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RECENT HISTORY AND MANAGEMENT OF THE STATE-LICENSED COMMERCIAL FISHERY FOR LAKE WHITEFISH IN THE MICHIGAN WATERS OF LAKE MICHIGAN[1]

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Abstract.—Over the past 20 years, a restructuring of the commercial fishing industry on Michigan's upper Great Lakes has resulted from a shift in the state's Great Lakes management policy. The state's policy stresses recreational rather than commercial fishing, implementation of limited entry, delineation of zone management, an effort to rehabilitate lake trout (*Salvelinus namaycush*), which entailed conversion from traditional gill nets to trap nets, and litigation by tribal entities.

Catch and effort data, reported obligatorily by commercial fishermen and supplemented by seasonal age and size data collected by the state, have allowed calculation of mortality, age distribution, growth, and catch quotas for lake whitefish (*Coregonus clupeaformis*). Trends in commercial yield during the 1980s show peak whitefish catches around 1985 in management zones WFM00 and WFM01, followed by decreasing harvests through 1988. Catches have been higher in zones WFM06 and WFM08 during the last few years than earlier in the decade.

Annual total mortality rates during 1983-88 were high for whitefish stocks in management units WFM00 (0.77-0.88) and WFM01 (0.73-0.86), but they were low in units WFM06 (0.45-0.51) and WFM08 (0.45-0.48). Whitefish stocks in zones WFM00 and WFM01 have sustained themselves at some level short of collapse despite high total mortality rates. Apparently collapse has been averted because an adequate spawning biomass composed of large, older whitefish was distributed in depths unavailable to trap nets for much of the fishing season, and because conditions in northern Green Bay have been consistently favorable for whitefish reproduction. Age distribution in landed catches was dependent on time of year and gear. Whitefish catches in zones WFM06 and WFM08 included larger proportions of older fish, and fish larger than 500 mm were significantly heavier when compared to catches of fish from the two northern zones.

Yields were simulated under minimum size limits (MSL) of 432 mm, 457 mm, and 483 mm in each management unit. The balance between the costs and benefits of various MSLs cannot be adequately evaluated without field testing. Contradictions between calculated catch quotas and reported yields may exist due to the use of 3-year averages for parameters used in models.

A summary of management observations and recommendations for Lake Michigan whitefish contained in this report includes: (1) commercial catches should continue to be sampled during May, July, and October in all zones except WFM06, which requires only May sampling unless fall fishing resumes; (2) zone WFM07 has the potential to support a modest harvest should interest arise, and exploitation of stocks in WFM06 and WFM08 has potential to expand; (3) the maximum trap-net depth restriction should be retained at 27 m; (4) the indiscriminate expansion of the trawl fishery should not be allowed; (5) target annual total mortality rates should be set at 65% and target instantaneous fishing rate should be 0.60; (6) the fisheries in zones WFM06 and WFM08 are suitable for experimental study sites to test effects of implementing different MSLs, and changing the MSL in zones WFM00 and WFM01 should be deferred until such field studies are complete; (7) an index of pre-recruit whitefish, accurate knowledge of age structure of the catch, and reliable reporting of catch and effort are important for forecasting yield; and (8) stocks in zones WFM00 and WFM01 should be managed jointly by Michigan and Wisconsin.

The state-licensed commercial fishing industry on the upper Great Lakes has been subjected to several revolutionary transformations that began in 1966. The impact of these transformations, which occurred over a period of approximately 20 years, was to reduce the number of state-controlled commercial fishing licenses on Lake Michigan from 405 in 1967 to 30 in 1987. The restructuring of the commercial fishery was the result of a change in Great Lakes management policy, limited entry, zone management, conversion from traditional gill nets to trap nets, and the displacement of state-licensed commercial fishermen from areas of the lake allocated for exclusive use by Indians fishing under treaty rights.

The purposes of this report are to: (1) describe briefly the events leading to the restructuring of the fishery and management of lake whitefish (*Coregonus clupeaformis*) stocks by catch quota; (2) document the biological data and commercial catch statistics that were used in the setting of quotas; and (3) present the yearly catch quotas from 1986 through 1989.

Recent History and Study Perspective

Restructuring of the Fishery

In 1966, the Michigan Department of Natural Resources (MDNR) established a Great Lakes fishery management policy which made recreational fishery management the primary goal and relegated the heretofore dominant commercial fishery to a secondary role (Keller and Smith 1989). Thus the essential framework, upon which subsequent management decisions would be based, was in place.

Limited entry was implemented on all of Michigan's waters of the upper three Great Lakes in 1969. The purposes of limiting entry to the commercial fishery were to: (1) preserve, protect, and enhance the fishery resource itself; (2) make the commercial fishery an asset that contributes to the public good rather than being a liability; and (3) restore and improve the economic viability of the commercial fishing business (W. R. Crowe, MDNR memorandum, 1968). Concurrent with limited entry, a Zone Management Plan was also enacted. The Zone Management Plan mostly excluded gill nets from areas and depths of Lake Michigan that were considered to be prime habitat for lake trout (*Salvelinus namaycush*) rehabilitation. The plan also prohibited commercial harvest of major sport species such as lake trout, walleye (*Stizostedion vitreum*), and yellow perch (*Perca flavescens*).

Michigan began rehabilitation of the Lake Michigan lake trout in 1965. Within several years, it became evident that a virtually unrestricted gill-net fishery was incompatible with restoration of lake trout. Consequently, a request by the MDNR to ban gill nets from the upper Great Lakes was tentatively approved by the Michigan Natural Resources

Commission in August, 1967 (Michigan Department of Natural Resources 1967). The fears of fishery managers were confirmed in 1968 when onboard inspections of Lake Michigan gill netters revealed that an estimated 71,000 lake trout were taken incidentally in the whitefish and chub fisheries; moreover, it was also estimated that these fisheries killed roughly 6% of the 1964 year class of lake trout in 1967-68 alone (R. Rybicki, MDNR, unpublished). In 1970, the Michigan Natural Resources Commission issued the directive that banned the deployment of large-mesh gill nets used by the whitefish fishery. However, the ban was not fully instated until 1977 because of contestation by the industry. The intent of the gill-net ban was not to destroy the commercial fishery, but rather to encourage the conversion to more selective, highly efficient, and less damaging trap nets, which were considered to be compatible with the goals of lake trout restoration.

In 1973, the Bay Mills Indian Community initiated litigation against the State of Michigan. The litigation was based on the tribe's assertion that they possessed unlimited fishing rights in parts of the upper Great Lakes under the terms of the Treaty of 1836. In 1979, the Federal District Court (Grand Rapids, Michigan) ruled in favor of the Indian tribes, which by this time also included the Sault Ste. Marie Tribe of Chippewa Indians and the Grand Traverse Band of Ottawa/ Chippewa Indians. The ruling propounded that the state had no regulatory authority over tribal fishing, although the state-licensed commercial and Indian fisheries competitively coexisted. A Court of Appeals ruling in 1981 essentially upheld the lower court's ruling, and the U. S. Supreme Court refused to accept further appeal. Consequently, the tribal commercial fishery has been expanding in Lake Michigan for the last decade (Keller and Smith 1989).

In 1983, the tribes filed a motion to allocate the fishery resources between themselves and the state. In 1984, the court appointed a Special Master, whose primary functions were to supervise pretrial matters and to facilitate settlement among the parties, which now included sport and non-Indian commercial fishing interests that were granted the status of amici curiae. A court-sanctioned consent agreement was reached in March 1985, of which the salient features pertaining to Lake Michigan were:

1. The tribes shall refrain from commercial fishing in management units WFM01, WFM06 (except grid 714), WFM07, WFM08, and Little Traverse Bay in WFM05 (Figure 1).

2. The state shall eliminate commercial fishing in all treaty waters reserved exclusively for Indian fishers. These waters were management units WFM02, WFM03, WFM04, and WFM05.

3. Whitefish harvest shall be regulated by catch quotas, or total allowable catch (TAC).

4. The state and tribes shall continue all current rules, regulations, or orders until modified in accordance with the requirements of the consent agreement.

5. The parties create the following standing committees:

    a) Joint Enforcement Committee, for the purpose of coordinating fishery law enforcement.

    b) Technical Fishery Review Committee, for the purposes of directing stock assessment activities and the setting of harvest quotas.

    c) Executive Council, for the purpose of implementing the consent agreement and resolving disputes before seeking relief from the court.

6. The agreement shall continue in effect until the year 2000.

Management by catch quota was thusly mandated as part of the consent agreement as stipulated in Item 3 above as well as in the court's ruling in 1979.

Management Units

In 1961 the Great Lakes were divided into statistical districts created to facilitate sorting and compilation of fisheries catch and effort data (Smith et al. 1961). Statistical districts in Lake Michigan were further divided into lake whitefish management units based on fishing patterns and general knowledge about local distributions of several reproductively discrete stocks. In 1984, somewhat different rationale and new information on whitefish stocks precipitated the realignment of unit boundaries to those indicated in Figure 1. Management units WFM00 and WFM01 originally were demarcated by treaty lines; WFM01 was entirely within the treaty area, WFM00 was entirely outside the treaty area (Figure 1). Green Bay is almost a lake all by itself that is shared between Michigan and Wisconsin. Ebener and Copes (1985) concluded from commercial catches of tagged whitefish that Green Bay contained at least two distinct spawning stocks—those that inhabited southern Green Bay but that spawned in the North Moonlight Bay area (east side of the Door Peninsula, Wisconsin), and those that spawned in the northern region of Big Bay de Noc (in WFM01, Michigan). These investigators also concluded that the North Moonlight Bay stock was highly migratory, whereas the Big Bay de Noc population was not. From 1979-82, Wisconsin's North Moonlight Bay stock contributed 78% to the commercial yield of the Michigan fishery in WFM00 and 33% of the catch from Big Bay de Noc (Rowe 1984). Imhof et al. (1980) concluded from the genetic heterogeneity of isoenzymes that at least four stocks of lake whitefish were present in northern Lake Michigan, and that two of these likely were from Big Bay de Noc and North Moonlight Bay.

Scheerer and Taylor (1985) determined that at least three discrete stocks of whitefish inhabit northern Lake Michigan outside of Green Bay. One of these stocks inhabits the coastal waters west of the Leelanau Peninsula from Cathead Point south to Empire which, for practical purposes, defines the boundaries of WFM06.

Localities containing discrete spawning stocks of whitefish need not be of large dimensions. Prout (1989) reported that discrete spawning stocks of whitefish are present in Grand Traverse Bay's East Arm (≈29 km in length, 5-7 km in width), West Arm (≈29 km in length, 5-7 km in width), and outer bay (≈24 km in length and ≈14 km in width). However, an unspecified number of east and west bay whitefish contributed to the outer bay catch at times other than the spawning season.

Tagging investigations have not been conducted on southern Lake Michigan whitefish to establish migratory range. Nevertheless, it is improbable that the stock is being exploited by any fishery other than that which already exists in the immediate Grand Haven-Muskegon area of WFM08.

Scope of Study

The whitefish investigation was divided into two segments:

Job 1. Monitor whitefish in the commercial trap-net fishery. The objective of this segment was to forecast the total allowable yield of whitefish in the treaty-defined waters of Lake Michigan under state jurisdiction. The jurisdiction included management units WFM00, WFM01, WFM06, and WFM08. The study began in 1984 and continued annually through 1988.

Job 2. Index pre-recruited whitefish. The objective of Job 2 is ultimately to set yield quotas based on the numerical strength of pre-recruited year classes. Problems with gear development and deployment prevented progress on this job from 1984 through 1987. Data were obtained in 1988 from a cooperating commercial trawler fishing in Green Bay. Since the quantity of data is insufficient for analysis, the pre-recruit project will not be further discussed.

Methods

Sampling sites and frequency.—The state-licensed trap-net fishery is prosecuted primarily from April through October in Green Bay and WFM08. Additionally, a winter (February-March) fishery has been in existence since 1986 in WFM01. In central Lake Michigan (WFM06), the whitefish fishery is of relatively short duration (usually April-July) largely because there is only one licensed trap netter who prefers to fish in those months. In all management units, the whitefish fishery is closed by statute during the November spawning season. The minimum legal size is 432 mm (total length) in all management units WFM00-WFM06. In WFM08, the minimum legal size is 432 mm in January-May and September-October and 483 mm in June-August. The rationale for the split minimum legal size in WFM08 is rooted in legality rather than biology. There is no whitefish fishery in WFM07, although that management unit has the potential to support a modest harvest. The ports from which the landed whitefish catches were sampled were Cedar River (WFM00), Escanaba and Fairport (WFM01), Leland (WFM06), and Muskegon (WFM08).

Sampling the landed commercial catch was scheduled for May, July, and October. Initially, the monthly sample was taken once per week for three successive weeks, but the man-power commitment was too great and frequently resulted in missed assignments. Consequently, the sampling frequency was changed to 200 legal-size whitefish per port in each of the 3 months; additionally, up to 100 sublegal whitefish were sampled in May and October. The data taken for each fish were total length, round weight, and scales for age determination. Sex was not determined because whitefish typically are sold in the round.

Catch and effort data by the commercial trap-net fishery and from the commercial trawler were obtained from mandatory reports submitted monthly by the state-licensed fishermen. As is the case with many mandatory reporting systems, there is considerable risk of inaccurate information being provided by the licensee.

Data analyses.—Total mortality rates were estimated from catch curves using the maximum likelihood model of Robson and Chapman (1961). To minimize violating the catch-curve requirement of constant recruitment, 3-year running means of age frequencies (Table 1) were used to dampen the effects of unequal annual recruitment. As a matter of consistency, three successive years of data were also used to compute growth parameters and average landed catches to minimize violation of assumptions.

