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

Final Report to the Species-at-Risk Program

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### Introduction

The shortjaw cisco (*Coregonus zenithicus*) is a widespread species in the salmonid subfamily, Coregoninae. Originally described from Lake Superior at Duluth, Minnesota by Jordan and Evermann in 1909, it was subsequently discovered in most of the Laurentian Great Lakes and many smaller lakes in central North America. Mature adults generally approach 300 g in mass, and exceptionally large fish can reach 1.0 kg. The biology is best known in the Great Lakes (including Lake Nipigon) where the species was once a major component of thriving commercial fishery, occupying depths between 40-200 m.

### Distribution

The shortjaw cisco was once a common chub species in Lakes Huron, Michigan, and Superior, but populations were extirpated in Lakes Erie, Huron and Michigan and greatly reduced in Lake Superior as a result of commercial overharvest. Shortjaw ciscoes have a widespread distribution throughout central Canada and have been reported from at least 22 lakes in Canada extending from Ontario to the Northwest Territories. The species was last verified in Lake Erie prior to 1970, in Lake Michigan in 1975, Lake Huron in 1982, and was never reported from Lake Ontario. In 2004, and again in 2005, a few individuals were identified from commercial catches in Georgian Bay, Lake Huron, but it is not known if these represent remnant stocks or migrants from Lake Superior (N. Mandrak and T.N. Todd, pers. Commun.). At the present time in the United States, viable populations of shortjaw ciscoes may exist only in Lake Superior and while they were once the dominant chub species there, they are now the rarest member of the chub assemblage. Small populations of uncertain status also occur in a few small lakes on the U.S.and Canadian border.

### Protection

No protection is provided for shortjaw cisco populations in the United States, nor has there been any attempt to regulate the chub (deepwater ciscoes) fishery or to manage and recover the stocks. In Canada, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed shortjaw ciscoes as Threatened, but no specific protection has been provided for the shortjaw cisco in Canada except for general protection afforded through the Fisheries Act.

### Population Sizes and Trends

Shortjaw ciscoes have been an important part of the food fishery in the Great Lakes since at least the mid-1800s. Landing records, on the whole, were not recorded by species, but were lumped into a general category, “chubs”, for all the deepwater cisco species that excluded the shallow-water lake herring. In Lake Superior, shortjaw cisco was the dominant chub species and was the target of a commercial chub fishery that thrived from the late 1800s through the mid-1970s. In 1921 Koelz found that shortjaw cisco represented 90% of the chub assemblage but even as late as 1953, shortjaw cisco was numerically the most common chub species in most areas of Lake Superior and were especially abundant in the eastern half of the Lake. Research assessment monitoring showed that populations declined precipitously in the 1960s and 1970s during the most intensive period of commercial harvest in the Lake's chub fishery history. By the early 1980s the fishery collapsed, and since the early 1970s bloaters have been the dominant chub species in Lake Superior. Today, the shortjaw cisco represents less than 1% of the chub assemblage of Lake Superior.

The species still persists in Lake Superior, but has declined in relative abundance from nearly 90% of the chub catch in the 1920s to about 50% of the catch in the early 1950s to about 25 % of the catch in the late 1950s, to 6-11 % in Michigan waters in the 1970s. Two small collections made in Michigan waters in 1997 revealed abundances of 5 % and 11 %, in the same range as the 1970s. In 1999-2001, USGS resampled areas sampled by Koelz in 1920-1921 and found that shortjaw cisco abundance had declined from greater than 90% to less than 1%. Similar comparisons of assessment sampling conducted by Smith in 1953 with assessment sampling conducted by USGS in 1999-2003 showed that abundances declined from >50% of the catch to <4% of the catch.

## Habitat

In Lake Superior, shortjaw cisco have been found to occur in waters of 40 to 200 m in depth, however, recent assessment data show that peak densities occur at depths of 80-160 m. In comparison to other chubs, the depth distribution of shortjaw cisco overlaps considerably with bloater (40-160 m) and kiyi (80-200 m).

## General Biology

In Lake Superior, spawning occurs in either the spring or the fall. Fecundity of shortjaw cisco is likely similar to that of other deepwater species such as the bloater, ranging from 3,230 eggs for a fish 241 mm total length.

As in most fish species, shortjaw cisco grow quickly in their first year of life. While the sexes have been found to have similar growth in length, females grew faster in weight than the males. In Lake Superior, maturity occurs in about the fifth year, compared to the third or fourth year for lake herring. Like most coregonines, shortjaw cisco are opportunistic, particulate feeders that generally ingest prey one item at a time. Because shortjaw cisco live in deepwater habitat, limnetic crustacea (copepods and cladocerans) and benthic organisms (*Mysis* and *Diporeia*) are the most common items they are likely to encounter.

## Limiting Factors

While commercial over-harvest is the most important factor known to be responsible for the decline of the shortjaw cisco and other chub species in the Great Lakes, other factors contributed or now may be deterring the recovery of stocks. In Lake Erie, profound ecological changes occurred that shifted the lake environment to a more mesotrophic condition, and while the physical conditions of Lakes Michigan and Huron have not changed as dramatically over the past 100 years (with the notable exception of Saginaw Bay), the biological community has become considerably altered by the introduction of many exotic species across several trophic levels. Reproductive capability of shortjaw cisco stocks were compromised in the early 1900s when the commercial fisheries targeted the larger individuals at first, and as densities of large fish dwindled, mesh sizes were periodically reduced to target smaller and smaller individuals as a means of maintaining catch levels. Introduced rainbow smelt and sea lamprey populations in Lake Superior peaked well after the start of the decline of shortjaw cisco stocks but their late arrival and continued increases after the decline indicate they may have an impact impeding recovery of shortjaw cisco by imposing unnatural sources of competition and predation. Rainbow smelt compete for food resources and larger individuals prey on larval coregonids; sea lamprey predation continues to take a toll not only on larger species such as lake trout, burbot, and lake whitefish, but also smaller species such as chubs and lake herring. Abiotic factors such as weather and thermal changes (e.g., those associated with global warming) in the lakes have also been suspected to play a role in population destabilization.

### Special Significance of the Species

The shortjaw cisco along with the lake herring, appear to be the ancestral colonizing species for most of the post-glacial distribution region of the Mississippi Refugium. Within the Great Lakes, the shortjaw cisco represented one lineage in the most spectacular radiation of sympatric forms in northern lakes. It is a unique form with a distribution that is intimately tied with post-glacial hydrology, and is thus of great scientific interest. Food fisheries in the Great Lakes, especially included this species as part of a highly desirable and commercialized smoked chub market, but it was not considered more desirable than other cisco species of its same size and condition.

### Evaluation

The absence of *Coregonus zenithicus* from Lakes Michigan (since 1975), Huron (since 1982, see earlier note about 2004 and 2005 occurrence), and Erie (since 1957) supports a conclusion that the species has been extirpated in these lakes. The decline of the species in Lake Superior during the 20$^{th}$ Century, coupled with its extirpation in the lower Great Lakes, should be viewed with alarm. The species is vulnerable to excessive food harvest, habitat degradation, and impact by introduced exotic species throughout its range. Low numbers of shortjaw cisco remain in Lake Superior, which suggests that the potential for recovery is good. However, recovery is unlikely to occur or to be sustained if protection is not afforded. Population levels of shortjaw cisco and other chubs should be monitored systematically throughout Lake Superior to determine population trends and population structure. Other studies focused on determining life history and identification of specific stocks (e.g., fall and spring spawning stocks) should be fully supported to provide information critical to development of recovery and management actions. The ultimate goal should be to fully recover shortjaw cisco stocks so that a well managed and valuable fishery can be supported indefinitely.

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ABSTRACT

The shortjaw cisco (*Coregonus zenithicus*) was once a common chub species in Lakes Huron, Michigan, and Superior, but populations were extirpated in Lakes Huron and Michigan and greatly reduced in Lake Superior largely as a result of commercial overharvest. We previously reported on a study conducted during 1999-2001 in Lake Superior, where we evaluated shortjaw cisco abundance in five areas in the U.S. waters of Lake Superior, and compared our results with a similar assessment conducted by W. Koelz in those areas in 1921-1922. Koelz found that shortjaw cisco was the dominant chub species at all of his survey locations in the 1920s. During 1999-2001, shortjaw cisco were present in four of the areas sampled but abundances were not significantly different from zero. To follow up that study, we proposed searching for historic capture records of shortjaw cisco that could potentially detail the rapid decline of the commercial chub fishery in the 1970s. We were successful in finding several sources of capture data and were also able to incorporate additional nearshore and deepwater trawl survey data collected by us in 2001-2003. The oldest historical dataset discovered was that from the 1953 survey of Lake Superior conducted by Stanford Smith, et al. They found that like Koelz, shortjaw cisco were widespread, abundant, and the dominant chub species of the lake. Their surveys provide invaluable baseline information on distribution and densities of shortjaw cisco, habitat associations, and gear catch efficiencies. Records from the years following the establishment of the Lake Superior Biological Station in 1957 also proved to be an invaluable resource. Small mesh gillnet surveys conducted in the Apostle Islands between 1958 and 1973 showed the abundance of shortjaw cisco plummeted in the early 1960s and were essentially at zero by 1970. Small mesh gillnet assessments conducted in Isle Royale between 1958 and 1992 showed a similar pattern to that in the Apostle Islands; however, shortjaw populations declined rapidly in the late 1960s and reached near zero levels by 1980. Records of the commercial catch of deepwater chubs in Lake Superior showed a period of increased yield between the late 1950s and 1980 and then abruptly dropped to low levels by 1990. Most of the residual catch of chubs after

1980 probably represents harvest of bloater chubs. The intense fishing pressure that occurred during 1958-1980 closely tracks the rapid depletion of shortjaw cisco in Lake Superior and supports previous assertions that population declines were the result of overfishing. Recent deepwater surveys in 2001-2003 show that shortjaw ciscos are still widely distributed in Lake Superior but at very low densities. The greatest frequency and densities were found in eastern Lake Superior and only a few specimens were taken in the western half of the lake.

The widespread, but low numbers of shortjaw cisco found in recent years suggests that recovery may yet be possible, but management strategies should be adopted to ensure that recovery. Population monitoring should continue to assess population trends and to evaluate success of recovery efforts.

## INTRODUCTION

Prior to European settlement of the Lake Superior basin, the shortjaw cisco (*Coregonus zenithicus*) was a dominant member of the Lake Superior fish community. Results of scientific surveys conducted in the early 1920s showed that shortjaw ciscoes represented, on average, 98% of the catch from small-mesh gillnet sets distributed across Lake Superior (Koelz 1929). The bloater (*C. hoyi*), now the dominant deepwater cisco in Lake Superior, represented only 1% of the catch from Koelz's surveys in the early 1920s. The kiyi (*C. kiyi*), now commonly taken from trawl samples at depths >80m, represented 0.1% of Koelz's catch. The rapid decline in the abundance of shortjaw cisco during the 20$^{th}$ century resulted in a dramatic shift in community structure in which the bloater and kiyi supplanted the once dominant shortjaw cisco in deepwater habitats of Lake Superior. During the late 19$^{th}$ and well into the 20$^{th}$ century, populations of shortjaw cisco in the upper Great Lakes were commercially harvested to satisfy a growing smoked fish market in the United States (Smith 1968, 1972; Lawrie and Rahrer 1972, 1973). By 1960s through 1970s shortjaw cisco became commercially extinct throughout its range and disappeared entirely from all lakes except for Superior (Smith 1968, 1972; Hoff and Todd 2004).

Recent surveys by Hoff and Todd (2004) of U.S. waters of Lake Superior found shortjaw cisco to be present in four of five areas sampled, but abundances were so low that they were not significantly different from zero. Subsequent to Hoff and Todd's work, the U.S. Fish and Wildlife Service funded us to conduct an assessment of the status of the species in order to determine the need for legal protection under the Endangered Species Act of 1973, 1996, as amended. In this *Status Assessment Report* we describe the legal status of the species in the United States and Canada; provide a description of the species, and its geographic distribution, biology, habitat associations and requirements, population abundance and trends, and threats and limiting factors; reports on current monitoring activities and management plans; provide a proposed conservation plan; summarize information and data by location; include maps showing locations of important populations; and list of names of people or agencies contacted for requests of historic and current capture data. The *Status Assessment Report* will include analysis of 1) comparison of abundance of shortjaw cisco in Lake Superior from current assessments and those from 1920-21; 2) trends in abundance of shortjaw cisco in recent years (1970s to 2000) as measured from gillnet and bottom trawl assessments; and 3) assessment of threats as outlined in the Five Listing Factors in ESA Section 4(a)(1). The included executive summary of the *Status Assessment Report* is written in laymen's terms to serve outreach activities. The report elements are addressed by the following objectives:

1. Summarize background information: description of the species, geographic distribution, biology, habitat associations and requirements, population abundance and trends, threats and limiting factors, and legal status in the United States and Canada.
2. Research existing databases to provide baseline information on the distribution and abundance of shortjaw cisco prior to the collapse of the population in Lake Superior.
3. Relate changes in distribution and abundance of shortjaw cisco to available commercial catch data on a lake ecoregional basis.
4. Determine the present distribution and abundance of shortjaw cisco populations in Lake Superior from ongoing research assessments.
5. Identify research and information needed to enhance management actions aimed at recovery of shortjaw cisco population in Lake Superior.
6. Provide proposed conservation measures that may be incorporated into a recovery plan.
7. Address the Five Listing Factors in the ESA-1973, section 4(a)(1) as to the status of shortjaw cisco in the United States.

## BACKGROUND

Species description.
The shortjaw cisco (*Coregonus zenithicus*) is a member of a related group of fishes, the ciscoes, which belong to the Salmonid subfamily Coregoninae, the whitefishes, and are further distinguished by being grouped into the subgenus *Leucichthys.* The shortjaw cisco, bloater (*C. hoyi*), and kiyi (*C. kiyi*) inhabit deep water (typically >60 m) and are referred to as the deepwater ciscoes or colloquially as "chubs." The widely distributed lake herring (*C. artedi*), is a pelagic cisco and is distinguished from the deepwater ciscoes in that it inhabits shallow and surface waters. The ciscoes were conspicuous members of the fish communities in all of the Great Lakes, but presently only Lake Superior retains an intact cisco assemblage (Smith 1968, 1972a). In lakes Michigan and Huron, the bloater is only remaining cisco and no viable cisco populations remain in lakes Erie and Ontario

The shortjaw cisco, along with the lake herring, appear to be the ancestral colonizing species for most of the post-glacial distribution region of the Mississippi Refugium (Todd and Smith 1992). Within the Great Lakes, the shortjaw cisco represents one lineage in a spectacular radiation of sympatric forms in northern lakes (Smith and Todd 1984). It is a unique form with a distribution that is intimately tied with post-glacial hydrology, and is thus of great scientific interest. The shortjaw cisco's morphological differences from the lake herring group of ciscoes appears to "adapt" it in some unique, but as yet unrevealed, manner to survival in northern aquatic ecosystems because of its persistence throughout the past millenia. Food fisheries in the Great Lakes especially included shortjaw cisco as part of a highly desirable and commercialized smoked chub market, but it was not considered more desirable than other deepwater cisco species of similar size and condition.

After Jordan and Evermann (1909) described the shortjaw cisco from specimens taken from western Lake Superior near Duluth, Minnesota (the "Zenith" city), it was subsequently discovered in most of the Laurentian Great Lakes and many smaller lakes in central North America (Scott and Crossman 1973; Clarke 1973; Clarke and Todd 1980). Like other ciscoes, the shortjaw cisco is elliptical in body shape, laterally compressed, and covered with large, smooth scales. The body is generally silvery in color, olive or tan dorsally shading to white ventrally with little pigmentation on the paired fins. The mouth is small and toothless, and the lower jaw is generally even with the upper jaw or shorter and included within the gape of the upper jaw (Eddy and Underhill 1978; Becker 1983). The lower jaw may occasionally extend beyond the premaxillaries in some populations, as was noted by Jordan and Evermann (1909) for populations in Lake Superior, although this is inaccurate. The premaxillaries generally make a distinct angle on the snout in contrast to most other cisco species where the premaxillaries are generally in line with the slope of the head or make only a very minor angle at the snout, e.g., bloaters. The gill rakers on the first branchial arch typically number less than 40, and are often in the mid-30s in contrast to most other cisco species that have counts not only more than 40 but even 45-55 (e.g., lake herring). In addition, the gill rakers tend to be moderate or short in length compared to those of most other cisco species (Becker 1983). Unfortunately, no single diagnostic character suffices alone to identify the species, but rather an association of characters must be used, of which the single most important is gill raker number. Considerable variation in size exists across the range of the species, and adults of some Canadian populations (e.g., George Lake, Manitoba and White Partridge Lake, Ontario) measure less than 100 mm standard length (SL) while adults of other populations reach lengths greater than 300 mm SL up to a maximum of about 400 mm (e.g., Lake Nipigon, Ontario). Large specimens generally approach 300 g in mass, and exceptionally large fish can reach 1.0 kg. The biology is best known in the Great Lakes (including Lake Nipigon and Lake Superior) where the species was once a major component of vigorous food fisheries, occupying intermediate depths between 20-180 m.

Distribution

The present distribution of shortjaw cisco in the United States is limited almost entirely to Lake Superior (Hoff and Todd 2004). Exceptions include the recent discovery of small populations of shortjaw cisco in two lakes in northern Minnesota that straddle the Canadian border (Lake Saganaga and Lake of the Woods) (Etnier and Skelton 2003, Todd 2003b). While best known from the Great Lakes, the shortjaw cisco has a widespread distribution throughout central Canada. Shortjaw cisco was present in all of the Great Lakes except for Lake Ontario. It was last verified in Lake Michigan in 1975 and Lake Huron in 1982 (Todd 1985). However, these fish could have been strays from Lake Superior where the species was still reasonably abundant (Ono et al. 1983). Reports of the longjaw cisco, *C. alpenae*, in Lake Erie (Scott and Smith 1962) should be attributed to *C. zenithicus* based on re-examination of the original specimens and the findings of Todd et al. (1981) that concluded *C. zenithicus* and *C. alpenae* were conspecific. Interestingly, the species was not known from Lake Ontario (Koelz 1929).

Habitat

In Lakes Superior, Michigan, and Huron, the shortjaw cisco generally inhabits waters 55 to 144 m in depth, although they have been recorded from as deep as 183 m and occasionally in more shallow water (Scott and Crossman 1973). Seasonal differences were noted in Lake Superior with movement into shallower water during spawning, and the fish inhabited 110-114 m in spring, 55-71 m in summer, and 73-90 m in winter (Dryer 1966). Hoff and Todd (2004) noted during 1999-2001 that Lake Superior shortjaw ciscoes were most abundant at the maximum depths at which they were collected in the 1920s, suggesting a shift to deeper water in the intervening decades. In Lake Nipigon, shortjaw ciscoes inhabit depths between 10-60 m, although the occasional individual has been captured deeper than 60 m (Turgeon et al. 1999).

Habitat preferences in smaller lakes are poorly known. Captures in George Lake, Manitoba from gillnets set in August 1996 between 36-57 m revealed that shortjaw ciscoes inhabited the very deepest stratum of the lake—occurring mostly in gillnets set at 45-47 m, but not in sets shallower than 42 m (Murray and Reist 2003). Likewise, shortjaw ciscoes were found to inhabit the deepest portions of Sandybeach Lake, Ontario, at depths ranging 22-38 m along with sympatric lake herring (Wain 1993). Certainly, once the lakes stratify, the fish will be found in the deeper waters of the hypolimnion. In contrast, shortjaw ciscoes were found quite shallow at depths of 2-16 m in Barrow Lake, Alberta (maximum depth=24 m; Steinhilber et al. 2002).

<u>Biology</u>

Shortjaw ciscoes spawn in either the fall or spring in the Great Lakes. In Lakes Michigan, Huron, and Erie spawning occurred solely in the fall (Koelz 1929; Scott and Smith 1962). However, in Lake Superior there is evidence that spawning occurs in spring or the fall (Koelz 1929; VanOosten 1936; Todd and Smith 1980). Eggs are deposited over the lake bottom (generally clay in the Great Lakes) and left to develop without parental care for a period of three or four months, depending on temperature (Berlin et al. 1977). Fecundity of shortjaw ciscoes is likely similar to that of other deepwater species such as the bloater, ranging from 3,230 eggs for a fish 241 mm total length (TL) to 18,768 for a fish 305 mm TL (Emery and Brown 1978).

As with other ciscoes, growth is rapid in the first year of life. Age-0 shortjaw cisco are likely to use relatively shallow nursery habitat in nearshore areas (<15 m depth) where temperatures and food resources are conducive to rapid growth. Laboratory studies have demonstrated that age-0 coregonids (post swim-up stage) require temperatures of ≥15°C for more than 90 days to attain sufficient size for over-winter survival (McCormick et al. 1971; Edsall and Rottiers 1976; Edsall and Frank 1997; Edsall and DeSorcie 2002; Edsall 1999a, 199b). Although growth rates in length are similar for both sexes, females grow faster in weight than the males—growing an average of about 30 g a year in mature fish with an annual length increase of about 25 mm (VanOosten 1936). Maturity occurs in about the fifth year and subsequent additional growth in weight is due primarily to gonadal development—nearly 60 % of potential maximum weight gain occurs after age-5 whereas 80% of growth in length is achieved by age-5 (VanOosten 1936). Maximum size for Lake Superior fish has been recorded at 276 g at 368 mm TL for males, and females at 292 g (VanOosten 1936). Larger sizes have been reported for Lake Nipigon shortjaw ciscoes—weights from 0.5 to 1.0 kg and lengths up to 400 mm TL (R. Salmon, Ontario Ministry of Natural Resources, Lake Nipigon Assessment Unit, pers. comm.). Some populations of shortjaw ciscoes mature at much smaller sizes—adult fish in George Lake, Manitoba, for example averaged only 158 mm (127-173 mm) SL (U.S.G.S., Great Lakes Science Center, unpublished data).

Coregonines are opportunistic feeders that generally ingest small prey items. Because shortjaw ciscoes typically inhabit deep, offshore waters , terrestrial input is limited, and limnetic crustacea (copepods and cladocerans) and benthic organisms (*Mysis* and *Diporeia*) dominate their diets (Koelz 1929; Bersamin 1958; Anderson and Smith 1971; Wain 1993; Turgeon et al. 1999). Such prey has been found to dominate the diet of shortjaw ciscoes even in shallower habitats—Barrow Lake, Alberta, for example (Steinhilber et al. 2002).

Up through the middle of the 20th century when shortjaw ciscoes were abundant in the upper Great Lakes, they along with other ciscoes constituted an important part of the forage base for predators such as lake trout and burbot (*Lota lota*). After sea lampreys invaded the Great Lakes, populations of lake trout and larger ciscoes were depleted by a combination of overfishing and lamprey depredation (Smith 1968; 1972a). It is likely that adult shortjaw ciscoes became vulnerable to depredation by sea lampreys in the Great Lakes as favored individuals of larger species became depleted (Smith 1968; 1972a).

Commercial fishery

Following European settlement of the Lake Superior drainage in the later 19th century, a vigorous lake whitefish, lake herring and chub fishery developed (Lawrie and Rahrer 1972, 1973). During 1895-1950, the total commercial yield of Lake Superior deepwater ciscoes exceeded 14,000 metric tons and most of that yield was shortjaw ciscoes. The shortjaw cisco represented more than 90% of deepwater cisco commercial catches in the early 1920s, when Koelz (1929) conducted surveys across Lake Superior. By the mid-1970s, shortjaw cisco represented 0-31% of the deepwater cisco annual harvest in the central Michigan waters of the Lake and bloaters dominated the catch (Peck 1977). The decline of Lake Superior shortjaw cisco populations has been attributed principally to commercial overharvest (Lawrie 1978).

Previously Hoff and Todd (2004) compared contemporary abundances of shortjaw cisco with that found in the early 1920s by W. Koelz of the Great Lakes Fishery Laboratory. They found that relative abundances (catch-per-unit-of-effort in standardized gill nets) of shortjaw cisco within the five areas sampled by Koelz in the U.S. waters of the lake declined by nearly 100%, and shortjaw ciscoes were present in only 4 of the 5 areas sampled.

