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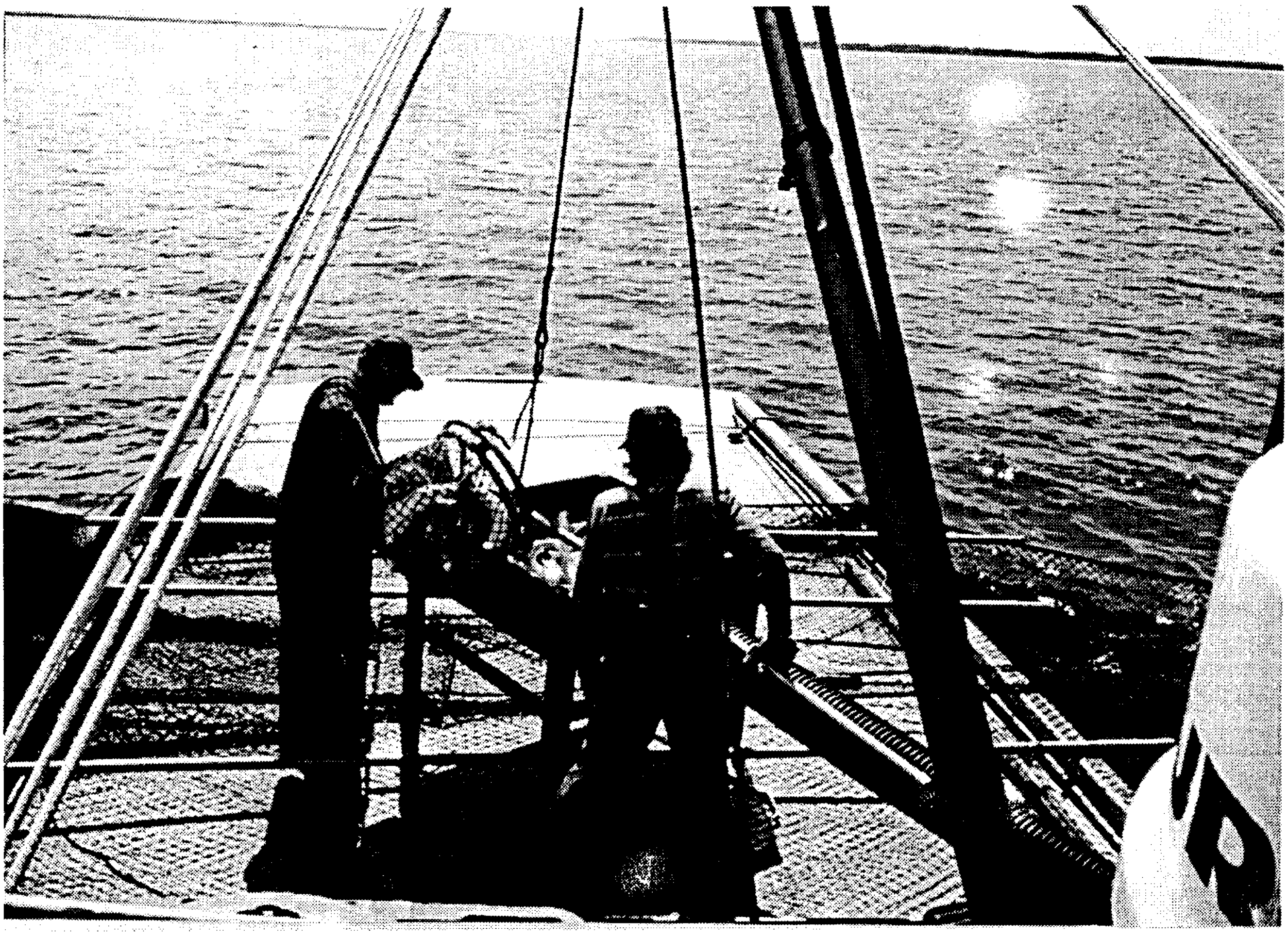

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Effects of Commercial Fishing on an Unexploited Lake Whitefish Population in Michigan's Waters of Lake Superior, 1983-1989

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Abstract.—Population parameters for a previously unexploited population of lake whitefish *Coregonus clupeaformis* at Upper Entry in Michigan waters of Lake Superior were measured in catches from a state-licensed trap-net fishery during 1983-1989 to obtain data from an unexploited population and to monitor the effect of trap-net fishing. A tribal gill-net fishery began on these lake whitefish in 1984. Annual trap-net catch decreased from 380,000 lb in 1984 to 44,000 lb in 1989. Catch per trap-net lift decreased from 690 lb in 1983 to 159 lb in 1989. Although age range of lake whitefish in catches was generally 4 to 15 years during 1983-1989, mean age decreased from 8.9 years in 1984 to 6.4 years in 1989. Modal age of lake whitefish in trap-net catches was 9 years in 1983 and 1984, 10 years in 1985, then decreased to 6 or 7 years during 1986-1989. Length-at-age of lake whitefish at Upper Entry was less than for exploited populations elsewhere in Lake Superior, and decreased during 1983-1987 as faster growing individuals of the initial stock were harvested. Lake whitefish at Upper Entry were not fully vulnerable to the 19-inch size limit until age 10. Differences in age composition and back-calculated length-at-age between lake whitefish in south and north areas of Upper Entry in 1983 suggested that they were separate stocks. Total annual mortality rates estimated using the Robson-Chapman method were 0.80 and 0.85 for age-9 and older lake whitefish from initial catches (May 1983) in south and north areas of Upper Entry, which actually represented natural mortality of these previously unexploited age groups. The Robson-Chapman total annual mortality estimate based on the total catch in 1983 was 0.75, but this method could not be used in subsequent years because fishing caused differences in survival among cohorts and strength of recruiting year classes was not constant. Total annual mortality rates estimated from survival of cohorts between ages 10 and 11 increased from 0.63 in 1983 to 0.82 in 1987. The mean mortality rate for ages 10-15 increased from 0.57 in 1983 to 0.84 in 1987. These rates were higher than rates for exploited and unexploited lake whitefish elsewhere in the Great Lakes, but were based on older age groups that represented less than half of the harvest. Fishing this previously unexploited lake whitefish population resulted in decreased biomass and growth and increased mortality, but initiation of the tribal gill-net fishery obscured the effect of the trap-net fishery. Although fishing effort by state and tribal fisheries decreased as lake whitefish biomass decreased and the population is not in immediate danger, it is recommended more representative estimates of mortality be obtained and that estimated annual quotas be used to regulate future lake whitefish harvest on the Upper Entry fishing ground.

Lake whitefish *Coregonus clupeaformis* has been the most important commercial species in Michigan waters of Lake Superior both in terms of monetary value and pounds landed. Harvest of other important commercial species available to state-licensed fishers has been depressed due to poor market demand (deep-water ciscoes *Coregonus* spp. since 1980), restriction of the fishery to depths greater than 360 feet (deep-water ciscoes and lake herring *Coregonus artedii* since 1974), or eliminated by closure (lake trout *Salvelinus namaycush* since 1962).

Lake whitefish fisheries historically occurred throughout Michigan waters of Lake Superior, but no commercial fishing had been done west of the Keweenaw Peninsula since 1959 (Figure 1). All commercial fisheries for lake whitefish during 1960-1982 were east of the Keweenaw Peninsula, and included state-licensed and tribal fisheries. State-licensed fishers for lake whitefish were restricted to the use of impoundment nets in waters no deeper than 90 feet after 1974 (Michigan Department of Natural Resources 1977). Trap nets have been the only impoundment nets used by state-licensed fishers in Michigan waters of Lake Superior. Native American tribal fishers, exercising rights granted by 1836 and 1842 treaties, began fishing lake whitefish east of the Keweenaw Peninsula in the early 1970's. State-mandated fishing gear and depth restrictions did not apply to tribal fisheries and they employed mainly gill nets in waters deeper and shallower than 90 feet. State-licensed fisheries for lake whitefish east of the Keweenaw Peninsula were reporting greater annual catches during 1976-1981 than the earliest recorded catches in 1929-1943, but catch per trap-net lift was decreasing (Rakoczy 1983). The addition of tribal fisheries and declining catch per trap-net lift in state-licensed fisheries indicated that there was no room for expansion of lake whitefish fisheries in waters east of the Keweenaw Peninsula.

