration were compared between the two time periods. We fished at least 18 one-night sets of our gangs in each area, and we used multiple-night sets at all locations except the Apostle Islands (Table 1).

Raw catch data for each mesh size were not available for the 1921–1922 assessments. Therefore, for each area the comparison between historic and our catch-per-unit-effort (CPUE = catch/305 m of 64-mm and 70-mm mesh gill net/night) was performed by calculating the 99% confidence interval for 1999–2001 geometric means and comparing the interval with the CPUE measured in 1921–1922. To test for differences in abundance between the two periods for all locations combined, the Mann-Whitney *U*-test compared ranked CPUEs using the null hypothesis that shortjaw cisco relative abundance was equal in the two time periods. To test for differences in abundance across areas in 1999–2001, the Kruskal-Wallis test compared ranked CPUEs from one-night sets using the null hypothesis that shortjaw cisco relative abundance was equal across areas. To test for differences between depths of net gangs with and without shortjaw cisco, the Mann-Whitney *U*-test compared ranked depths, which were calculated as the mean of the beginning and end depths of each gill-net gang using the null hypothesis that net mean depths with and without shortjaw cisco were equal. All data analyses were performed using SYSTAT (SPSS 1996), and null hypotheses were rejected at $\alpha = 0.05$.

The stomach contents of each shortjaw cisco were examined. For each food-item taxon, percentage of the total number of food items, percentage of the food item total weight, percentage frequency occurrence, Absolute Importance Index (AII = percentage of the total number of food items + percentage of food item weight + percentage frequency of occurrence), and Relative Importance Index (AII × 100/3AII) were calculated. The stomach contents of all shortjaw ciscoes from each location were pooled for the data summaries.

Shortjaw cisco ages were estimated from scales, which were removed from below the anterior insertion of the dorsal fin. Scales were magnified at 40–50× so that two biologists, who had 15–26 years of experience aging coregonids, could independently count discontinuous circuli (i.e., putative annuli) at the anterior-lateral and posterior-lateral areas of the scales. At least three

Table 1. Gill-net effort (m) and shortjaw cisco catch-per-unit-effort (CPUE) during the historic (1921–1922) and present (1999–2001) assessment periods. CPUE for 1999–2001 is the geometric mean, and 99% confidence intervals for those means are in parentheses.

		Gill-net effort (m) and (number sets)		CPUE	
Location	Nights set	1921–1922	1999–2001	1921–1922[1]	1999–2001
Grand Marais, MN	1	0	3290 (18)	–	0.18 (0.00–0.52)
	7	1068 (1)	1097 (6)	81	0.22 (0.00–0.63)
Apostle Islands, WI	1	671 (1)	3290 (18)	136	0.00 (0.00–0.00)
Ontonagon, MI	1	0	3290 (18)	–	0.18 (0.00–0.52)
	7	763 (1)	1097 (6)	40	0.15 (0.00–0.50)
Marquette, MI	1	0	3290 (18)	–	0.15 (0.00–0.51)
	5	763 (1)	1097 (6)	20	0.21 (0.00–0.55)
Whitefish Bay, MI	1	0	3290 (18)	–	0.28 (0.00–0.78)
	2	549 (1)	1097 (6)	55	0.36 (0.00–2.22)

[1] Cotton or linen gill nets were used in the 1920s and catch fish at about 0.50 percent the rate of modern, nylon gill nets (Hile & Buettner 1955, Pycha 1962).

scales were viewed by each biologist, and when differences existed in age estimates, the biologists worked together to reach a consensus on age estimate. We considered that the growing season was nearly completed for shortjaw ciscoes collected in late August and September, a convention supported by data collected by Dryer & Beil (1964, 1968) from Lake Superior lake herring (*Coregonus artedi*) and bloater.

Results

We lifted 18 gill-net gangs set for one night in each of the five areas, and we also lifted six gangs set for two nights at Whitefish Bay, six gangs set for five nights at Marquette, and six gangs set for seven nights at Grand Marais and Ontonagon. Depths sampled ranged from 15 to 121 m, but 84% of the effort ranged from 30 to 90 m, which Koelz (1929) found was most frequently inhabited by shortjaw ciscoes in the early 1920s. There was a significant difference (Mann-Whitney $U = 2226$, $P < 0.0001$) between the depths of nets that captured shortjaw cisco (mean depth = 89 m, SD = 14, $N = 48$) and those that did not (mean = 68 m, SD = 25, $N = 180$). Thus, shortjaw cisco were captured in the deeper end of the sampled depth range.