Threats and limiting factors

No single factor is known to be responsible for the decline of the shortjaw cisco in the Great Lakes. In Lake Erie, for example, profound ecological changes have occurred that have shifted the lake to a more mesotrophic condition (although the lake has rebounded from eutrophy because of phosphorus controls and the effects of zebra mussels), to the detriment of the deep-water, more oligotrophic community that historically existed there (Hartman 1972). While the physical conditions of Lakes Michigan and Huron have not changed much, with the notable exception of Saginaw Bay, the biological community has become considerably altered (Smith 1972a). Undoubtedly, the vigorous food fisheries had a negative impact earlier in the 1900s, especially on the larger individuals, at first, then on smaller individuals as mesh sizes were reduced to maintain catch levels (Smith 1968, 1972a). However, competition and predation from rainbow smelt and alewives have certainly had more of an impact during the last 30 years—years in which the food fisheries for chubs have been much less extensive than historical levels (Crowder 1980; Rice et al. 1987; Fleischer 1992). Sea lamprey predation continues to take a toll on Great Lakes species, and has had well documented impacts on lake trout populations (Bronte et al. 2003) and unquantified impacts on smaller species such as chubs and lake whitefish (U.S.G.S., Great Lakes Science Center, unpublished data). Abiotic factors such as weather and thermal changes in the lakes have also been suspected to play a role in population destabilization (Brown et al. 1987; Eck and Wells 1987; Taylor et al. 1987). Such destabilization can favor one species over another, resulting in competitive displacement or hybridization (Smith 1964; Todd and Stedman 1989; Davis and Todd 1998). The overwhelming preponderance of work on Great Lakes chubs has been with adults or relatively large young-of-the-year fish, primarily because of their vulnerability to capturing gear in both food fisheries and scientific assessment programs. The growing knowledge of how biotic and abiotic changes in the system have influenced populations has revealed that the larval and juvenile stages are the most vulnerable, and factors limiting survival at these stages need better understanding.

<u>Status and protection</u>

The absence of shortjaw cisco from Lakes Michigan (since 1975), Huron (since 1982), and Erie (since 1957) supports a conclusion that the species has been extirpated in these lakes (Todd 1985). The great and gradual decline of the species in Lake Superior throughout the $20^{th}$ century, coupled with its extirpation in the lower Great Lakes, should be viewed with alarm. The species is vulnerable to excessive food harvest, habitat degradation, and introduced exotic species throughout its range. 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. Currently, the species occupies an indeterminate status following elimination of these categories (Department of Interior 1996). Presently, the U.S. Fish and Wildlife Service is considering the shortjaw cisco for designation as a Candidate for potential listing as Threatened or Endangered , and, in support of this potential designation, is considered as a "Species at Risk" by the U.S. Geological Survey for priority in research. The shortjaw cisco was designated as "Threatened" by the Committee On Status of Endangered Wildlife In Canada (Houston 1988; Todd 2003a), considered as "May Be at Risk" by the Province of Alberta (Steinhilber and Ruhde 2001), listed as "Threatened" by the Michigan Department of Natural Resources (MIDNR 1974, Latta 1998), and listed as "Endangered" by the Wisconsin Department of Natural Resources (WDNR 1975). Although the 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 and Steinhilber 2002), and Mandrak and Todd (2004, pers. comm.) recently identified a few specimens from Georgian Bay, Lake Huron that could represent a remnant stock or could also be immigrants from Lake Superior.

## SAMPLING AREAS AND METHODS

<u>Ecoregions of Lake Superior</u>

In order to provide more meaningful regional analyses of Lake Superior aquatic communities, we divided the lake in to logical, ecosystem-based units (Table 1 and Fig. 1). In most cases, these units are compatible with politically-based management units. Exceptions include: WLS- Western Lake Superior ecoregion includes a portion of Minnesota up to the Big Sucker River where the bathymetry changes rather abruptly from a medium gradient, sandy bottom to a steep gradient, rocky and mud bottom; WFBY- Whitefish Bay included both Canadian and U.S. components.

Description of Ecoregions

WLS- Western Lake Superior. This ecoregion consists of low-slope sandy shore areas west of the Apostle Islands (Squaw Point, Wisconsin) region around the western end of Lake Superior to the mouth of the Big Sucker River, Minnesota. Maximum depth is approximately 60 m in the nearshore area (<5 km from shore).

MNNS- Minnesota North Shore. This ecoregion consists of steep-slope granitic and basaltic rocky shore areas northeast of WLS from Two Harbors up to Wauswaugoning Bay, Minnesota. Maximum depth exceeds >100 m within 5 km of shore.

WCAN- Western Canada. This ecoregion consists of steep to moderate slope granitic and basaltic rocky shore areas from Cloud Bay to Heron Bay, Ontario. Maximum depth typically exceeds 100 m within 5 km of shore.

ECAN- Eastern Canada. This ecoregion consists of moderate slope granitic rocky shore areas from Otter Island to Alona Bay, Ontario. Maximum depth typically reaches 100 m within 5 km of shore.

WFBY- Whitefish Bay. Nearshore areas in this ecoregion are dominated by low-slope sandy shorelines. The region ranges from Pancake Point in Canadian waters to Whitefish Point in U.S. waters. Maximum depth reaches approximately 60 m within 5 km of shore.

MISS- Michigan South Shore. Nearshore zones in this area are dominated by low-slope sandy shorelines but steep rocky areas occur in the vicinity of Grand Island. The region ranges from Crisp Point west of Whitefish Point to Big Bay, Michigan. Maximum depth typically exceeds 60 m within 5 km of shore.

EKEW- Eastern Keweenaw. Nearshore zones in this area are dominated by low-slope sandy and rocky shorelines and but some steep slope areas occur inside Keweenaw Bay in the vicinity of Sand Bay. The region ranges from Huron Bay to Bete Grise near the tip of the Keweenaw Peninsula, Michigan. Depths typically exceed 100 m within 5 km of shore.

WKEW- Western Keweenaw. Nearshore near the north end of the Keweenaw Peninsula are steep and rocky, exceeding 100 m depth within 5 km. Nearshore areas west of Upper Entry are dominated by sandy low-slope shorelines, and depths rarely exceed 60 m within 5 km of shore. The region extends from Eagle River to Little Girls Point, Michigan.

APIS- Apostle Islands. Nearshore areas in this archipelago consist of a mix of low-slope sandy shorelines and moderate slope sandstone shorelines. Maximum depths range from less than 60 to more than 100 m within 5 km of shore.

ISRO- Isle Royale (not shown in figure). Nearshore waters of the largest island in Lake Superior are typically rocky, steep, and complex. Very difficult to find trawlable areas. Maximum depths typically exceed 100 m within 5 km of shore.

THBY- Thunder Bay. Nearshore areas in this large bay consist of low and moderate slope shorelines. Maximum depths range from less than 60 to more than 100 m within 5 km of shore.

BLKB- Black Bay. Nearshore areas in this large bay consist of low slope shorelines where maximum depths are typically less than 50 m within 5 km of shore.

NIPB- Nipigon Bay. Nearshore areas in this large bay consist of low and moderate slope shorelines. Maximum depths range from less than 50 to more than 100 m within 5 km of shore.

**TABLE 1. Eco-Regions of Lake Superior[1]**

| Eco-Region Name | Stations in Eco-Region |
|---|---|
| WLS – Western Lake Superior | 76-Squaw Point, 151-Bark Point, 186-Lester River, 187-Big Sucker River, 205-Port Wing, 206-Brule River, 210-Superior Entry |
| MNNS – Minnesota North Shore | 36-Two Harbors, 65-Grand Marais, 172-Baptism River, 188-Encampment Island, 190-Poplar River, 191-Wauswaugoning Bay, 207-Chicago Bay, 208-Cascade River, |
| WCAN – Western Canada | 400-Cloud Bay, 404-Thunder Cape, 410-Borden Island, 411-Shesheeb Bay, 418-Terrace Bay, 419-Jackfish Bay, 420-Ashburton Bay |
| THBY – Thunder Bay | 401-MacKenzie Bay, 402-Sawyer Bay, 403-Pie Island |
| BLKB – Black Bay | 405-Blk. Bay: S. Demers Point, 406-Blk. Bay: Georges Point, 407-Blk. Bay: Central, 408-Blk. Bay: Northwest |
| NIPB – Nipigon Bay | 412-Nip. Bay: Southwest, 413-Nip. Bay: Red Rock, 414-Nip. Bay: Dublin Creek, 415-Nip. Bay: Rainboth Point, 416-Simpson Island, 417-Schreiber Channel |
| ECAN – Eastern Canada | 450-Michipicoten Island, 451-Dog River, 454-Red Rock River Bay, 455-Gargantua Bay, 456-Agawa Bay, 457-Alona Bay, 462-Dore Bay, 463-The Flats, 464-Wheat Bin/Crane Island, 465-Otter Island, 466-Richardson Harbor |
| WFBY – Whitefish Bay | 79-Tequamenon Island, 174-Iroquois Island, 175-Tom Brown's, 193-Salt Point, 194-Paradise, 195-Whitefish Point, 459-Maple Island, 460-Goulais Point, 461-Pancake Point |
| MISS – Michigan South Shore | 88-Shelter Bay, 120-Shot Point, 142-Big Bay, 176-Crisp Point, 177-Sucker River, 178-Beaver Lake, 196-Bakers Point, 209-Grand Island |
| EKEW – Eastern Keweenaw | 82-Jacobsville, 84-Sand Bay, 85-Gay, 100-Traverse Island, 101-Bete Grise, 140-Traverse Bay, 158-Huron Bay |
| WKEW – Western Keweenaw | 57-Ontonagon, 180-Eagle River Shoal, 181-Hill Creek, 182-Freda, 183-Fourteen Mile Point, 184-Little Girls Point, 192-Black River |
| APIS – Apostle Islands | 2-Stockton Island, 24-Michigan Island, 44-Outer Island (west), 45-Cat Island, 52-Outer Island (east), 71-Raspberry Point, 75-Bear Island, 86-Basswood Island, 87-Stockton Island (NW), 139-Sand Island |
| ISRO – Isle Royale | No existing trawl stations, but record of gillnet assessments from 1958-1993. |

[1]The designation of these eco-regions was developed by Owen Gorman, Lake Superior Biological Station, USGS Great Lakes Science Center, Ashland, Wisconsin.

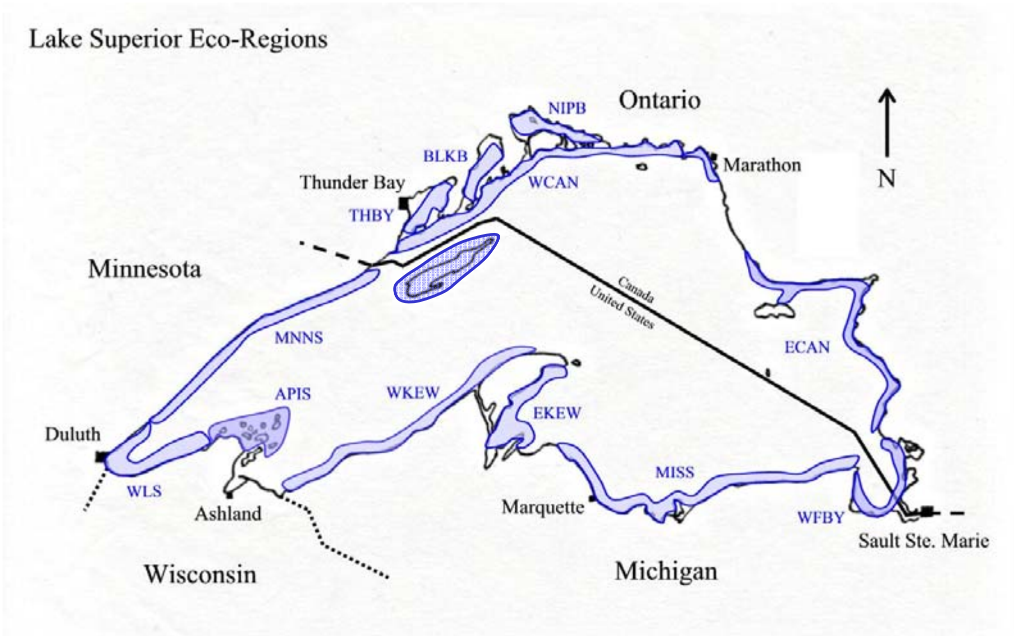



**FIGURE 1**. Ecoregions of Lake Superior. Note that the area around Isle Royale constitutes one of the Lake Superior Ecoregions. Ecoregions are APIS- Apostle Islands, WLS- Western lake Superior, MNNS- Minnesota North Shore, WCAN- Western Canada, THBY- Thunderbay, BLKB- Black Bay, NIPB- Nipigon Bay, ECAN- Eastern Canada, WFBY- Whitefish Bay, MISS- Michigan South Shore, EKEW- Eastern Keweenaw, WKEW- Western Keweenaw, ISRO- Isle Royale.

Databases

We used data from a number of sources to determine the status and trends of shortjaw cisco in Lake Superior (Table 2).

*1895-2003 Historical Commercial Catch records*

The Great Lakes Fishery Commission and the Lake Superior Technical Committee compile and maintain commercial fishery catch records for Lake Superior dating back to the late 1800s. Chubs represent one of the categories of the commercial catch records and includes the deepwater ciscoes or chubs, i.e., shortjaw cisco, bloater (*Coregonus hoyi*), and kiyi (*Coregonus kiyi*). Chubs are distinguished from herring, i.e., lake herring (*Coregonus artedi*) in the catch records. Generally chubs were taken with small mesh gillnets (< 74 mm stretch mesh) set along lake bottoms at depths greater than 40 m. Most lake herring were captured with larger mesh gillnets set near or at the surface. Throughout much of the 20$^{th}$ century, shortjaw cisco was the target of the chub fishery as it is the largest of the three deepwater ciscoes and dominated the catch up through the 1960s; thus trends in catch records indicate the relative viability of the chub populations that are being exploited. Catch records in the database are recorded as both dressed and round weights; we converted all records to round weights for consistency.

*1921-1923 Lake Superior Survey*

During 1921-1923, Walter Koelz from the U.S. Bureau of Fisheries, conducted a survey of Lake Superior to inventory the coregonid assemblage, including data on species distribution and abundance (Koelz 1929). His principal survey tools were specially-made 2.5" and 2.75" stretch-mesh cotton or linen gillnets, but he also utilized data from commercial fishermen's lifts of gillnet and pound nets. Data were gathered from 50 sites lake-wide, 29 from U.S. waters and 21 from Canadian waters. Of the 50 sites, he set special assessment gillnets at 15 sites, totaling ~30000' of net for 59 set nights. Data from the 35 non-assessment samples came largely from commercial sets. Koelz's systematic work on the Great Lakes coregonids guided the work of biologists at the Great Lakes Fishery Laboratory, such as Stanford Smith, Ralph Hile, and Paul Eschmeyer, who conducted a major survey of the Lake Superior fish community in 1953.

*1953 Lake Superior Survey*

In 1953, Stanford Smith, Ralph Hile and Paul Eschmeyer of the Great Lakes Fishery Laboratory (now the Great Lakes Science Center) conducted an extensive survey of Lake Superior for the entire field season (May-October). The results we present were taken from the original field records and serve as a baseline for the status and trends of shortjaw cisco in Lake Superior in the second half of the $20^{th}$ century. Smith, et al. sampled 41 locations in U.S. and eastern Ontario waters of the Lake with gillnets and 47 locations with bottom trawls. A range of gillnet mesh sizes varying from 1 to 6" stretch mesh were set in 300' length panels at each site.

*1958-1973 Small-mesh gillnet assessments of the Apostle Islands*

Shortly after the establishment of the Lake Superior Biological Station in 1957, a regular series of small-mesh gillnet stations were established by William Dryer and Joseph Beil for monitoring chub populations. The gillnet assessments ended in 1973, but some of the stations became the locations for the USGS annual spring trawl assessments. Dryer and Beil worked very closely with Stanford Smith and Ralph Hile to correctly identify chub species found in the Apostle Islands.

*1958-1992 Gillnet assessments of Isle Royale*

As with the Apostle Islands, a regular series of gillnet stations were established along Isle Royale and sampled annually or biennially between 1958 and 1992. Gillnets of mesh sizes varying from 1.5 to 6.0 inches stretch mesh were set in multi-mesh panels from shore to depths greater than 100 meters. The goal of the assessment was to monitor lake trout and prey species as part of a lake trout recovery program. Ralph Hile accompanied most of the Isle Royale surveys through the 1960s and provided consistency of chub identification across the 1953, Apostle Islands, and Isle Royale surveys.

**TABLE 2. Primary Data used in determining the status and trends of Lake Superior shortjaw cisco populations**

| *Description of data* | *Time period* | *Area* | *Source* |
|---|---|---|---|
| Commercial catch records for Lake Superior chubs | 1895-2003 | Lake-wide, state jurisdictions (Michigan, Wisconsin, Minnesota), Canada (1941-2003 only) | Great Lakes Fishery Commission, Lake Superior Technical Committee |
| 1953 R/V Cisco survey of Lake Superior | May-October 1953 | U.S. waters and ecoregions, Eastern Canada ecoregion | U.S. Geological Survey, Great Lakes Science Center |
| 1958-1973 Apostle Islands small-mesh gillnet assessments | Spring and fall small mesh gillnet assessment records from 1958-1973 | Apostle Islands ecoregion | U.S. Geological Survey, Lake Superior Biological Station |
| 1958-1992 Isle Royale gillnet assessments | Summer gillnet assessment data records from 1958-1992 | Isle Royale ecoregion | U.S. Geological Survey, Lake Superior Biological Station |
| 1963-1965 Lake Superior trawl surveys | Summer bottom trawl assessment from 1963-1965 | U.S. waters of Lake Superior: APIS, WKEW, EKEW, MISS, WFBY | U.S. Geological Survey, Great Lakes Science Center |
| 1999-2002 Special Gillnet Surveys (USGS) | Summers of 1999-2001 | MNNS, APIS, WKEW, MISS, ECAN, WFBY | U.S. Geological Survey, Lake Superior Biological Station; Ontario Ministry of Natural Resources |
| 2000-2001, 2004 Special Gillnet Surveys (OMNR; DFO Canada) | Summers of 2000-2001, 2004 | WCAN, ECAN | Ontario Dept. Natural Resources; Dept. Fisheries and Oceans Canada |
| 2001-2003 Lake Superior Deepwater Surveys | Summer bottom trawl surveys of open lake from 2001-2003 | APIS, MNNS, ECAN, WFBY, WKEW ecoregions | U.S. Geological Survey, Lake Superior Biological Station |
| 2000-2003 annual lake-wide assessments | Spring bottom trawl surveys of nearshore zones from 2001-2003 | All ecoregions except ISRO (Isle Royale) | U.S. Geological Survey, Lake Superior Biological Station |

*1999-2001 Gillnet survey of selected Walter Koelz sample sites in Lake Superior*
Hoff and Todd (2002) conducted gillnet surveys in 5 areas of Lake Superior where Walter Koelz found shortjaw cisco to be the predominant chub species in 1921-1923. The five sample areas were distributed among the MNNS, APIS, WKEW, MISS, and WFBY ecoregions. A mix of 2.5" and 2.75" stretch-mesh multi-filament gillnets were set at 114 locations distributed among the five areas. Total effort was 20838' of gillnet set for a total of 26 set nights.

*2000-2001 Gillnet surveys of eastern Ontario waters of Lake Superior*
In 2000-2001, Mike Petzold of the Ontario Ministry of Natural Resources, conducted gillnet surveys of deepwater chubs of in eastern Ontario waters of Lake Superior (Petzold 2002). Sample areas were located in Michipicoten and Whitefish bays. For the two areas, 42 sites were sampled with a total effort of 76800' of gillnet set for a total of 42 sample nights. For consistency, the same nets used by Hoff and Todd (2002) were used in Petzold's survey.

*2001-2003 Deepwater trawl surveys of Lake Superior fish communities*
In 2001 the Ontario Ministry of Natural Resources funded a deepwater survey of eastern Ontario waters of Lake Superior conducted by OTG to determine the status of shortjaw cisco in the Canadian portion of the lake that was the target of a vigorous chub fishery up until the mid 1970s. Offshore deepwater trawl stations (>5 km from shore) were chosen to complement the spring assessment trawl locations in shallower, nearshore areas in the Eastern Canada and Whitefish Bay ecoregions. Trawl depths generally ranged from 60 to more than 200 m depth. In 2002 the stations in eastern Ontario were resampled and new sample stations were added. In 2003, OTG conducted a new survey of deepwater sites in the Western Lake Superior, Minnesota North Shore, Apostle Islands and Western Keweenaw ecoregions.

*2000-2003 Annual lake-wide assessment of Lake Superior fish communities*
The USGS Lake Superior Biological Station conducts an annual lake-wide assessment of Lake Superior fish communities, which consists of bottom trawl samples from more than 85 stations dispersed around the periphery of the lake. The data collected in these assessments provide an excellent opportunity to gain annual distribution and abundance data on shortjaw cisco around Lake Superior. Starting in 1999, increased training of technical staff has lead to greater awareness and ability to distinguish shortjaw cisco from other chub species. When putative shortjaw cisco are taken in trawls, they are enumerated, photographed and preserved for expert verification or identification.

*Metadata*
Early in the execution of this project we came to realize that very few of the small mesh gillnet catch records were entered into our Oracle database for years prior to 1974. In particular, field records of chub captures from our Apostle Islands small-mesh gillnet assessments were not entered into the Oracle database. In order to search existing data records, we developed a meta-database of all gillnet and trawl assessment sampling conducted between 1958 and 1978 (1978 marks the start of lake-wide trawl assessments). For Isle Royale, we extended the range to 1992, the last year small mesh gillnets were included in this ecoregion's biennial assessments. The metadata was then used to identify which data were already entered into our master Oracle fish community assessment database system. Based on this approach, we then searched for original

field data sheets and entered missing data into the Oracle database system.

The 1953 Lake Superior survey records provided invaluable baseline data on the status of the Lake's fish communities in the mid-20th century. The original records were stored in Ann Arbor and transferred to the Oracle database at the Lake Superior Biological Station. Because none of these data existed in electronic format, we reviewed the original field records, developed metadata and entered catch records for chubs from gillnet and bottom trawl sampling.

Parameters for population status and trends

Where possible, we use catch per unit effort (CPE) data expressed as density per unit area or number per 1000' of gillnet. Commercial catch data is presented as round weight, total metric tons.

## RESULTS

Commercial Catch Record, 1895-2003

Chubs are caught with bottom-set gillnets of relatively small mesh, ranging from 2.0" to 3.5" stretch mesh, panels 6' high by 100-300' length, set in waters typically exceeding 60 m depth. This method contrasts with the use of larger mesh gillnets set near the surface to capture lake herring. Early netting material consisted of linen or cotton and was largely replaced with multi-filament nylon material in the early 1950s.

Commercial harvest of Lake Superior fish started well before the commencement of recording commercial catches in 1895. Following the rapid settlement of the Lake Superior basin in the 1870s-1880s, fishing effort focused on stocks that were easily exploited (river runs, embayments, nearshore areas) (Lawrie and Rahrer, 1972, 1973). Early targets included river run populations of lake trout, lake whitefish, coaster brook trout, and nearshore lake trout and lake herring populations. So like other Lake Superior stocks, the first chub populations to be exploited were those that inhabited nearshore areas accessible by oar or sail powered small vessels. In addition, areas close to population centers of the day were exploited earlier and more intensely. Fisheries in western Lake Superior supported the growing cities of Superior and Duluth; fisheries in the Apostle Islands supported the city of Ashland; Keweenaw Bay supported Houghton-Hancock-Calumet population centers; the Grand Island and south shore supported Marquette; and Whitefish Bay supported the cities of Saulte Ste. Marie. Note that in the commercial catch records, there is no separation of chub species (bloater, shortjaw, kiyi), but the target species was the larger shortjaw cisco (and closely related forms, the Lake Nipigon shortnose and Lake Superior bluefin (blackfin) ciscoes), and early evidence indicates that shortjaw cisco was the dominant chub species in the fisheries of the late 19th and early 20th centuries (Koelz 1926, 1929). Small mesh (<3" stretch) linen or cotton gillnets were the primary means of catching chubs and in the late 19th and early 20th centuries, and most of these nets were manually set and lifted from oar and sail powered boats (dories and mackinaws, respectively). With the advent of affordable outboard motors, gillnet tugs, powered gillnet lifters in the 1920s and 1930s; fishermen were able to exploit chub stocks in deeper water and further offshore. Following World War II, the proliferation of engine-powered fishing equipment expanded and the adoption of nylon net material increased catch efficiencies two- to three-fold (Hile & Buettner 1955, Pycha 1962). Also following the War, the wide use of refrigerated rail and truck transportation increased the population areas served by the fisheries and resulted in increased market demand and value of the fisheries. The simultaneous collapse of the chub fisheries in the lower Lakes in the 1950s resulted in unprecedented demand and market prices for Lake Superior chubs in the late 1950s and 1960s. As a result, commercial yield increased to meet the demand.