The Kolmogorov-Smirnov two-group test was used to compare age frequencies of whitefish within each management zone between paired sampling months, and between management zones WFM00 and WFM01 by month. Briefly, the Kolmogorov-Smirnov two-sample test makes use of a cumulative frequency distribution for each set of observations, with common intervals for both distributions (Siegel 1956). For each interval, one step function is subtracted from the other. The test focuses on the largest of the observed deviations.

Clark and Smith's (1985) Stock Assessment Program 1 (SAP1) was used to compute catch quotas. The program was designed to calculate catch quotas based on classical yield-per-recruit models. The SAP1 program consists of four modules: (1) Calculator: a) estimates von Bertalanffy growth parameters given length-at-age data; b) calculates weight-length regression; and c) catch-curve regression which performs a linear regression on catch at age data (not used in this analysis); (2) Yield-per-recruit-F_{opt}-F_{max}: estimates the fishing rate that results in maximum yield per recruit, and the fishing rate that provides the maximum economic return based on growth and mortality data; (3) Recruitment estimator: estimates the average number of recruits entering a fishery and the age structure of the population (number), catch (number), and yield (weight); and (4) Quota estimator: a multiple-cohort yield-per-recruit model which estimates harvest quotas for a user-specified number of years into the future. User inputs required by the quota estimator are: optimal fishing rate (either preselected or calculated from the yield-per-recruit-F_{opt}-F_{max} module), growth parameters, partitioned mortality rates, mean yield, and mean weight per fish in the catch.

Vital statistics of whitefish presented in this report may not agree precisely with values of like variables tabled in reports prepared by the Technical Fishery Review Committee (TFRC 1984, 1985, 1986, 1987, 1988) or in annual project performance reports. This is because the inclusion or exclusion of data for this report depended upon criteria which were more stringent than for the aforementioned reports. Our criteria were:

1. Only data obtained in May, July, or October were used. The exception was the inclusion of data collected from the winter fishery in management unit WFM01. Pooled monthly data were used to compute growth and mortality parameters.

2. In the computation of von Bertalanffy growth parameters and weight-length regression coefficients, data for both legal- and sublegal-sized whitefish were included. If there were less than five fish in an age group, that age group was excluded from the von Bertalanffy growth calculations.

3. Survival estimates were based on the exploitable (legal-size) segment of the population only.

Results and Discussion

Trends in Commercial Yield

In Lake Michigan, four lake whitefish management areas under state jurisdiction contribute quite variably to the total annual catch of whitefish. Catch statistics for state-licensed commercial fishermen during the past 6 years indicate that of the total harvest of lake whitefish from Lake Michigan waters, 26-38% are caught in management unit WFM00, 51-66% are caught in WFM01, 0.4-3% are caught in WFM06, and 4-10% are caught in WFM08.

In WFM00, annual commercial catches (trap nets and trawls) of lake whitefish tended to increase from 1983 to a peak in 1986, then decrease in 1987 and drop precipitously in 1988 (Table 2). Catches per unit effort (CPEs) for both types of gear followed roughly the same pattern as catches. Effort was more or less stable during this period and variation in catches is probably best explained by variable recruitment of year classes to the fishery. Judging from the relative abundance index summed across ages 4-6 (Table 3), the 1981 year class was the strongest (CPE of 130) and the 1979 year class the weakest (CPE of 48). The exceptionally low catch in 1988 is attributed to a series of years of relatively poor recruitment combined with a weather pattern which was not beneficial to the fishermen. The unusually hot, dry summer of 1988 may have altered the normal distribution of whitefish and made them less vulnerable to fishing gear, while stormy weather during October prevented many fishermen from tending their nets during the usually very productive last few weeks of the fishing season.

The peak trap-net catch in WFM01 occurred in 1985 (Table 2) and was heavily supported by the very strong 1981 year class (Table 3). Thereafter, harvest levels declined, although the decline between 1987 and 1988 was somewhat less drastic than in WFM00. Trends in trap-net CPEs closely matched catch trends. Trawl catches and CPEs in WFM01 were quite variable with no general trend (Table 2). The curtailment of tribal fishing in WFM01 in mid-1985 had the effect of reducing fishing pressure on the fish in this management zone and helped account for the relatively high catches by state-licensed fishermen in 1985, 1986, and 1987. The weather pattern in 1988 affected fishing success in WFM01 as it did in WFM00.

State commercial yields of lake whitefish declined in management zone WFM06 from 1983 to 1986, then rebounded to moderate levels in 1987 and 1988 (Table 2). Harvest levels reflected effort, which decreased 74% during the period of declining catches, then increased steadily through 1988. CPEs fluctuated widely and were unpredictable during the 1980s. Tribal gill netting has accounted for the harvest of around 42 thousand kg of whitefish in WFM06 during the past 6 years. Gill netters have generally caught less than half of the total annual yield in WFM06, though in 1986 and 1988, gill-net catches were larger than those of state commercial trap-net fishermen. In general, for unknown reasons, gill-net CPEs were high (except for 1985) and trap-net CPEs were low in WFM06 relative to other management zones.

A slightly decreasing trend was observed for lake whitefish catches in WFM08 between 1983 and 1985. Effort decreased during these same years even while CPE was increasing (Table 2). In 1986, both catch and effort increased to values which were nearly double those of 1985, and catches have remained moderately high through 1988. The whitefish stock in WFM08 appears to be underexploited and has the potential to expand. CPEs are about as high in WFM08 as in WFM01 and are quite large relative to the other management zones in Lake Michigan.

Mortality Rates

Several investigators have estimated natural mortality rates of exploitable whitefish in Lake Michigan to be in the range of 33-46% (Humphreys 1978; Ebener and Copes 1985; Scheerer and Taylor 1985). Because whitefish in the East and West arms of Grand Traverse Bay were unexploited commercially from 1968 to 1979, all mortality in that period was attributed to natural causes. Catch-curve analysis of whitefish captured in experimental gill nets fished by the MDNR in these bays during 1976-79 provided a natural mortality rate of 36% ($1-e^{-0.45}$) for ages 6-13 (Rybicki 1980; Figure 2), which is used throughout this report.

Annual total mortality rates (A) of exploitable whitefish stocks were exceedingly large in management unit WFM00, where the rates ranged from 77% to 88% (Table 4). Total mortality rates of whitefish in WFM01 were of similar magnitude, with a range of 73-86%. Given an instantaneous natural mortality rate (M) of 0.45, instantaneous fishing rates (F) in these two management units ranged from 0.86 to 1.67 (Table 5), or yearly exploitation rates (u) of 48%-69%.

Annual total mortality rates of exploitable whitefish stocks in units WFM06 and WFM08 were similar to each other (differing by a maximum of only 4%) and ranged from 45% to 51% (Table 4). Instantaneous fishing rates ranged 0.15-0.26 (Table 5), and exploitation rates were from 11% to 18%. As compared to units WFM00 and WFM01, the much lower fishing-induced mortality in WFM06 and WFM08 was clearly evident in the consistently large proportion and number of older age groups represented (Figure 3).

Age Structure of the Trap-net Catch

The age distributions of whitefish in landed catches were strongly dependent upon the month in which the samples were drawn in three out of the four management zones (Table 6; Appendix A). In units WFM00 and WFM01, 3-year-old whitefish were progressively recruited to the fishery as growth occurred from July through October (Figure 4), and older age groups (≥ age 6) were somewhat better represented in October (perhaps because of pre-spawning aggregations) than in May or July. The age structure of the whitefish in the landed catch also differed significantly between units WFM00 and WFM01 in July and October but not in May (Table 7). The major difference was that age-3 fish were proportionately more prevalent in the WFM00 samples than in the WFM01 samples (Figure 4). We speculate that maturing 3-year-old whitefish, which originated in Wisconsin waters and had travelled to WFM01 earlier in their lives, begin to withdraw in early fall on their southward journey (via WFM00) to return to and spawn in the region of Moonlight Bay, Wisconsin in November. Because of whitefish body shape, catches are especially affected by gear selectivity. Although the mesh size in the pot of the trap nets did not change, the October condition factor of 3-year-old whitefish in WFM00 was significantly larger than for those in WFM01 (Table 8), perhaps enhancing the vulnerability of the population while in unit WFM00.

The age composition of the whitefish catch in management unit WFM06 contained larger proportions of older fish in May than in October, for reasons that are not clear. However, the age frequencies in the May catch were not quite significantly different ($P = 0.052$; Table 6) from the October sample. Comparison of whitefish age frequencies in 1984/1986-88 showed no significant difference ($P = 0.15$) between May and July samples.

In zone WFM08, the monthly age structure of the landed whitefish catch is confounded by a seasonally regulated minimum legal size limit. Prior to 1986, the minimum size limit was 483 mm; however, the erratic seasonal fishing pattern and/or failure to sample the catch before 1986 resulted in data that were not comparable. Since 1986, the minimum legal size limit has been 432 mm in January-June and September-October, and 483 mm during July-August. As a consequence of the inconsistency in the minimum size regulation, a change in the commercial fishing statute is required to correct the regulatory contradiction. Regardless of the minimum size regulation, the age composition of the landed catches in management unit WFM08 was well represented by numerous age groups (Figure 4), although the monthly age composition did vary considerably. The large proportion of 5- and 6-year-old fish in July was due to the aforementioned 483-mm minimum size limit in effect during July and August. The larger proportion of 7- to 12-year-old fish in the May catch than in the October catch appears to be more closely related to the age-structure pattern of the whitefish catches in WFM06 than to those in Green Bay. The appearance of older age groups in the late spring samples rather than as pre-spawning aggregates in the fall is not readily explainable. In any case, the differences in seasonal age distribution were very significant ($P < 0.00$) and cannot be explained by insufficient sample sizes or too few years covered (Table 6). Perhaps pre-spawning aggregations in October are at depths deeper than the trap nets are permitted to fish (27 m). Much of the inshore area of southern Lake Michigan is beach sand that lacks rocky substrate; consequently, the whitefish may be forced to spawn at greater depths. Alternatively, according to a former commercial fisherman, now retired, pre-spawning whitefish may migrate to the region of White Lake (about 25 miles north of the Muskegon sampling location), where there is some inshore, rocky substrate. Trap netters rarely fish the White Lake grounds; consequently, the larger, pre-spawning whitefish would be partially unavailable to the fishery in the fall.

Annual calculations of size-at-age and mortality were determined from overall age frequencies of May, July, and October samples combined. Since the age distribution of the whitefish catch was strongly dependent upon the month in which the samples were drawn, it is recommended that the commercial catch in management units WFM00, WFM01, and WFM08 continue to be sampled in May, July, and October at the very minimum. In WFM06, only a May sample of the landed whitefish catch in trap nets need be taken; however, if fall fishing occurs, then that fishery should be sampled as well.

Weight-at-length in Trap Nets

Weight-at-length curves (Figure 5) clearly indicate that Green Bay whitefish differed in growth patterns from those stocks in WFM06 and WFM08. Whitefish populations in WFM06-WFM08 were much heavier at lengths over 500 mm than whitefish stocks in WFM00 and WFM01. The Green Bay populations were quite similar in growth patterns ($P = 0.68$), while those in WFM06 and WFM08 were statistically different ($P < 0.05$) but more similar to each other than to fish in either WFM00 or WFM01 (Figure 5). Although the Green Bay whitefish are believed to be from two discrete spawning stocks, the similarity in weight-at-length curves likely was due to samples being collected during the non-spawning season when stocks were mixed.

Age-Size Distribution in Trap-net versus Trawl Catches

Despite intensive exploitation, the whitefish populations in WFM00 and WFM01 have not collapsed. We hypothesize that the stocks have not crashed because the depth distribution of larger, older whitefish makes them unavailable to trap nets for much of the fishing season. Escapement of the spawning biomass has thus been adequate to prevent collapse. This is suggested by the occurrence of larger proportions of older age groups in the fall samples (Figure 4) than are seen in the spring and summer catches. We have consistently found large whitefish in relatively deep water (55-73 m) in Grand Traverse Bay in mid-May. By statute, trap nets are restricted to depths of 27 m or less, thus older whitefish may become available to that gear mainly in the fall as pre-spawning aggregates migrate from deep to fishable waters.

Further evidence to support our hypothesis came from commercial trawl catches. Trawls are not restricted to a maximum depth as are trap nets. Consequently, the age and size structure of whitefish during midsummer in trawl catches may differ from those in trap nets. Both commercial trawl and trap-net catches of whitefish in WFM00 were sampled in July, 1988. The age and size structure of the trawl catches did indeed differ significantly ($P \leq 0.01$) from trap-net catches. The trawl catches contained four older age groups (9-, 10-, 13-, and 14-year-old fish; Figure 6) and ten larger length classes (57-66 cm; Figure 7) than were observed in the trap-net catches. The modal age and length of whitefish in the trawl catch was 6 years and 49 cm, as compared to 5 years and 43 cm in the trap-net sample. However, it is not clear whether the age and size differences of the catch between the two gear types were the result of depth distribution of the whitefish or due to net selectivity. From the age and size distributions shown in Figures 6 and 7, it appears that gear selectivity was at work. Trap-net catches are manually sorted for whitefish 432-mm TL and larger, whereas the mesh size in the trawl is designed to pass almost all (92%) fish below the minimum size (Schorfhaar 1986). Confounding the issue is the significantly ($P < 0.05$) larger average size of ages 3, 5, 6, and 7 whitefish in the trawl when compared to those caught in trap nets (Figure 8). Several possible explanations are: the trawl selected the faster growing individuals in those age groups; the trap nets selected the slower growing individuals in those age groups; or the faster growing and older segments of the stock were segregated from slower growing and younger fish during July. The most plausible explanation is a combination of gear selectivity and a tendency for the larger whitefish to be distributed in deeper water. If larger, older fish were available to trap nets in the spring and summer, there is no reason to suspect that trap nets would not have retained them; the age distribution of whitefish in the October catch in WFM00 contained fish up to 12 years old (Figure 4). Although the data do not permit us to conclude that there is a depth-size/age distribution, the circumstantial evidence justifies a cautious regulatory response. The 27-m depth restriction on trap nets may have allowed escapement of adult whitefish in numbers sufficient to prevent collapse of the population despite large fishing rates; therefore, the trap-net depth restriction should remain in effect. An increase in trawling efficiency or effort conceivably could disrupt what may be a delicate balance between catch and escapement; consequently, it would be prudent not to allow indiscriminate expansion of the trawl fishery.