The best opportunity for expansion of the lake whitefish commercial fishery in Michigan waters was west of Keweenaw Peninsula where lake whitefish had not been exploited since 1959. The highest catch recorded for these waters between 1929 and 1959 was 158,000 pounds (Baldwin et al. 1979). The Marquette Fisheries Station of the Michigan Department of Natural Resources (MDNR) assessed lake whitefish populations in this area with graded-mesh (3.0 to 5.0 in) gill nets in 1981. Average total length of whitefish in these nets was 20.7 in, and catch (dressed weight) per 1,000 ft of gill net was 134 lb (MDNR, Marquette Fisheries Station, unpublished data). Catch per 1,000 ft of gill-net rarely exceeded 40 lb on fishing grounds east of Keweenaw Peninsula during 1929-1972 (MDNR, Marquette Fisheries Station, unpublished data).

This study presents fishery statistics and fish parameters from a state-licensed trap-net fishery during 1983-1989 on previously unexploited lake whitefish in Michigan waters of Lake Superior west of Keweenaw Peninsula. Initial catch statistics and parameter data would be from unexploited populations which are "prized rarities in fishery literature" according to Ricker (1949). Objectives of this study were to document biomass, age composition, growth, and mortality parameters for the previously unexploited lake whitefish, and to measure effect of a trap-net fishery employing 10 nets on these parameters. A tribal gill-net fishery for lake whitefish began on this fishing ground in 1984.

Methods

A research fishing permit was issued to a state-licensed commercial fisher in 1983. The fishery was restricted to the Upper Entry fishing ground in Michigan's Lake Superior management zone MI-3, which extended between Fourteen Mile Point and Five Mile Point and included statistical grids 1219, 1220, 1121, 1122, 1023, and 1024 (Figure 1). The fishery operated in the south (grids 1219, 1220), middle (grids 1121, 1122), and north (grids 1023, 1024) areas of the ground at different times within and among years so data were collected and analyzed for each area. The permit authorized harvest of lake whitefish 19 inches and longer, burbot *Lota lota*, common carp *Cyprinus carpio*, white sucker *Catostomus commersoni*, and longnose sucker *C. catostomus* with up to 10 trap nets during January through October each year. The permit was amended in July 1986 to permit retention of lake whitefish 17 inches and longer. All fish captured in trap nets other than those authorized were to be returned to the water dead or alive. In general, trap-net pots were 40 ft long by 20 ft wide and 20 ft deep, with two 100-ft wings and a 1,000-ft lead that converged at a series of one or more chambers called hearts (Schorfhaar and Peck 1993). Hearts incorporated the net entrance and tunnel leading to the pot. Mesh was tarred nylon; mesh sizes (stretch measure) were 4.5-inches for the pot, 4.5- to 6-inches for the wings and hearts, and a 14-inches for the lead. Catch and effort data on this fishery were obtained from summaries of Daily Report of Commercial Fisheries of the Great Lakes (Form R8005) prepared by MDNR, Fisheries Division Great Lakes Program personnel in Lansing, Michigan. Data on this form included date, location (statistical grid), number of nets fished, and catch of lake whitefish and other species. Catch of legal-size lake whitefish was reported as dressed weight (lb), whereas catch of sub-legal lake whitefish and other species was reported as number of fish. Catch per unit of effort (CPE) for legal-size lake whitefish was defined as dressed weight (lb) per trap-net lift. Trap-net CPE was not adjusted for number of days fished between lifts.

Marquette Fisheries Station personnel accompanied the state-licensed fisher on daily fishing trips 1-4 d per month and sampled trap-net catches. Fisheries personnel from the MDNR District Office in Crystal Falls assisted with sampling in 1983. Sampling was done during all months fished during 1983-1987, but only 1-2 months in 1988 and 1989 (Table 1). Percentage of total trap nets lifted annually that were sampled ranged from 10% to 23% with a mean of 13%. On each sampling day, net-run samples of 50-100 legal-sized lake whitefish were measured (total length in inches) and scales collected to determine age. Other fish were counted and mortality assessed for a report on non-target catch and mortality in trap nets (Schorfhaar and Peck 1993).

Total weights of individual lake whitefish were sampled infrequently during 1983-1989. Individual weights were measured to the nearest 0.01 lb on shore at the Lake Superior Fisheries fish-processing facility in Hancock, Michigan. Numbers of fish weighed were 183 from the middle area in September 1983, 99 from the south area in June 1986, 104 from the north area in October 1986, 102 from the north area in June 1988, and 102 from the south area in June 1989. These weight data were used to determine mean weight of lake whitefish in the catch for all years, and 1983 and 1986 data were used to calculate weight-length relationships.

Age structure of lake whitefish catches were determined by counting annuli on plastic impressions of scales. Growth of lake whitefish was compared among years and among different areas of the fishing ground based mainly on mean total length-at-age. Even though the size limit was changed from 19 inches to 17 inches in 1986, length-at-age was determined for fish 19 inches and larger in 1987-1989 for comparison among all years. Scale and annuli diameter measurements were used to back-calculate lengths at ages prior to capture (Lagler 1956) for lake whitefish in catches sampled in 1983 and 1987. Differences in mean or back-calculated length-at-age were based on non-overlapping 95% confidence intervals. Length-at-age data were used to calculate parameters of the von Bertalanffy growth equation.

Total annual mortality rate (A) was determined from the number of fish in vulnerable age groups (descending limb of the catch curve) using the method described by Robson and Chapman (1961), and from relative abundance of cohorts in successive years of vulnerability to the 19-inch size limit (Ricker 1975). Relative abundance of cohorts was number of fish per trap-net lift, with number derived from annual catches based on age composition and mean weight-at-age in the sampled portion of the catch. Total annual mortality estimated from initial catches of these unexploited lake whitefish in 1983 was considered to be natural mortality.

Results

Fishery

The state-licensed trap net fishery operated May-October in 1983 and 1984, June-October in 1985, 1986, and 1989, and July-October in 1987 and 1988 (Table 1). All areas of the fishing ground were fished during May 1983 and it was found that CPEs in the south area (grids 1219, 1220) were the highest (Figure 1; Table 2). Catches in the south remained good through July, so most fishing was done there during May-July in 1983-1986. No fishing was done in the south in 1987-1988 and little in 1989 (Table 3), probably due to low CPEs in 1986. Highest CPEs during July-October 1983 were in the north area (grids 1023, 1024), so effort was shifted to this area each year during late July and early August. The north area received most fishing effort each year during 1983-1989. The middle area (grids 1121, 1122) received the least effort and was not fished in 1989. The middle area was fished mainly during August as nets were shifted from south to north. Some fishing occurred there most months during July-October despite higher CPEs north possibly because there was not enough room to fish all 10 nets in the north, and nets in the middle area would be en route to nets in either south or north areas and could be easily checked.

Lake whitefish catches in the fishery approached 380,000 lb in 1983 and 1984 then decreased to about 44,000 lb in 1989 (Table 3). The CPEs in all three areas of the fishing ground decreased during 1983-1989. Effort (trap-net lifts) was highest in 1984, decreased during 1985-1988, then increased somewhat in 1989. Since all the permitted trap nets (10) were usually in use throughout the fishing season each year, increased effort in 1984 was due to increased lifting frequency. Number of days nets were fished between lifts increased from 2 to 4 during 1983-1989 in response to decreased CPEs.

Age Composition

Age composition of lake whitefish under a 19-inch size limit changed in all areas of the Upper Entry fishing ground during 1983-1989 (Table 4). Composition changed to older ages during 1983-1985, characterized by a shift in modal age from 9 in 1983-1984 to 10 in 1985 with greater representation by ages 11 and 12. In 1986, modal age decreased to 6 when a strong 1980 year class entered the fishery. The 1980 year class remained modal as age 7 in 1987 and age 8 in 1988, and the 1984 year class was modal in 1989 at age 5. Lake whitefish ages ranged from 4 to 15 most years during 1983-1989, with mean age increasing from 8.5 in 1983 to 9.3 in 1985 then decreasing to 6.4 in 1989. Lake whitefish age composition was different in south and north areas when the fishery commenced in 1983. In June 1983 samples, age 9 was modal (59%) in the south, and age 8 was modal (55%) in the north. Some differences in annual age composition among areas were noted, but none were substantial except in 1985 when older ages were much better represented in the south than in the north and the difference in mean age was significant.