Each state (Michigan, Minnesota, Wisconsin) reported commercial catch of chubs starting in the 1890s (Fig. 2). There are gaps and omissions in these early records, but all states began to provide regular annual yield reports by 1903. By interpolating values between years with reported yields, we reconstructed an early U.S. catch record expressed as 5-year annual means (Fig. 4). This approach follows the existing trends and compensates for gaps in the catch record. Canada began to report commercial harvest of chubs in 1941, but data are not divided into smaller jurisdictions (Fig. 3).

Among U.S. jurisdictions, Michigan reported the greatest yield of chubs (representing three areas of commercial fishing), particularly in the late 1800s and early 1900s (Fig. 2). Wisconsin and Minnesota had much smaller total yields in the early period, but each fishery was focused on a single area (Apostle Islands and western Lake Superior, respectively). During the period of 1926-1954, the greatest harvest of chubs occurred in Wisconsin waters, and during the last phase of the chub fishery (1955-1987), both Michigan and Wisconsin reported substantial harvests, exceeding 800 metric tons annually (Fig. 2). The timing and duration of the last phase in the chub fishery varied among the states; both Michigan and Wisconsin jurisdictions showed a sharp rise in harvest in 1958-1960 but in Wisconsin yields tapered off by the mid-1970s and nearly collapsed by 1983 (Fig. 2). By contrast, commercial harvest persisted throughout the 1970s in Michigan waters, but abruptly collapsed by 1983. Commercial harvest of chubs in Minnesota waters was substantially lower than in Michigan or Wisconsin and reported harvests were very low after 1980. The last phase of the chub fishery in Canada was delayed until the mid-1970s, but only persisted until the mid 1980s (Fig. 3). Short-term increases in chub harvests in Wisconsin and Canadian waters between 1984 and 1988 may be due to an increase in harvest of bloaters as the principal component of the chub catch. Recent assessments of deepwater chub populations in eastern Ontario waters of Lake Superior (Petzold 2002; this report) have shown that shortjaw cisco represents <4% of the total catch of chubs. These results indicate that shortjaw cisco populations have not recovered in areas where they were once the dominant chub species.

During the earliest period of the commercial catch record (1895-1908), there was relatively intense harvest of chubs (mean annual harvest of 576 metric tons/yr; Figs. 3, 4; Koelz 1926). The target of this early chub fishery was *C. nigripinnis cyanopterus*, or bluefin, (now considered as synonymous with C. zenithicus) because of its larger size and market value (Lawrie and Rahrer 1972, 1973). It is very likely that moderate levels of harvest preceded the commercial catch record, probably for a period of 10 years, because of the existence of population centers and established fisheries in Lake Superior (Lawrie and Rahrer 1972, 1973). The early chub fishery declined sharply after 1908 and only began to recover in the late 1920s (Figs. 3, 4). Effort in this early chub fishery was focused on stocks that were close to shore, reachable with oar and sail powered boats, and fished with hand-lifted gillnets and pound nets. It is likely that these vulnerable chub stocks were depleted by this and later fishing pressure. The recovery of the chub fishery in the late 1920s is most likely due to the exploitation of new offshore fishing grounds reachable with engine-powered vessels equipped with powered gillnet lifters. Even with the recovery of the chub fishery, the annual and total harvest of chubs was modest compared to the 1895-1908 period. The deepwater, offshore fishing grounds came under prolonged and heavy fishing pressure during the 1955-1987 period, averaging annual harvests of ~600 metric tons with a total harvest exceeding 20,000 metric tons (~44,000,000 lbs; Figs. 4, 5).

Comparisons of the assessment catch of chubs with reports of commercial harvest provide further insight as to the changing state of the fishery (Figs. 4, 5). In the early 1920s, Walter Koelz conducted an assessment of chubs in Lake Superior during a period when commercial catch of chubs was at historical lows. Koelz's survey (Koelz 1929) indicated that shortjaw cisco were abundant and the dominant chub species throughout U.S. waters of Lake Superior over the 30-180 m depth range sampled, averaging 56.2 fish per 1000' of gillnet per night and were particularly abundant at depths of 40-100 m and somewhat less so at depths of 100-180 m. By 1953, the survey of Lake Superior conducted by Stanford Smith, Ralph Hile, and Paul Eschmeyer showed that shortjaw cisco, while still abundant and the dominant chub species, had declined to 33.9 fish per 1000' of net (39 of 41 gillnet sample locations in U.S. waters; Figs. 4, 11). This comparison is all the more extreme when considering that the nylon gillnets used in the 1953 assessment were 2-3x more efficient at capturing fish than Koelz's cotton and linen nets in the early 1920s. Assessments of the Apostle Islands and Isle Royale areas between 1958 and 1992 showed that densities of shortjaw cisco dropped rapidly through the 1960s and 1970s and reached 0.15 fish per 1000' of net in the Apostle Islands in 1973 and zero catch in Isle Royale by 1982. Commercial catch of chubs peaked in the mid-1970s, at the time their populations were crashing. We suspect the continued high catch rates of chubs after the early 1970s consisted largely of bloaters.

Comparison of mean annual harvest for five chub fishing periods (1895-1908, 1909-1925, 1926-1954, 1955-1987, 1988-2000) provides a relative scale of the different levels of fishing pressure on Lake Superior chubs (Figure 5). Total harvest of chubs during the first period was estimated at 7489 metric tons but was a period of relatively short duration (14 years). Current reported harvest of chubs is similar to that of the 1909-1925 period, but note that Koelz found shortjaw cisco to be abundant in the 1920s while gillnet assessments after the 1980s indicated that shortjaw cisco were very rare. The 1926-1954 harvest period was intermediate in annual harvest rate and total harvest. The 1955-1987 period sustained the highest annual harvest rates (617 metric tons/yr) over a 33 year period, yielding 20366 metric tons of chubs (Fig. 5).

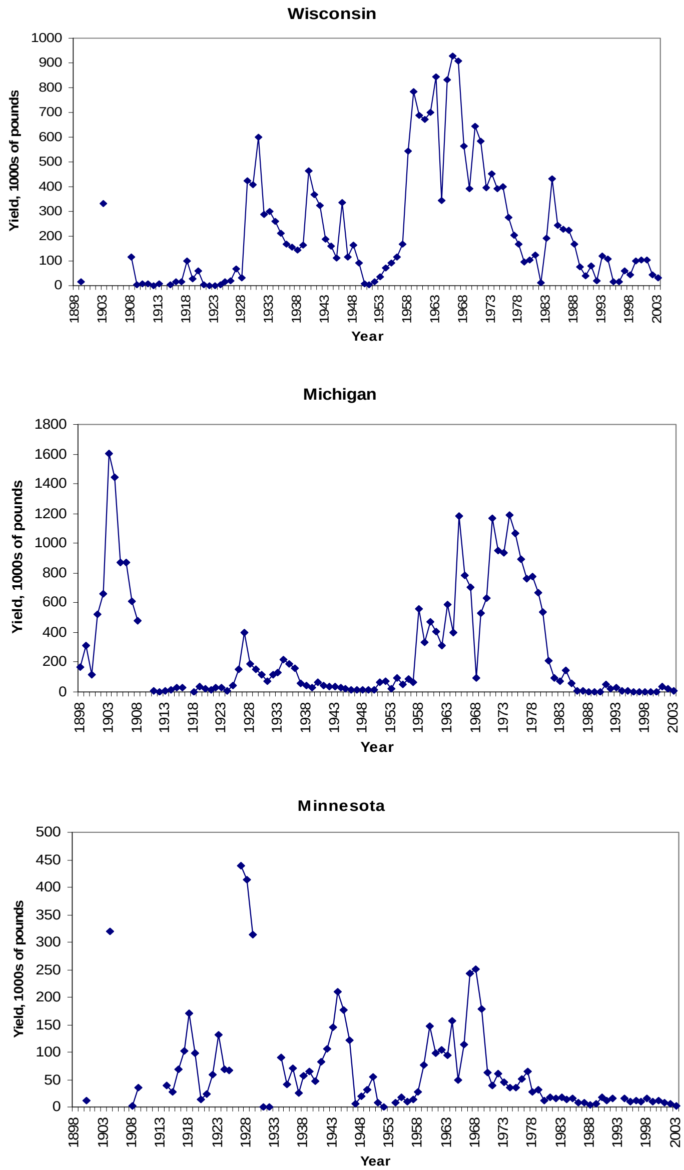



**FIGURE 2**. Commercial harvest of chubs in U.S. jurisdictions of Lake Superior, 1898-2003. Yield is shown in 1000s of pounds.

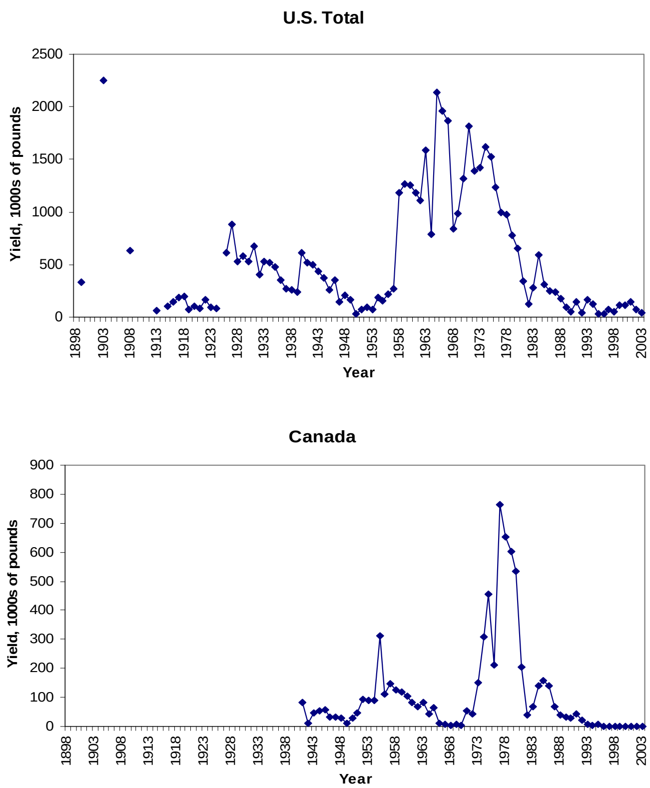



**FIGURE 3.** Commercial yield of chubs in U.S. and Canadian waters of Lake Superior. Records for U.S. waters range from 1898 to 2003. Records for Canada start in 1941 and extend to 2003.

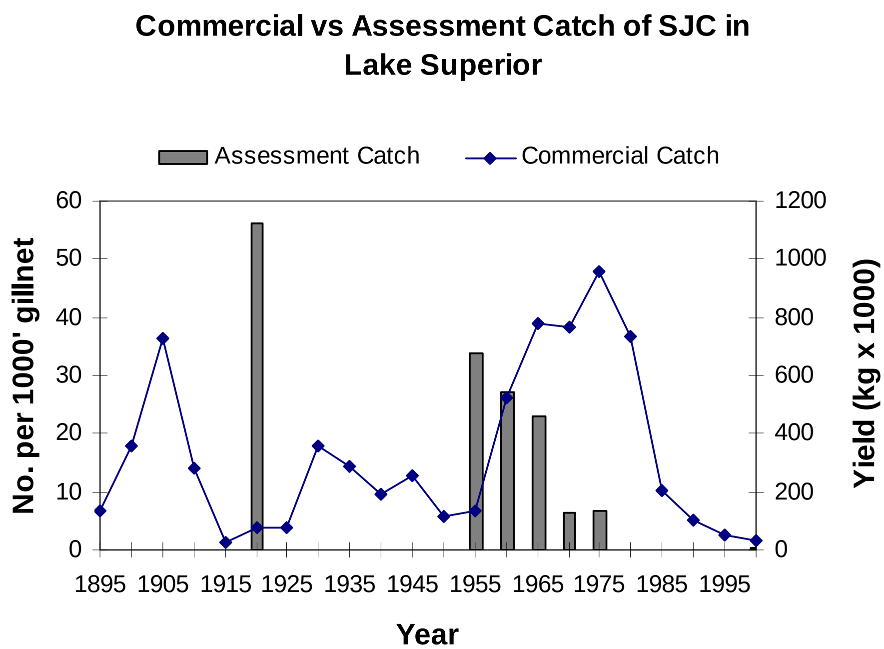
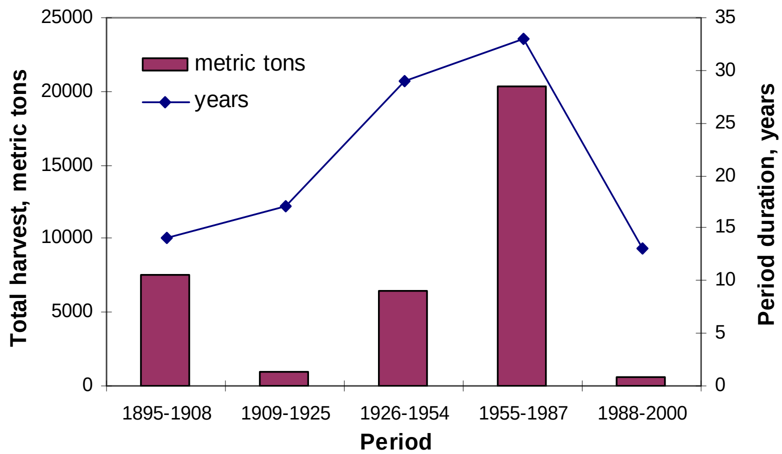



**FIGURE 4.** Comparison of 5-year means of commercial harvest of chubs in Lake Superior (metric tons, round weight) with mean assessment catches for selected periods (No. per 1000' of gillnet). Selected assessment periods are: 1920-1921 (Koelz's survey); 1953 (Smith and Hile's survey); 1958-2001(USGS assessment data from the Apostle Islands, Isle Royale, and Hoff and Todd's 1999-2001 survey of Koelz's 1920-1921 sample sites).



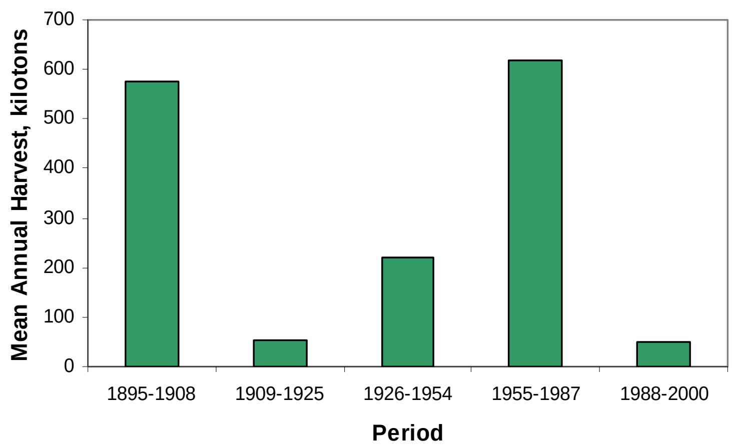




**FIGURE 5.** Comparison of mean annual harvest and total harvest of chubs in Lake Superior for selected commercial fishing periods between 1895 and 2000. Harvest data is expressed as round weight. For reference, the length of each period is indicated by the line in the upper graph.

1921-1923 Koelz Survey of Lake Superior

Walter Koelz conducted a survey of Lake Superior coregonids during 1921-1923 (Koelz 1929) with several goals in mind. First, he intended to inventory and describe the coregonid assemblage of Lake Superior; second, determine the distribution of members of the assemblage across the lake; third, determine the relative densities of the coregonid populations; and finally, describe the depth distribution of the species. His principal survey tools were specially-made 2.5" and 2.75" stretch-mesh cotton or linen gillnets. He also used information from commercial fishermens' lifts of gillnet and pound net sets to augment information on distribution of coregonids in Lake Superior. Data were gathered from 50 sites lake-wide, 29 from U.S. waters and 21 from Canadian waters (Fig. 6.). Of the 50 sites, he set special assessment gillnets at 15 sites, totaling ~30000' of net for 59 set nights. It is from the special assessment net sets that catch-per-effort (CPE) calculations were derived for comparing to data from more contemporary assessments. Data from the 35 non-assessment samples came largely from commercial sets and provided additional information on geographic distribution, assemblage composition, and depth distribution for Lake Superior ciscoes.

Koelz recognized three species of *Coregonus* that today we consider all to be members of the species *C. zenithicus*: *C. reighardi dymondi, C. nigripinnis cyanopterus, and C. zenithicus* (Todd and Smith, 1980). Throughout most of our analysis of Koelz's data, we preserve his distinctions, but remind readers that presently, we do not discriminate *C. zenithicus* among these three forms. Our reasoning for adherence to Koelz's delineation of species is that it represents additional information, and we find that there are patterns in distribution and habitat use that are consistent with his classification system.

Koelz's assessment gillnets were set over a 31 to 166 m depth range. Shortjaw cisco were found most commonly starting at depths of 50 m and deeper and was the dominant chub species at depths of 50 or more meters (Fig.7).

We used Koelz's data to reconstruct the deepwater chub assemblages that were present in Lake Superior in the 1920s for the ecoregions that he sampled (Figs. 8, 9). We described the cisco assemblages of the 7 ecoregions of Lake Superior from Koelz's data in four ways: frequency of occurrence, composition based on Koelz's Table 1, density based on CPE gillnet catch data, and composition based on CPE gillnet catch data. The aggregate of *C. reighardi dymondi, C. nigripinnis cyanopterus,* and *C. zenithicus* (*sensu* Koelz) were the dominant chub species in all ecoregions and represented, on average, 98% of all fish captured across all ecoregions based on CPE gillnet data (Fig. 9).

Of the three forms of shortjaw cisco recognized by Koelz, *C. zenithicus* and *C. nigripinnis cyanopterus* were the most widespread across ecoregions, based on frequency of occurrence (Fig. 8). The form that Koelz identified as *C. reighardi dymondi* was the most commonly encountered shortjaw cisco in the western Canada ecoregion and *C. nigripinnis cyanopterus* was the most commonly encountered shortjaw cisco in the eastern Canada ecoregion. CPE gillnet data shows that *C. zenithicus* was the most abundant shortjaw cisco in all ecoregions, except for the Thunder Bay ecoregion where *C. reighardi dymondi* was most abundant. Interestingly, the only form of shortjaw cisco in nearby Lake Nipigon (connected currently and historically to

Lake Superior through the Nipigon River) is the *C. reighardi dymondi* form. CPE gillnet data showed that densities of shortjaw ciscoes were highest in the Whitefish Bay, Apostle Islands, and Minnesota north shore ecoregions (Fig. 9).

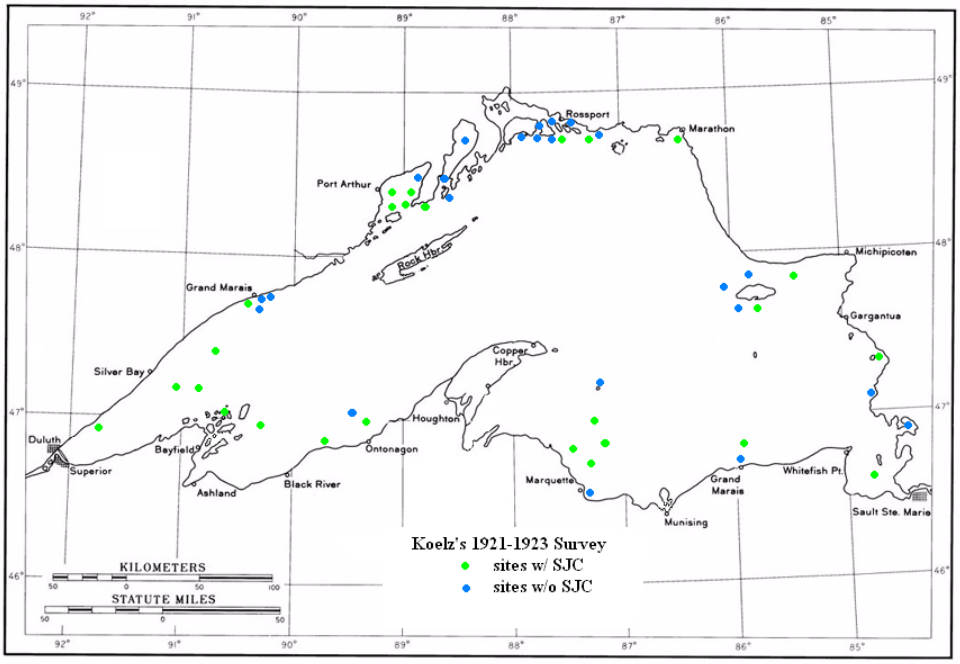
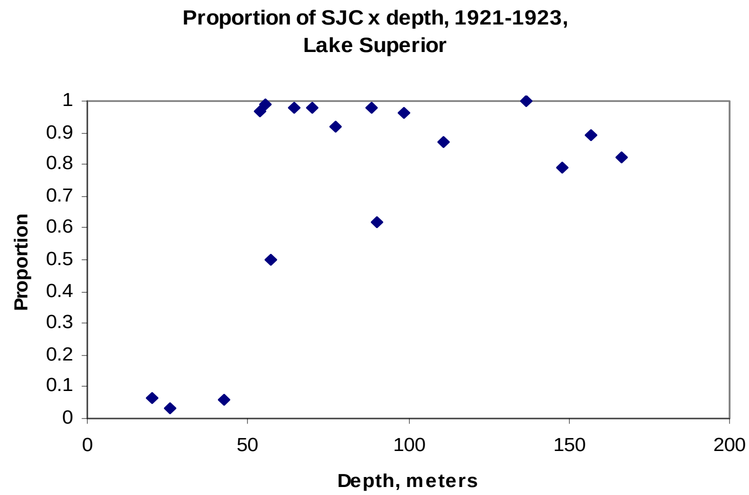



**FIGURE 6.** Map of Lake Superior showing sampling locations for Walter Koelz's 1921-1923 survey of coregonids (from Koelz, 1929). "SJC" records include the three Lake Superior forms recognized by Koelz: *C. reighardi dymondi, C. nigripinnis cyanopterus,* and *C. zenithicus.*

Koelz's data shows that shortjaw ciscoes strongly dominated the cisco assemblage of Lake Superior in the early 1920s (Figs. 8, 9). *C. hoyi*, the bloater, was widely distributed and second in relative abundance in the cisco assemblage, but it was absent from Koelz's samples taken in the eastern Canada ecoregion. *C. kiyi* was less abundant than bloater and was encountered only in the western Canada, Michigan south shore, and Minnesota north shore ecoregions.

The distribution of ciscoes by depth of gillnet sets showed that of the three shortjaw ciscoes, *C. reighardi dymondi* was associated with depths of 20-100 m range (60 m modal depth) while *C. zenithicus* and *C. nigripinnis cyanopterus* showed a much deeper modal depth of 100 m (Fig. 10a). The association of *C. reighardi dymondi* with shallower depths may be an artifact of the prevalence of this shortjaw cisco in the western Canada ecoregion where maximum depths sampled rarely exceeded 100 m. Bloater showed a similar depth distribution to *C. zenithicus* and *C. nigripinnis cyanopterus,* with a modal depth of 100 m (Fig. 10b). Kiyi were encountered only in gillnets set in the 80-100 m depth bin or deeper. Lake herring (*C. artedi*) were strongly associated with waters less than 60 m depth, but were encountered over the entire depth range of 20-200 m (Fig. 10b).