Shortjaw ciscoes were found in four of the five areas sampled. We did not capture shortjaw cisco in the Apostle Islands sampling area, whereas a CPUE of 136 fish there in 1922 was the highest observed of all five areas sampled in 1921–1922 (Table 1). Historic CPUEs were not within the range of the 1999–2001 99% confidence intervals. CPUE for shortjaw cisco at all areas combined were greater in 1921–1922 than in 1999–2001 (Mann-Whitney $U = 210.00$, $N = 5$ for 1921–1922, $N = 42$ for 1999–2001, $P < 0.0001$). No difference existed in CPUE from one-night sets across the five areas sampled in 1999–2001 (Kruskal-Wallis statistic = 4.33, $N = 90$, $P > 0.05$), even though relative abundance was zero in the Apostle Islands sampling area.

Lake herring and bloaters were collected at all five areas, and kiyis were collected at Grand Marais, Ontonagon, and Marquette (Table 2). Hybrid-appearing ciscoes were collected at Grand Marais, Ontonagon, Marquette, and Whitefish Bay. Shortjaw cisco represented 0%–12% of the ciscoes captured.

All of the shortjaw cisco stomachs collected at Ontonagon were empty. The only food-item taxa found in the stomachs of shortjaw ciscoes collected from Grand Marais, Marquette, and Whitefish Bay were *Mysis relicta*, *Diporeia* spp., and Pelecypoda (Table 3). Relative Importance Index values (RII) showed that *Mysis relicta* was the most important shortjaw cisco food item at Grand Marais (RII = 96) and Marquette (RII = 100), whereas *Diporeia* was the most important food item at Whitefish Bay (RII = 76).

Shortjaw ciscoes collected at Ontonagon were slightly younger, on average, than those collected from the other locations. Ontonagon and Whitefish Bay shortjaw ciscoes had completed an average of eight growing seasons (SD = 0.8, $N = 6$ for Ontonagon; SD = 0.9, $N = 9$ for Whitefish Bay), whereas those from Marquette and Grand Marais had completed an average of 9 growing seasons (SD = 1.3, $N = 7$ for Marquette; SD = 1.7, $N = 9$ for Grand Marais). The number of growing seasons completed by shortjaw ciscoes ranged from 7 to 11. The modal value for growing seasons completed by all shortjaw ciscoes was 8 at all four locations combined. Mean length at the end of each growing season were:

Table 2. Cisco species composition (%) caught with gill nets in Lake Superior during 1999–2001. Specimens which displayed appearances of being cisco hybrids, were classified as hybrids. However, those specimens may not necessarily be true hybrids.

Location	Shortjaw cisco	Lake herring	Bloater	Kiyi	Hybrid	*N*
Grand Marais, MN	2.4	38.1	35.4	9.0	15.1	378
Apostle Islands, WI	0.0	98.3	1.7	0.0	0.0	119
Ontonagon, MI	4.7	46.7	29.3	2.0	17.3	150
Marquette, MI	11.9	27.1	40.7	10.2	10.2	59
Whitefish Bay, MI	6.2	71.7	21.4	0.0	0.7	145

7 seasons averaged 312 mm (SD = 23, N = 6), 8 averaged 285 mm (SD = 20, N = 12), 9 averaged 287 mm (SD = 8, N = 6), 10 averaged 293 mm (SD = 9, N = 2), and 11 averaged 277 mm (SD = 22, N = 5). Shortjaw ciscoes from six cohorts (1990–1995) were represented in the catches at all locations combined. Five cohorts were in the Grand Marais collection, four in the Whitefish Bay collection, and three in the Ontonagon and Marquette collections.

Discussion

The shortjaw cisco was found in four of the five areas sampled, but the CPUE was so low in those four areas that it was not significantly different from zero. The relative abundance of the shortjaw cisco has declined significantly by at least 99% in each area since the 1920s. Although populations nearly vanished at each area, the loss was greatest at the Apostle Islands, where CPUEs were particularly high historically. The decrease is even larger than the CPUE numbers would at first suggest because our use of nylon-meshed nets permitted us a greater ability to catch fish than the cotton or linen nets that Koelz used in the 1920s. Generally, it has been found that nylon nets catch two to three times as many fish as comparable meshes of cotton or nylon (Hile & Buettner 1955, Pycha 1962). This factor did not influence our results except to make the significant differences found between our sampling and that from the 1920s even greater.