Under the change to a 17-inch size limit in 1986, the 1980 year class was still modal as age 6 in 1986 and age 7 in 1987, but its representation was increased (Table 5). Age 7 (1981 year class) was modal in 1988, and age 6 (1983 year class) was modal in 1989.

Growth in length

Length-at-capture for principal age groups (ages 7-11) of lake whitefish 19 inches and larger decreased during 1983-1986 in both north and south areas of Upper Entry (Table 4; Figure 2). This trend reversed in 1988-1989, with lengths for ages 9-11 in the north in 1988 equal to or greater than lengths for similar groups in 1987. In the south, lengths in 1989 were greater than in 1986 for all but age 9. Length-at-age data were available only for 1983-1985 in the middle area and there were no consistent trends among ages. Length-at-age of lake whitefish in the south was greater than that for lake whitefish in the north during 1983-1986. Comparable data for years after 1986 were not available. Length-at-age in the middle area generally fell between those for the north and the south. Under the 17-inch size limit (Table 5), number of fish in age groups younger than 10 were greater and mean lengths in these age groups were significantly less than for corresponding ages harvested under a 19-inch limit (Table 4). This suggests that lake whitefish were not fully vulnerable to a 19-inch size limit until age 10. Only a little more than 50% of the age-9 fish harvested under the 17-inch limit in 1986 would have been legal under the 19-inch limit.

The decrease in lake whitefish length-at-capture for each age class between 1983 and 1987, and the differences in lake whitefish length-at-age between south and north areas were also evident in length-at-age back-calculated from all age groups (Table 6) and back-calculated from age 9 (Figure 3). Although calculated length at the end of the first year was similar for all samples, lengths at subsequent years of life diverged, with lake whitefish from the south growing faster than those in the north, and growth in the north faster in 1983 under the 19-inch limit than in 1987 under the 17-inch limit. There were no significant differences in calculated lengths-at-age for lake whitefish between May and June samples in the south area in 1983, or between July and October samples in the north area in 1987 (Table 6).

Lake whitefish lengths at ages 7-11 and calculated lengths at ages 1-11 were used to calculate von Bertalanffy growth parameters for fish harvested from the three areas of the Upper Entry fishing ground (Table 7). Growth parameters based on length-at-age for lake whitefish 19 inches and larger from the south and north areas generally exhibited a decrease in L_∞ and increase in K between 1983 and 1986. The L_∞ increased and K decreased in the north in 1987-1988. No trend was evident in growth parameters for lake whitefish from the middle area during 1983-1985. Samples of lake whitefish 17 inches and larger in 1986-1988 had greater L_∞ and lower K growth parameters based on calculated length, and differed from those based on measured length with higher values for L_∞ and t_0, and lower values for K.

Weight

Weight of individual fish in the catch was sampled too infrequently to conclusively show differences among areas or years on the Upper Entry fishing ground. Lake whitefish in a sample from the middle area in June 1983 under the 19-inch size limit had a mean total weight of 3.37 lb and a range of 2.68 to 11.24 lb for ages 5-13. The weight-length relationship was: [Log_n weight (lb) = -8.977 + 3.29 · Log_n length (in)], with R^2 = 0.931 and N = 183. Fish in a sample from the south area in June 1986 under the 19-inch size limit had mean total weight of 2.66 lb and a range of 2.13 to 4.27 lb for ages 4-12. The weight-length relationship was: [Log_n weight (lb) = -7.651 + 2.85 · Log_n length (in)], with R^2 = 0.871 and N = 99. Lake whitefish in a sample from the north area in October 1986 under the 17-inch size limit had a mean total weight of 1.94 lb and a range of 1.50 to 3.41 lb for ages 5-13. The weight-length relationship from this sample was [Log_n weight (lb) = -9.418 + 3.45 · Log_n length (in)], with R^2 = 0.905 and N = 104. Mean weights of lake whitefish in catches sampled in 1988 in the north and 1989 in the south were 2.21 lb and 3.12 lb, respectively.

Mortality rates

Lake whitefish total annual mortality rates estimated by the Robson-Chapman method were highest during the first year of fishing (1983), decreased during 1983-1986, then increased between 1986 and 1989 (Table 8). Total annual mortality (A) estimates in 1983 ranged from 0.72 to 0.80 depending on the area, with a rate of 0.75 for combined areas (Table 8). Total annual mortality estimated from the first catches sampled (May 1983 in the south) were 0.80-0.85. The commercial harvest during 1983-1985 and/or change in year class strength apparently reduced the difference between number of fish in the modal age groups and number in older age groups. This resulted in successively flatter catch curves and mortality rates that decreased from 0.75 to 0.52 during 1983-1986. Mortality estimates increased after 1986 to 0.73 by 1989. Under the 17-inch size limit, total mortality increased from 0.54 in 1986 to 0.66 in 1988, then decreased to 0.59 in 1989. Chi-square values in excess of 3.84 for some estimates indicated that one or more of the assumptions associated with the Robson-Chapman method had been violated. To compensate for possible variations in strength of recruiting year classes (Robson-Chapman assumes constant strength), mortality rates for age 10 and older were estimated for combined 2-year and 3-year sample age distributions under the 19-inch size limit adjusted for sample size. Total mortality rates estimated from these combined samples were 0.73 (1983-1984), 0.70 (1983-1985) and 0.65 (1984-1986) in the south area, and 0.82 (1983-1984), 0.74 (1983-1985), 0.64 (1984-1986), 0.59 (1985-1987), and 0.57 (1986-1988) in the north area.

Lake whitefish total annual mortality rates determined from survival of fully-vulnerable age 10 and older cohorts between successive years during 1983-1988 were lower than Robson-Chapman rates for the first year, but increased and exceeded Robson-Chapman rates by 1986 (Table 9). Abundance data for all areas of the fishing ground were combined because of high variability among areas. Lake whitefish of ages 10 and 11 were fully-vulnerable to the trap nets in all years and provided the most consistent rates which ranged from 0.63 in 1983 to 0.82 in 1987. Mortality rates between older ages were more variable, with rates between ages 11 and 12 ranging from 0.04 to 0.95. The mean total mortality rates for ages 10-15 also increased, with rates slightly less than between ages 10 and 11 during 1983-1986 and slightly higher during 1986-1987.

Discussion

Biomass (CPE = lbs per trap-net lift), age composition, and growth parameters of lake whitefish at Upper Entry during 1983-1989 were certainly those of an unexploited population. Even the lowest trap-net CPEs at Upper Entry were higher than most CPEs reported for exploited lake whitefish on other fishing grounds in Michigan waters of Lake Superior (Rakoczy 1983; MDNR, Marquette Fisheries Station, unpublished data). Total annual catch at Upper Entry during 1983-1986 was more than double the highest previously reported annual catch for this statistical district (Baldwin et al. 1979). Modal age and mean age were greater and growth (mean length-at-age) was less for Upper Entry lake whitefish than for exploited lake whitefish on the other fishing grounds in Michigan waters of Lake Superior (Rakoczy 1983; MDNR, Marquette Fisheries Station, unpublished data). Lake whitefish from Upper Entry had a similar mean age but slower growth than lightly-exploited lake whitefish populations at Isle Royale (Koziol 1982). Mean total length-at-age was less at Upper Entry than for most North American populations reported by Carlander (1969). Fishing at Upper Entry during 1983-1986 resulted in even slower growth as faster growing members of the initial unexploited population were selectively harvested. This was indicated by decreased mean length-at-age and trends in von Bertalanffy growth parameters (Ricker 1975).