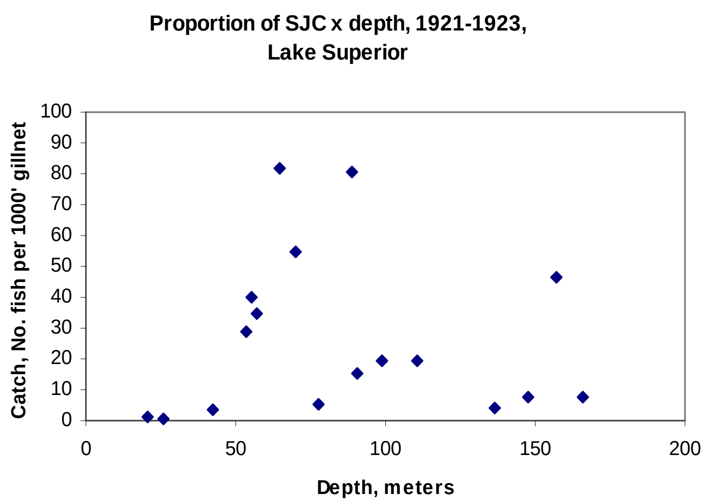




**FIGURE 7.** Occurrence and densities of shortjaw cisco by depth bins from Koelz's 1921-1923 survey of coegonids of Lake Superior (data from Koelz, 1929). "SJC" records include the three Lake Superior forms recognized by Koelz: *C. reighardi dymondi, C. nigripinnis cyanopterus,* and *C. zenithicus.*

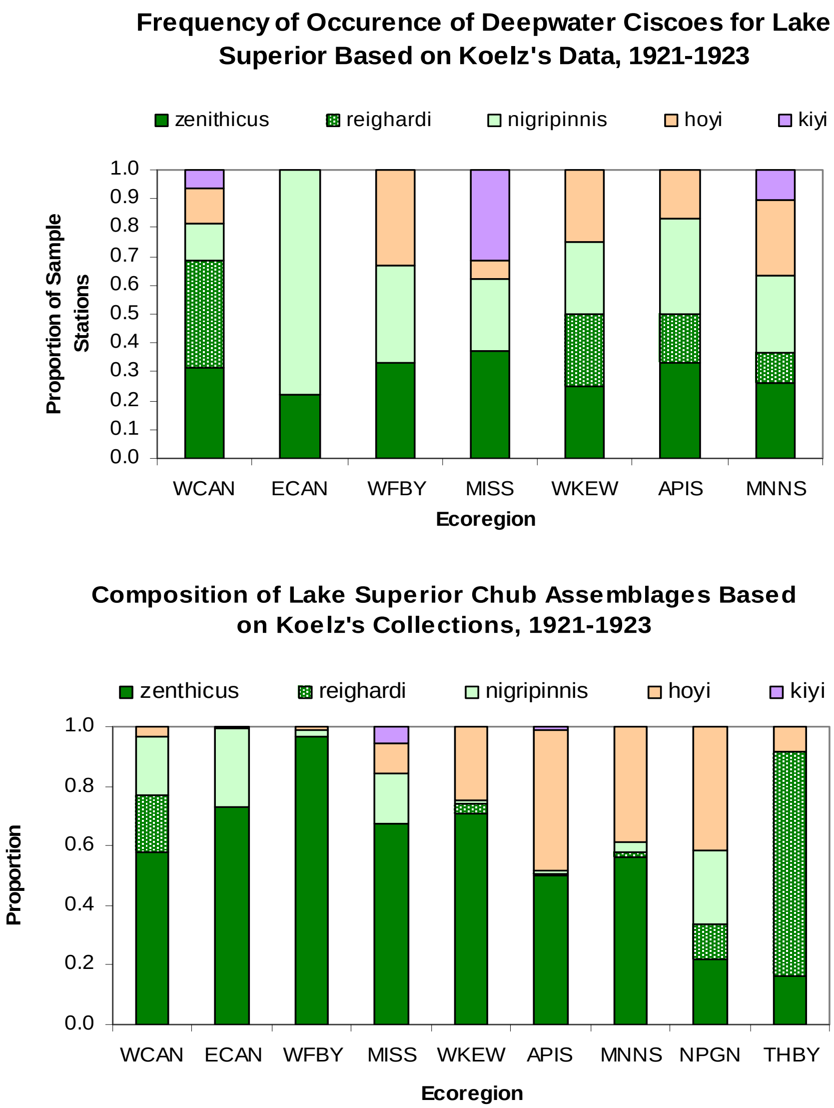
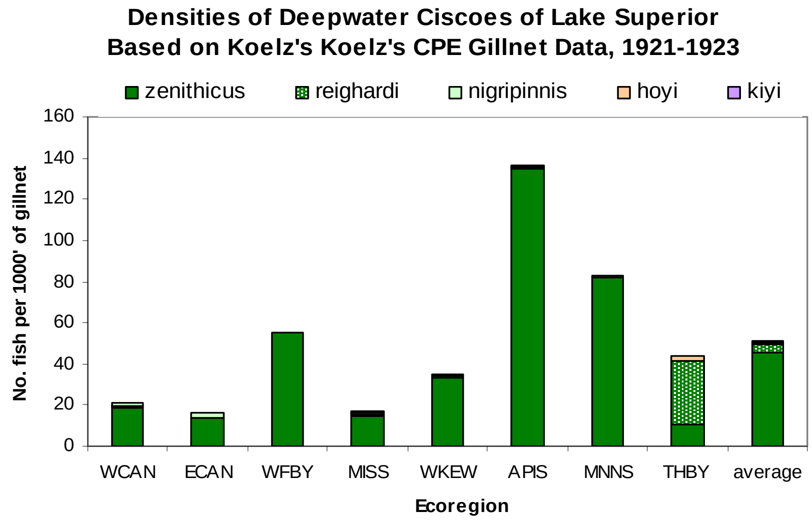



**FIGURE 8.** Composition of deepwater cisco assemblage of Lake Superior, 1921-1923. Upper panel uses data based on frequency of occurrence by ecoregion. Lower panel uses collection data from Koelz's Table 1 (Koelz, 1929). "Zenithicus, reighardi, and nigripinnis" represent Lake Superior forms of shortjaw cisco recognized by Koelz: *C. zenithicus, C. reighardi dymondi,* and *C. nigripinnis cyanopterus,* respectively.



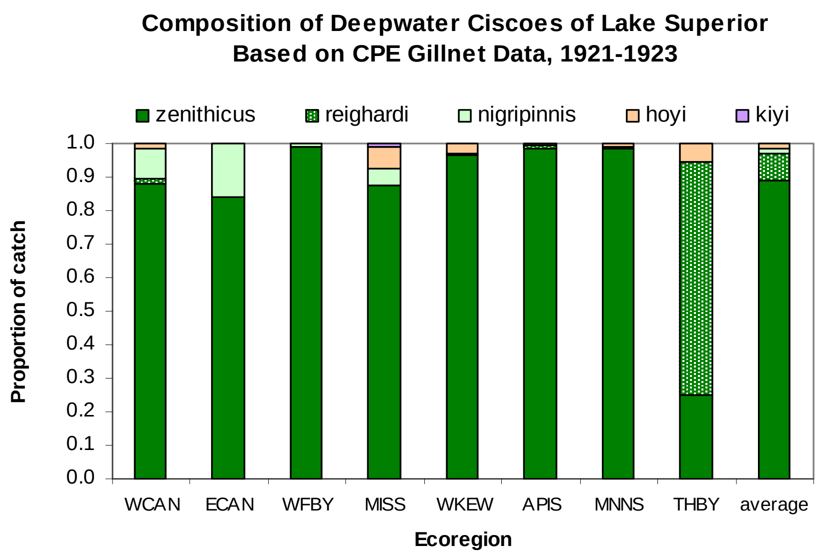
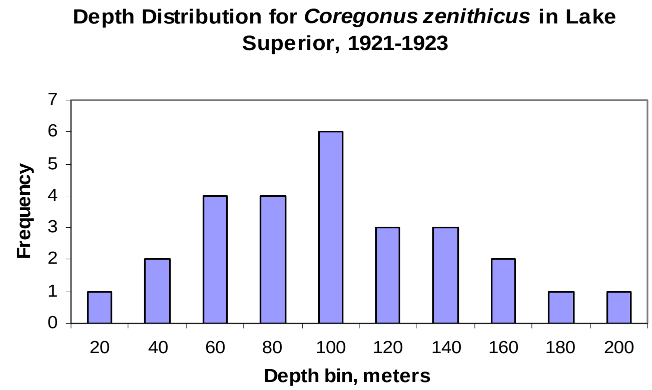
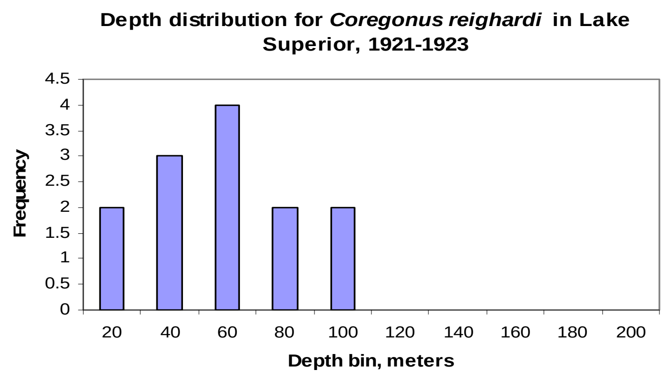




**FIGURE 9.** Densities and composition of deepwater ciscoes of Lake Superior in 1921-1923 based on CPE data from Koelz's survey of coregonids (Koelz, 1929). "Zenithicus, reighardi, and nigripinnis" represent Lake Superior forms of shortjaw cisco recognized by Koelz: *C. zenithicus, C. reighardi dymondi,* and *C. nigripinnis cyanopterus,* respectively.



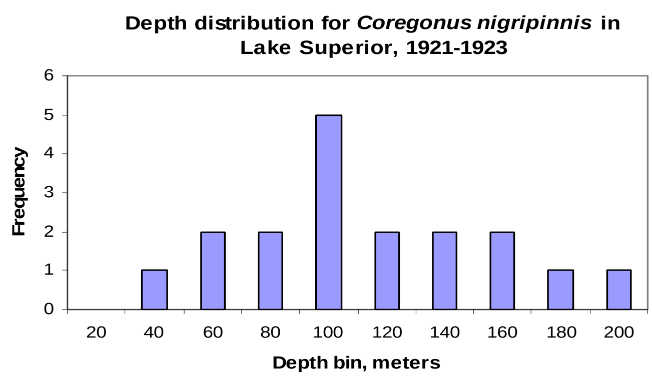




**FIGURE 10a.** Depth distribution of deepwater ciscoes of Lake Superior, 1921-1923, from Koelz's survey (Koelz, 1929). Depth distributions were constructed from frequency of occurrence data by depth bin for all sample locations. *C. zenithicus, C. reighardi,* and *C. nigripinnis* represent Lake Superior forms of shortjaw cisco recognized by Koelz: *C. zenithicus, C. reighardi dymondi,* and *C. nigripinnis cyanopterus,* respectively.

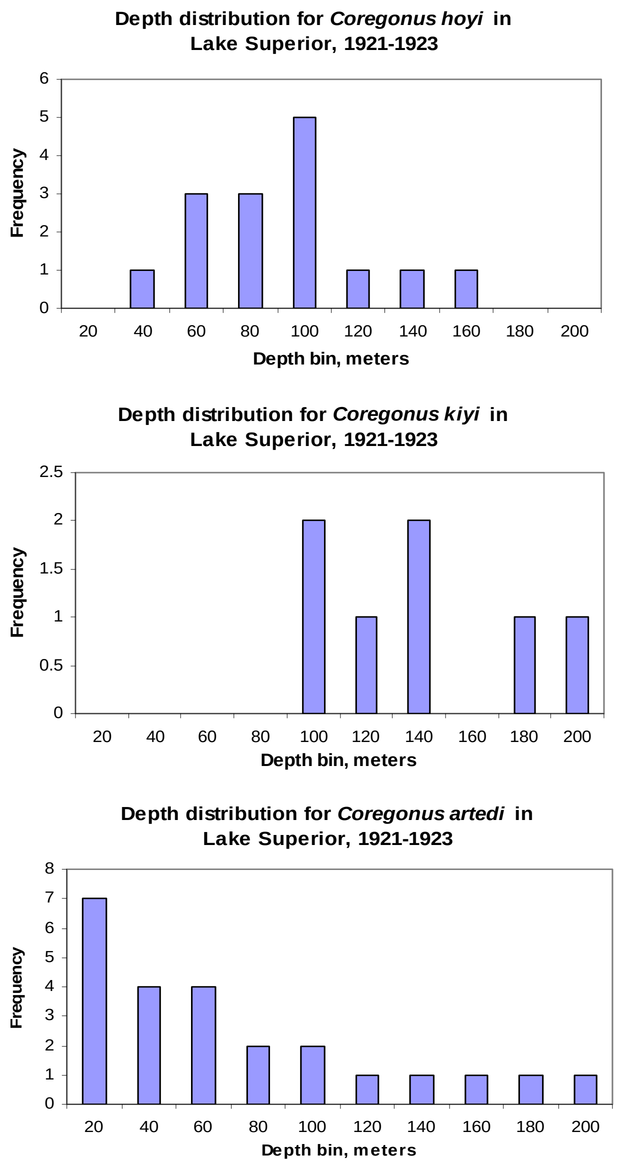



**FIGURE 10b.** Depth distribution of deepwater ciscoes of Lake Superior, 1921-1923, from Koelz's survey (Koelz, 1929). Depth distributions were constructed from frequency of occurrence data by depth bin for all sample locations.

1953 Lake Superior Survey

The 1953 survey of Lake Superior by the Great Lakes Fishery Laboratory (presently the Great Lakes Science Center) remains as the most extensive survey of its kind to date. Led by Stanford Smith, Paul Eschmeyer, and Ralph Hile, the survey was conducted over 6 months and included 129600' of gillnet set over 379 set nights at 41 sampling locations and 245 trawl samples taken at 49 stations distributed largely over U.S. waters of Lake Superior (Fig. 11). The results of the 1953 survey serves as a mid-century benchmark for Koelz's 1921-1923 survey and the present-day state of the lake fish community following a long period of intense population harvest (1955-1985; Fig. 4).

Sampling effort was not uniformly distributed across ecoregions; the greatest number of gillnet and trawl samples were concentrated in the APIS, EKEW, MISS, and ISRO ecoregions (Figs. 11, 12). Mean depths generally reflected the common depths of fishing waters in each ecoregion (Fig. 12); e.g., the greater mean depth for MNNS reflects the steep slope and great depth of offshore waters in that ecoregion. Because of the large number of samples taken with different gear types across a range of depths, we were able to address vulnerability of ciscoes to various sample gear, describe habitat associations and geographic distributions, and assemblage composition.

Sample depths for small-mesh gillnetting and bottom trawling ranged from 20 meters to more than 200 meters (Fig 13, 14). For both methods, most of the sampling was restricted to depths < 100 m, which contrasts with the recent 2001-2003 deepwater surveys where most samples were taken at depths > 100 m (Fig. 14). This difference produced a distinct bias in the data; notice that the modal depth where shortjaw ciscos were caught in gillnets and trawls in 1953 was 70 m, while the modal depth in 2001-2003 bottom trawl samples was 120 m (Fig. 13). Nearly all gillnet sets in waters > 100 m contained *C. zenithicus*, while trawls were less efficient. Nevertheless, *C. zenithicus* was caught more frequently in bottom trawls at depths > 60 m that expected (Fig. 14). What the two distributions tell us is that shortjaws were uncommon in waters < 60 m depth, common in waters 60-140 m depth and uncommon at depths > 140 m depth.

As with Koelz, Smith et al., recognized three forms of shortjaw cisco, however, for some analyses we aggregated *C. zenithicus* and *C. reighardi dymondi* for simplicity but always treated *C. nigripinnis cyanopterus* as distinct from the other shortjaw ciscoes. Smith et al. used multifilament nylon gillnet ranging in stretch mesh size from 1" to 6". We divided the data in to small mesh (< 3") and large mesh (>3") data sets after determining that catch efficiency for ciscoes was <5% for mesh sizes > 3" (Fig. 15). We found that the most efficient mesh size was 1" for *C. hoyi*, 1.5" for *C. zenithicus* and *C. kiyi,* and 2" for *C. nigripinnis cyanopterus* (Fig. 15). This contrasts with common usage of 2.5-3.0" mesh in the commercial fishery; however, we suspect that catch efficiency is related to the size of the fish and that the use of larger mesh by commercial fishery is intended to target larger, marketable fish. To further resolve the relationship between gillnet mesh size and catch efficiency, further analysis of Smith et al's data with respect to fish size is required.

Gillnet catch rates for the three principal deepwater chub species, *C. zenithicus, C. hoyi,* and *C. kiyi* varied with depth. Gillnet catch rates indicated that *C. zenithicus* was most abundant at depths of

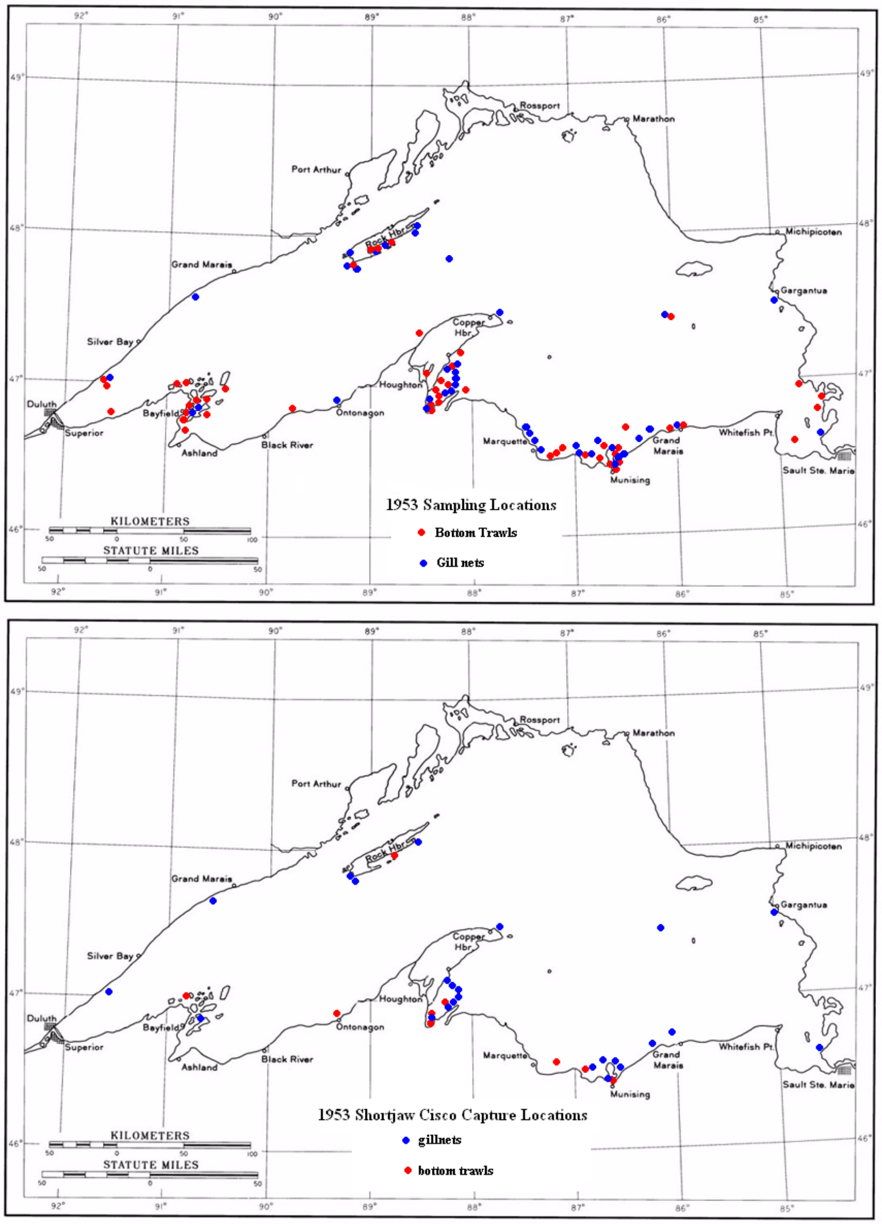



**FIGURE 11.** Map of Lake Superior showing the sample locations for the 1953 survey of Lake Superior and locations of occurrence of shortjaw cisco. Data is from Smith, et al. (unpubl.). "SJC" records include the three Lake Superior forms recognized by Smith et al.: *C. reighardi dymondi*, *C. nigripinnis cyanopterus*, and *C. zenithicus.*

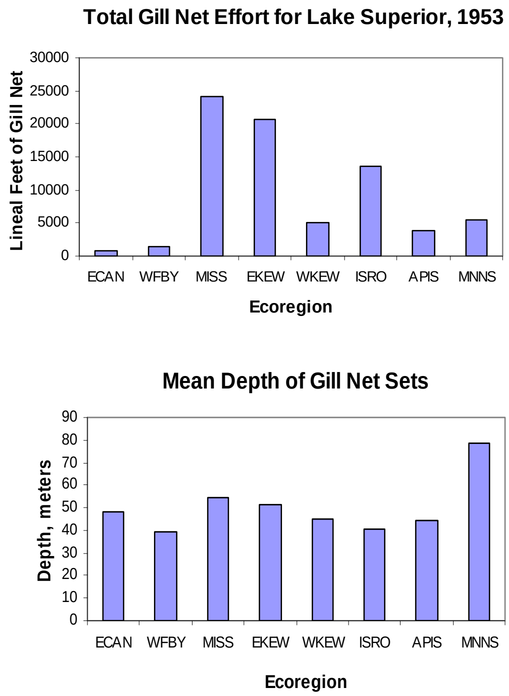



**FIGURE 12**. Total gillnet effort and mean depth of gillnet sets for the 1953 survey.

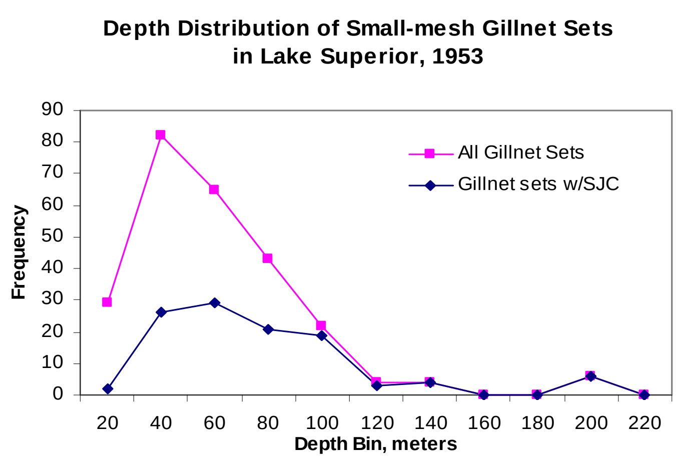



**FIGURE 13.** Depth distribution of small-mesh (<3" stretch mesh) gillnet sets for the 1953 Lake Superior survey.

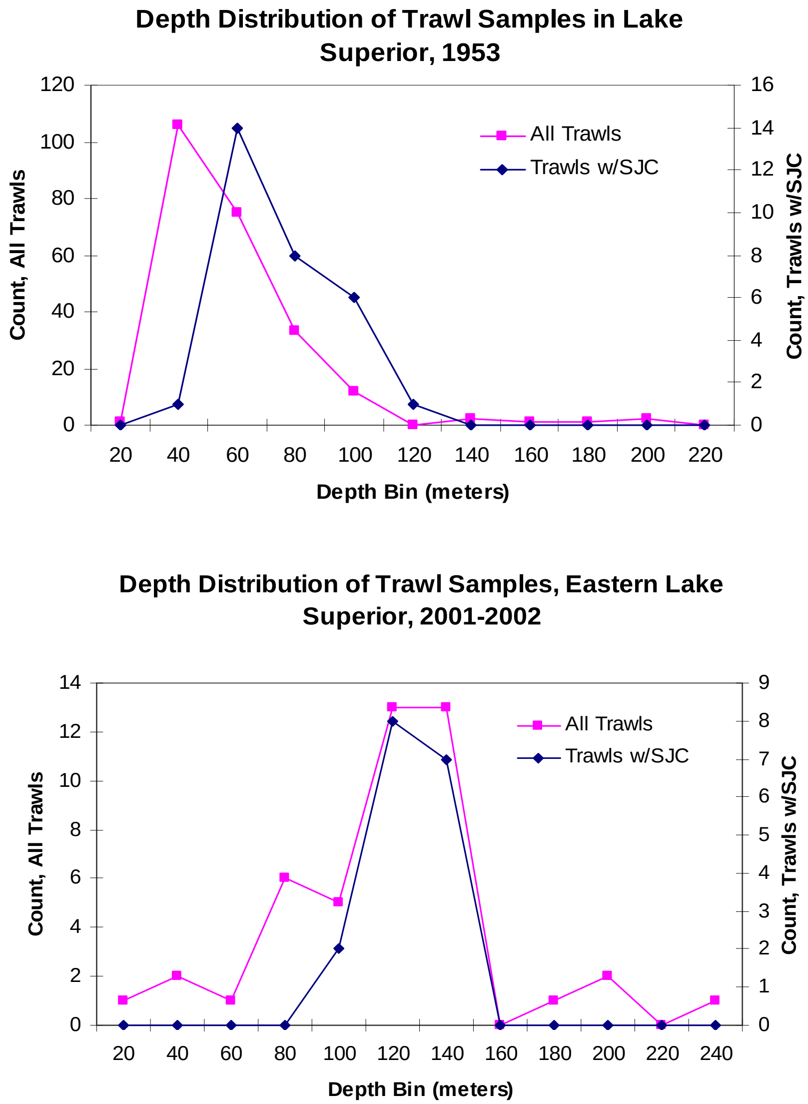
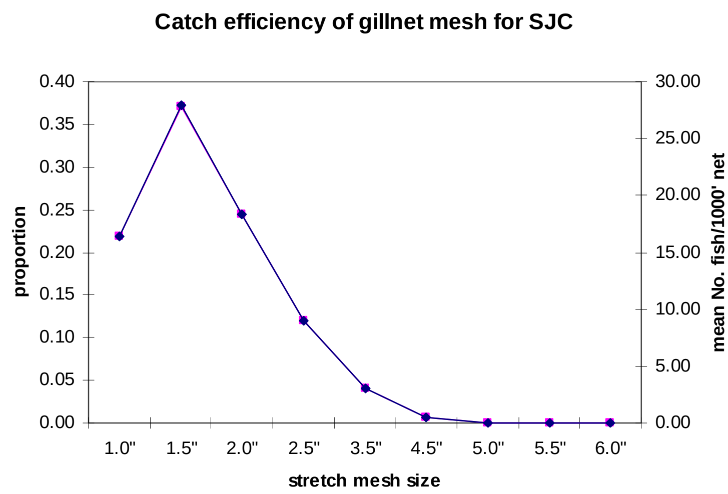



**FIGURE 14.** Distribution of bottom trawl samples by depth for the 1953 survey and the 2001-2003 deepwater surveys of Lake Superior.