Optimal Harvest Rate

From a thorough review of the literature, Clark (1984) concluded that an ideal exploitation rate for lake whitefish appears to be one that causes annual total mortality to be in the range of 60-70%. In general, according to Clark, historical records seem to indicate that whitefish fisheries are in serious danger of collapsing when exploitation (or some other source of mortality, such as sea lamprey depredation) causes the mortality of adult whitefish to exceed 70% per year.

That the whitefish populations in Green Bay apparently can sustain themselves at total mortality rates in the 73-88% range is indeed astonishing. In addition to the escapement hypothesis previously discussed, a partial solution to the puzzle may lie in Freeberg's (1985) work on larval whitefish in Grand Traverse Bay. Through a well-designed combination of laboratory larval feeding studies and field work, Freeberg showed that:

1. Annual variations in overwintering egg survival appear to influence whitefish year-class strength. Mild winters that produced little or no ice cover over spawning grounds resulted in significantly lower relative numbers of hatching whitefish than in severe winters when ice cover predominated.

2. Growth and survival of larval whitefish varied in proportion to the number of zooplankton available to each fish. After yolk absorption, mortality of the laboratory larval whitefish increased when the zooplankton to fish ratio was reduced to 18 or less.

3. Initial spring densities of zooplankton (principally copepods) may be influenced by the severity of the winter through which they passed. Mild winters allow wave action to disperse and thereby decrease densities of periphyton, which serve as food for the zooplankters. Consequently, zooplankton density, upon which larval whitefish are dependent, is also decreased.

Much of the Green Bay shoreline is in the lee of winter's prevailing northwesterly winds, and the Bays de Noc are small enough to freeze relatively early in the winter in the northerly latitude. With little fetch, deposited eggs would receive considerable protection even in mild winters. Thus, with Green Bay's fertile, potentially ideal spawning and incubation habitat, its whitefish stocks may be capable of withstanding large mortality rates at relatively low levels of spawner biomass.

The foregoing discussion notwithstanding, it would seem prudent to choose a conservative target total mortality rate of not more than 70%. Because the mortality estimates are subject to statistical error, it is further desirable to lower the target mortality by the amount of the confidence bound (mostly in the ±3-4% range; Table 4) on the mortality estimates. At an instantaneous total mortality rate (Z) of 1.05 (A = 65%) and an instantaneous natural mortality rate (M) of 0.45, the target fishing rate is 0.60. Based on output from the yield-per-recruit-F_{opt}-F_{max} module of Clark and Smith's (1985) SAP1 model (briefly described in the Methods section), a target F value of 0.6 is approximately the correct fishing rate in WFM00 (F_{opt} = 0.62) and WFM01 (F_{opt} = 0.59), but it is slightly high (although not unreasonably so) for units WFM06 and WFM08 (F_{opt} = 0.54). Thus we recommend that a target total annual mortality rate be set at 65% annually.

Optimal Harvest Size

For many years, the minimum size limit (MSL) of whitefish in trap nets has been 432 mm, although the origin of the regulation is unknown. The idea of establishing a minimum legal size of 483 mm and eliminating whitefish catch quotas has surfaced from time to time; the concept presumes that 483 mm would allow adequate escapement of spawning stock, thus there would be no need for target fishing rates. SAP1 may also be used to simulate the potential effects of altering the minimum size-at-harvest. The yield-per-recruit -F_{opt}-F_{max} program estimates the optimum fishing rate at the new length-at-harvest, which may then be input to the Quota Estimator module of the SAP1 program.

Taken at face value, the 483-mm MSL does not appear to be an attractive management option. An abrupt increase in the MSL of whitefish to 483 mm in units WFM00 and WFM01 would have an immediate catastrophic economic impact on the fisheries. If the MSL of 483 mm would have been implemented in 1989, projected yield in WFM00 would have plummeted from 294.3 thousand kg (1986-88 average harvest) to 67.3 thousand kg, a decrease of 77%; however, yield would stabilize in 1995 at about 204.7 thousand kg (Figure 9). Similarly, yield of whitefish in WFM01 would drop from an average of 595 thousand kg in 1986-88 to 215.2 thousand kg in 1989 (a decline of 64%) and would stabilize in 1995 at 445.6 thousand kg. Simulated yields drop sharply because the stock has to grow into the new size, and the fishing rate would not be unregulated as was presumed by the proponents of a 483-mm MSL. Clearly, implementation of a 483-mm MSL requires a strategy that would phase in the new regulation over a period of years.

If the target fishing rate (F) of 0.60 were fully implemented immediately, the impact would be far less severe than would an increase in the MSL. Projected yield in WFM00 would fall from 294.3 thousand to 182.6 thousand kg (-38%), and in WFM01 would dip from 595 thousand kg to 436.9 thousand kg (-27%). By 1995, the projected loss in yield from the 1986-88 level would be 15% in WFM00 and 12% in WFM01.

It is possible that the loss in yield may be offset by an increase in recruitment as a consequence of spawner escapement under the larger minimum size limit. Smale and Taylor (Michigan State University, unpublished) reported that recruit-per-parent ratios in a commercially exploited whitefish stock in northern Lake Michigan were correlated with stock size, winter ice cover, and mild spring temperatures. They also stated that if egg density and resultant fry are less than the carrying capacity of the habitat, then a larger number of spawners may very well enhance recruitment. Clearly, the larger the MSL, the greater the escapement of the mature female segment of the stock and hence the greater the egg deposition. Under the conditions that prevailed in 1979-83, the cumulative frequency of mature female whitefish was 3% at 432 mm, 17% at 457 mm, and 62% at 483 mm (Figure 10; Appendix B). Thus, at an MSL of 483 mm, about one-half of the mature female whitefish would have escaped the fishery to spawn one or more times. Christie and Regier (1973) noted that female whitefish should have the opportunity to spawn an average of 1.5 times in order to maintain the stock. In contrast, the mean number of spawning opportunities of captured female whitefish in management units WFM00 and WFM01 presently are only 0.3 and 0.5 times, respectively (Table 9). The mean number of spawning opportunities rises to 0.7 times when the MSL remains at 432 mm and F_{opt} is 0.60 in both units. At a minimum size of 457 mm, the average number of spawning opportunities becomes 1.0. When the MSL is increased to 483 mm with its corresponding F_{opt}, the mean number of spawnings increases to 1.6, which approximates Christie and Regier's (1973) ideal of 1.5.

Presently, the balance between costs and benefits associated with a larger MSL cannot be evaluated. The simulation exercise does not consider the net response of density-dependent variables, such as growth, recruitment, and natural mortality, to larger minimum sizes and lower fishing rates because the behavior of each variable is unknown. Since the costs and benefits of a 483-mm MSL remain quantitatively unresolved, we recommend that: (1) a larger minimum legal size limit in WFM00 and WFM01 be deferred; and (2) an experimental management project be designed and implemented to evaluate quantitatively the merits of a 483-mm minimum size limit.

Increasing the MSL for whitefish in management units WFM06 and WFM08 apparently would benefit the fishing industry. Under the various regimens of MSL and F_{opt}, the projected yields in management units WFM06 and WFM08 sharply increase from the 1986-88 average yield (Figure 9). That is because the current instantaneous fishing rate of 0.15 (in both units) is much less than F_{opt} of

0.60. Because of the healthy condition of the whitefish populations and the fishery being in the extraordinary position of underexploiting the stocks, WFM06 and WFM08 should be considered as prime study sites for the above recommended experimental management project.

Catch Quotas

Apparent contradictions exist between several past catch quotas and reported yields (Table 10). For example:

1. In WFM00 the fishing rate of 1.67 during 1985-87 was nearly three times larger than the optimum fishing rate of 0.60, but the 1988 catch quota and yield were nearly identical.

   Actual fishing rate may exceed the optimum rate and yet produce the same quota when the yield-fishing rate curve becomes asymptotic. If this is in fact the case, then a relatively large increase in fishing rate will produce a very small change in catch, which not only places the fish stock at risk but decreases economic yield as well.

2. In WFM01, the total allowable catch was 30% larger than the reported yield in 1988. However, the reported trap-net catch and catch per unit effort in this management unit have been decreasing each year from 1985 through 1988 (Table 2), which suggest a shrinking whitefish population.

   The present technique of using 3-year averages as input to the yield model was designed to dampen the effects of annual variation of recruitment, growth, and effort. However, this adjustment to minimize violations of the model's assumptions also prohibits timely response to potentially rapid changes in the whitefish population. In years when the population is declining the quota will be too large, and in years when it is expanding the quota will be too small. Over the long term, the fishing rates should average close to optimal. Keys to the timely forecasting of allowable yield are indexing of pre-recruits, accurate knowledge of age structure of the catch, and reliable reporting of catch and effort.

3. In two-thirds of the cases, yield exceeded the quota by wide margins (64-106%) in WFM00 and WFM01, which created the impression that the model under-estimated yield.

The interpretation of the model's results should be that overfishing has occurred relative to the inputs of optimum mortality, growth rates, and mean 3-year yield. In reality, the total allowable catches predicted by the model have not been used or enforced, which permitted catch to exceed quotas by large amounts. Consequently, the model should not be blamed for the failure of fishery managers to brake the free-wheeling commercial fishery.

Given the large contribution (73%) that whitefish originating in Wisconsin waters make to the catches in WFM00 and WFM01, that state's interests should also be considered. Therefore, we recommend that Green Bay whitefish stocks be managed jointly by the two jurisdictions.

In WFM06 and WFM08, the catches were consistently less than the quotas (Table 10) because of differences between optimal and actual fishing rates as described earlier. The whitefish catch quota in WFM08 has increased annually since 1986 at least in part because the minimum legal size of whitefish was decreased from 483 mm to 432 mm for all months except July-August, which allowed the catch in number to expand without materially changing the average fishing rate. The 1988-89 quotas in WFM08 likely are artificially large, but it will be several years before the 3-year averaging system will produce a more realistic quota. When the average growth and mortality parameters extant in 1986-88 are used to project the quota 10 years hence, the projected quota stabilizes in 1994 at a reasonable 123 thousand kg.

Acknowledgments

We wish to thank district supervisors Bill Bullen, Gary Schnicke, Dell Siler, and John Trimberger and technicians for faithfully collecting much of the data used in this report; and James Peck and Dr. Carl Latta for their editing efforts.

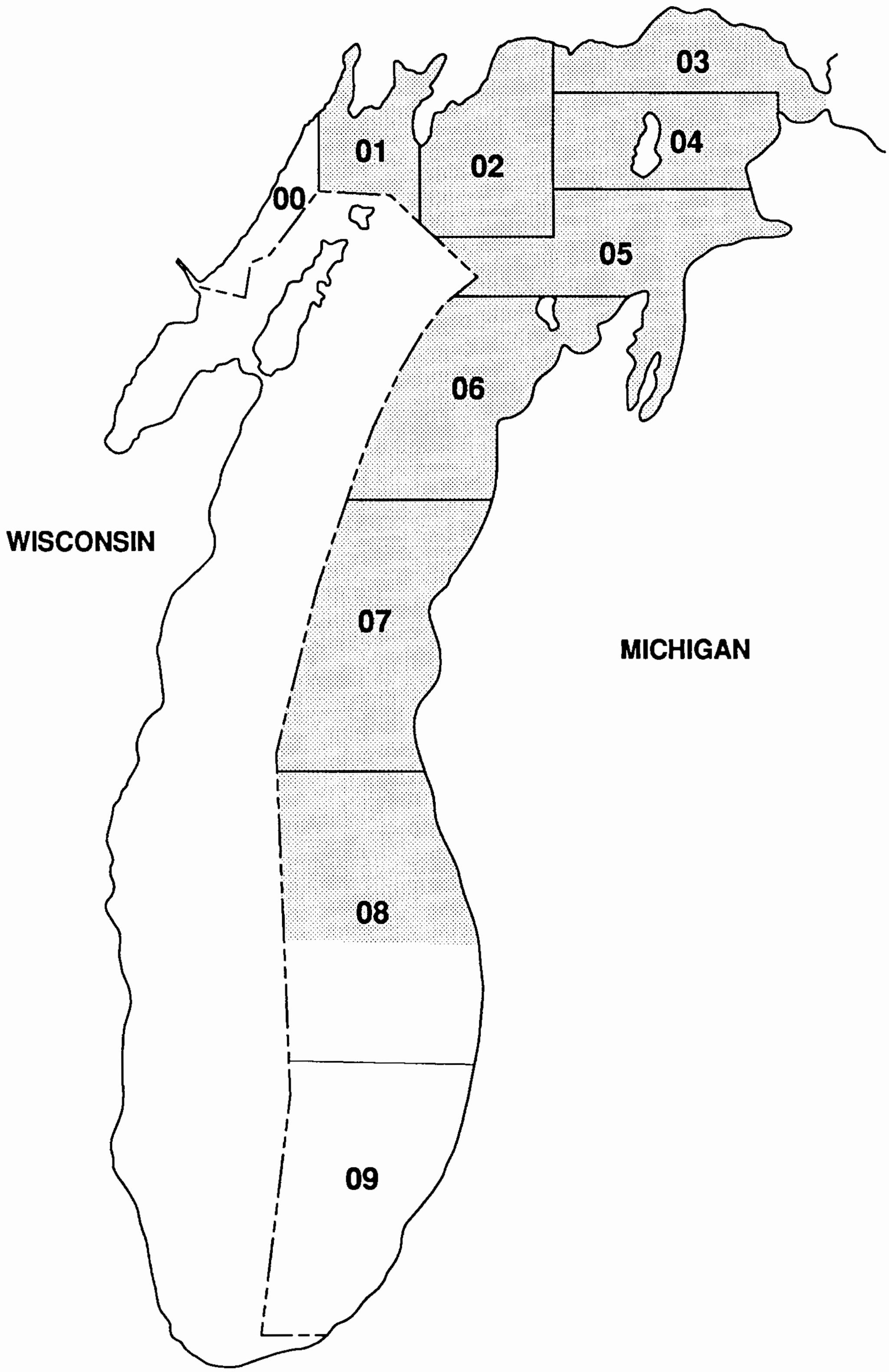


Figure 1.—Waters of Lake Michigan ceded by the Treaty of 1836 (shaded area) and whitefish management units (WFM).