Differences in age composition and back-calculated length-at-age for lake whitefish between south and north areas of the Upper Entry fishing ground in June 1983 indicated that fish in these areas were two separate stocks. Population parameters are acceptable for identification of sympatric fish stocks (Booke 1981, Ihssen et al. 1981), and have been used in other studies to identify lake whitefish stocks. Age composition and growth were used to separate stocks in Lake Superior

(Dryer 1962, Koziol 1982) and Lake Huron (Casselman et al. 1981). Although lake whitefish from the south and north areas weredifferent stocks in terms of population parameters, they may originate from a common spawning stock. The only known lake whitefish spawning ground west of the Keweenaw Peninsula is in the north area of Upper Entry fishing ground at Eagle River Shoals (Organ et al. 1978). Forty percent of lake whitefish tagged at Eagle River Shoals by Ebener (1990) were recaptured in the north area (within 10 miles of Eagle River Shoals), but an equal number had moved southwest and were recaptured on the middle and south areas. It is very likely that additional lake whitefish spawning grounds exist south of Eagle River Shoals. Organ et al. (1978) used mainly commercial-fisher sources to identify spawning grounds and few of these were probably available west of the Keweenaw Peninsula because there had been no commercial fishery there since 1959.

Total annual mortality rates estimated by the cohort-abundance method were more likely than Robson-Chapman estimates to approximate true rates for lake whitefish at Upper Entry because the former rates behaved appropriately (increased with the advent of fishing) and were independent of variations in year-class strength. Although Robson-Chapman estimates for the first year of fishing (1983) should be valid, estimates for subsequent years were not because assumptions for this method were violated. Increased fishing during 1983 and 1984 followed by decreased fishing the remainder of the period would certainly result in different survival rates among vulnerable cohorts, and age composition data indicated that strength of recruiting year classes was not constant among years, especially after 1985. Although 2-year and 3-year combined age compositions may have reduced the effect of variable recruitment, they apparently did not offset the effect of fishery intensification, which resulted in progressively flatter catch curves and lower mortality estimates.

Total annual mortality rates estimated from trap-net catches were higher than rates for other lake whitefish populations in Michigan waters of Lake Superior. Koziol (1982) reported total mortality rates of 0.51 and 0.56 for lightly exploited lake whitefish populations at Isle Royale. Rakoczy (1983) reported total mortality rates of 0.35-0.57 from trap-net catches of exploited lake whitefish populations in Lake Superior during 1977-1980, and rates for these same populations during 1983-1989 were 0.28-0.49 (MDNR, Marquette Fisheries Station, unpublished data). Total annual mortality rates were higher at Upper Entry because they were estimated from age groups older than those used to estimate mortality elsewhere in Lake Superior. Slow growth and a 19-inch size limit at Upper Entry resulted in age at full vulnerability (age 10) being within a few years of maximum age for lake whitefish in Lake Superior. Although lake whitefish as old as 15 years were found, few lake whitefish at Upper Entry were older than age 12. Lake whitefish as old as ages 16-20 have been found in other populations in Michigan waters of Lake Superior during 1983-1989, but the numbers in these age groups generally made up less than 5% of the catch (MDNR, Marquette Fisheries Station, unpublished data). As a consequence, mortality was estimated for age groups whose few members were dying of old age.

The "prized rarity" of an estimate of natural mortality on an unexploited lake whitefish population was obtained. Total mortality rates of 80-85% determined by the Robson-Chapman method for initial catches at Upper Entry were natural mortality rates. These rates were 2-4 times higher than natural mortality reported for other exploited and unexploited populations for some of the same reasons that total annual mortality rates were higher. Natural mortality of unexploited lake whitefish populations in Lake Huron and Lake Michigan was reported to be 34-36% (Cucin and Regier 1965, Rybicki 1980). Rakoczy (1983) believed that annual natural mortality rates for exploited lake whitefish populations in Michigan waters of Lake Superior were 20-25%. Natural mortality averaged only about 18% in a slow growing unexploited Canadian inland lake population (Ricker 1949). Natural mortality estimates from the above Great Lakes studies were for younger age groups, which would explain their being lower than at Upper Entry. Estimates from the Canadian inland lake were for ages as old or older than at Upper Entry, but this was an exceptionally slow-growing, long-lived population with good numbers in age groups up to age 22 and fish as old as age 27 in the population. No mortality factor other than old age could be identified as responsible for the high natural mortality rates at Upper Entry estimated from initial catches in 1983. Sea lamprey *Petromyzon marinus* abundance (based on lake trout wounding at Upper Entry during the 1980s) was less than much of the remainder of Michigan waters (Peck and Schorfhaar 1991) where lake whitefish natural mortality was considerably lower. A more representative estimate of natural mortality at Upper Entry may have been obtained had the initial fishing been done with smaller mesh nets to sample a younger range of age groups.

Effects of the trap-net fishery on the previously unexploited lake whitefish population could not be determined because they were not readily distinguishable from those induced by the tribal gill-net fishery which began in 1984. Total gill-net effort on Upper Entry fishing ground was around 500,000 ft in 1984, peaked at just over 2,900,000 ft in 1986, then decreased to about 1,600,000 ft in 1989 (Ebener and Bronte 1986, Ebener and Bronte 1987, Ebener et al. 1989, Ebener et al. 1990). Catch in the gill-net fishery exceeded that in the trap-net fishery after 1984. Gill-net CPEs decreased steadily during 1984-1987 as they did in the trap-net fishery, but increased slightly in 1988-1989. Combined catch in the two fisheries decreased from 470,000 lb in 1984 to 178,000 lb in 1989. The trap-net fishery should have had less effect considering that the size limit (19-inch) was higher the first 4 years of fishing (1983-1986) and trap nets were restricted to depths of 90 ft and shallower. That the two fisheries had a definite effect on lake whitefish biomass was evidenced by decreased CPEs, changes in age composition and growth, and increased mortality.

The contemporary lake whitefish population on the Upper Entry fishing ground survived its initial exposure to exploitation. The combined state-licensed and tribal commercial fisheries substantially reduced lake whitefish biomass but they did not bring about the demise of lake whitefish on the Upper Entry ground. Even the lowest CPEs at Upper Entry were higher than those on other traditionally exploited fishing grounds in Lake Superior, and apparently strong lake whitefish year classes were recruiting to the Upper Entry fishery in 1986-1989. Mortality rates exceeded the 0.70 maximum level suggested by Clark (1984) for Lake Michigan stocks, but this maximum level was based on much younger age groups and likely does not apply to age groups at Upper Entry. Lake whitefish fisheries have persisted in areas of Lake Michigan where mortalities have exceeded the 0.70 level (Rybicki and Schneeberger 1990), enhancing the reputation of lake whitefish as the most exploitable species in the Great Lakes. Commercial fisheries at Upper Entry responded appropriately to decreased CPEs at Upper Entry by reducing fishing effort, but there is no guarantee that future responses will be as appropriate. Since the State of Michigan no longer has complete control over total fishing effort applied to lake whitefish on the Upper Entry fishing ground, it is recommended that more representative estimates of mortality be obtained, that harvest be regulated with quotas estimated from growth and mortality parameters, and that allocation of these quotas between state-licensed and tribal commercial fishers be negotiated.

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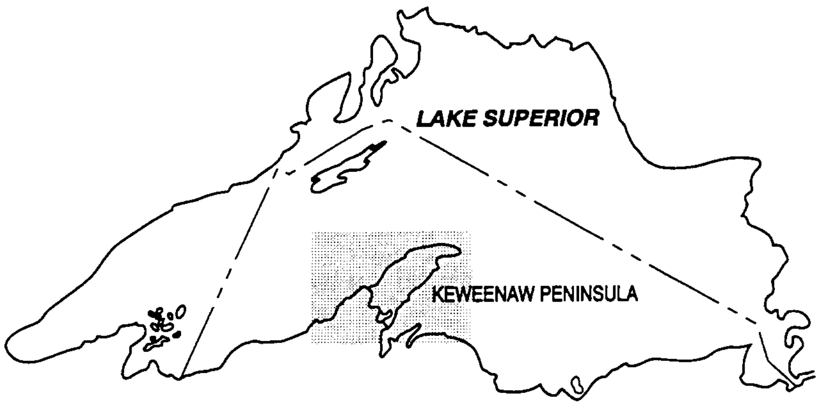