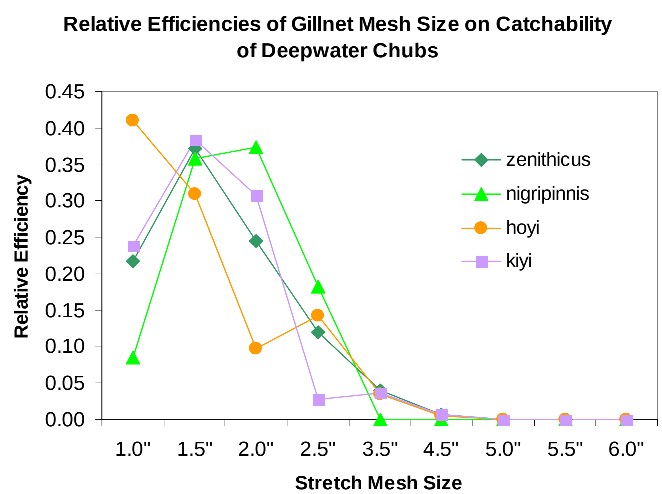
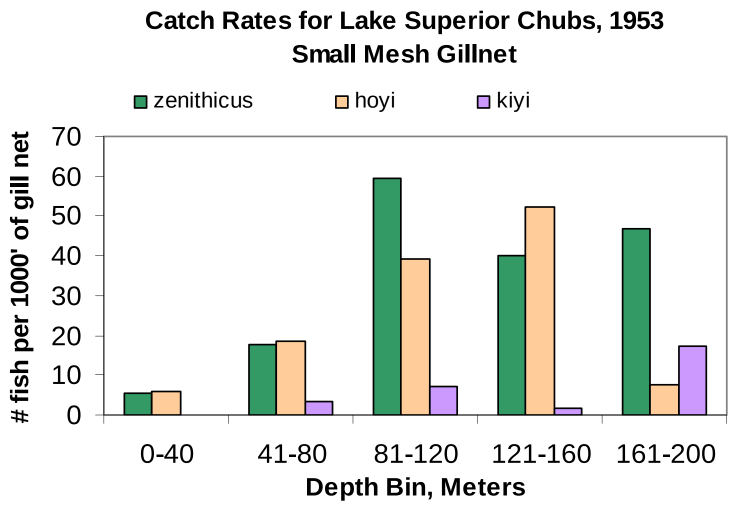




**FIGURE 15.** Relative catch efficiencies for deepwater chub species of Lake Superior, 1953 gillnet survey data. Relative efficiency represents the proportion of the total catch based on mean CPE data for a species taken in 1.0, 1.5, 2.0, 2.5, 3.5, 4.5, 5.0, 5.5, and 6.0" stretch mesh multifilament nylon gillnet. "SJC" and "zenithicus" includes the shortjaw cisco forms *C. zenithicus*, and *C. reighardi dymondi*. "Nigripinnis" includes the shortjaw cisco *C. nigripinnis cyanopterus.*



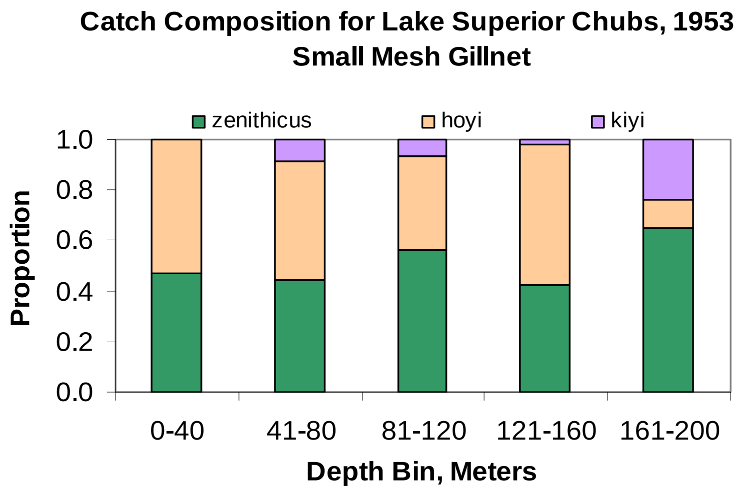
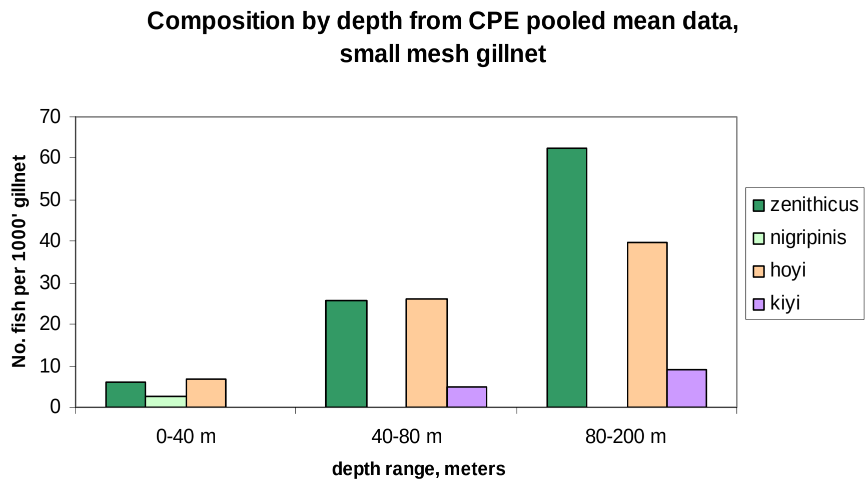




**FIGURE 16.** Densities and composition of the Lake Superior chub assemblage by depth bin, 1953 gillnet survey data. "Zenithicus" includes the shortjaw cisco forms *C. zenithicus, C. reighardi dymondi*, and *C. nigripinnis cyanopterus.*



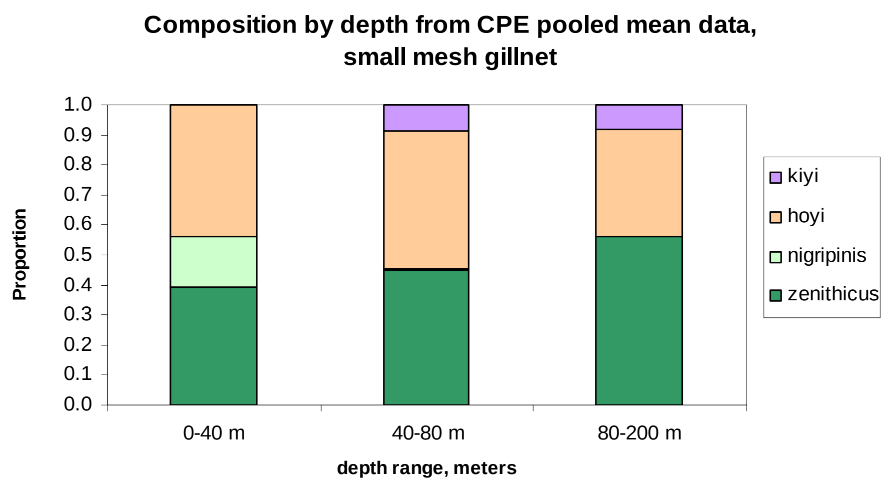
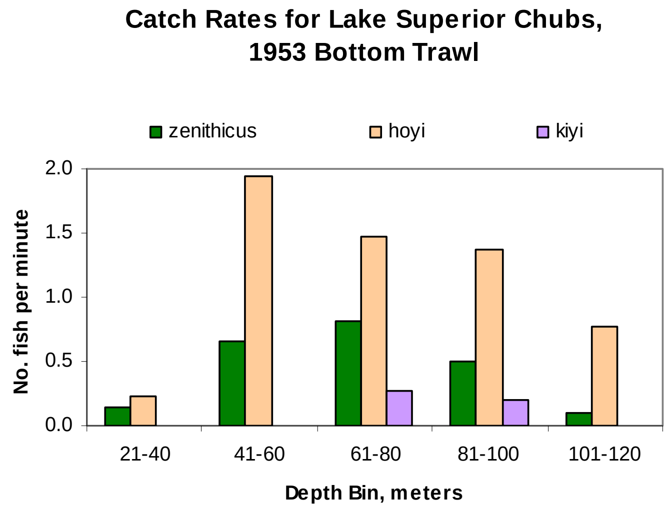




**FIGURE 17.** Composition of chub assemblages by coarse depth bins, including *C. nigripinnis*, for 1953 survey of Lake Superior. "Zenithicus" includes the shortjaw cisco forms *C. zenithicus*, and *C. reighardi dymondi*. "Nigripinnis" includes the shortjaw cisco *C. nigripinnis cyanopterus.* Compare to Fig. 14.



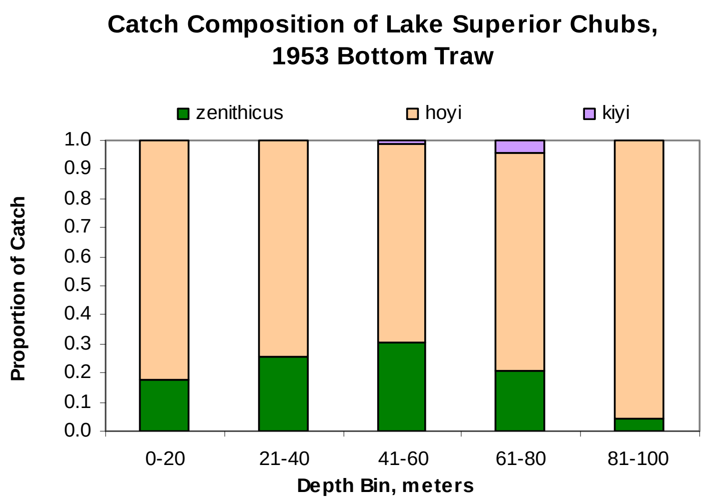
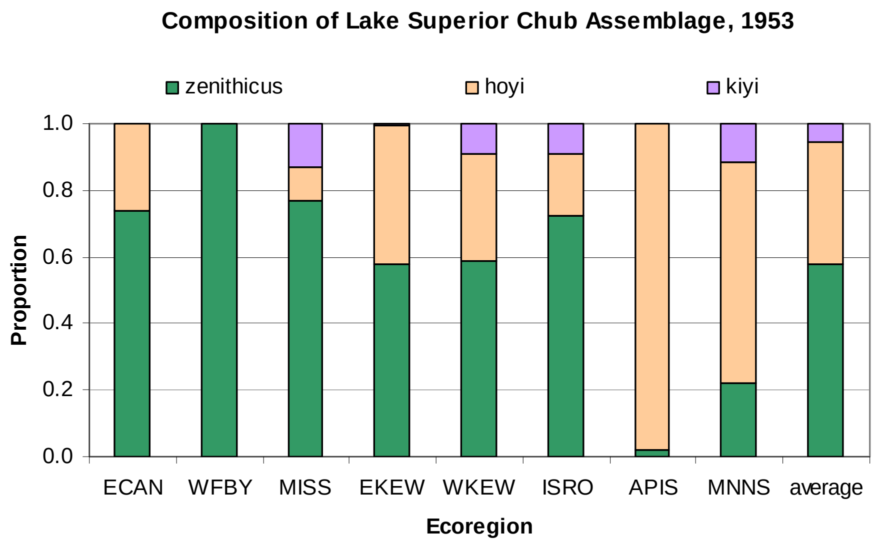




**FIGURE 18.** Catch rates and composition of the Lake Superior chub assemblages by depth bin, 1953 bottom trawl survey data. "Zenithicus" includes the shortjaw cisco forms *C. zenithicus*, *C. reighardi dymondi* and *C. nigripinnis cyanopterus.*



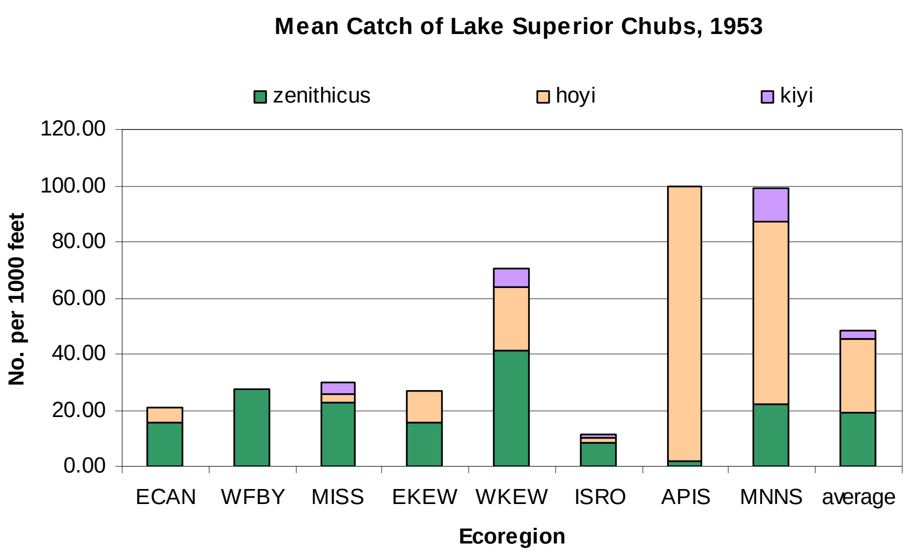




**FIGURE 19.** Composition of chub assemblages of Lake Superior by ecoregion, 1953 small mesh gillnet survey data. "Zenithicus" includes the shortjaw cisco forms *C. zenithicus*, *C. reighardi dymondi* and *C. nigripinnis cyanopterus.*

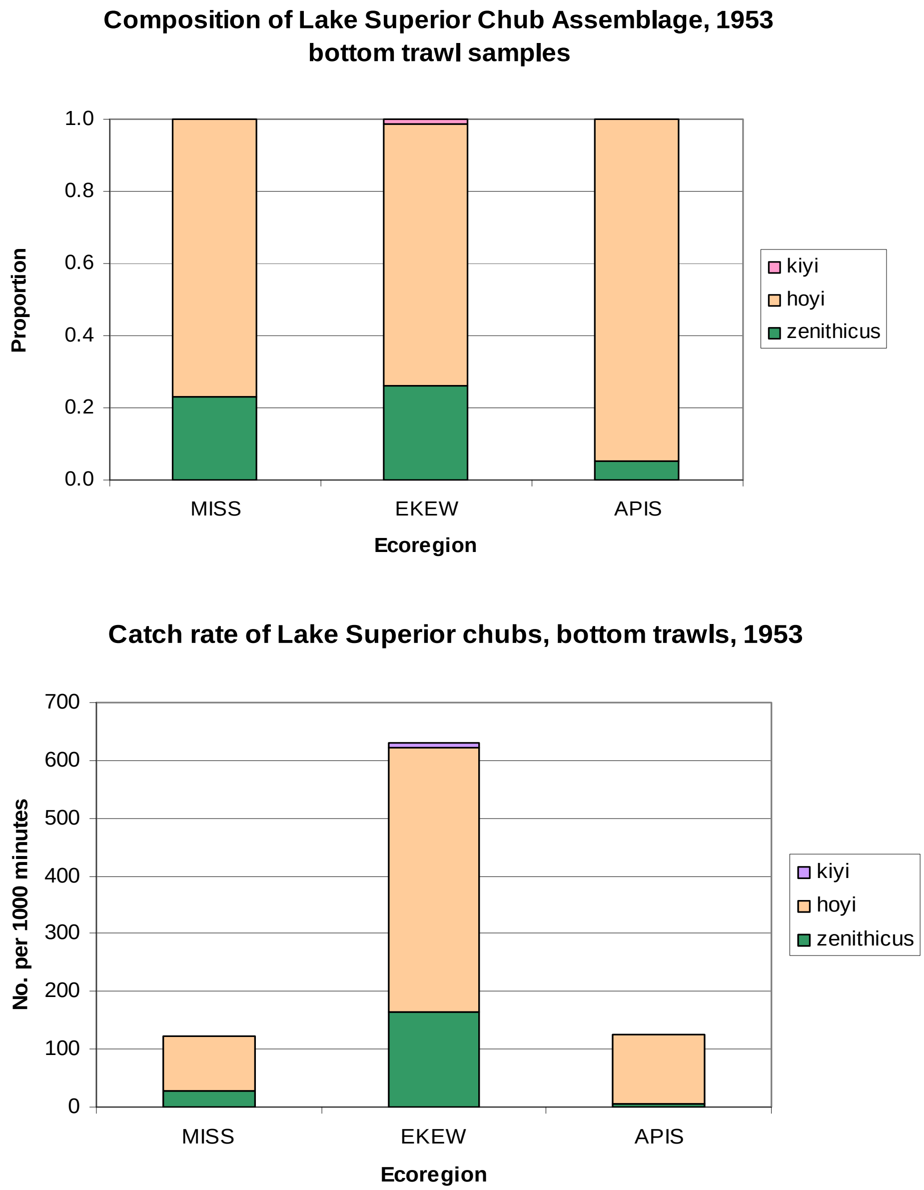



**FIGURE 20.** Composition of chub assemblages by ecoregion, 1953 bottom trawl survey data. "Zenithicus" includes the shortjaw cisco forms *C. zenithicus*, *C. reighardi dymondi* and *C. nigripinnis cyanopterus.*

81-200 m; *C. hoyi* was abundant at depths of 81-160 m; and *C. kiyi* was most abundant at depths >160 m (Fig. 16, 17). Across all depth bins, *C. zenithicus* was dominant or co-dominant with *C. hoyi* (Fig. 16). These results vary from those from the Koelz 1921-1923 survey in which the three chub species reached peak abundances at shallower depths and *C. zenithicus* was always the predominant species (Figs 7, 10a, 10b). Use of coarse depth bins summarizes the depth distribution, densities, and relative composition of the chub assemblage (Fig. 17); catch rates of *C. zenithicus* and *C. hoyi* at depths <40 m were low, moderate at intermediate depths (40-80 m) and highest at depths > 80 m. *C. zenithicus* was the dominant chub only at depths > 80 m and *C. nigripinnis cyanpterus* was captured in numbers only in the shallowest depth bin (0-40 m).

Results from bottom trawl samples showed a different pattern (Fig. 18). In contrast to the gillnet samples, *C. hoyi* was the dominant chub species at all depths. As with the Koelz 1921-1923 survey, *C. zenithicus* and *C. hoyi* reached relatively high abundances at shallower depths (41-60 m) but too few chubs were taken at depths >120 to discern patterns at greater depths. *C. kiyi* appeared to decline at greater depth, but this is likely the result of few bottom trawl tows at depths greater than 100 m depth.

While Smith et al.'s data showed that *C. zenithicus* was the predominant chub species in their small-mesh gillnet survey of Lake Superior in 1953, the abundance and composition of the chub species varied by ecoregions (Fig. 19). In particular, *C. hoyi* dominated the chub assemblages of western ecoregions APIS and MNNS; *C. zenithicus* was the dominant chub species in the central and eastern part of the Lake and reached maximum abundances in the MISS, EKEW, and WKEW ecoregions. (Fig.19). Sufficient trawl samples were taken in the MISS, EKEW, and APIS ecoregions to evaluate composition and abundance of chub species relative to the gillnet surveys (Fig. 20). *C. hoyi* dominated the chub assemblage especially in the APIS ecoregion, but the highest catch rates were observed in the EKEW ecoregion (Fig. 20).

1958-1973 Apostle Islands Survey Series

Following the establishment of the Lake Superior Biological Station in 1957, Bill Dryer worked closely with S. Smith, R. Hile, and P. Eschmeyer at the Great Lakes Fishery Laboratory to develop a gillnet monitoring program in the Apostle Islands following the 1953 lake-wide survey. For these data series we synonymized all forms of shortjaw cisco as *C. zenithicus.* Small-mesh gillnet assessments were conducted during spring and fall from 1958 through 1973 (Figs. 21, 22). The fall and spring surveys spanned the periods 1958-1966 and 1959-1973, respectively. Data from Station 2, a historic long-term sampling site off of Stockton Island, is shown separately. Although Smith et al. found that densities of *C. zenithicus* were relatively low in the APIS ecoregion during summer 1953 (4.3 fish per 1000' gillnet/night), Bill Dryer and Joseph Beil found densities during 1959-1962 to be higher, 9-30 fish per 1000' gillnet/night. Following the peak density in 1962, catch rates of shortjaw cisco declined rapidly to near zero by 1967, despite the increased sampling effort during the time of the decline (Figs. 21, 22).

Our analysis of a summary the Apostle Islands gillnet surveys conducted during 1958-1963 (Dryer 1966) provided a picture of the status of the Apostle Islands chub assemblage during a time when shortjaw cisco populations were being rapidly depleted by high levels of commercial harvest (Figs. 2-4, 23). During 1958-1963, more than 300,000 feet of gillnet were set over a depth range of <10 to >100 m depth. As expected, the depth distribution of shortjaw cisco was strongly overlapped by that of bloater, and kiyi were more prevalent at depths >100 m (Fig. 23). Consistent with the results of Smith et al.'s 1953 survey, bloater dominated the chub assemblage and shortjaw cisco was a minor component, accounting for >77% and <11% of the total number of chubs captured, respectively. Dryer also duplicated Koelz's 1922 experimental gillnet sets between Cat and South Twin Is. In 1922 shortjaw cisco represented 99% of the catch (Koelz 1929) but during 1958-1965 the catch composition consisted of 90% bloaters, 8% shortjaw cisco, and 2% kiyi (Dryer and Beil 1968). In 1953, Smith et al. found shortjaw cisco to represent a smaller proportion (2%) of the total chub catch from gillnet samples in the Apostle Islands (Fig. 19). These results suggest that the shortjaw cisco population in the Apostle Islands ecoregion declined sharply between Koelz's 1921-1923 survey and Smith et al.'s 1953 survey. Continued high levels of commercial harvest of chubs in Wisconsin waters of Lake Superior during the 1950s and 1960s coincided with the near-extinction of shortjaw cisco in the APIS ecoregion by 1970.

<u>1958-1992 Isle Royale Survey Series</u>

Biennial or triennial gillnet surveys of Isle Royale were initiated in 1958 by Bill Dryer, Joseph Beil, and Ralph Hile. The purpose of these surveys was to monitor the status of lake trout and prey fish populations in the Isle Royale area of Lake Superior. All forms of shortjaw cisco were synonymized as *C. zenithicus.* Gillnet size ranged from 6" down to 1.5" stretch mesh; we addressed the small mesh catch data (≤ 3" stretch mesh) that is effective in catching chubs and other smaller species. Catch rates were considerably higher than observed in the Apostle Islands, peaking at 72.8 fish/1000' gillnet in 1961 (Figure 24). Catch rates dropped off sharply after 1966, reaching near-zero levels by 1977. Low densities of shortjaw ciscoes in the gillnet surveys persisted for more than 10 years after their disappearance from Apostle Islands surveys.