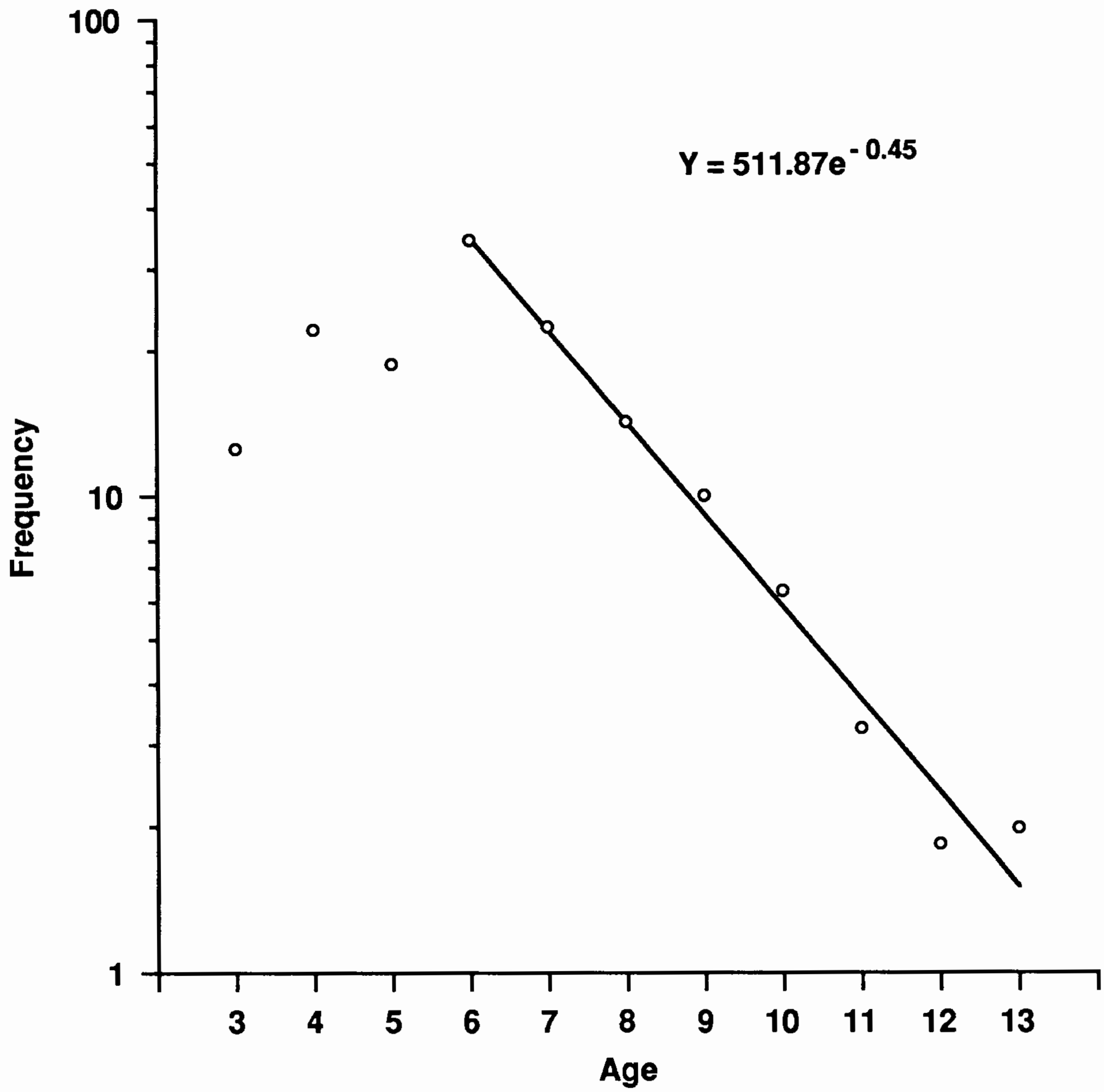


Figure 2.—Catch curve of unexploited whitefish caught in graded-mesh gill nets fished in Grand Traverse Bay, 1976-79. Each data point is the mean of four observations.

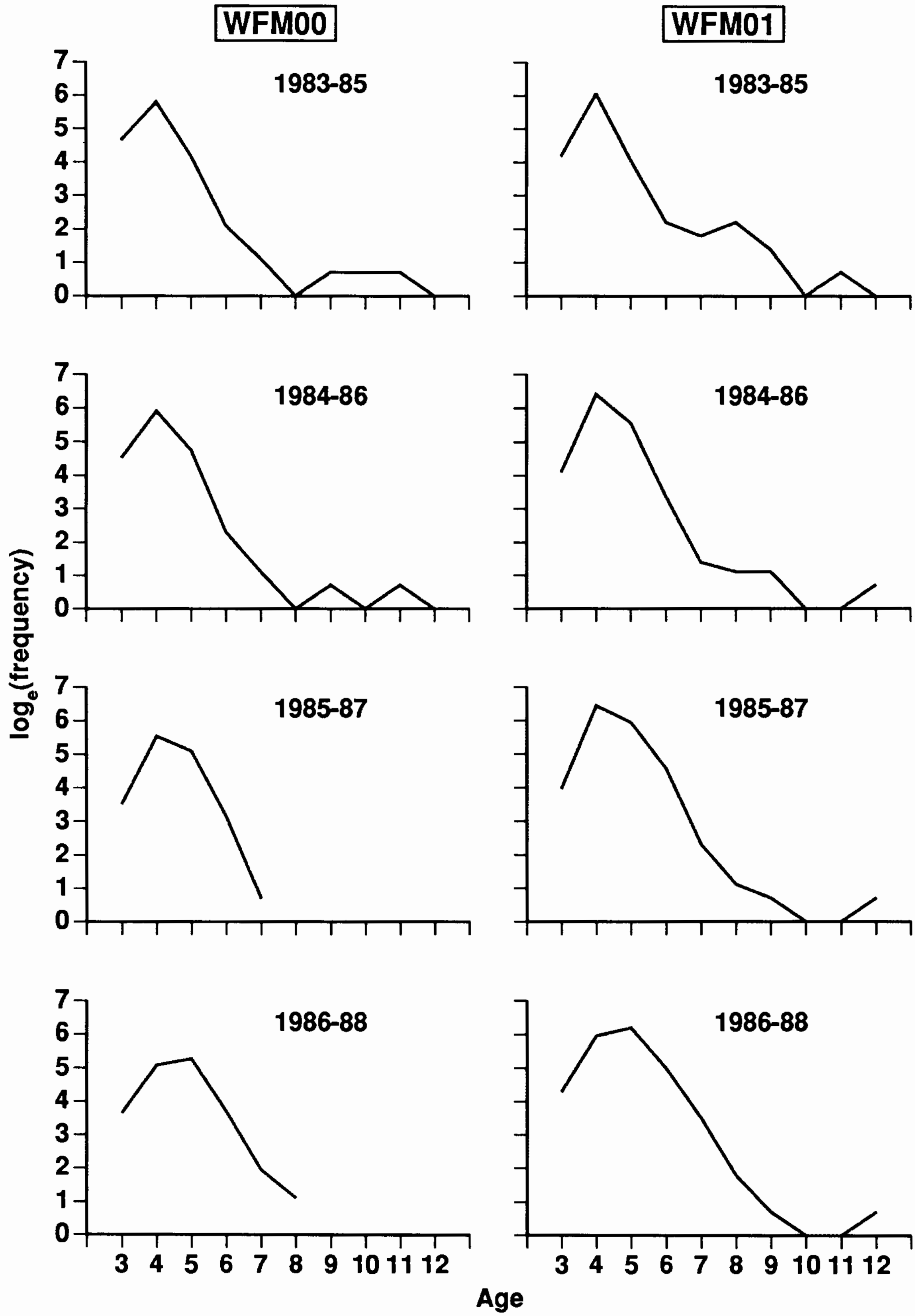
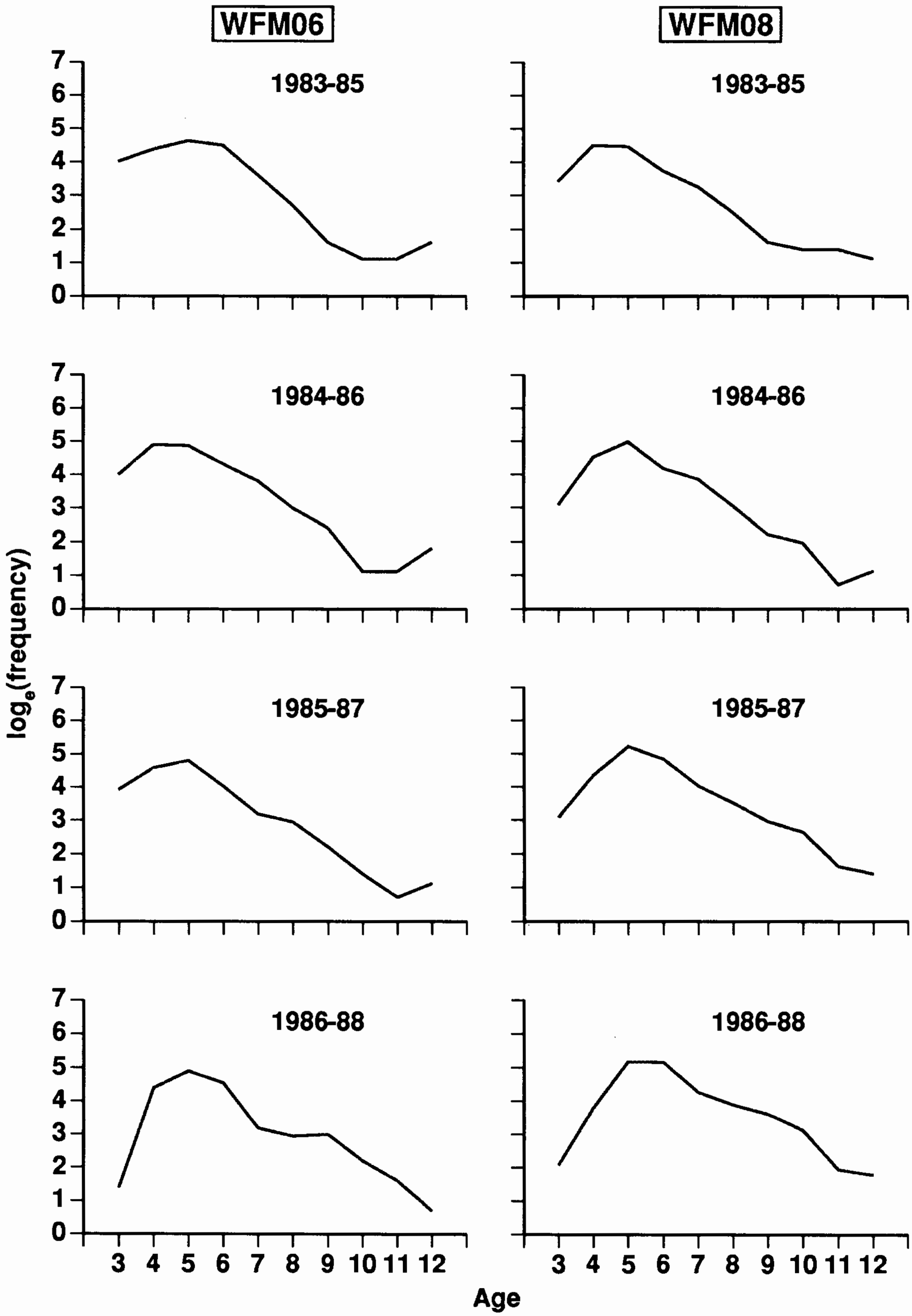


Figure 3.—Catch curves of whitefish in the landed trap-net catch based on 3-year mean frequencies of ages, by Lake Michigan management unit.