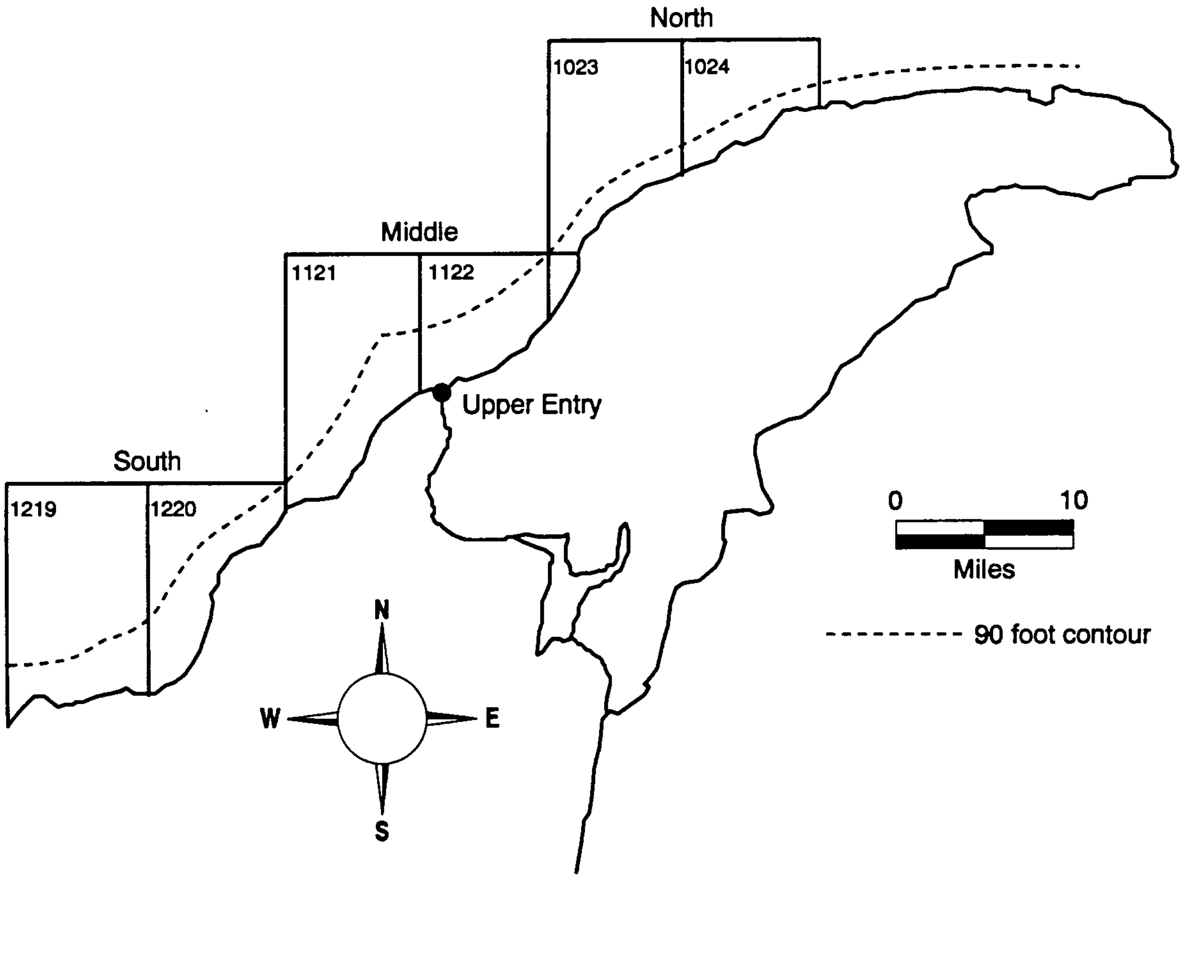

Figure 1.—Areas and inclusive grids of the Upper Entry fishing ground in Michigan waters of Lake Superior, 1983-1989.

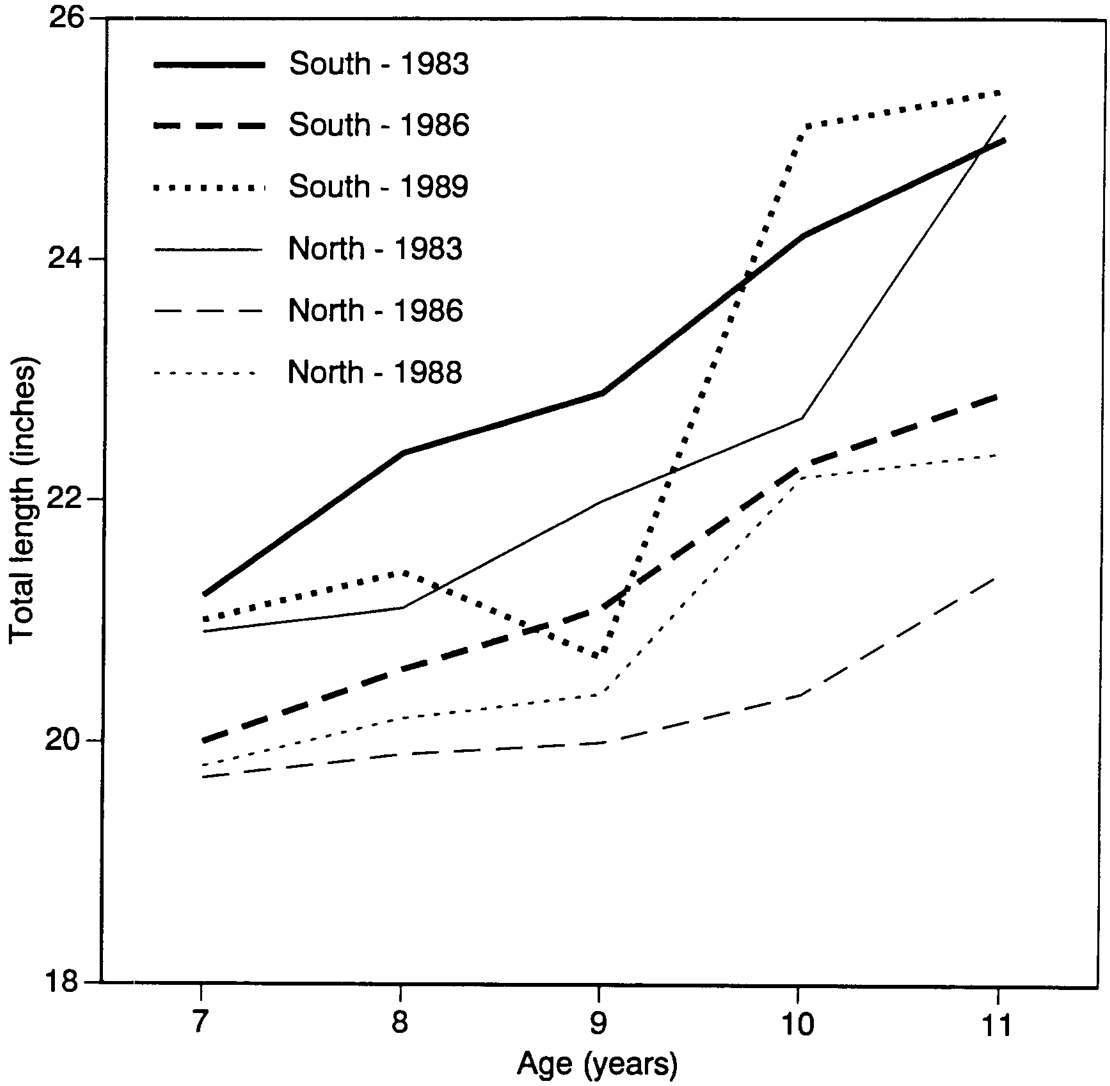

Figure 2.—Mean total length at capture for each age of lake whitefish from south (grids 1219, 1220) and north (grids 1023, 1024) areas of the Upper Entry fishing ground in Michigan waters of Lake Superior, 1983-1989.