<u>Reigle Surveys 1963-1965</u>

During 1963-1965 the Great Lakes Fishery Laboratory (now the Great Lakes Science Center) conducted an intensive survey of U.S. waters of Lake Superior to determine suitable areas for commercial trawling of deepwater ciscoes (Reigle 1969). Some 340 trawl tows were conducted in six cruises over a three-year period. Unfortunately, Reigle did not distinguish among chub species in his report. To determine if Reigle distinguished among chubs during the cruises, we searched the archives at the Great Lakes Science Center and were able to locate the original field data forms for all of the cruises but we are uncertain as to the completeness of the collection. On data forms for only one of the cruises, #20 of August 1964, chubs were differentiated by species for just 14 of 54 tows and these tows were taken from the EKEW and MISS ecoregions. For these 14 trawl samples, shortjaw cisco represented 9.5% of the total catch. This figure is comparable to proportions of shortjaw cisco recorded by Dryer in the Apostle Island ecoregion during the same time period (Fig. 23).

<u>1999-2004 Surveys in Lake Superior</u>

Over the period 1999-2003 a number of special and routine surveys in Lake Superior were conducted that provide a comprehensive inventory of the current distribution and abundance of shortjaw cisco in Lake Superior. For these recent surveys, all forms of shortjaw cisco were synonymized as *C. zenithicus.*

1. *Annual lake-wide spring preyfish assessments.* More than 85 sites were trawled around the perimeter of the Lake at depths ranging from 15 to 100 m (Figure 25). Shortjaw ciscoes were taken in Keweenaw Bay (EKEW), and Thunder Bay (THBY), Heron Bay (WCAN), and Whitefish Bay (WFBY).

2. *Deepwater fish community surveys*. During the summers of 2001-2003 we conducted a series of deepwater surveys in the eastern and western portions of Lake Superior (Fig. 25). Depths sampled ranged from 40 to more than 300 m. Of 66 deepwater trawl samples, shortjaw cisco were present in 17, and were always at low densities (4% or less of the chub assemblage). Similar to the results of Koelz's 1921-1923 and Smith et al.'s 1953 surveys, we found shortjaw cisco occurred most frequently at depths of 81-160 m (Fig. 26). Like the 1953 trawl data, the 2001-2003 trawl data showed that *C. hoyi* was the predominant chub species at depths of 40 to 160 m. At depths >160 m, *C. kiyi* was the predominant chub species. Composition of the chub assemblage varied with ecoregion; we found that *C. hoyi* was the dominant chub species in the ECAN, APIS, and WLS ecoregions while *C. kiyi* was dominant in the WFBY ecoregion and co-dominant with *C. hoyi* in the WKEW ecoregion. Shortjaw cisco occurred most frequently in eastern Ontario waters of Lake Superior, although individual specimens were taken near or in the Apostle Islands (APIS) (Fig. 27). *C. zenithicus* was only taken in the APIS, ECAN and WFBY ecoregions and represented a minor component of the chub assemblage (Fig. 27).

3. *Special gillnet surveys*. During the summers of 1999 through 2001, Hoff and Todd (2004) conducted gillnet surveys at 5 locations sampled by W. Koelz in the early 1920s (Fig. 25). Collectively, Hoff and Todd (2004) found shortjaw cisco to be present at 4 locations in the MNNS, WKEW, MISS, WFBY ecoregions, but at greatly reduced levels not significantly different from zero. During 2000-2001, Mike Petzold (Ontario Ministry of Natural Resources) conducted surveys with Hoff and Todd's experimental gillnets in the eastern Ontario waters (ECAN ecoregion) of Lake Superior in Michipicoten and Whitefish bays and found shortjaw cisco to represent 2% of the chubs captured in both areas (Petzold 2002). Our deepwater trawl sampling in this area of Lake Superior was intended to complement Petzold's gillnet sampling; our results were similar in that shortjaw cisco, though present, represents a minor component of the chub assemblage. In the summer of 2004, Tom Pratt, Dept. Fisheries and Oceans – Canada, used our experiment gillnets to survey Lake Superior at two sites in the vicinity of Rossport, Ontario (WCAN ecoregion). He found shortjaw cisco to be present at 5.5 fish/km of gillnet, which represents ~10% the density recorded by Koelz in the early 1920s (Tom Pratt, pers. comm.)-- exceptional among contemporary capture locations.

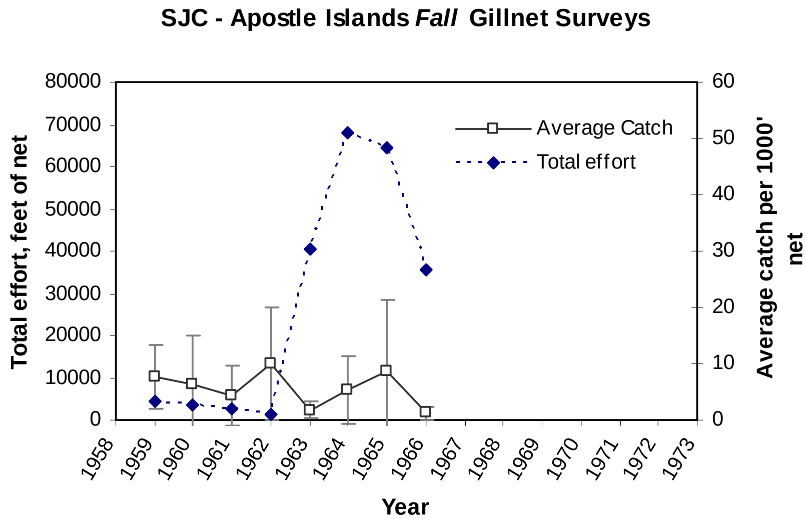
Overall, the recent surveys show that shortjaw cisco are present in many areas of the Lake but unlike Koelz's and Smith et al.'s surveys, we found the densities of shortjaw cisco and relative importance in the chub assemblage to be greatly reduced

Changes in the Lake Superior Chub Assemblage during the 20th Century

The three 20th-century data series document the progressive decline in the abundance and predominance of *C. zenithicus* in Lake Superior (Figs 9, 19, 27). During the early 1920s, Koelz

(1929) found that shortjaw cisco was the predominant species in the chub assemblage in all areas of the lake. Densities varied considerably from region to region with the highest densities found in the APIS and MNNS ecoregions. By the early 1950s Smith et al. found that bloater had supplanted shortjaw as the predominant chub in the APIS and MNNS ecoregions (Fig. 19), but shortjaws continued to predominate in other areas of the lake, especially in the eastern ecoregions. However, the abundance of bloaters and kiyi had increased in most ecoregions, signaling a change in assemblage structure. The results of our deepwater trawl surveys in 2001-2003 reveal the nearly complete loss of the once dominant shortjaw cisco; the species is now rare or absent in most areas of the lake, never representing more than 4% of the chub assemblage which is now comprised almost entirely of bloaters and kiyi (Fig. 27).

To summarize trends in distribution and abundance of *C. zenithicus* in Lake Superior over the past 80 years, we compared the frequency of occurrence at sample sites by ecoregion (Fig. 28) and compared small-mesh gillnet CPE by ecoregion (Fig. 29). *C. zenithicus* was present at all sample stations in the ECAN, WKEW, and APIS ecoregions in Koelz's 1921-1923 survey and the weakest showing was presence at 1 of only 2 stations sampled in WFBY (Fig. 24). By the 1950s, the frequency of occurrence had slipped in most ecoregions with only ECAN and WFBY reporting the presence of *C. zenithicus* at all stations. The most dramatic change was the sharp decline in *C. zenithicus* in the APIS ecoregion. The contemporary 2001-2003 survey showed that *C. zenithicus* was reported from 46% of all stations in the ECAN ecoregion and 36% of those in WFBY. Shortjaw ciscoes were absent from WLS and were taken at only one or two sites in the remaining ecoregions (Fig. 27). While *C. zenithicus* was infrequently encountered in most areas of the Lake during 1999-2003, it is still present in low numbers in most ecoregions. Densities of shortjaw cisco as reflected by small-mesh gillnet CPE declined markedly from the early 1920s to 1953; average CPE declined from 47.5 to 19.3 fish/1000 ft, respectively (Fig. 29). Densities declined to low levels between after 1953, reaching an average of 0.4 fish/1000 ft in 1999-2003. Average densities of *C. zenithicus* in the 1999-2004 period are <1% of those observed by Koelz in the early 1920s (Fig. 29).



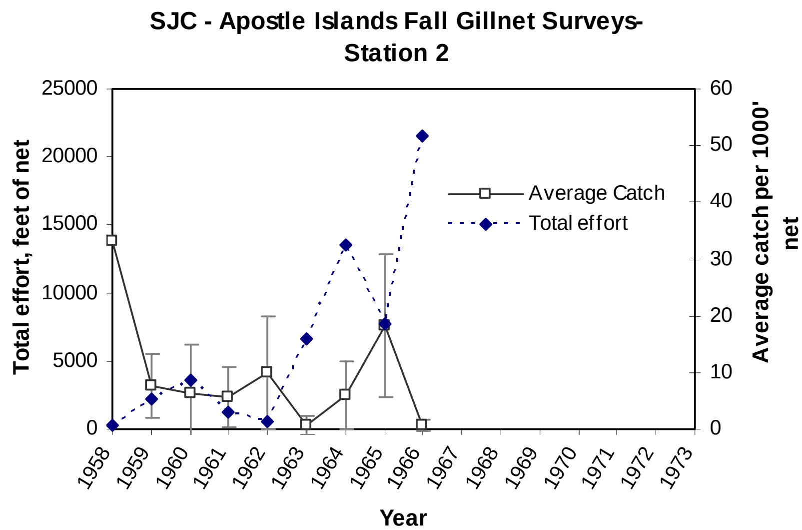
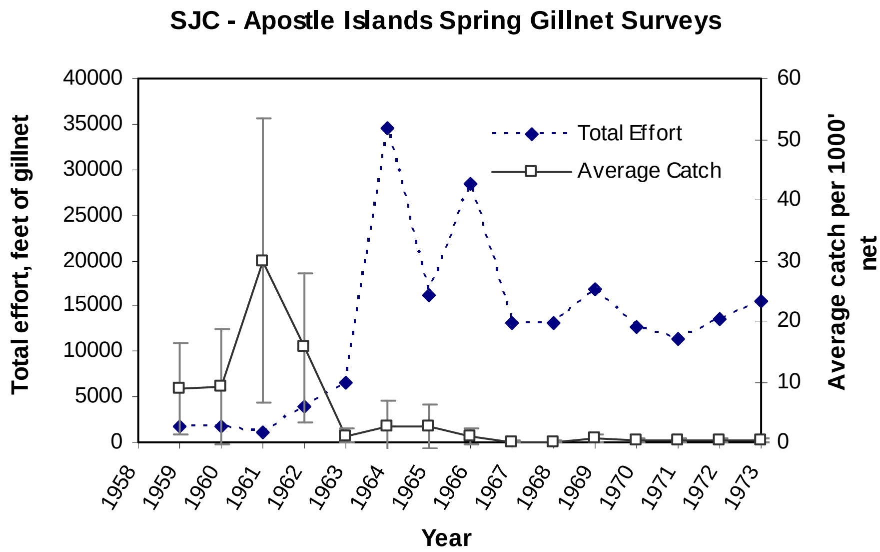




**FIGURE 21**. Trends in catch of shortjaw cisco from fall gillnet surveys in the Apostle Islands, 1958-1966. "SJC" includes the shortjaw cisco forms *C. zenithicus*, *C. reighardi dymondi* and *C. nigripinnis cyanopterus.*



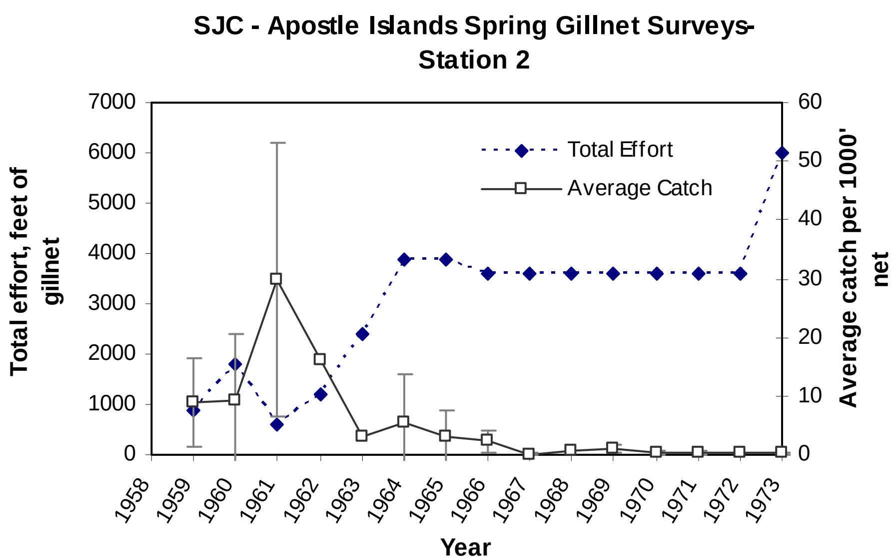
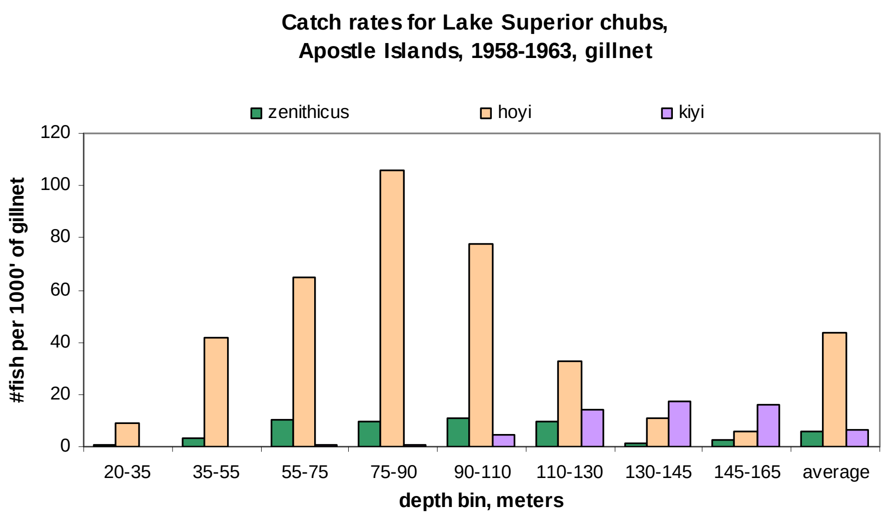




**FIGURE 22.** Trends in catch of shortjaw cisco from spring gillnet surveys in the Apostle Islands, 1959-1973. "SJC" includes the shortjaw cisco forms *C. zenithicus*, *C. reighardi dymondi* and *C. nigripinnis cyanopterus.*



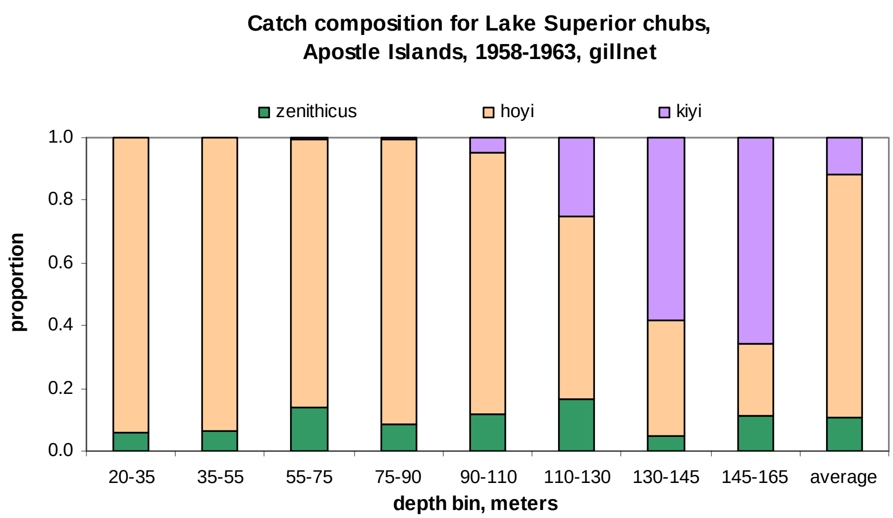




**FIGURE 23.** Catch rates and composition of chub assemblages from gillnet surveys of the Apostle Islands, 1958-1963. "Zenithicus" includes the shortjaw cisco forms *C. zenithicus*, *C. reighardi dymondi* and *C. nigripinnis cyanopterus*

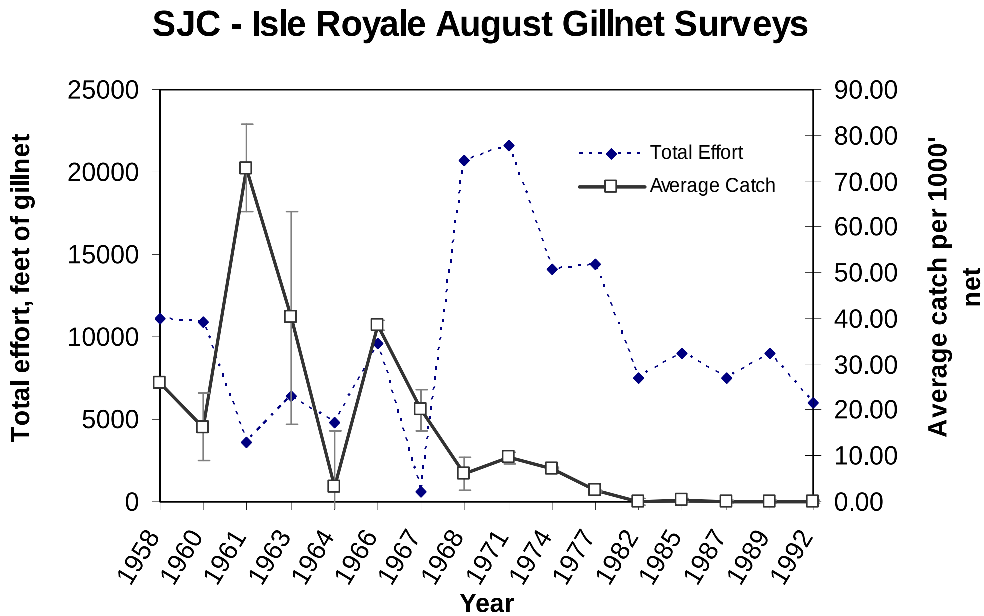



**FIGURE 24.** Trends in catch of shortjaw cisco from Isle Royale gillnet surveys, 1958-1992. "SJC" includes the shortjaw cisco forms *C. zenithicus*, *C. reighardi dymondi* and *C. nigripinnis cyanopterus.*

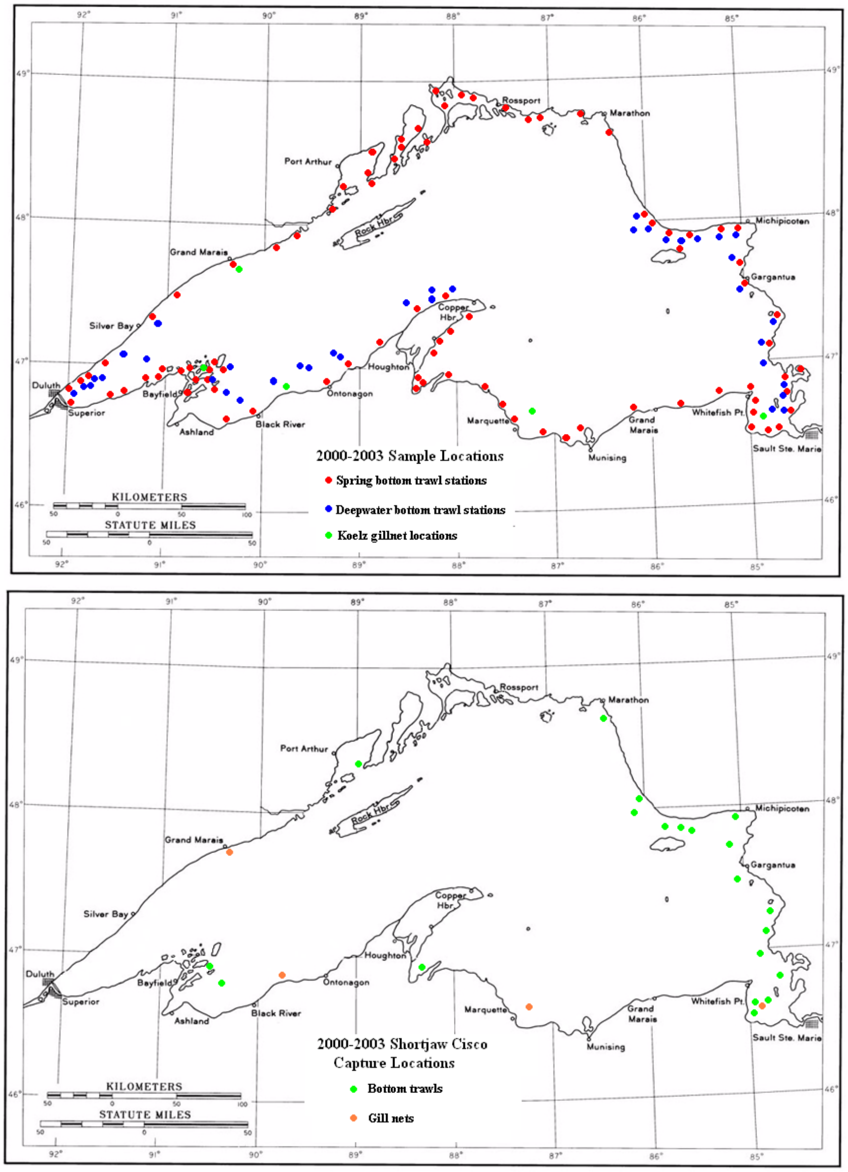
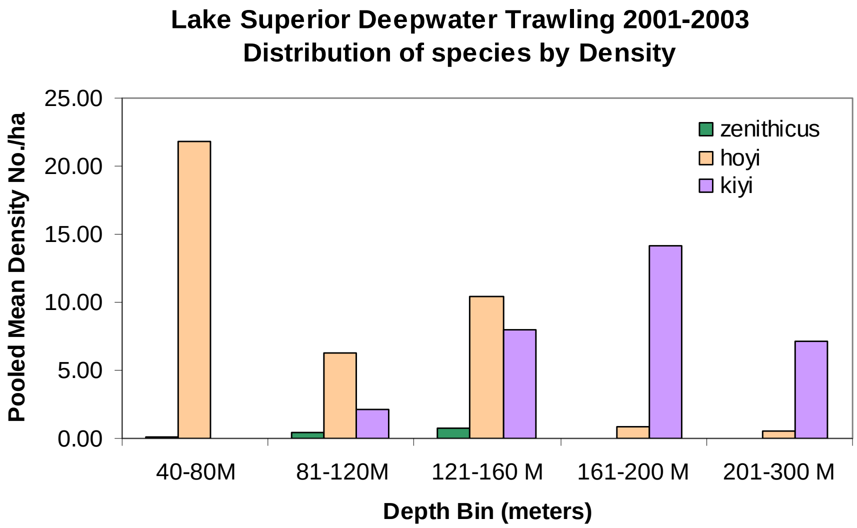



**FIGURE 25.** Map of Lake Superior showing sample locations of the 2000-2003 annual spring bottom trawl forage fish assessment, deepwater trawl surveys, and resampling of 5 of Koelz's 1921-1923 gillnet survey sites. "Shortjaw cisco" includes the shortjaw cisco forms *C. zenithicus*, *C. reighardi dymondi* and *C. nigripinnis cyanopterus.*