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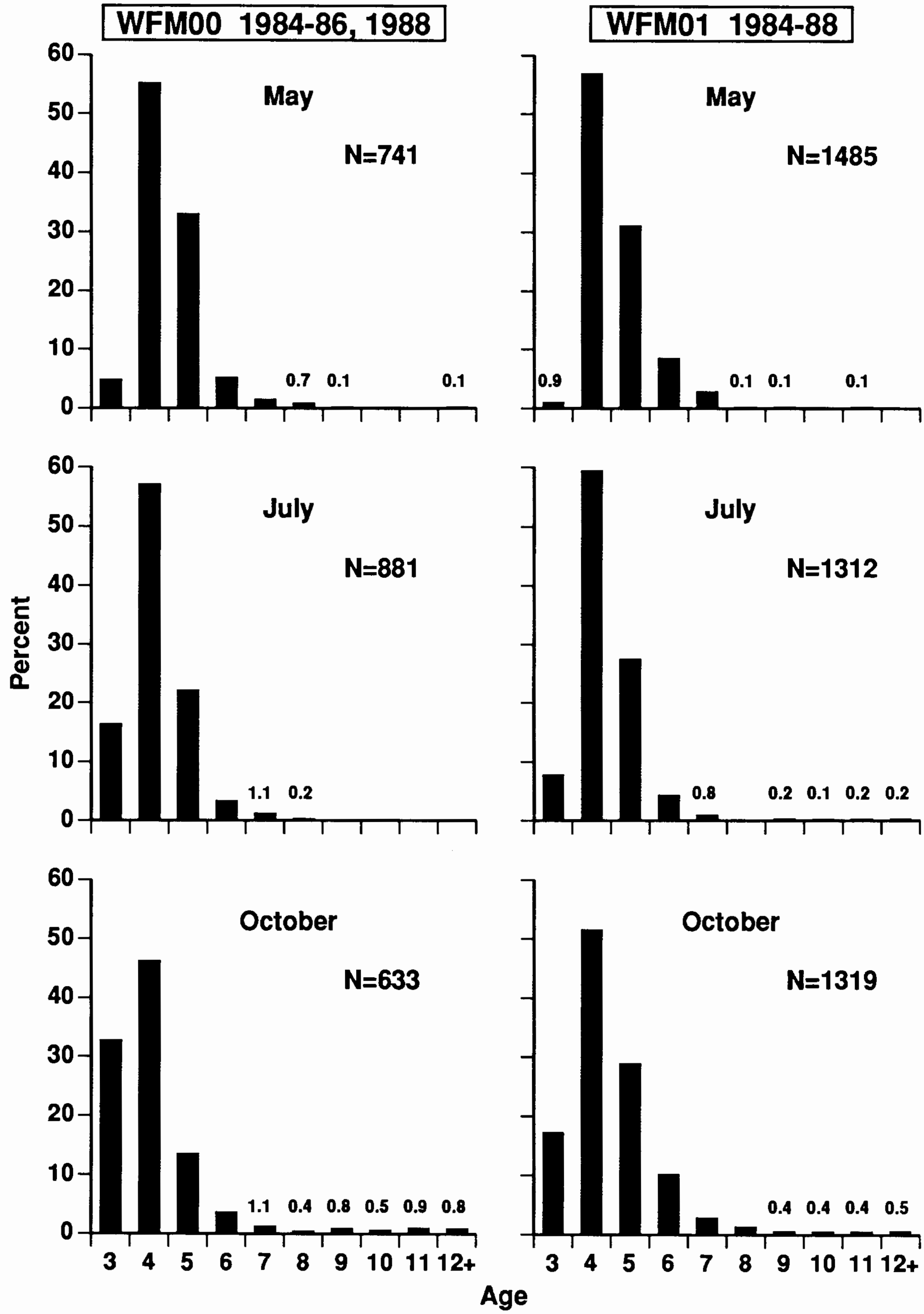

Figure 4.—Age frequency of whitefish in the landed commercial catch in trap nets, by Lake Michigan management unit and month sampled.

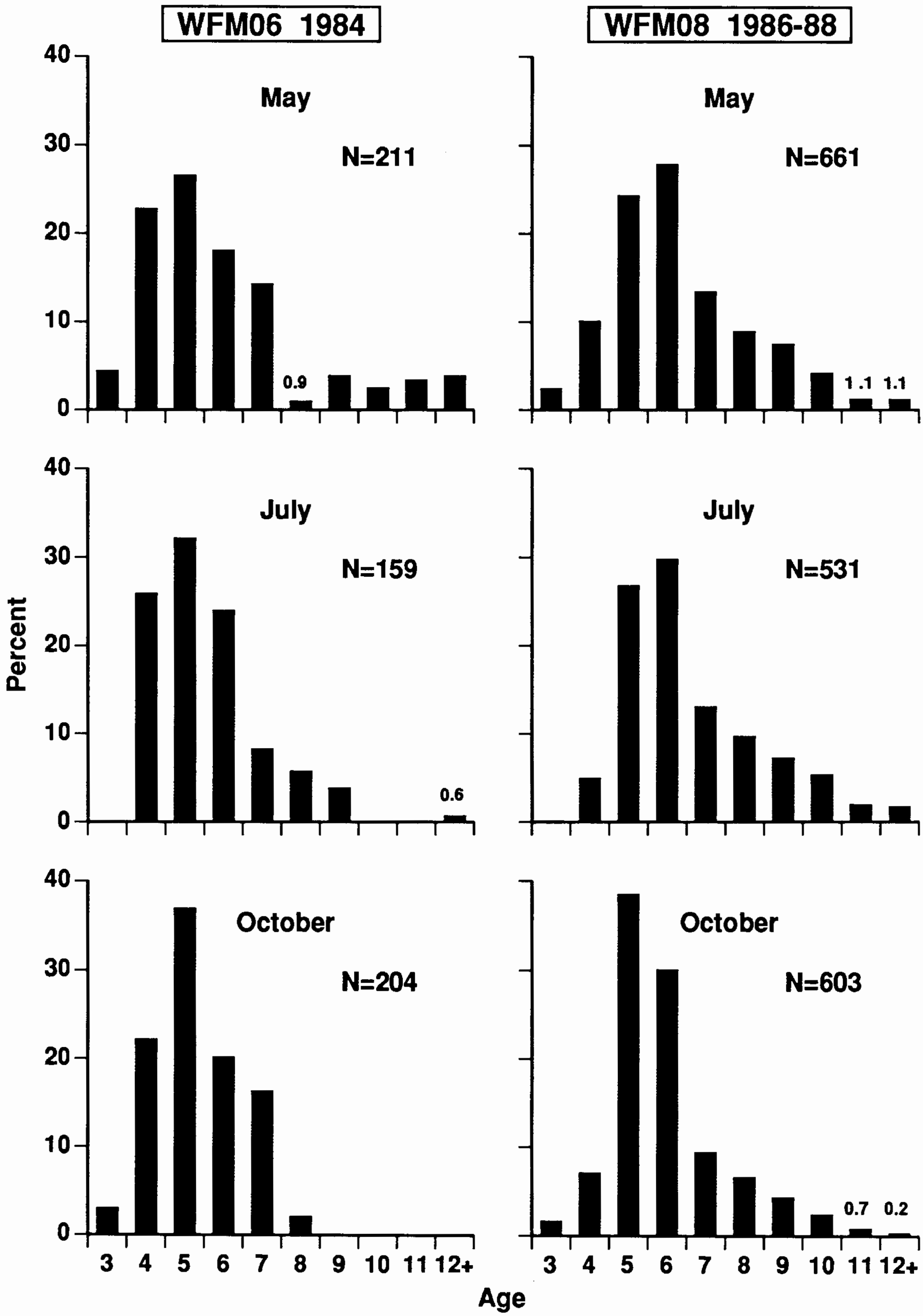

Figure 4.—Continued:

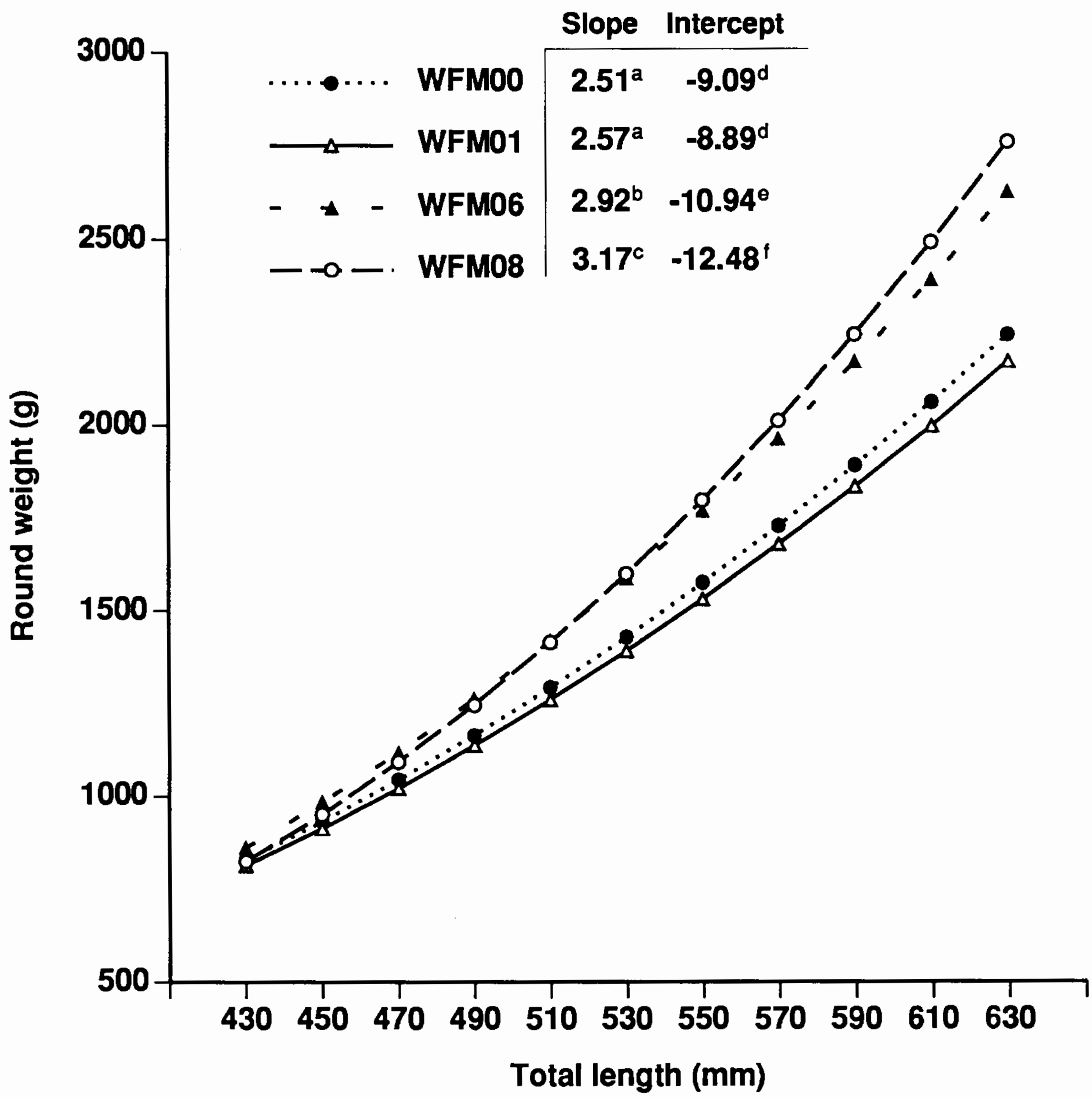

Figure 5.—Predicted weight-at-length of whitefish (≥432 mm) caught in commercial trap nets in May 1986-88, by Lake Michigan management unit. Slope and intercept values with the same superscript are not significantly different.

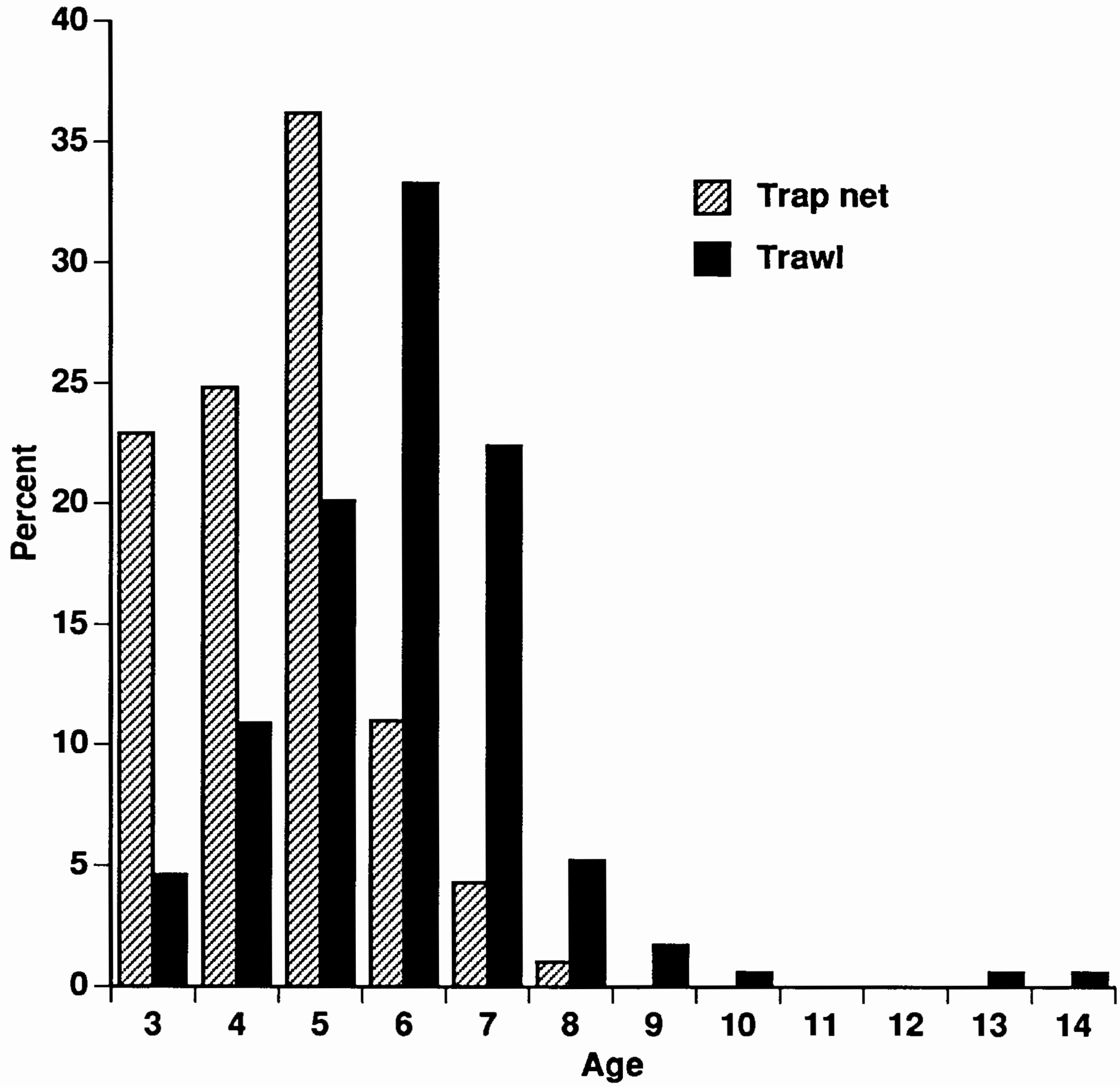

Figure 6.—Age frequency of whitefish caught in commercial trap nets and trawls in Lake Michigan management unit WFM00, July 1988.