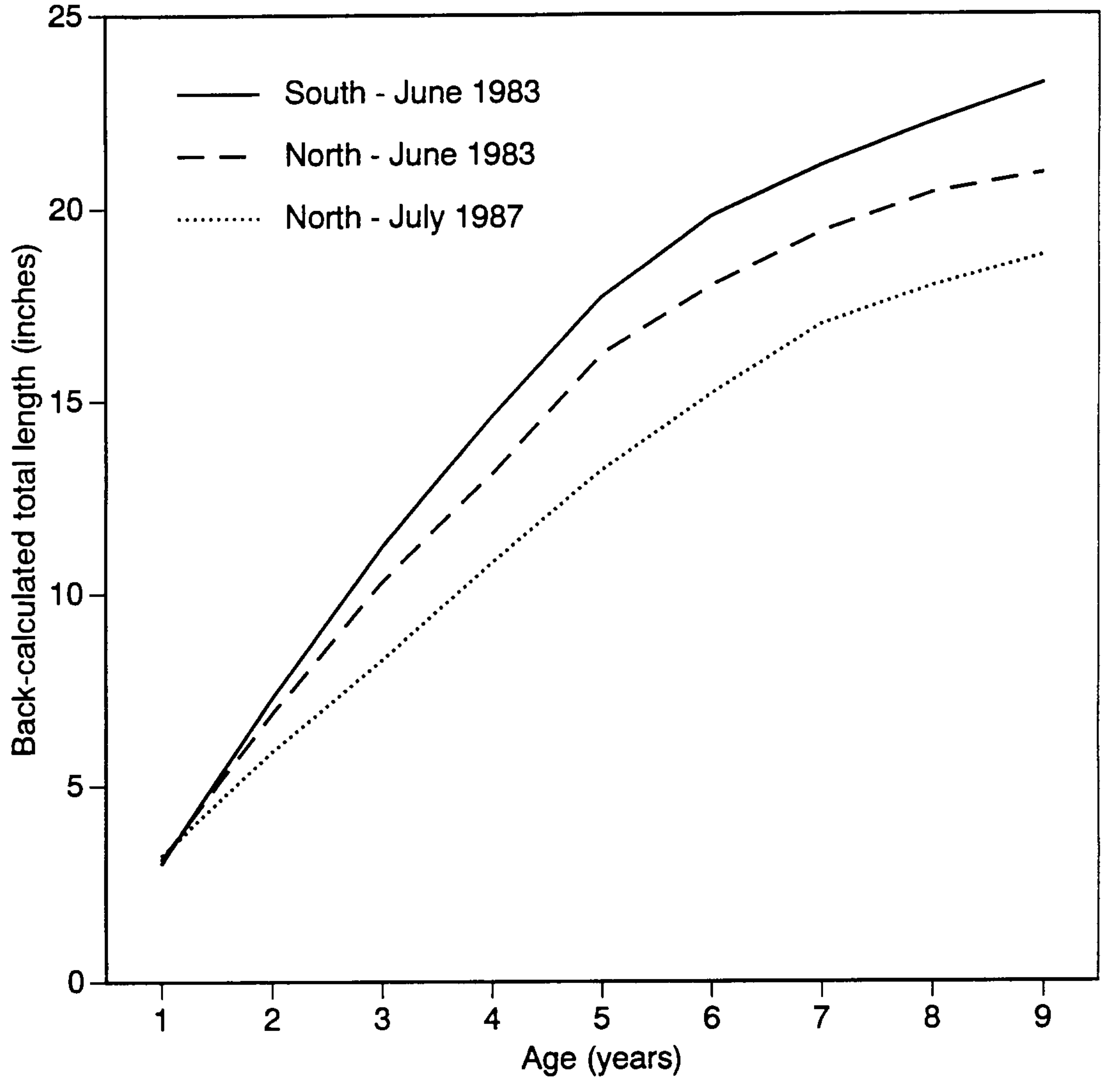

Figure 3.—Mean total length-at-age back-calculated from age-9 lake whitefish from the south (grids 1219, 1220) and north (grids 1023, 1024) areas of the Upper Entry fishing ground in Michigan waters of Lake Superior, June 1983 and July 1987.

Table 1.– Sampling effort for the state-licensed commercial fishery for lake whitefish in the Upper Entry fishing ground in Michigan waters of Lake Superior, 1983-1989.

Year	Months		Days sampled	Trap-net lifts	
	Fished	Sampled		Total	Number and percent sampled
1983	May-Oct	May-Oct	9	546	55 (10)
1984	May-Oct	May-Oct	11	716	76 (11)
1985	Jun-Oct	Jun-Oct	7	440	51 (12)
1986	Jun-Oct	Jun-Oct	7	367	54 (15)
1987	Jul-Oct	Jul-Oct	7	234	54 (23)
1988	Jul-Oct	Jul-Aug	4	210	30 (14)
1989	Jun-Oct	Jun	4	277	40 (14)
Total			49	2,790	360 (13)

Table 2.–Distribution of fishing effort (number of trap-net lifts with percent of total lifts in parentheses) and CPE (pounds dressed weight per trap-net lift) by month and year in areas of the Upper Entry fishing ground in Lake Superior, 1983-1987.

Area[a]	Year		Months May	Jun	Jul	Aug	Sep	Oct	Total
South	1983	Effort	38(13)	140(50)	76(27)	23(8)	6(2)	0	283
		CPE	648±247	688±129	408±83	146±42	134±66	-	552±77
	1984	Effort	77(23)	168(51)	83(25)	1(<1)	0	0	329
		CPE	323±41	293±42	635±104	80	-	386±38	
	1985	Effort	0	130(66)	66(34)	0	0	0	±196
		CPE	-	307±40	234±31	-	-	-	282±29
	1986	Effort	0	76(75)	25(25)	0	0	0	101
		CPE	-	98±11	59±18	-	-	-	88±10
	1987	Effort	0	0	0	0	0	0	0
		CPE	-	-	-	-	-	-	-
Middle	1983	Effort	3(10)	0	6(20)	21(70)	0	0	30
		CPE	42±53	-	357±341	375±252	-	-	338±109
	1984	Effort	0	0	13(7)	115(68)	37(22)	5(3)	170
		CPE	-	-	442±166	489±43	473±163	13±14	468±47
	1985	Effort	0	0	17(20)	48(56)	20(24)	0	85
		CPE	-	-	599±176	114±47	135±40	-	216±59
	1986	Effort	0	0	6(27)	12(55)	4(18)	0	22
		CPE	-	-	10±4	324±266	282±216	-	231±150
	1987	Effort	0	0	14(30)	14(30)	9(19)	10(21)	47
		CPE	-	-	149±45	136±58	158±167	246±198	167±50
North	1983	Effort	4(2)	12(5)	19(8)	57(24)	35(15)	106(45)	233
		CPE	53±24	631±438	1,523±459	780±152	572±287	1,030±402	903±1
	1984	Effort	0	0	15(7)	69(32)	54(25)	79(36)	217
		CPE	-	-	642±226	618±102	987±237	885±129	796±85
	1985	Effort	0	0	0	47(30)	95(60)	17(10)	159
		CPE	-	-	-	394±104	471±33	753±139	478±42
	1986	Effort	0	0	23(10)	40(16)	64(26)	117(48)	244
		CPE	-	-	163±59	291±55	388±56	430±58	371±34
	1987	Effort	0	0	33(17)	37(20)	39(21)	78(42)	187
		CPE	-	-	217±39	266±44	519±127	401±43	366±36

[a]South = grids 1219, 1220; Middle = grids 1121, 1122; North = grids 1023, 1024.

Table 3.–Commercial catch (pounds dressed weight), CPE, and effort expended for lake whitefish in state-licensed trap-nets in the areas of the Upper Entry fishing ground in Michigan waters of Lake Superior, 1983-1989.

Year	Area[a]	State-licensed trap nets		
		Catch	CPE[b]	Effort[c]
1983				
	South	156,223	552±77	283
	Middle	10,147	338±109	30
	North	210,365	903±108	233
	Total	376,735	690±63	546
1984				
	South	127,203	386±38	329
	Middle	79,477	468±47	170
	North	172,861	796±85	217
	Total	379,541	530±24	716
1985				
	South	55,365	282±29	196
	Middle	18,385	216±59	85
	North	76,060	478±42	159
	Total	149,810	340±25	440
1986				
	South	8,890	88±10	101
	Middle	5,085	231±150	22
	North	90,533	371±34	244
	Total	104,508	285±28	367
1987				
	South	0	-	0
	Middle	7,871	167±50	47
	North	68,491	366±36	187
	Total	76,362	326±32	234
1988				
	South	0	-	0
	Middle	990	50	20
	North	53,103	279	190
	Total	54,093	258	210
1989				
	South	17,686	100	177
	Middle	0	-	0
	North	25,943	265	98
	Total	43,629	159	275

[a]South = grids 1219, 1220; Middle = grids 1121, 1122; North = grids 1023, 1024.
[b]CPE is dressed pounds per trap-net lift.
[c]Effort is number of nets lifted.