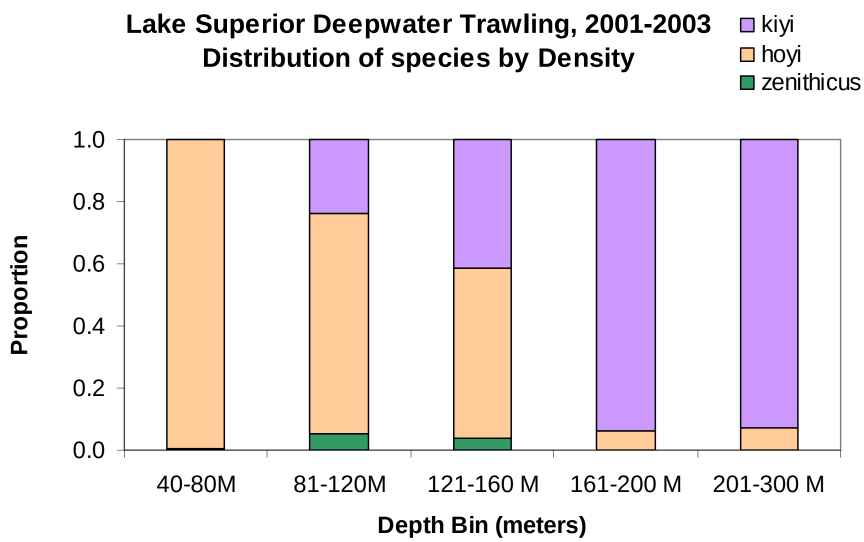




**FIGURE 26.** Densities and composition of the Lake Superior chub assemblage by depth bin, 2001-2003 deepwater trawl survey data. "Zenithicus" includes the shortjaw cisco forms *C. zenithicus*, *C. reighardi dymondi* and *C. nigripinnis cyanopterus.*

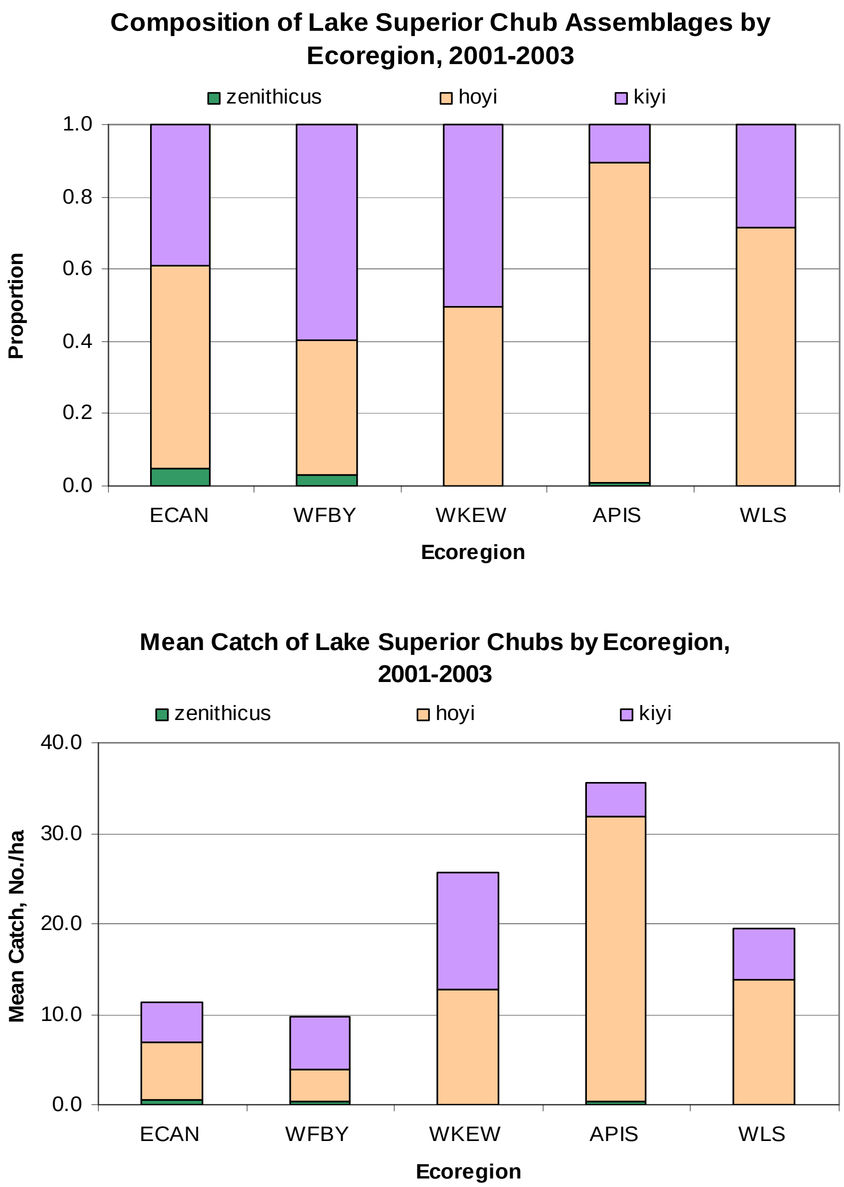



**FIGURE 27.** Composition of chub assemblages by ecoregion, 2001-2003 deepwater bottom trawl survey data. “Zenithicus” includes the shortjaw cisco forms *C. zenithicus*, *C. reighardi dymondi* and *C. nigripinnis cyanopterus.*

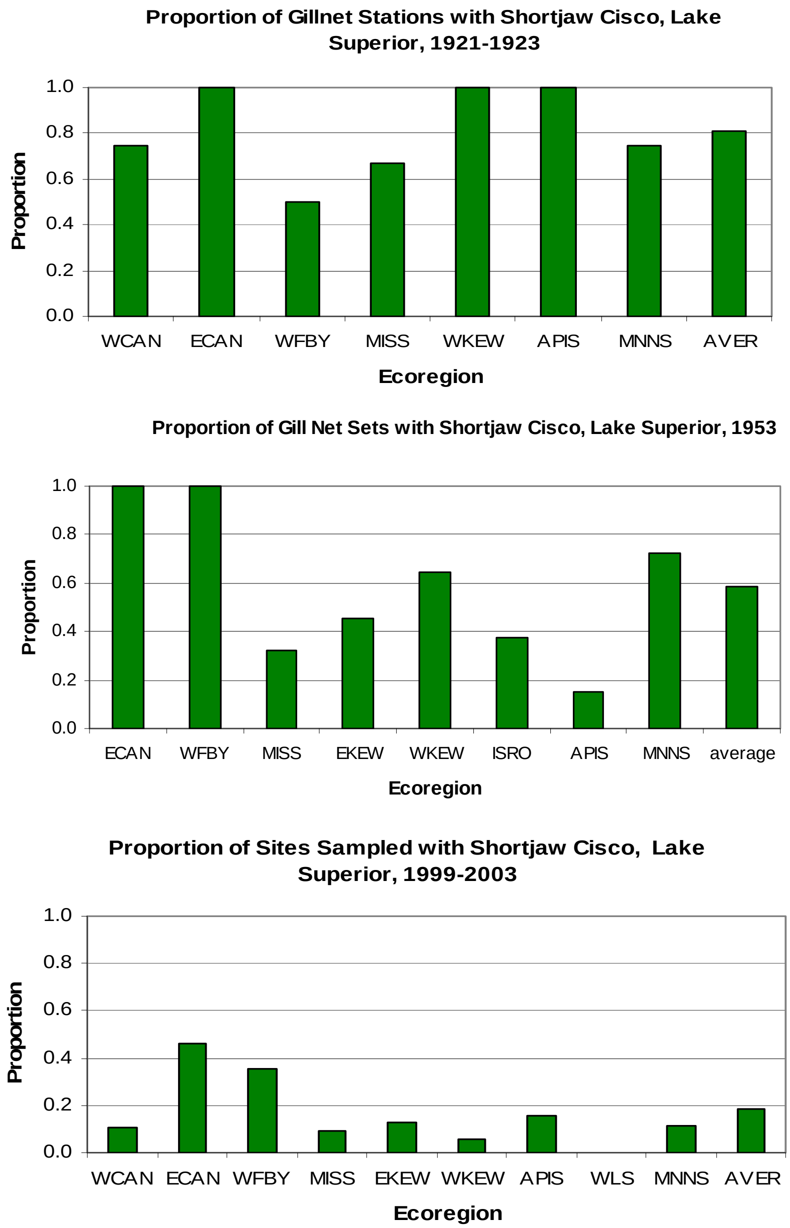



**FIGURE 28**. Comparison of frequency of capture of shortjaw cisco in Lake Superior by ecoregion for 1921-1923, 1953, and 2001-2003 periods. "Shortjaw Cisco" includes the forms *C. zenithicus*, *C. reighardi dymondi* and *C. nigripinnis cyanopterus.*

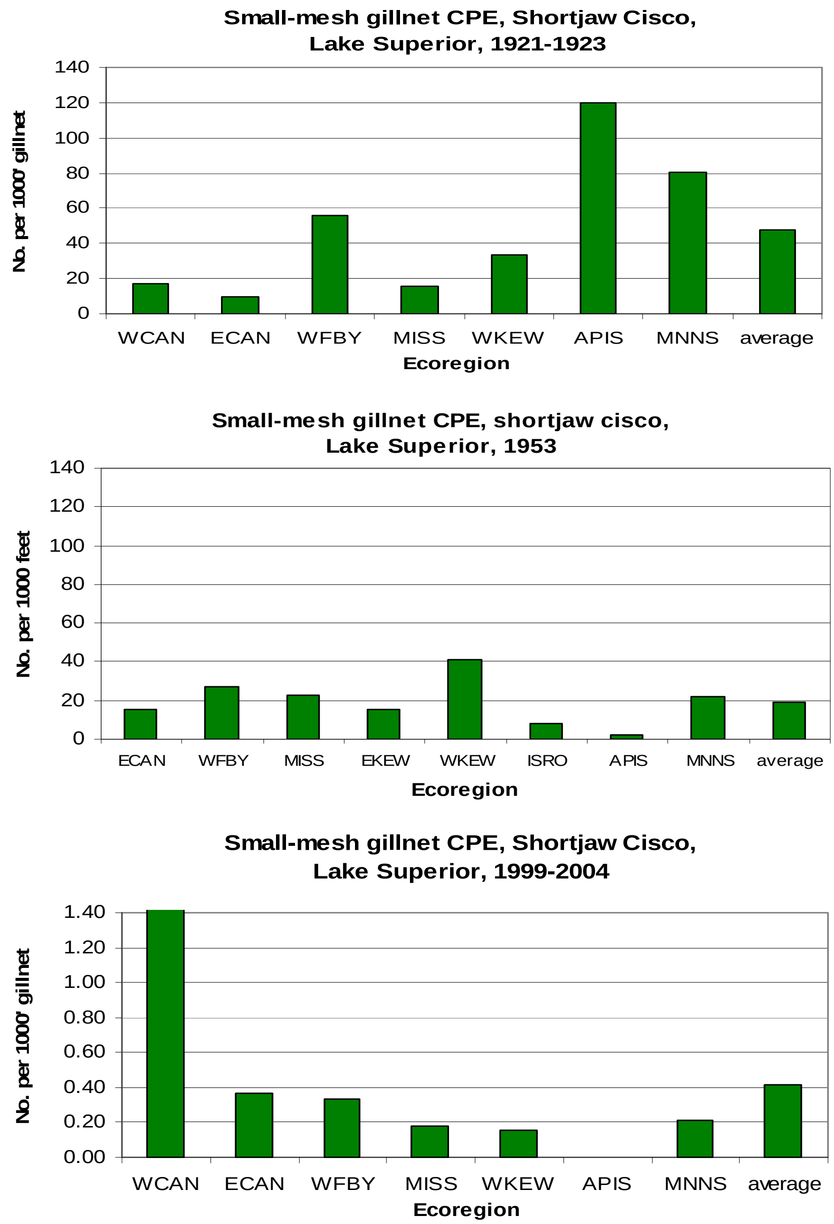



**FIGURE 29**. Comparison of small-mesh gillnet catch-per-effort (CPE) for shortjaw cisco in Lake Superior by ecoregion for 1921-1923, 1953, and 1999-2004 periods. "Shortjaw Cisco" includes the forms *C. zenithicus*, *C. reighardi dymondi* and *C. nigripinnis cyanopterus.* Note that the CPE values in lower panel are shown at 0.10 scale of the upper panels.

## DISCUSSION

Prior to the influx of European settlers into the Lake Superior watershed in the late 19th century, shortjaw cisco was a conspicuous element of the Lake Superior fish community. Given the preponderance of shortjaw cisco in Koelz's surveys of the early 1920s, shortjaw cisco at this time was likely second only to lake herring in contributing to total fish community biomass. This realization reminds us of how different the structure of the Lake Superior fish community was 100 years ago. The present day chub assemblage is dominated by or consists entirely of two species, bloater and kiyi. These two species were minor components of the chub assemblage in the early 20th century, by the mid-century bloater was the predominant chub in some areas of Lake Superior, and by the 1970s, bloater was the dominant chub species, lake-wide. It is fortuitous that Smith et al.'s comprehensive 1953 survey of Lake Superior occurred on the eve of the final commercial depletion of shortjaw cisco stocks. Even in 1953, shortjaw cisco was the dominant chub species in Lake Superior, representing as much as 60-100% of the catch in gillnet surveys in some ecoregions (ECAN, WFBY, MISS, EKEW, WKEW, ISRO).

Following European settlement in the late 19th century, the pristine stocks of shortjaw cisco in Lake Superior were subjected to very intense harvest and were the primary target of the chub fishery. Koelz (1926) noted that larger mesh gillnets (>3" stretch) were very successful in catching the large-sized fish in these unexploited stocks. Annual commercial harvest of chubs in Lake Superior averaged 576 metric tons during 1895-1908 and afterwards the fishery abruptly collapsed and a low mean annual harvest of 55 metric tons was reported for the period 1909-1925. The decline in yield of chubs after 1908 was compensated by a sharp increase in the harvest of lake herring, which remained high until the collapse of the lake herring fishery in the late 1950s (Lawrie and Rahrer 1973). By the time of Koelz's 1921-1923 surveys, shortjaw cisco stocks appeared to be in a state of recovery. Commercial harvest of chubs increased sharply in 1926, apparently in response to the market demand trigged by the collapse of the lake herring fishery in Lake Erie. At that time, the shortjaw cisco was the only chub species that was large enough to be of value to the commercial fishery (VanOosten 1936). From 1927 to 1950 commercial yield of deepwater chubs tended to decline and the mean annual harvest was 221 metric tons. During that period, the target species of the fishery began to switch from shortjaw cisco to bloater (Lawrie 1978), which had begun to grow faster and to larger sizes (Dryer and Beil 1968), probably as a result of decreased competition from reduced populations of shortjaw cisco (Lawrie 1978). However, shortjaw cisco remained the predominant species in the deepwater chub assemblage at the time of Smith et al.'s 1953 survey of Lake Superior, representing ≥60% of the chubs captured in all ecoregions except for APIS and MNNS (Fig. 20). Mean annual harvest for the period 1955-1987 was 617 metric tons. Following the rapid decline of the Lake Superior chub fishery in the mid-1980s, mean annual harvest of chubs dropped to a low 49 metric tons. Our analysis chronicles the shift in predominance by shortjaw cisco in the chub assemblage in the early 20th century to near co-dominance with bloater by the mid-century, to near-disappearance of shortjaw cisco by the end of the 20th century.

Trends for the deepwater cisco fisheries of Lakes Michigan and Huron appear to have influenced those of Lake Superior. Koelz (1929) reported that declining yields of large deepwater chubs in Lake Michigan resulted in a rapid increase in the harvest of Lake Superior chubs in the 1890s;

that fishery collapsed by 1908 as large deepwater chubs in Lake Superior (*C. nigripinnis cyanopterus)* became commercially extinct (Lawrie and Rahrer 1973). Bloaters began to dominate the Michigan and Huron chub fishery in the 1930s as a result of over harvest of larger chub species (e.g., *C. zenithicus, C. alpenae, C. reighardi*) so that by the 1950s, bloater was the predominant chub species (Brown et al. 1985; 1987). Increased size of bloater populations in the 1950s followed the loss of natural predators (lake trout) and competitors (larger deepwater ciscoes) that was a result of overexploitation and sea lamprey depredation (Smith 1964, 1968; Brown et al. 1985; 1987). During the bloater population expansion of the 1950s, mean size and marketability decreased. Meanwhile, the chub fishery of Lake Superior expanded rapidly in the mid- to late 1950s. By the early 1970s, the chub fisheries of Lakes Huron and Michigan collapsed from over harvest (Brown et al. 1985; 1987) and resulted in the closure of chub fisheries in the late 1970s. By the early1980s, the bloater populations of Lakes Huron and Michigan rebounded, fishery closures were lifted, and the chub fisheries of Lake Superior declined rapidly.

The first period of high exploitation of Lake Superior chub stocks in 1895-1908 removed an estimated 7489 metric tons over a 14-year period. We reasoned that most of the stocks that were depleted were relatively close to shore, accessible by oar and wind-powered vessels, and most fishermen hand-lifted their nets. Following the sharp decline of the fishery in 1909, total harvest was a mere 930 metric tons for 18 years, and by the early 1920s the stocks appeared to be in a state of relative recovery. We suspect that the apparent rapid recovery was the result of expansion of relatively intact offshore stocks. Even by the time of Koelz's 1921-1923 survey, few motorized fishing tugs were on Lake Superior, but with the advent of affordable outboard motors and powered fishing tugs in the 1920s, the offshore deepwater chub stocks were now accessible for harvest. The more modest annual harvest rate of 221 tons for the 1926-1954 period removed 6422 metric tons and was responsible for shifting the predominance of shortjaw cisco to bloater in the western portion of Lake Superior. During the final 33-year period of exploitation (1955-1987) 20366 metric tons of chubs were harvested. The 1955-1987 fishery lasted more that twice as long and removed nearly 3 times the number of fish as the first period of exploitation in 1895-1908. Given the duration and the available fishing equipment, we suspect that every population of shortjaw cisco in Lake Superior was depleted or nearly so. In the 20 years following the decline of the Lake Superior chub fishery in the mid-1980s, shortjaw cisco populations have shown little evidence of recovery.

Koelz (1929) found that the shortjaw cisco represented >90% of the catches from small-mesh gillnets in all areas of the lake where he sampled in 1921-1923. Gillnet assessments of ciscoes in eastern Lake Superior in 1959 revealed that shortjaw cisco represented only a slightly smaller percentage of the cisco catch (34%) than did bloater (37%) (Brown, unpublished). Peck (1977) found that the shortjaw cisco catches had declined to 0-23% of deepwater cisco commercial catches in the Keweenaw Peninsula area of the lake, 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 might have been equivocal because of small sample sizes and differences in sampling through time. We suspect that his peak catch in 1974 may have been caused by recruitment of a strong year class; note that catches peaked in Isle Royale in 1971-1974 and declined sharply thereafter (Fig. 24). Two opportunistic collections in 1997 from Lake Superior near Whitefish Bay and Grand Marais, Michigan revealed shortjaw ciscoes represented 5% and 11% of cisco catches (USGS, Great Lakes Science Center, unpublished data), which was within the range found by Peck (1977) at nearby Marquette. Overall, these data suggest that there was a significant decline of shortjaw cisco abundance prior to 1960, and that abundance may have stabilized at its current low level during the 1970s. Our small-mesh gillnet assessment data reveal the collapse of the shortjaw populations in the Apostle Islands in the 1960s and at Isle Royale in the 1970s (Figs. 21-24). After the mid-1960s most of the chubs harvested in U.S. waters of Lake Superior were bloaters (Fig. 4).

The contrast between the apparent resilience observed in shortjaw cisco stocks in the early 20th century demonstrated by their rapid recovery following a sharp decline and the apparent failure of contemporary shortjaw cisco stocks to recover since their nadir in the early 1970s suggests a different dynamic has occurred in Lake Superior, perhaps even since the 1950s. This could be related to management and harvest regulations for the chub fishery (see Listing Factors Analysis, below). Despite regulations that were put into place following the decline of chub and lake herring fisheries in the early 1960s (MacCallum and Selgeby 1987), stocks continued to decline, and this decline was attributed to overfishing (Lawrie and Rahrer 1972, 1973; Lawrie 1978; MacCallum and Selgeby 1987; Selgeby 1982). It has been noted that no species of deepwater cisco in the Great Lakes has made a conspicuous or sustained recovery after a severe decline (Smith 1972). The lack of resiliency of deepwater cisco populations has been attributed to competition with other species of ciscoes (notably bloater) and a continuing fishery that selects for the largest individuals present (Smith 1972). However, reported commercial harvest of chubs in Lake Superior over the past 20 years has been relatively low, not exceeding a lake-wide average of 50 metric tons/yr. Thus, present-day harvest of chubs in Lake Superior does not appear to be a likely factor in the continuing failure of shortjaw cisco stocks to recover. The practice of sequentially fishing-up of individual cisco stocks to maintain yield results in local and regional extinction of stocks and surviving stocks are scattered and have low population levels (Brown et al. 1987). In such a situation, recovery to pre-harvest conditions is prolonged or may not occur due to the slowness of remnant stocks to recover and disperse to areas previously occupied and undergo local adaptation (Selgeby 1982). We hypothesize that the failure of shortjaw cisco stocks to recover in Lake Superior is likely the result of sequential extinction of stocks from overfishing during the 1950s-1970s coupled with the slowness of scattered remnant stocks to rebuild and disperse throughout the Lake. Moreover, we hypothesize that competition from large populations of other ciscoes, e.g., bloater and kiyi, is hampering the ability of the remnant shortjaw cisco stocks to rebuild. Current management efforts through such agreements as “A Joint Strategic Plan for the Management of Great Lakes Fisheries (Great Lakes Fishery Commission 1997) are cognizant of this history, and mechanisms are in place to provide for more intensive management of the chub fishery should it revive in the future. We caution, however, that the factors that are limiting the recovery of shortjaw cisco in Lake Superior remain unexplained.

Shortjaw cisco are still present in Lake Superior, but at very low densities compared to 50 years ago. Our surveys found shortjaw cisco to be present in most of the areas where they have been found historically, particularly in the eastern Ontario waters of Lake Superior and Whitefish

Bay. Hoff and Todd (2004) found evidence of multiple age classes in shortjaw ciscoes captured in MNNS, WKEW, MISS, and WFBY ecoregions and estimated ages indicated that there has been successful recruitment since 1990-this is encouraging. However, we did not find shortjaw cisco in the western arm of Lake Superior, an area where they were historically abundant. We still have not completed deepwater surveys in the central part of Lake Superior, WCAN, ISRO, EKEW, and MISS ecoregions, thus our contemporary assessment of shortjaw cisco stocks in Lake Superior remains incomplete.

## INFORMATION NEEDS

1. Life history and age and growth data on shortjaw cisco of Lake Superior is lacking. We suspect that this species, which inhabits the cold, deep waters of Lake Superior, grows slowly and matures at a later age than lake herring, which inhabits shallower, more productive waters. Life history characteristics of slow growth and maturity at older age suggest that shortjaw cisco is a species that is vulnerable to over-harvest.

2. Additional deepwater surveys are needed to complete a full inventory of Lake Superior shortjaw cisco stocks. Available aging structures (scales, otoliths) from historic and present-day shortjaw cisco populations should be used to determine age structure and growth characteristics.

3. Available voucher specimens of shortjaw cisco should be examined for diet, reproductive condition, parasites, etc.

4. Regular monitoring of remaining stocks of shortjaw cisco should be conducted to track improvement or declines.

5. Genetic evaluation of remaining stock structure should be undertaken to evaluate differences and effective population sizes of extant populations.

## CONSERVATION PLAN

To date, no recovery or conservation plans have been developed to restore shortjaw cisco stocks in Lake Superior. The development of a scientifically-based recovery plan will require a substantial knowledge base, which is lacking. However, there is sufficient information and understanding of the ecology of shortjaw cisco synthesized in this report to propose a provisional conservation plan. The history of depletion of deepwater ciscoes in the Great Lakes demonstrates that these fish are vulnerable to overfishing (Smith 1964, 1968, 1972a). We suspect that the major reasons for this vulnerability are: high catchability of adults in nylon gillnets, slower growth and maturation (longer generation time), and highly variable recruitment success (shared with other ciscoes). The extensive sampling done by Smith et al. during the 1953 survey of Lake Superior provides invaluable data on the catchability of shortjaw cisco by mesh size of gillnet and depth. Gillnet with stretch mesh in excess of 3.5” catches few shortjaw cisco or any other chubs (Fig. 15). During the early 1950s shortjaw ciscoes were most commonly captured at depths ranging from 41 to 200 m, but especially depths>80m (Fig. 16). Because so little gillnet effort is required to effectively remove most of the adult population in a short period of time, it is critical that commercial harvest of chubs in areas where shortjaw cisco are present be terminated. This appears to be the only way to allow escapement of adult shortjaw cisco from the fishery so that they may reproduce and rebuild stocks. Such a closure should encompass a large enough area to include spawning, rearing, and adult habitat. Using the information from Smith et al. we suggest that no gillnet of <4” stretch mesh be set on lake bottoms (typical “chub sets”) at depths >60m (>200 ft). This would not preclude use of larger mesh bottom set gillnets that target lake trout, or smaller mesh gillnets suspended within 20m (65 ft) of the surface that target lake herring. Currently there is not a viable chub fishery on Lake Superior and reported commercial yields are at historic lows (Fig. 2). Thus, the sacrifice to suspend the chub fishery will not have significant negative economic impacts, but the potential benefits include averting extinction and possible recovery of commercially important stocks. As a corollary to stock protection we strongly recommend that a research program be initiated to address the information needs listed above. When shortjaw cisco populations recover, the information base will allow development of a scientifically sound management plan govern wise harvest without jeopardizing the health of recovered stocks.