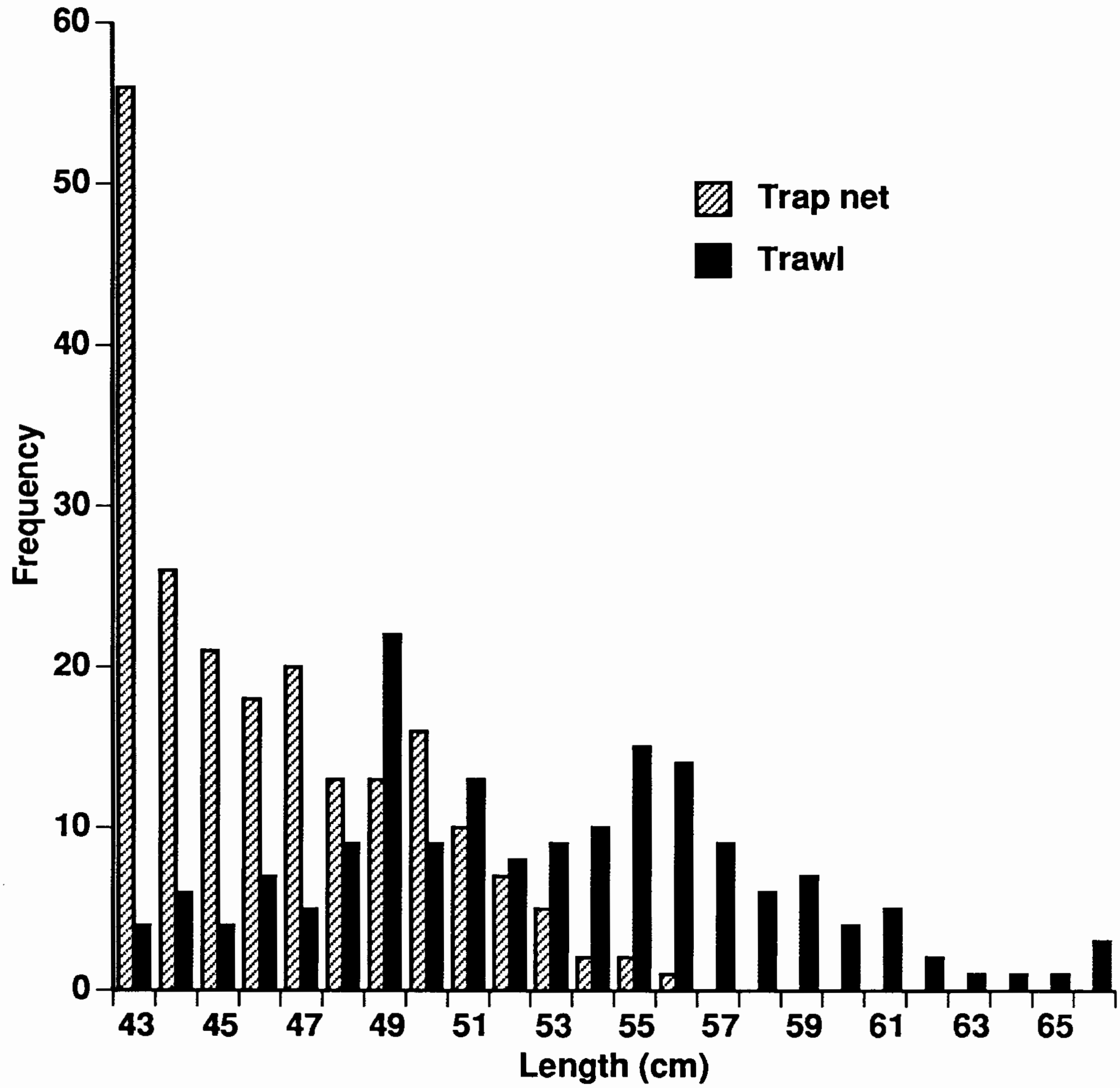

Figure 7.—Length frequency of whitefish (≥432 mm) caught in trap nets and trawls in Lake Michigan management unit WFM00, July 1988.

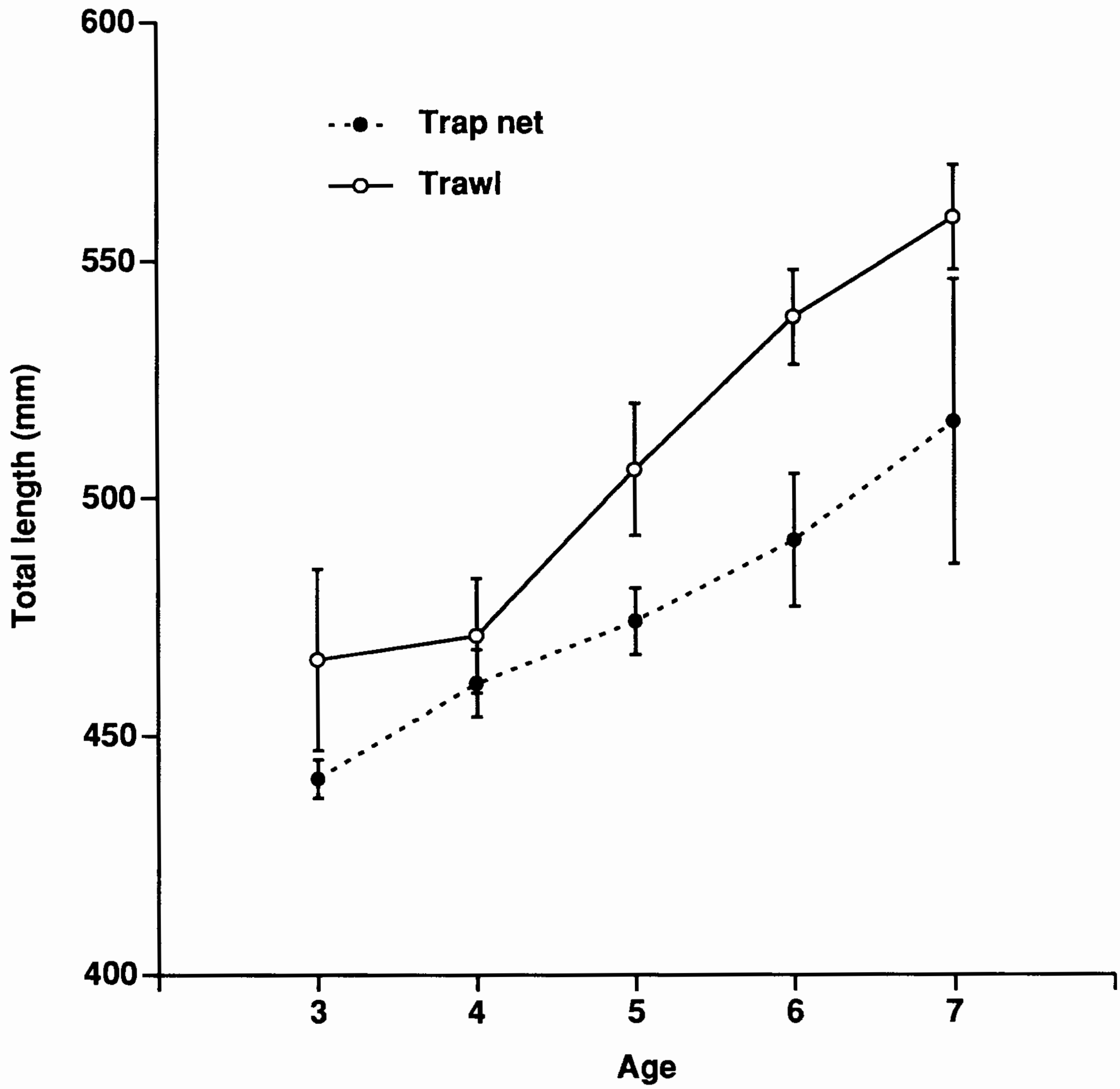

Figure 8.—Mean total length of whitefish (≥432 mm) caught in trap nets and trawls in Lake Michigan management unit WFM00, July 1988. Vertical bars are 95% confidence limits on means.

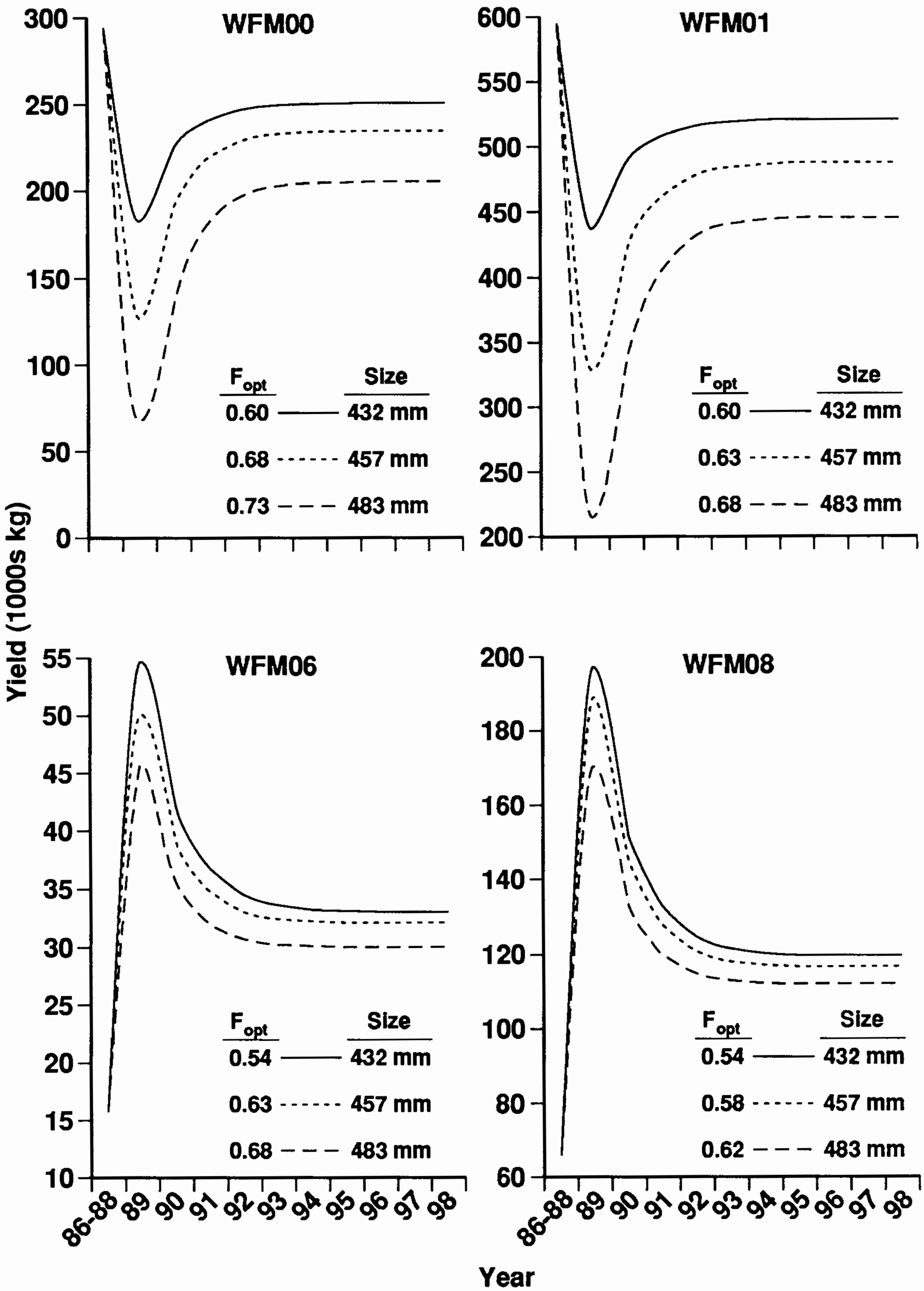

Figure 9.—Yields of whitefish simulated annually for 10 years at three minimum sizes at harvest and associated optimal fishing rates. Simulations were based on mean growth, mortality, and yield parameters in 1986-88.