Table 4.–Age composition (number) and mean total length-at-capture (inches ± 95% confidence intervals) for lake whitefish 19 inches and larger sampled in the commercial trap-net fishery in areas of the Upper Entry fishing ground in Michigan waters of Lake Superior, 1983-1989.

			Age												Overall mean	
Year	Area[a]	Variable	4	5	6	7	8	9	10	11	12	13	14	15	Length	Age
1983	South	Number	0	1	14	29	43	89	18	2	0	0	0	1	197	197
		Total length	-	22.1	20.6	21.2	22.4	22.9	24.2	25	-	-	-	29.5	22.6	8.4
		±95%CI	-	-	0.5	0.4	0.3	0.2	0.8	24.1	-	-	-	-	0.3	0.2
	Middle	Number	0	4	7	35	85	112	34	4	3	1	1	0	286	286
		Total length	-	22.9	20.8	21.2	21.5	22.4	23.3	24.5	27.4	30.6	28.6	-	22.2	8.5
		±95%CI	-	1.4	1	0.6	0.3	0.3	0.5	5.1	3.9	-	-	-	0.2	0.1
	North	Number	0	5	7	50	135	135	47	3	2	0	0	0	384	384
		Total length	-	20.8	20.8	20.9	21.1	22	22.7	25.2	27.1	-	-	-	21.6	8.4
		±95%CI	-	1.7	2.2	0.3	0.2	0.2	0.5	0.3	0	-	-	-	0.2	0.1
	Total	Number	0	10	28	114	263	336	99	9	5	1	1	1	867	867
		Total length	-	21.8	20.7	21.1	21.4	22.4	23.2	24.9	27.3	30.6	28.6	29.5	22	8.5
		±95%CI	-	1	0.5	0.2	0.1	0.1	0.3	1.7	1.4	-	-	-	0.1	0.1
1984	South	Number	1	0	14	22	40	110	79	15	5	2	1	1	290	290
		Total length	20	-	21.1	21.4	22.7	23.1	23.6	25.3	26.1	22.6	26.9	30.3	23.2	9
		±95%CI	-	-	0.9	0.5	0.3	0.2	0.2	1.1	2.6	0	-	-	0.2	0.2
	Middle	Number	0	0	13	12	16	36	18	6	2	1	0	0	104	104
		Total length	-	-	20.8	21.6	22.2	22.5	23.1	23.4	25.2	28.5	-	-	22.4	8.6
		±95%CI	-	-	1.6	1.4	0.8	0.4	0.4	1.6	17.8	-	-	-	0.3	0.3

Table 4.–Continued.

Year	Area[a]	Variable	Age												Overall mean	
			4	5	6	7	8	9	10	11	12	13	14	15	Length	Age
1984	North	Number	0	1	6	19	48	60	49	14	1	0	0	0	198	198
		Total length	-	19.2	20.5	21.3	21.2	21.8	22.5	22.8	25.3	-	-	-	21.8	8.8
		±95%CI	-	-	1.5	0.6	0.4	0.4	0.5	1	-	-	-	-	0.2	0.2
	Total	Number	1	1	33	53	104	206	146	35	8	3	1	1	592	592
		Total length	20	19.2	20.9	21.4	21.9	22.6	23.2	24	25.8	24.6	26.9	30.3	22.6	8.9
		±95%CI	-	-	0.7	0.4	0.3	0.2	0.2	0.7	1.5	8.5	-	-	0.2	0.1
1985	South	Number	1	1	1	22	18	19	63	35	7	1	0	0	168	168
		Total length	19	20.8	20.2	20.7	21.2	22.3	23.4	23.7	24	24.2	-	-	22.7	9.5
		±95%CI	-	-	-	0.6	0.5	0.5	0.3	0.3	0.4	-	-	-	0.2	0.2
	Middle	Number	1	1	1	25	27	43	67	26	10	2	0	0	203	203
		Total length	20	19	21.2	20.4	20.8	22.7	23.2	23.2	25	27.5	-	-	22.5	9.3
		±95%CI	-	-	-	0.3	0.4	0.3	0.2	0.7	1.4	30.3	-	-	0.2	0.2
	North	Number	0	5	3	11	26	51	33	11	9	0	0	0	149	149
		Total length	-	19.9	21.3	19.8	21.1	21.3	22.2	23.6	24.8	-	-	-	21.7	9
		±95%CI	-	1	3.6	0.3	0.5	0.3	0.4	1.2	1.4	-	-	-	0.3	0.2
	Total	Number	2	7	5	58	71	113	163	72	26	3	0	0	520	520
		Total length	19.5	19.9	21.1	20.4	21	22	23.1	23.5	24.6	26.4	-	-	22.3	9.3
		±95%CI	6.4	0.8	1.4	0.3	0.3	0.2	0.2	0.3	0.6	7.6	-	-	0.1	0.1

Table 4.–Continued.

Year	Area[a]	Variable	Age 4	5	6	7	8	9	10	11	12	13	14	15	Overall mean Length	Overall mean Age
1986	South	Number	2	19	57	33	27	22	25	22	13	1	1	0	222	222
		Total length	19.3	20.4	20	20	20.6	21.1	22.3	22.9	23.9	24.5	25.8	-	21	8
		±95%CI	1.3	0.6	0.2	0.2	0.3	0.4	0.6	0.6	0.7	-	-	-	0.2	0.3
	North	Number	0	1	28	20	16	28	17	12	8	3	0	0	133	133
		Total length	-	21	19.9	19.7	19.9	20	20.4	21.4	23.2	22.4	-	-	20.4	8.5
		±95%CI	-	-	0.3	0.3	0.4	0.5	0.4	0.7	1.6	1.7	-	-	0.3	0.3
	Total	Number	2	20	85	53	43	50	42	34	21	4	1	0	355	355
		Total length	19.3	20.4	20	19.9	20.4	20.5	21.5	22.3	23.7	23	25.8	-	20.8	8.2
		±95%CI	1.3	0.5	0.2	0.2	0.3	0.4	0.4	0.4	0.7	1.9	-	-	0.2	0.2
1987	North	Number	1	3	17	183	63	43	30	16	2	2	1	0	361	361
		Total length	20.3	20.9	20.7	19.7	19.9	19.9	20.5	21.6	25.2	25.9	27.4	-	20.1	7.8
		±95%CI	-	3.7	0.9	0.1	0.3	0.3	0.5	1.2	38.8	15.3	-	-	0.2	0.1
1988	North	Number	1	8	55	84	33	16	4	1	1	0	0	0	203	203
		Total length	20.1	19.4	19.6	19.8	20.2	20.4	22.2	22.4	23	-	-	-	19.9	8
		±95%CI	0.4	0.3	0.1	0.2	0.3	0.5	2.4	-	-	-	-	-	0.2	0.1
1989	South	Number	3	106	73	44	36	30	4	1	1	0	0	0	298	298
		Total length	20	21.2	20.5	21	21.4	20.7	25.1	25.4	30.6	-	-	-	21.1	6.4
		±95%CI	0.3	0.2	0.3	0.4	0.6	0.2	5.7	-	-	-	-	-	0.2	0.2

[a]South = grids 1219, 1220; Middle = grids 1121, 1122; North = grids 1023, 1024.

Table 5.–Age composition (number) and mean total length (inches ± 95% confidence intervals) for each age of lake whitefish 17 inches and larger sampled in the commercial trap-net fishery in areas of the Upper Entry fishing ground in Michigan waters of Lake Superior, 1986-1989.