The six cohorts of shortjaw ciscoes in our catches show that at least some reproduction and recruitment occurred every year during 1990–1995. The modal number of growing seasons (8) completed by shortjaw ciscoes collected in our study was identical to that found by Van Oosten (1937) for a sample of 589 shortjaw ciscoes collected from Lake Superior in 1922 near Duluth, Minnesota. Mean growth to the end of the seventh season was 1% higher for fish collected by us than by Van Oosten, whereas growth to the end of the eighth through tenth seasons was 5%, 12%, and 11% higher in his sample. However, actual growth differences were somewhat higher than those latter percentages, because Van Oosten measured lengths of fish after they were fixed in

Table 3. Stomach contents of Lake Superior shortjaw cisco collected during 1999–2001. Data are pooled for fish collected from each location.

Location	Taxon	No. of food items	Percentage of total food item number	Weight of food items (g)	Percentage of total food item weight	No. of stomachs containing food item	Frequency of occurrence (%)	AII[1]	RII[2]
Grand Marais[3]	*Mysis relicta*	104	99.0	4.50	100.0	6	66.7	265.7	95.6
	Pelecypoda	1	1.0	< 0.01	0.0	1	11.1	12.1	4.4
Marquette[4]	*Mysis relicta*	108	100.0	2.31	100.0	2	28.6	228.6	100.0
Whitefish Bay[5]	*Mysis relicta*	32	4.1	1.06	15.2	3	33.3	52.6	19.7
	Diporeia hoyi	752	95.6	5.90	84.8	2	22.2	202.6	76.0
	Pelecypoda	3	0.4	< 0.01	0.0	1	11.1	11.5	4.3

[1] Absolute Importance Index (AII) = Percentage of total food item number + Percentage of total food item weight + Frequency of occurrence.
[2] Relative Importance Index (RII) = 100 × AII/ΣAII.
[3] 9 stomachs, 3 (33.3%) empty.
[4] 7 stomachs, 5 (71%) empty.
[5] 9 stomachs, 5 (55.6%) empty.

formalin and preserved in alcohol. He did not correct the lengths of those fish for shrinkage. Length was not an accurate predictor of age — means for five age groups ranged in length from 255 to 315 mm. Van Oosten also found that length was a poor index of age, because fish of the same length in his sample were classified to as many as four ages. The higher mortality of the faster growing fish of each year class results in the appearance of slower growth at older ages, as was found by Smith (1956) for lake herring in Lake Michigan.

Mysis relicta was the most important shortjaw cisco prey, although our sample sizes of shortjaw ciscoes were small for an in-depth analysis of diets. *Mysis* was also important in the diet of adult shortjaw cisco collected in Lake Michigan in the early part of the 20th century (Koelz 1929, Bersamin 1958) and in Lake Superior in the 1960s (Anderson & Smith 1971).

Shortjaw ciscoes are now distributed deeper than in 1921–1922. In our study, the mean depth of nets with shortjaw cisco was nearly at the maximum depth where Koelz (1929) found most of the shortjaw cisco. However, limitations of the gillnets used in the 1920s likely prohibited fishing in deeper water (Pycha 1962), but even so, Koelz (1929) reported shortjaw cisco to be more abundant at depths shallower than his deepest sets in the 1920s. Populations of lean lake trout (*Salvelinus namaycush*) have been restored in much of Lake Superior, and those larger populations have contributed to reductions in abundances of lake herring, ninespine stickleback (*Pungitius pungitius*), rainbow smelt (*Osmerus mordax*), and slimy sculpin (*Cottus cognatus*) (M. H. Hoff & O. T. Gorman unpubl. data). Lake trout predation may have reduced shortjaw cisco populations on the shallow margins of their bathymetric distributions and caused a shift to deeper habitats in Lake Superior. Knowledge of that shift will aid future shortjaw cisco population assessment efforts.