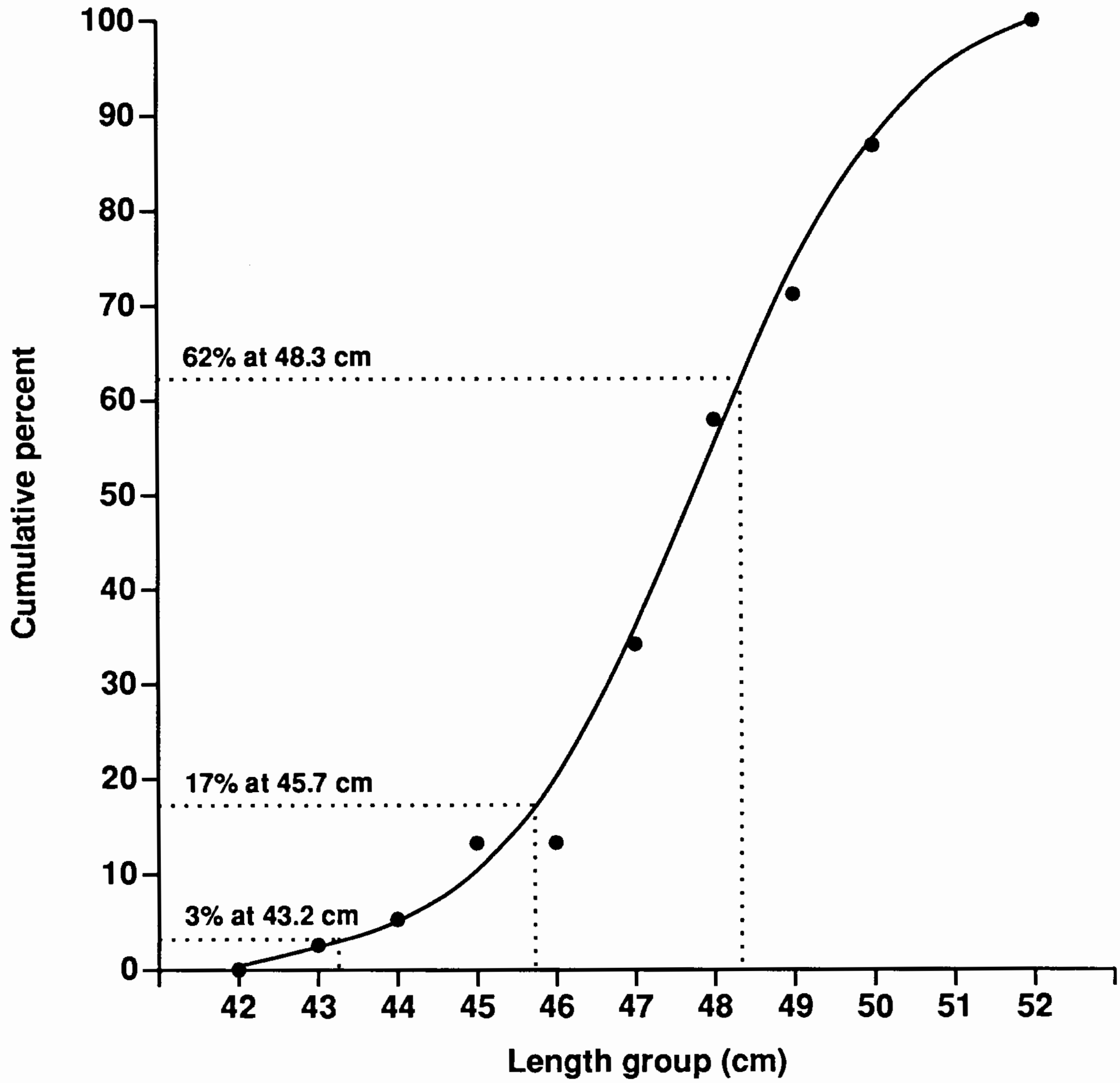

Figure 10.—Cumulative percentage of mature female whitefish captured in multi-mesh gill nets in Lake Michigan management unit WFM01, 1979-83.

Table 1.—Mean frequency-at-age of whitefish in the landed trap-net catch, by Lake Michigan management unit.

Management unit	Age group	Mean frequency 1983-85	1984-86	1985-87	1986-88
WFM00	3	105	93	34	39
	4	327	364	251	160
	5	65	115	164	193
	6	8	10	23	40
	7	3	3	2	7
	8	0	1	0	3
	9	2	2	0	0
	10	2	1	0	0
	11+	3	3	0	1
	All	515	592	474	443
WFM01	3	66	61	53	73
	4	427	608	623	384
	5	58	259	376	484
	6	9	29	94	147
	7	6	4	10	33
	8	9	3	3	4
	9	4	3	2	2
	10	1	1	1	1
	11+	3	3	3	3
	All	583	971	1,165	1,131
WFM06	3	56	55	51	4
	4	80	133	98	81
	5	102	129	122	132
	6	90	75	56	93
	7	37	45	24	24
	8	15	20	19	19
	9	5	11	9	20
	10	3	3	4	9
	11+	8	9	5	7
	All	396	480	388	389
WFM08	3	31	22	22	8
	4	90	92	77	45
	5	87	144	183	177
	6	42	65	126	174
	7	26	47	56	71
	8	12	21	33	49
	9	5	9	19	37
	10	4	7	14	23
	11+	7	5	9	13
	All	304	412	539	597

Table 2.—Whitefish yield (kg), effort (trap-net lifts, trawl hours, 1,000s of gill-net feet) and catch per effort (CPE) in state and tribal fisheries, by Lake Michigan management unit and year.

Management unit	Jurisdiction	Gear	Statistic	Year 1983	1984	1985	1986	1987	1988
WFM00	State	Trap net	Yield	201,591	227,000	213,727	264,045	254,000	131,000
			Effort	2,482	2,365	1,890	2,523	2,138	1,873
			CPE	81.2	96.0	113.1	104.7	118.8	69.9
		Trawl	Yield	70,182	86,682	97,000	111,227	81,682	41,091
			Effort	447.50	589.20	568.60	607	547	408.10
			CPE	156.8	147.1	170.6	183.2	149.3	100.7
		Total	Yield	271,773	313,682	310,727	375,272	335,682	172,091
WFM01	State	Trap net	Yield	341,864	475,409	705,909	686,182	593,182	402,955
			Effort	3,147	3,743	4,432	4,848	4,954	4,415
			CPE	108.6	127.0	159.3	141.5	119.7	91.3
		Trawl	Yield	18,500	12,045	8,591	13,773	43,455	13,000
			Effort	87.5	84.0	48.5	97.0	242.7	140.0
			CPE	211.4	143.4	177.1	142.0	179.0	92.9
	Tribal	Trap net	Yield	31,409	36,591	12,682	---	---	---
			Effort	486	584	230	---	---	---
			CPE	64.6	62.7	55.1	---	---	---
		Gill net	Yield	95,136	173,727	260,182	---	---	---
			Effort	3,116.8	3,607.7	4,328.1	---	---	---
			CPE	30.5	48.2	60.1	---	---	---
	All	Total	Yield	486,909	697,772	987,364	699,955	636,637	415,955
WFM06	State	Trap net	Yield	23,773	16,227	9,045	4,864	11,273	9,727
			Effort	504	446	334	130	208	240
			CPE	47.2	36.4	27.1	37.4	54.2	40.5
	Tribal	Gill net	Yield	6,409	8,409	818	8,864	4,227	13,200
			Effort	152.1	127.5	131.5	286.0	97.2	260.4
			CPE	42.1	66.0	6.2	31.0	43.5	50.7
	All	Total	Yield	30,182	24,636	9,863	13,728	15,500	22,927
WFM08	State	Trap net	Yield	50,000	44,182	42,545	80,682	53,409	63,995
			Effort	523	370	315	610	427	531
			CPE	95.6	119.4	135.1	132.3	125.1	120.5

Table 3.—Relative abundance at age of whitefish in the landed trap-net catch as expressed by the number caught per trap-net lift, by Lake Michigan management unit and year class.

Management unit	Year class	Age 3	4	5	6	7	8	9	10
WFM00	1977	---	---	---	1.7	0.6	0.0	0.0	0.0
	1978	---	---	18.0	1.4	0.4	0.2	0.0	0.0
	1979	---	41.0	6.1	1.3	0.2	0.0	0.0	---
	1980	15.0	59.7	17.2	2.6	0.6	1.0	---	---
	1981	21.9	71.1	44.2	14.8	2.6	---	---	---
	1982	17.7	50.9	57.9	7.9	---	---	---	---
	1983	1.7	40.9	24.8	---	---	---	---	---
	1984	0.0	15.2	---	---	---	---	---	---
	1985	15.2	---	---	---	---	---	---	---
WFM01	1977	---	---	---	5.7	2.0	0.1	0.1	0.3
	1978	---	---	7.3	2.7	0.1	0.3	0.2	0.1
	1979	---	21.8	14.2	0.7	0.4	0.4	0.2	---
	1980	31.9	87.3	17.0	7.8	2.7	0.7	---	---
	1981	9.5	143.1	64.7	21.7	5.3	---	---	---
	1982	13.4	62.3	42.3	12.7	---	---	---	---
	1983	6.8	32.5	33.6	---	---	---	---	---
	1984	0.3	19.4	---	---	---	---	---	---
	1985	11.6	---	---	---	---	---	---	---
WFM06	1977	---	---	---	11.1	2.9	1.2	1.0	1.0
	1978	---	---	7.0	4.4	1.2	0.9	1.1	0.8
	1979	---	3.7	6.9	2.9	1.8	1.3	1.5	---
	1980	0.4	5.1	3.0	2.2	1.4	1.3	---	---
	1981	0.6	3.3	7.8	6.4	1.2	---	---	---
	1982	6.2	10.8	17.2	8.4	---	---	---	---
	1983	0.1	3.2	4.7	---	---	---	---	---
	1984	0.2	1.3	---	---	---	---	---	---
	1985	0.3	---	---	---	---	---	---	---
WFM08	1977	---	---	---	7.2	8.4	3.0	2.1	0.8
	1978	---	---	11.7	4.7	5.9	4.2	3.6	2.5
	1979	---	14.9	18.9	10.0	8.4	4.4	4.7	---
	1980	5.5	25.5	19.9	12.1	5.7	5.4	---	---
	1981	0.0	16.1	26.4	22.4	6.7	---	---	---
	1982	8.6	10.2	19.2	16.4	---	---	---	---
	1983	0.6	2.7	9.5	---	---	---	---	---
	1984	0.0	1.4	---	---	---	---	---	---
	1985	1.5	---	---	---	---	---	---	---

Table 4.—Annual total mortality rates of Lake Michigan whitefish based on 3-year averages, by management unit.

		Management zone			
Years	Statistic	WFM00	WFM01	WFM06	WFM08
1983-85	Mortality	0.81	0.83	0.51	0.48
	95% C.L.	±0.03	±0.03	±0.05	±0.07
	Ages	4-7	4-7	6-12	5-9
1984-86	Mortality	0.77	0.86	0.46	0.48
	95% C.L.	±0.03	±0.03	±0.04	±0.04
	Ages	4-8	4-7	5-12	5-12
1985-87	Mortality	0.88	0.78	0.49	0.45
	95% C.L.	±0.04	±0.03	±0.04	±0.03
	Ages	5-7	5-10	5-12	5-12
1986-88	Mortality	0.80	0.73	0.45	0.45
	95% C.L.	±0.04	±0.03	±0.04	±0.03
	Ages	5-8	5-8	5-12	6-12

Table 5.—Vital statistics of whitefish used to generate quotas with the Stock Assessment Program (Clark and Smith 1985).

Management unit	Years	Instantaneous mortality rates: Fishing (F)	Optimum Fishing	Natural (M)	Weight-length coefficients[1]: Intercept (a)	Slope (b)	von Bertalanffy coefficients: K (years^{-1})	L_∞ (mm)	t_0 (years)	Mean weight of fish in catch (kg)	Mean yield (1,000s kg)
WFM00	1983-85	1.21	0.60	0.45	-17.59	2.86	0.23	763.29	-0.03	1.0	298.7
	1984-86	1.02	0.60	0.45	-17.80	2.89	0.24	733.97	-0.03	1.0	333.2
	1985-87	1.67	0.60	0.45	-17.18	2.79	0.33	618.24	-0.01	1.0	340.6
	1986-88	1.16	0.60	0.45	-17.02	2.77	0.33	603.67	-0.01	1.0	294.3
WFM01	1983-85	1.32	0.60	0.45	-17.69	2.87	0.25	717.30	-0.02	1.0	724.0
	1984-86	1.52	0.60	0.45	-16.05	2.60	0.25	718.15	-0.01	1.0	807.3
	1985-87	1.04	0.60	0.45	-18.67	3.03	0.25	698.54	-0.02	1.0	786.9
	1986-88	0.86	0.60	0.45	-18.60	3.02	0.29	647.53	-0.02	1.1	595.0
WFM06	1983-85	0.26	0.60	0.45	-19.66	3.21	0.28	703.24	-0.04	1.5	21.7
	1984-86	0.17	0.60	0.45	-19.06	3.11	0.26	708.61	-0.04	1.5	16.2
	1985-87	0.22	0.60	0.45	-18.74	3.06	0.28	687.88	-0.03	1.5	13.0
	1986-89	0.15	0.60	0.45	-18.29	2.99	0.27	697.12	-0.02	1.5	15.8
WFM08	1983-85	0.20	0.60	0.45	-18.91	3.09	0.32	711.10	-0.02	2.0	45.6
	1984-86	0.20	0.60	0.45	-19.49	3.18	0.35	673.67	-0.01	1.5	55.8
	1985-87	0.15	0.60	0.45	-19.51	3.18	0.38	644.71	-0.01	1.5	58.9
	1986-89	0.15	0.60	0.45	-19.30	3.15	0.32	677.23	-0.01	1.6	66.0

[1]The intercept is "a" and the slope is "b" in the equation ln(Weight) = a + b (ln[length]).