Year, area[a]	Age												Overall mean	
and variable	4	5	6	7	8	9	10	11	12	13	14	15	Length	Age
1986														
North														
Number	5	215	71	74	54	20	12	9	3	0	0	0	463	463
Total length	18.3	18.2	18.5	18.4	19.1	20.1	21.4	22.7	22.4	-	-	-	18.7	7.3
±95% CI	1.9	0.1	0.3	0.2	0.3	0.5	0.7	1.8	1.7	-	-	-	0.1	0.1
1987														
North														
Number	2	3	45	388	119	68	39	18	2	2	1	0	687	687
Total length	19	20.9	18.9	18.9	19.1	19.3	20.1	21.3	25.2	25.9	27.4	-	19.2	7.6
±95% CI	16.5	3.7	1	0.1	0.2	0.2	0.5	1.1	38.8	15.2	-	-	0.1	0.1
1988														
North														
Number	2	43	125	115	40	16	4	1	1	0	0	0	347	347
Total length	18.7	17.8	19	19.4	20	20.4	22.2	22.4	23	-	-	-	19.1	7.6
±95% CI	18.5	0.3	0	0.2	0	0.4	2.4	-	-	-	-	-	0.1	0.1
1989														
South														
Number	4	126	129	48	36	31	4	1	1	0	0	0	380	380
Total length	19.3	20.7	19.4	20.8	21.4	20.6	25.1	25.4	30.6	-	-	-	20.4	6.3
±95% CI	1.2	0.3	0.3	0.5	0.6	0.3	5.7	-	-	-	-	-	0.2	0.1

[a]South = grids 1219, 1220; Middle = grids 1121, 1122; North = grids 1023, 1024.

Table 6.– Back-calculated total length (inches ± 95% confidence intervals) for each age of lake whitefish sampled in the commercial trap-net fishery in areas of the Upper Entry fishing ground in Michigan waters of Lake Superior, 1983 and 1987.

Year[a]	Area[b]	Month	Number of fish	Age 1	2	3	4	5	6	7	8	9	10	11	12
1983															
	South	May	44	3.3	7.4	11.2	14.5	17.6	19.7	21	22	23	22.4	-	-
				±0.2	±0.3	±0.4	±0.5	±0.4	±0.4	±0.3	±0.3	±0.4	±5.0	-	-
		June	46	3	7.3	11.2	14.6	17.7	19.8	21.1	22.2	23.2	24.7	26.1	-
				±0.1	±0.3	±0.4	±0.4	±0.4	±0.3	±0.3	±0.3	±0.4	±0.9	±10.0	-
	North	June	44	3.1	6.9	10.3	13.1	16.2	18	19.4	20.4	20.9	21.4	-	-
				±0.1	±0.2	±0.4	±0.4	±0.4	±0.4	±0.3	±0.4	±0.7	±3.1	-	-
1987															
	North	July	138	3.2	5.9	8.3	10.8	13.2	15.2	17	18	18.8	19.5	19.9	21.2
				±0.1	±0.2	±0.2	±0.3	±0.4	±0.4	±0.3	±0.3	±0.4	±0.6	±5.0	±11.3
		October	87	3.1	5.9	8.5	11.1	13.7	16	17.6	18.6	19.4	20.7	21.8	24.2
				±0.1	±0.2	±0.2	±0.3	±0.4	±0.4	±0.4	±0.5	±0.9	±1.7	±6.6	-

[a]Catches in 1983 were under a 19-in size limit and those in 1987 were under a 17-in size limit.
[b]South = grids 1219, 1220; Middle = grids 1121, 1122; North = grids 1023, 1024.

Table 7.--Von Bertalanffy growth parameters calculated for lake whitefish ages 7-11 sampled in the commercial trap-net fishery in areas of the Upper Entry fishing ground in Michigan waters of Lake Superior, 1983-1988. Size limits listed in parentheses.

Year	Area[a]	L_∞ (in)	K	t_0	R^2
		From sampled lengths			
1983 (≥19 in)	South	27.9	0.2012	-0.0008	0.999
	Middle	26.5	0.2179	-0.0017	0.996
	North	28.1	0.1799	-0.0045	0.985
	Total	27.4	0.1973	-0.0026	0.993
1984 (≥19 in)	South	27.3	0.2165	-0.0010	0.996
	Middle	24.0	0.3248	-0.0001	1.000
	North	23.2	0.3316	-0.0004	0.998
	Total	25.1	0.2637	-0.0006	0.999
1985 (≥19 in)	South	26.1	0.2186	-0.0006	0.998
	Middle	25.8	0.2204	-0.0003	0.996
	North	25.9	0.2032	-0.0012	0.996
	Total	25.9	0.2144	-0.0007	0.999
1986	South (≥19 in)	24.7	0.2281	-0.0010	0.998
	Middle (≥19 in)	20.5	0.4551	-0.0001	1.000
	North (≥17 in)	23.1	0.2124	-0.0029	0.996
	Total	23.1	0.2686	-0.0009	0.996
1987	North (≥19 in)	21.7	0.3193	-0.0007	0.994
	North (≥17 in)	21.9	0.2629	-0.0014	0.993
1988	North (≥19 in)	22.6	0.2700	-0.0014	0.990
	North (≥17 in)	24.0	0.2060	-0.0022	0.993
		From back-calculated length-at-age			
1983 (≥19 in)	South	31.4	0.1604	-0.1722	0.995
	North	26.6	0.1813	-0.1604	0.994
1987 (≥17 in)	North	27.4	0.1316	-0.0703	0.997

[a]South = grids 1219, 1220, Middle = grids 1121, 1122, North = grids 1023, 1024.

Table 8.–Total mortality rates estimated using the method described by Robson and Chapman (1961) for numbers of lake whitefish in vulnerable age groups sampled in the commercial trap-net fishery in areas of the Upper Entry fishing ground in Michigan waters of Lake Superior, 1983-1989. Size limits listed in parenthesis.

			Total mortality		
Year	Area[a]	Age groups[b]	Annual (A)	Instantaneous (Z)	Chi square[c]
1983 (≥19 in)	South	9-15	0.80	1.59	0.59
	Middle	9-14	0.72	0.27	0.02
	North	9-12	0.76	1.42	5.81
	Total	9-15	0.75	1.40	1.15
1984 (≥19 in)	South	10-15	0.73	1.54	3.43
	Middle	10-13	0.67	1.10	0.00
	North	10-12	0.80	1.60	1.91
	Total	10-15	0.74	1.33	0.95
1985 (≥19 in)	South	10-13	0.67	1.10	7.81
	Middle	10-13	0.67	1.10	1.13
	North	10-12	0.64	1.03	0.23
	Total	10-13	0.66	1.09	7.61
1986	South (≥19 in)	10-14	0.53	0.75	7.57
	North (≥19 in)	10-13	0.51	0.72	2.40
	North (≥17 in)	9-13	0.54	0.77	0.12
	Total	10-14	0.52	0.74	10.41
1987	North (≥19 in)	10-14	0.62	0.98	0.75
	North (≥17 in)	9-14	0.58	0.86	3.81
1988	North (≥19 in)	10-13	0.70	1.20	0.23
	North (≥17 in)	9-13	0.66	1.09	0.25
1989	South (≥19 in)	9-15	0.73	1.31	6.80
	South (≥17 in)	9-15	0.73	1.31	7.10

[a]South = grids 1219, 1220; Middle = grids 1121, 1122; North = grids 1023, 1024.
[b]Numbers of fish in age groups are presented in Tables 4 and 5.
[c]Chi square in excess of 3.84 indicates inconsistent year-class strength, survival, or vulnerability to the trap nets (Robson and Chapman 1961).

Table 9.–Lake whitefish total mortality rates (A) from cohort survival (A=1-S) during successive years of vulnerability to a 19-inch minimum size limit in trap nets on the Upper Entry fishing ground in Michigan waters of Lake Superior, 1983-1989.

Age[a]	1983 CPE[b]	A	1984 CPE	A	1985 CPE	A	1986 CPE	A	1987 CPE	A	1988 CPE
9	92.04		58.76		34.20		16.69		11.11		11.60
		0.55		0.40		0.42		0.54		0.49	
10	27.12		41.68		35.11		14.02		7.63		5.62
		0.63		**0.63**		**0.68**		**0.70**		**0.82**	
11	2.40		10.00		15.51		11.29		4.14		1.40
		0.04		0.44		0.55		0.95		0.92	
12	1.42		2.30		5.59		7.00		0.53		0.34
		0.37		0.71		0.75		0.92		0.33	
13	0.24		0.90		0.66		1.38		0.53		0.36
		(0.17)				0.47		0.80			
14	0.30		0.29				0.35		0.27		
		0.07									
15	0.28		0.28								
10-15 mean[c]		0.57		0.61		0.65		0.84		0.84	

[a]Ages fully vulnerable to the 19-in limit determined to be age 10 and older.
[b]All CPEs = number of fish per trap-net lift determined from sample weight-at-age distribution applied to total catch.
[c]Geometric mean.

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