Shortjaw cisco declined apparently as the result of commercial overharvest (Lawrie 1978). Yield for all deepwater ciscoes (mostly shortjaw cisco) averaged 395 metric tons during 1895–1908, declined sharply to 2.7 metric tons in 1909, and remained low (mean of 38 metric tons) through 1925 (Lawrie 1978, Baldwin *et al.* 1979). In 1926, deepwater cisco yield increased sharply in response to the increased demand resulting from the collapse of the Lake Erie lake herring fishery. At that time, the shortjaw cisco was the only deepwater cisco species that was large-bodied enough to be of value to the commercial fishery (Van Oosten 1937). Experiments on gill net selectivity in catches of lake herring and bloater show that larger individuals have a higher probability of being captured in gill nets, and this fact could have made shortjaw ciscoes more vulnerable to the fishery (Rudstam *et al.* 1984). Deepwater cisco commercial yield tended to decline from 1927 to 1950, when the fishery switched from shortjaw ciscoes to bloaters (Lawrie 1978), which had begun to grow faster and achieved larger sizes (Dryer & Beil 1968), probably as the result of decreased competition from reduced populations of shortjaw cisco (Lawrie 1978). Additionally, the fishery changed to nylon gill nets by 1950, and not only were such nets more effective at catching fish, but they caught a wider variety of sizes in a given mesh including many individuals of smaller species such as the bloater (Hile & Buettner 1955). Competition between bloaters and shortjaw ciscoes in the shallow margins of their historic bathymetric distribution may be contributing to reduced abundance there.

Koelz (1929) found that shortjaw ciscoes constituted "virtually" the entire catch at all five areas in 1921–1922. Lake trout (*Salvelinus namaycush*), lake herring, and bloater dominated catches in our assessments. Gill-net assessments of ciscoes in eastern Lake Superior in 1959 revealed that shortjaw ciscoes were only a slightly smaller percentage (34%) of the cisco catch than were bloater (37%) (E. H. Brown Jr. unpubl. data). Peck (1977) found that the shortjaw cisco had been reduced to 0%–23% of deepwater cisco commercial catches near the Keweenaw Peninsula, and 0%–31% of the catches near Marquette during 1974–1976. He also found that the shortjaw cisco was relatively more abundant in 1974 (2%–23% of catches) than in 1975 and 1976 (0%–9%), but he concluded that trend may have been equivocal because of small sample sizes and differences in sampling through the years. Two collections in 1997 from Lake Superior near Whitefish Bay and Grand Marais, Michigan, showed that shortjaw ciscoes were 5% and 11% of all ciscoes caught (USGS, Great Lakes Science Center unpubl. data), proportions within the range found by Peck (1977) at Marquette. These data suggest that the decline of shortjaw cisco occurred primarily before 1960, and that abundance may have stabilized at its current low level during the 1970s. However, proportional abundance of shortjaw cisco may be unrelated to absolute abundance, and further study of USGS gill-net data collected from Lake Superior assessments conducted during 1958–1997 may result in a statistically tenable description of shortjaw cisco dynamics since 1958.

Lake Superior shortjaw cisco populations have declined so significantly from the 1920s to the present that abundance in one area was zero, and abundance in the other four areas was not statistically different from zero. Therefore, management agencies should develop a rehabilitation program for shortjaw cisco in Lake Superior as well as in Lakes Huron and Michigan where they are extirpated. Interagency rehabilitation plans have been developed for Lake Superior brook trout (*Salvelinus fontinalis*) (Newman *et al*. 2001), walleye (*Stizostedion vitreum*) (Hoff 2001), and lake sturgeon *(Acipenser fulvescens*) (Auer 2003). The goal of Lake Superior fishery management agencies is to rehabilitate and maintain diverse, healthy, reproducing, and self-regulating fish communities that are composed largely of indigenous species and that are sustainable and ecologically efficient (Horns *et al*. 2003). One of the guiding principles used in formulating management policy and fish community objectives for Lake Superior was that depleted native species should be protected and enhanced, and two of the fish community objectives are to manage for a self-sustaining assemblage of prey species at population levels capable of supporting populations of desired predators and a managed commercial fishery, and protect and sustain the diverse community of indigenous fish species (Horns *et al*. 2003). One of the specific objectives for maintaining diversity is to protect species by maintaining self-sustaining populations. An accompanying strategy calls for monitoring abundance so that significant population declines are detected early and can be acted upon. Thus, the interagency management objectives and strategies support rehabilitation of shortjaw cisco populations to maintain species diversity and adequate forage for salmonine predators, and continued shortjaw cisco population monitoring, as a product of a comprehensive program to monitor all species of ciscoes and other fishes in Lake Superior.

Shortjaw cisco dominated the deepwater cisco fishery in Lake Superior for the first half of the 20th century (Lawrie 1978), and were therefore economically important. Juvenile shortjaw ciscoes must also have been ecologically important as prey for lake trout during that period, and could become important prey again if populations are rehabilitated. While Lake Superior shortjaw cisco rehabilitation strategies are being developed, a program of continued assessment and monitoring should be implemented to set the stage for evaluating rehabilitation efforts. A further understanding of the biology and population dynamics of the shortjaw cisco is warranted for Lake Superior, which is now its entire range within the United States.

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