Table 6.—Comparison of whitefish age frequencies between months, by Lake Michigan management unit.

Management unit	Years	Months compared	Sample size	D_{max}	Two-tailed probability
WFM00	1984-86, 1988	May vs July	741 881	0.137	<0.001
		May vs October	741 633	0.280	<0.001
		July vs October	881 633	0.162	<0.001
WFM01	1984-88	May vs July	1,485 1,312	0.093	<0.001
		May vs October	1,485 1,319	0.161	<0.001
		July vs October	1,312 1,319	0.092	<0.001
WFM06	1984, 1986-88	May vs July	841 698	0.058	0.147
	1984	May vs October	211 204	0.133	0.052
	1984	July vs October	159 204	0.081	0.601
WFM08	1986-88	May vs July	661 531	0.074	0.082
		May vs October	661 603	0.127	<0.001
		July vs October	531 603	0.159	<0.001

Table 7.—Comparison of whitefish age frequencies between Lake Michigan management units WFM00 and WFM01, by month, 1984-86.

Management unit	Month sampled	Sample size	D_{max}	Two-tailed probability
WFM00 vs	May	531	0.024	0.986
WFM01		996		
WFM00 vs	July	671	0.076	0.007
WFM01		861		
WFM00 vs	October	572	0.155	<0.001
WFM01		859		

Table 8.—Comparison of mean condition factors (K) of 3-year-old whitefish from Lake Michigan management units WFM00 and WFM01, by month, 1984-86.

Management unit	Month	K[1]	Degrees freedom	F ratio	Two-tailed probability
WFM00 vs	May	1.0997	1,506	1.32	0.251
WFM01		1.0830			
WFM00 vs	October	0.9937	1,710	136.63	<0.001
WFM01		0.9112			

[1]$K=(W/L^3)10^5$

Table 9.—Mean number of spawnings per captured female whitefish at various minimum size limits and fishing rates, 1986-88, in Lake Michigan management units WFM00 and WFM01.

Management unit	Minimum legal size (mm)	Fishing rate (F_{opt})	Mean number of spawnings
WFM00	432	1.16[1]	0.33
	432	0.60	0.66
	457	0.68	0.95
	483	0.73	1.61
WFM01	432	0.86[1]	0.52
	432	0.60	0.71
	457	0.63	1.04
	483	0.68	1.61

[1]Observed fishing rate

Table 10.—Quota estimate and yield of whitefish, by Lake Michigan management unit, 1986-89.

Management unit	Year	Quota (1,000s kg)	Reported yield (1,000s kg)	Percent yield over quota
WFM00	1986	182.3	375.3	106
	1987	226.0	335.7	49
	1988	172.8	172.1	0
	1989	182.6	---	---
WFM01	1986	407.6	700.0	72
	1987	356.8	636.6	78
	1988	539.2	416.0	-23
	1989	436.9	---	---
WFM06	1986	43.5	13.7	-69
	1987	48.6	15.5	-68
	1988	29.6	22.9	-23
	1989	59.2	---	---
WFM08	1986	138.9	80.7	-42
	1987	145.6	53.4	-63
	1988	193.5	64.0	-67
	1989	212.7	---	---

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APPENDIX

Appendix A.—Age frequency of whitefish in the landed trap-net catch, by year and Lake Michigan management unit. Unless specified, all whitefish were 432 mm or larger.

Manage-ment unit	Year	Age group	Month				Total
			Feb	May	Jul	Oct	
WFM00	1983	3	Not	24	Not	21	45
		4	fished	16	sampled	107	123
		5	---	7	---	47	54
		6	---	0	---	5	5
		7	---	0	---	2	2
		8	---	0	---	0	0
		9	---	0	---	0	0
		10	---	0	---	4	4
		11	---	0	---	0	0
		12+	---	0	---	0	0
	1984	3	Not	4	65	106	175
		4	fished	116	239	122	477
		5	---	10	18	21	49
		6	---	0	0	11	11
		7	---	0	0	5	5
		8	---	0	0	1	1
		9	---	0	0	5	5
		10	---	0	0	2	2
		11	---	0	0	5	5
		12+	---	0	0	3	3
	1985	3	Not	4	31	60	95
		4	fished	160	101	120	381
		5	---	41	17	34	92
		6	---	3	1	3	7
		7	---	0	1	1	2
		8	---	0	0	0	0
		9	---	1	0	0	1
		10	---	0	0	1	1
		11	---	0	0	1	1
		12+	---	0	0	0	0
	1986	3	Not	1	1	6	8
		4	fished	87	110	38	235
		5	---	99	83	22	204
		6	---	5	4	3	12
		7	---	0	0	1	1
		8	---	0	0	1	1
		9	---	0	0	0	0
		10	---	0	0	0	0
		11	---	0	0	0	0
		12+	---	0	0	1	1

Appendix A.—Continued:

Manage-ment unit	Year	Age group	Month				Total
			Feb	May	Jul	Oct	
WFM00	1987	3	Not	0	0	Not	0
		4	fished	50	87	sampled	137
		5	---	112	84	---	196
		6	---	22	28	---	50
		7	---	0	2	---	2
		8	---	0	0	---	0
		9	---	0	0	---	0
		10	---	0	0	---	0
		11	---	0	0	---	0
		12+	---	0	0	---	0
	1988	3	Not	26	48	35	109
		4	fished	45	52	12	109
		5	---	94	76	8	178
		6	---	29	23	5	57
		7	---	10	9	0	19
		8	---	5	2	0	7
		9	---	0	0	0	0
		10	---	0	0	0	0
		11	---	0	0	0	0
		12+	---	1	0	1	2
WFM01	1983	3	Not	Not	32	47	79
		4	sampled	sampled	23	31	54
		5	---	---	5	13	18
		6	---	---	1	13	14
		7	---	---	1	9	10
		8	---	---	1	19	20
		9	---	---	0	6	6
		10	---	---	0	2	2
		11	---	---	0	1	1
		12+	---	---	0	0	0
	1984	3	Not	4	6	18	28
		4	sampled	173	51	34	258
		5	---	28	8	6	42
		6	---	6	0	2	8
		7	---	1	0	5	6
		8	---	1	0	4	5
		9	---	2	1	1	4
		10	---	0	1	0	1
		11	---	1	3	1	5
		12+	---	0	1	1	2

Appendix A.—Continued:

Management unit	Year	Age group	Month				Total
			Feb	May	Jul	Oct	
WFM01	1985	3	Not	3	38	50	91
		4	sampled	357	396	217	970
		5	---	76	16	23	115
		6	---	3	0	2	5
		7	---	0	0	1	1
		8	---	0	0	1	1
		9	---	0	0	2	2
		10	---	0	0	1	1
		11	---	0	0	1	1
		12+	---	0	0	1	1
	1986	3	1	1	6	57	65
		4	53	187	164	192	596
		5	117	148	156	198	619
		6	14	12	12	36	74
		7	1	0	0	3	4
		8	1	0	0	2	3
		9	1	0	1	0	2
		10	0	0	0	0	0
		11	0	0	0	0	0
		12+	0	0	1	0	1
	1987	3	0	0	1	2	3
		4	56	66	66	114	302
		5	172	92	52	77	393
		6	88	47	7	60	202
		7	6	4	0	15	25
		8	0	0	0	5	5
		9	1	0	0	1	2
		10	1	90	0	2	3
		11	0	0	0	3	3
		12+	0	0	0	4	4
	1988	3	0	5	50	97	152
		4	58	65	101	30	254
		5	170	119	126	25	440
		6	59	56	36	15	166
		7	18	34	11	7	70
		8	6	1	0	2	9
		9	2	0	0	0	2
		10	0	0	0	1	1
		11	1	0	0	0	1
		12+	0	0	0	0	0

Appendix A.—Continued:

Manage-ment unit	Year	Age group	Month Feb	May	Jul	Oct	Total
WFM06	1983	3	Not	2	Not	1	3
		4	fished	19	fished	8	27
		5	---	47	---	4	51
		6	---	63	---	18	81
		7	---	6	---	2	8
		8	---	1	---	0	1
		9	---	1	---	0	1
		10	---	1	---	0	1
		11	---	2	---	0	2
		12+	---	1	---	0	1
	1984	3	Not	9	0	6	15
		4	fished	48	41	45	134
		5	---	56	51	75	182
		6	---	38	38	41	117
		7	---	30	13	33	76
		8	---	2	9	4	15
		9	---	8	6	0	14
		10	---	5	0	0	5
		11	---	7	0	0	7
		12+	---	8	1	0	9
	1985	3	Not	24	Not	125	149
		4	fished	23	fished	57	80
		5	---	41	---	31	72
		6	---	33	---	38	71
		7	---	18	---	10	28
		8	---	15	---	14	29
		9	---	1	---	0	1
		10	---	2	---	0	2
		11	---	1	---	0	1
		12+	---	2	---	2	4
	1986	3	Not	1	1	Not	2
		4	fished	96	88	fished	184
		5	---	67	65	---	132
		6	---	13	24	---	37
		7	---	7	24	---	31
		8	---	7	8	---	15
		9	---	5	12	---	17
		10	---	0	1	---	1
		11	---	1	0	---	1
		12+	---	3	1	---	4

Appendix A.—Continued:

Manage-ment unit	Year	Age group	Month Feb	May	Jul	Oct	Total
WFM06	1987	3	Not	2	0	Not	2
		4	fished	21	9	fished	30
		5	---	117	44	---	161
		6	---	36	24	---	60
		7	---	11	2	---	13
		8	---	6	6	---	1
		9	---	5	5	---	10
		10	---	8	1	---	9
		11	---	1	2	---	3
		12+	---	1	1	---	2
	1988	3	Not	5	2	Not	7
		4	fished	17	11	fished	28
		5	---	50	53	---	103
		6	---	97	86	---	183
		7	---	11	16	---	27
		8	---	18	11	---	29
		9	---	7	25	---	32
		10	---	7	11	---	18
		11	---	6	6	---	12
		12+	---	1	0	---	1
			(≥432 mm)	(≥483 mm)	(≥432 mm)		
WFM08	1983	3	Not	Not	8	24	32
		4	fished	sampled	47	40	87
		5	---	---	31	37	68
		6	---	---	22	20	42
		7	---	---	9	4	13
		8	---	---	5	6	11
		9	---	---	0	5	5
		10	---	---	0	2	2
		11	---	---	1	6	7
		12+	---	---	3	2	5
	1984	3	Not	0	Not	Not	0
		4	fished	70	fished	sampled	70
		5	---	52	---	---	52
		6	---	13	---	---	13
		7	---	23	---	---	23
		8	---	5	---	---	5
		9	---	2	---	---	2
		10	---	3	---	---	3
		11	---	0	---	---	0
		12+	---	4	---	---	4

Appendix A.—Continued:

Management unit	Year	Age group	Month				Total
			Feb	May	Jul	Oct	
				(≥432 mm)	(≥483 mm)	(≥432 mm)	
WFM08	1985	3	Not	2	23	36	61
		4	fished	37	44	33	114
		5	---	11	100	30	141
		6	---	1	42	28	71
		7	---	2	26	14	42
		8	---	0	17	4	21
		9	---	1	5	1	7
		10	---	0	4	2	6
		11	---	0	4	1	5
		12+	---	0	0	0	0
	1986	3	Not	5	0	0	5
		4	fished	52	21	19	92
		5	---	87	91	61	239
		6	---	31	35	44	110
		7	---	27	22	27	76
		8	---	10	13	15	38
		9	---	8	4	7	19
		10	---	3	1	8	12
		11	---	1	1	0	2
		12+	---	3	3	0	6
	1987	3	Not	0	0	0	0
		4	fished	6	4	14	24
		5	---	37	35	97	169
		6	---	82	46	69	197
		7	---	27	8	15	50
		8	---	21	13	5	39
		9	---	19	10	3	32
		10	---	11	10	4	25
		11	---	3	3	2	8
		12+	---	4	3	0	7
	1988	3	Not	10	0	9	19
		4	fished	8	1	9	18
		5	---	36	15	73	124
		6	---	71	76	67	214
		7	---	34	39	14	87
		8	---	27	25	19	71
		9	---	22	24	15	61
		10	---	13	17	2	32
		11	---	3	6	2	11
		12+	---	0	3	1	4

Appendix B.—Maturity schedule of female whitefish in Lake Michigan management unit WFM01, 1979-83, cross-referenced by length and age.

Length group (cm)	Statistic	Age 3	4	5	6	≥7	Total
≤43	Sample N	178	45	2	---	---	225
	N mature	0	1	0	---	---	1
	% mature	0	2.2	0	---	---	0.4
44-45	Sample N	5	18	4	---	---	27
	N mature	1	3	0	---	---	4
	% mature	20.0	16.7	0	---	---	14.8
46-47	Sample N	1	11	8	---	---	20
	N mature	0	3	5	---	---	8
	% mature	0	27.3	62.5	---	---	40.0
48-49	Sample N	---	8	8	---	---	16
	N mature	---	7	7	---	---	14
	% mature	---	87.5	87.5	---	---	87.5
50-51	Sample N	---	4	5	---	---	9
	N mature	---	3	5	---	---	8
	% mature	---	75.0	100	---	---	88.9
52-53	Sample N	---	---	3	1	---	4
	N mature	---	---	3	1	---	4
	% mature	---	---	100	100	---	100
54-55	Sample N	---	---	3	1	---	4
	N mature	---	---	3	1	---	4
	% mature	---	---	100	100	---	100
≥56	Sample N	---	---	1	1	4	6
	N mature	---	---	1	1	4	6
	% mature	---	---	100	100	100	100
Total	Sample N	184	86	34	3	4	311
	N mature	1	17	24	3	4	49
	% mature	0.5	19.8	70.6	100	100	15.8