## LISTING FACTORS ANALYSIS

Under Section 4(a)(1) of the Endangered Species Act 1973 as amended, the status of a species as threatened or endangered is determined by assessment of Five Listing Factors. The following assessment of the status of shortjaw cisco in the United States under the Five Listing Factors was written as distinct from the *Status Report* to facilitate separate publication as needed.

<u>Section 4(a)(1) of the Endangered Species Act of 1973</u>
Determination of Endangered Species and Threatened Species

Sec. 4.

(a) GENERAL.-

(1) The Secretary shall by regulation promulgated in accordance with subsection (b) determine whether any species is an endangered species or a threatened species because of any of the following factors:

- (A) the present or threatened destruction, modification, or curtailment of its habitat or range;
- (B) overutilization for commercial, recreational, scientific, or educational purposes;
- (C) disease or predation;
- (D) the inadequacy of existing regulatory mechanisms;
- (E) other natural or manmade factors affecting its continued existence.

Evaluation of Factors A-E

Factor A: Present or threatened destruction, modification, or curtailment of its habitat or range

Comment [lt1]: Suggest focusing this paragraph on adult habitat and the following paragraph on what is known about juvenile habitat—hence the rearrangement of sentences.

In Lake Superior there are presently no known significant losses, destruction, modification, or curtailment of its habitat or range. The Lake Superior ecosystem appears to be in a relatively good state of health and lake trout (*Salvelinus namaycush*), lake herring (*Coregonus artedi*) and bloater (*C. hoyi*) populations have recovered or are recovering from their nadir in the 1970s (Bronte, et al. 2003; Gorman and Hoff 2005). Deepwater habitat (>80m depth), which is used primarily by adult ciscoes, does not appear to be altered or degraded in Lake Superior. Spawning habitat is unknown, but is likely to occur in deepwater areas. There are no known perturbations of deepwater habitat in Lake Superior where shortjaw cisco are known to exist, therefore, there is no apparent link between the decline of shortjaw cisco populations and habitat degradation. In contrast, there have been significant changes in lake habitat in Lake Erie due to sedimentation and eutrophication during the late 19th and throughout the 20th centuries. How these changes contributed to the decline of shortjaw cisco in Lake Erie are not known.

Juvenile shortjaw cisco (<1-yr) are likely to use relatively shallow nursery habitat in nearshore areas (<15 m depth) where temperatures and food resources are conducive to rapid growth. Laboratory studies have demonstrated that age-0 coregonids (post swim-up stage) require temperatures of $\geq 15^oC$ for more than 90 days to attain sufficient size for over-winter survival (McCormick et al. 1971; Edsall and Rottiers 1976; Edsall and Charlton 1997; Edsall and Frank 1997; Edsall and DeSorcie 2002; Edsall 1999a, 199b). Nearshore nursery habitats are shared with other ciscoes, and because all ciscoes except shortjaw cisco are relatively abundant and reproduce successfully, these habitats are likely to be of suitable quality and quantity for shortjaw cisco.

The high percentage of forest (88%) and lack of large, expansive urbanized areas and heavy industry in the Lake Superior watershed suggests that anthropogenic impacts to nearshore areas may be negligible over the next 50 years. During the period 1880-1970, the Lake Superior basin was settled by Europeans who rapidly developed industries based on resource extraction of forests, minerals, and fisheries (Lawrie and Rahrer 1973). Compared to that period, the current populations in the Duluth-Superior, Ashland, Houghton-Hancock, Marquette, and Sault Ste. Marie areas are much smaller; for example, the present population of Ashland is ~25% of its 1910 population (Ashland Historical Society). Impacts to nearshore habitat during the exploitative period was severe in some areas and the principal causes were discharge of human waste and industrial effluents, high sedimentation from destructive forestry practices, and disposal of mine tailings (Lawrie and Rahrer 1973). Since 1950, there has been steady decline in human population levels, and after 1970 waste treatment plants were widely adopted, modern low-impact forestry practices were instituted, and mining operations were curtailed, which together reduced the impacts on nearshore habitat. Less than 5% of Lake Superior's shoreline is developed, but future expansion of urban and suburban zones will target shorelines as these areas are highly preferred (Lake Superior Binational Program 2000). Unfortunately, there is no coordinated effort at the present time to protect and conserve these sensitive habitats and impacts to these areas are far greater than the basin's low population density would suggest. Of particular concern is the tremendous popularity of developing shorelines for second homes, particularly on the U.S. side of the Lake (Lake Superior Binational Program 2000). The impact of future development on nursery habitat of lake fishes is not known, however, the level of development and impact of expanding human populations on Lake Superior is expected to be far less on than the other Great Lakes. Through such alliances as the Lake Superior Binational Program, efforts are being made to develop information bases, strategies, and management plans to protect Lake Superior habitat (Lake Superior Binational Program 2000).

Factor B: Overutilization for commercial, recreational, scientific, or educational purposes

The shortjaw cisco was once a common cisco species in Lakes Huron, Michigan, and Superior, but populations were extirpated in Lakes Erie, Huron and Michigan (Smith 1964) and greatly reduced in Lake Superior as a result of commercial overharvest (Smith 1968, 1972a; Lawrie and Rahrer 1972; Lawrie 1978). Following the development of the chub fisheries in the Great Lakes during the 1890s, a combination of selecting for the largest individuals and sequentially "fishing up" local stocks in spawning aggregations, resulted in the rapid depletion or extirpation of the larger deepwater cisco species (Smith 1968, Lawrie and Rahrer 1972, 1973). The decline of the blackfin cisco (*C. nigripinnis cyanopterus)* form of shortjaw cisco in 1907 and its disappearance from the commercial fishery by 1915 is the earliest example of this practice of exploitation from Lake Superior (Koelz 1926, 1929; Lawrie 1978; Lawrie and Rahrer 1972, 1973). The widespread adoption of nylon gillnets may have been a significant factor in the final cycle of overharvest of deepwater ciscoes in Lake Superior in the 1950s through 1970s Lawrie and Rahrer (1972, 1973). Pycha (1962) reported that increased efficiency of nylon gillnet to entangle coregonines was due primarily to increased catchability of larger individuals. Once nylon gillnets were widely adopted, stock depletions occurred so rapidly that fishery managers were unable to propose restrictions in time to regulate the fishery and protect stocks (Lawrie and Rahrer 1972, 1973). When regulations were put into effect in the 1960s and 1970s by various management agencies to restrict harvest of chubs, it was changing market conditions and declining CPUE of deepwater ciscoes that resulted in a curtailment of the chub fishery in Lake Superior in the early 1980s (MacCallum and Selgeby 1987). Results from assessment sampling indicated a real decline in the abundance of shortjaw cisco in Lake Superior over this time period (this report). This unfortunate outcome appears to be the result of not having sufficient data to assess the status of stocks prior to a new cycle of exploitation nor information on the relative efficiency of nylon gillnetting to harvest fish (Lawrie and Rahrer 1972, 1973).

Smith (1972a) has noted that deepwater ciscoes are very sensitive to exploitation and no species of deepwater cisco has made a conspicuous or sustained recovery after a severe decline in the Great Lakes. To understand why this is the case, we will compare aspects of life history characters of lake herring and shortjaw cisco in the context of exploitation in Lake Superior. Because of over-harvest, abundance of lake herring in Lake Superior declined precipitously in the late 1950s and remained low until the maturation of the large 1984 year class in 1988 (Selegby 1982; Gorman and Hoff 2005). During the 30-yr period of low abundance, exotic rainbow smelt replaced lake herring as the primary preyfish in Lake Superior (Lawrie and Rahrer 1972, 1973; Lawrie 1978; MacCallum and Selgeby 1987) and may have been cofactor in the suppression of lake herring recovery (Anderson and Smith 1971; Smith 1972a, 1972b; Cox and Kitchell 2004). Although lake herring has been the dominant prey fish species in assessments of Lake Superior fish communities during 1988-2004 (Gorman and Hoff 2005), fishery managers do not feel that lake herring populations have recovered to pre-1950 levels (Kitchell et al. 2000; Ebener 2005). It has been recognized that the high variation in year class strengths in lake herring populations has hindered population recovery (Lawrie 1978, Selgeby 1982), but early maturation or short generation time coupled with reduced commercial harvest and declining abundance of rainbow smelt may have increased the likelihood of residual lake herring stocks to rebound to relative abundance (Gorman and Hoff 2005; Cox and Kitchell 2004). Lake herring become sexually mature at age 3 while shortjaw cisco become mature at age 5 (VanOosten 1936; Dryer and Beil 1964; Lawrie and Rahrer 1973). For shortjaw cisco, the longer period for a year class to reach maturity will protract population recovery, especially if, like lake herring, variation in year class strength is also high; Gorman and Hoff (2005) have shown that another deepwater cisco, the bloater, has highly variable year class strengths that are largely synchronized with those of lake herring. Thus, although lake herring have reached a state of relative recovery in Lake Superior after 30 years of decline, it is likely to take longer for remnant shortjaw cisco populations to manifest similar levels of recovery.

We have shown that shortjaw cisco populations in Lake Superior appeared to reach their nadir in the 1970s, so we may expect these populations to show some signs of recovery during 2000-2020 so long as the residual populations are sufficiently large to allow successful reproduction and commercial harvest of adults is minimized. This discussion is meant to emphasize that shortjaw cisco populations are vulnerable to overharvest, and may not be able to recover from episodes of overharvest if most of the reproductive adult population is removed. The principal life history characters that confer this sensitivity to exploitation include a combination of variable recruitment success, sexual maturity achieved at an older age, and slow growth.

The primary reasons Smith (1972a) provided for the decline and lack of recovery of deepwater ciscoes in the Great Lakes were the continuation of commercial harvest that systematically removed the remaining largest individuals and the sequentially "fishing up" stocks or species throughout each of the Great Lakes. Following the decline was the invasion and expansion of marine species, i.e., alewife and rainbow smelt, which functionally replaced ciscoes in the restructured Great Lakes fish communities (Smith 1972b). The combination of continual harvest pressure on the remaining large ciscoes and the presence of exotic competitors and predators precluded an opportunity to recover and led to extinction of ciscoes in the lower Great Lakes (Smith 1972a, 1972b). However, this sequence of events was not followed in Lake Superior; when the yield of deepwater ciscoes declined, the fishery declined to low levels and has remained at relatively low levels to the present time--nearly 20 years (McCallum and Selgeby 1987; this report). And, unlike the lower Great Lakes, lake trout populations began to recover in the late 1970s and expanded rapidly in the 1980s and subsequent increased trout predation led to a sharp decline in rainbow smelt populations (Bronte et al. 2003; Gorman and Hoff 2005). Since the early 1980s densities of adult smelt have remained relatively low in Lake Superior, a state which reduced potential competition with native ciscoes and thus may have been an important factor in the recovery of lake herring (and deepwater cisco) populations in Lake Superior (Cox and Kitchell 2004; Gorman and Hoff 2005). The immense size, depth, and complex bathymetry of Lake Superior and the relatively low human population density in its basin are additional factors that may have allowed small populations shortjaw cisco to persist, particularly in the eastern portion of the lake where the fishery started later and was not as intense as in the western arm. Since 1999 adult shortjaw ciscoes have been captured regularly over broad areas in eastern Lake Superior (this report), suggesting that the residual populations may be sufficiently large to sustain a recovery.

Presently, the level of harvest of chubs from Lake Superior remains at a historic low while abundance of the most common chub, the bloater, remains relatively high compared to pre-1980 levels (Bronte et al. 2003; Gorman and Hoff 2005; this report). Like lake herring, bloater populations showed a sustained recovery throughout Lake Superior starting in the late 1980s as a result of the successful recruitment of large year classes (Gorman and Hoff, 2005). Thus, it appears that stocks of Lake Superior deepwater ciscoes, including shortjaw cisco, have had an opportunity to recover over the past 20 years in the absence of a targeted fishery and the successful recruitment of multiple year classes. However, we caution that any level of harvest of shortjaw cisco during the recovery phase reduces the probability of recovery. This is because commercial harvest with gillnets removes the largest individuals with utmost efficiency and as a result seriously hinders the reproductive capacity of residual populations. The conservation of large, mature shortjaw ciscoes in Lake Superior should be viewed as critical to population recovery. At the present time there are no available data to determine the level of harvest of shortjaw cisco in Lake Superior either from the small chub fishery or from by-catch from the lake trout commercial fishery. Problematic is the ability of biologists and fishermen to correctly identify shortjaw ciscoes in the field with a high degree of certainty. While the number and length of gillrakers on the first gill arch are the single-most diagnostic characters for shortjaw ciscoes, sufficient variability exists to cause overlap with other species of deepwater ciscoes. Concordance of several key characters such as fin length and snout shape (primarily the angle of the premaxillaries), are often needed for positive identification. The reliance on several characters, each with its own levels of variability, makes identification of deepwater ciscoes problematical in some areas and generally requires individuals with considerable experience to produce reliable results. We have found that heightened awareness of the species' existence in Lake Superior coupled with agency participation in identification workshops has resulted in numerous recent catch records. Regardless, shortjaw ciscoes are likely being harvested from these fisheries, and the largest fish are most vulnerable to removal. Should shortjaw cisco populations begin to rebound, this commercially valuable fish would likely become a target for harvest, which would have deleterious consequences for sustained recovery.

Factor C: Disease or predation

Expansion of introduced rainbow smelt and sea lamprey populations in the Great Lakes peaked well after the decline of shortjaw cisco and other deepwater cisco stocks, so predation or competition from these exotics are not considered significant factors in the decline of deepwater ciscoes in Lake Superior (Lawrie and Rahrer 1972, 1973; Lawrie 1978; Smith 1968, 1972a). However, the predominance of rainbow smelt populations in Lake Superior following the decline of lake herring and the deepwater ciscoes may have suppressed recovery of these native species through a combination of competition and predation (Anderson and Smith 1971; Smith 1972a; Lawrie and Rahrer 1972; Lawrie 1978; Cox and Kitchell 2004). Now that lake trout populations have recovered substantially and increased trout predation has reduced rainbow smelt populations to relatively low levels and lake herring and deepwater cisco populations have rebounded (Bronte et al. 2003; Gorman and Hoff 2005; Cox and Kitchell 2004), smelt no longer appear to significantly impact the status of the native ciscoes. However, smaller rainbow smelt still abound in Lake Superior (Gorman and Hoff 2005) and still may impose unnatural competition and predation on juvenile coregonids, including shortjaw cisco. Because rainbow smelt and larval coregonids occupy the same shallow, warm, nearshore habitats they may compete for food resources and larger smelt prey on larval coregonids (Anderson and Smith 1971; Selgeby et al. 1978; Crowder 1980; Hrabik et al. 1998). Although sea lamprey depredation has been identified as significant factor in the decline of larger species such as lake trout, burbot, and lake whitefish in the Great Lakes, lamprey depredation is unlikely to have contributed significantly to the decline of ciscoes as their declines preceded the major expansion of sea lamprey populations (Lawrie and Rahrer 1972, 1973; Lawrie 1978; Smith 1968, 1972a). However, it is likely that sea lamprey can prey on smaller species such as lake herring and deepwater chubs. Nevertheless, control programs have greatly reduced impact of sea lamprey on native fish communities and have been credited with recovery of wild lake trout populations in Lake Superior (Bronte et al. 2003).

**Comment [lt2]:** Wasn't aware that shortjaw adults and rainbow smelt competed for food resource; there depth ranges are so different.

The success of the sea lamprey control program, harvest closures, and establishment of refugia have been credited as the primary factors in the recovery of native lake trout populations in Lake Superior (Bronte et al. 2003). Both the shallow water (lean) lake trout and deepwater (siscowet) forms of lake trout have shown strong recovery since late 1970s (Bronte et al. 2003; Gorman and Hoff 2005). More recently it has become apparent that in the absence of pressure from commercial harvest, siscowet lake trout populations have continued to expand more than those of lean lake trout (Bronte et al. 2003). Because siscowet lake trout prey heavily on chubs, (Ray 2004; Ray et al. 2005) large populations of these predators may pose a significant natural mortality factor for shortjaw cisco, especially juveniles and smaller fish. However, deepwater ciscoes have coevolved with siscowet lake trout, were not a factor in their decline, and are not likely to be a significant impediment to their recovery. It should be noted that larger deepwater ciscoes are not vulnerable to lake trout predation because of their size, but larger ciscoes are more vulnerable to commercial harvest (Smith 1964, 1968, 1972). The key to recovery is conservation of larger, reproductively valuable individuals in the population.

There are no known diseases or parasites that are impeding the recovery or were a factor in the decline of shortjaw cisco or other ciscoes found in Lake Superior.

Factor D: Inadequacy of existing regulatory mechanisms

**Comment [lt3]:** Regulation of the fishery by the states/tribes should be detailed in the second paragraph. Also, what protections are currently afforded the species through their federal endangered species legislation. Include a separate paragraph on that and when a recovery plan will be published for the Canadians etc. Another paragraph should detail current regulations on ballast water introductions and other modes of non-native species introductions.

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 Federal Committee On Status of Endangered Wildlife in Canada (Houston 1988, Todd 2003a), 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 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, populations of shortjaw cisco are found outside the Lake Superior drainage in glacial lakes distributed from western Ontario to Great Slave Lake in the Northwest Territories (Todd and Steinhilber 2002; Murray and Reist 2003; Todd 2003a). Mandrak and Todd (2004, pers. com.) recently identified a few specimens from Georgian Bay, Lake Huron that could represent a remnant stock or could also be immigrants from Lake Superior. In the U.S., small populations of shortjaw cisco outside the Lake Superior drainage were recently discovered in two lakes in northern Minnesota that straddle the Canadian border (Lake Saganaga and Lake of the Woods) (Etnier and Skelton 2003; Todd 2003b). Other Canadian lakes in this area (Loonhaunt and Basswood) harbor small populations of shortjaw cisco (Murray and Reist 2003). Shortjaw cisco found in Lake Superior and Lake Nippigon constitute the remaining metapopulations that have been subject to exploitation and thus are the greatest concern for conservation and recovery.

Regulation of commercial fisheries in the Great Lakes is under the authority of the individual states, tribal governments, and the Canadian province of Ontario (MacCallum and Selgeby 1987). Minnesota regulates harvest of deepwater ciscoes by a limited entry policy (limited number of licenses or individual fishermen) and a limit on amount of net that can be fished (effort). Wisconsin also has a limited entry policy, but limits areas that can be fished and the mesh sizes of gillnet that can be used to harvest deepwater chubs. Michigan regulates the deepwater cisco fishery through quotas and restriction of effort to waters >110 m depth. Tribal agencies regulate harvest of deepwater ciscoes through a system of quotas, limited entry, effort and boat restrictions (numbers and size). Ontario uses a system of restricted entry with quotas by management zone. To our knowledge there has not been any coordination of these diverse controls and regulations to meet regional or lake-wide management objectives with respect to deepwater chub populations. Moreover, to our knowledge there has not been a concerted effort to regularly assess the status of deepwater cisco stocks, which has precluded formulation of management goals. The present system of controls and regulations are intended to maintain control over the fishery but without knowledge of how effective those controls are in conservation of deepwater ciscoes. As previously noted, most of these regulations and controls were instituted after the decline of shortjaw cisco stocks in the 1960s-1970s. Thus, they should not be viewed as a management program that aims at recovery of shortjaw cisco stocks. Regardless of recognition of the imperiled status of shortjaw cisco stocks in Lake Superior by federal, state, and provincial entities, no recovery plans or restrictive harvest regulations have been developed nor instituted, although the Department of Fisheries and Oceans Canada is currently working on a Recovery Plan for the species.

As we have noted previously, harvest of deepwater ciscoes in Lake Superior is at historic low levels. However, since the deepwater small mesh gillnet fishery is most effective in removal of the largest fish, shortjaw cisco are the most vulnerable of the deepwater ciscoes to capture because of their larger size (Smith 1968, 1972a; Lawrie 1978; Lawrie and Rahrer 1972, 1973). Thus we suspect that adult shortjaw ciscoes continue to be harvested and that harvest of adult fish is likely to impair the recovery of shortjaw cisco stocks in Lake Superior.

Factor E: Other natural or manmade factors affecting its continued existence

**Comment [lt4]:** Small stock size issue should be included in this factor.

**Comment [lt5]:** It would be appropriate in this section to describe the difficulty in identifying this species among other cisco species in the lake. This difficulty creates significant challenges in monitoring catch and take by species (as opposed to lumping them as chubs).

**Comment [lt6]:** Citations needed throughout this factor.

In Lake Erie, profound ecological changes occurred that shifted the lake environment to a more mesotrophic condition, and while the physical conditions of Lakes Michigan and Huron have not changed as dramatically over the past 100 years (with the notable exception of Saginaw Bay), their biological communities have become considerably altered by the introduction of many exotic species across several trophic levels (Smith 1972a, 1972b, Mills et al. 1993; Eshenroder and Burnham-Curtis 1999). Lake Superior has been less affected by anthropogenic influences and unlike the other Great Lakes still retains its native fauna, although exotic species have altered the community, notably the sea lamprey and rainbow smelt (Smith 1972a, 1972b, Lawrie 1978; Lawrie and Rahrer 1972, 1973). Abiotic factors such as weather and thermal changes (e.g., those associated with global warming) during the 20$^{th}$ century have resulted in small changes in annual temperature and precipitation patterns in Lake Superior, but do not appear to be significant factors in the observed changes in the fish community (Magnuson et al. 1997). As noted previously, anthropogenic factors such as over-exploitation and introduction of exotic species have been the principal factors affecting the Lake Superior ecosystem. However, climate change has been suspected to play a role in the decline of native fish species and susceptibility to invasion by exotic species in the other Great Lakes (Mills et al. 1993). The impacts of these anthropogenic and climatic factors are reduced in Lake Superior because of the Lake's more northerly location, large volume of deep, cold water, relatively low human population levels, fewer urban areas, higher proportion of forest cover, and less agriculture. For example, although Dreissenids have invaded the lower Great Lakes and have substantially altered the trophic structure of these lakes (Mills et al. 1993), they have yet to expand beyond thermally altered harbors of Duluth-Superior and Thunder Bay. Low average temperature and low levels of calcium appear to inhibit reproduction of Dreissenids in Lake Superior. Similarly, although alewife is present in Lake Superior, low average temperature inhibits expansion of this exotic species (Bronte et al. 2003). Predicted changes in the Lake Superior fish community due to global climate change over the next 50 years are limited largely to nearshore communities that occupy depths < 80 m. In these areas, increased temperature should lead to the expansion of populations of lean lake trout, lake whitefish, lake herring, yellow perch, walleye and northern pike (Bronte et al. 2003). Exotic species such as pacific salmon, sea lamprey, rainbow smelt, and alewife are also expected to benefit from warming of nearshore habitats (Bronte 2003). Thermal changes in the deepwater areas (>80 m depth) occupied by deepwater ciscoes are expected to be minimal, and given that 76% of the area of the lake is deepwater, effects of global climate change on the quantity and quality of habitat used by shortjaw cisco are expected to be minimal.

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Deleted:

CONTACTS

The following individuals or agencies and organizations were contacted to request capture records of shortjaw cisco from Lake Superior. Requests for capture records of shortjaw cisco were made by sending a formal letter dated July 2, 2002.

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**Responses to Letters of Solicitation**:
Capture records for shortjaw cisco generally do not exist. This is because shortjaw ciscoes are not distinguished from other "chubs", e.g., bloater and kiyi in commercial catch records or from assessments. Data on shortjaw cisco captures were received from Michael Petzold, Ontario Ministry of Natural Resources and Tom Pratt, Dept. Fisheries and Oceans – Canada. These individuals were collaborating with us to assess the distribution and abundance of shortjaw cisco in Lake Superior. They used our experimental gillnets (described in Hoff and Todd 2004) to survey shortjaw ciscoes in Ontario waters of Lake Superior.

Sources of shortjaw cisco capture records are listed in Table 2.