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BIOLOGICAL BASIS FOR MANAGEMENT OF LAKE WHITEFISH IN THE MICHIGAN WATERS OF NORTHERN LAKE MICHIGAN

MERCER H. PATRIARCHE

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BIOLOGICAL BASIS FOR MANAGEMENT OF LAKE WHITEFISH IN THE MICHIGAN WATERS OF NORTHERN LAKE MICHIGAN[1]

By Mercer H. Patriarche

ABSTRACT

Stocks of lake whitefish have supported an intensive commercial fishery in the Michigan waters of Lake Michigan for over a century. However, certain biological indicators suggest that recent upsurges in the catch reflect overfishing, and fish managers are instituting measures to assure a stabilized population and fishery. A biological basis for establishing quotas is described in this paper, using information from the 1968-1973 commercial fisheries in statistical districts MM-1 and MM-3 and a modification of Ricker's dynamic pool model. Natural mortality rates computed for an unfished population of whitefish in the lower end of nearby Grand Traverse Bay were important components of the model.

Quota recommendations were based on the premise that the annual harvest should be confined to weight gained each year by the harvestable portion of the population. Six computations of equilibrium yields were made. A comparison of actual harvests and adjusted yields revealed an annual overharvest, on the average, of 30% during this period in the two statistical districts.

Total biomass for six age groups (I-VI) in three Michigan statistical districts of northern Lake Michigan was computed to be 21.9 million kilograms in 1972. In MM-1 and MM-3, approximately 15.6 million kilograms (18.3%) of the total biomass was susceptible to exploitation. Corrected 1972 yields based on both biomass calculations and the modified dynamic pool model produced adjusted yields that differed by only 1.5%. A change in the minimum size limit (from 432 to 482 mm) to build up a depleted stock also was discussed. Increased spawning stock, more spawning opportunities and greater egg deposition should result from this regulation change.

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Introduction

Over the years the lake whitefish Coregonus clupeaformis (Mitchill), has provided a substantial portion of the commercial harvest in Lake Michigan, especially in Green Bay and the northern waters of the lake (Fig. 1). Large fluctuations are known to have occurred, as aptly described in a number of papers beginning with Milner (1874) and most recently by Wells and McLain (1973). Suffice to say here, whitefish were the backbone of the early fishery before 1900 with reported annual catches of over 4.5 million kilograms. By 1900, however, commercial production had dropped to around 726.4 thousand kilograms annually and stayed mostly in the range of 0.5 to 1.2 million kilograms for some 53 years. There were two brief periods during that time (1928-32 and 1947-49) when yearly harvests rose abruptly to over 2.3 million kilograms because of gear improvements, increases in fishing pressure and strong year classes. The latter peak was followed by a sharp decline to an average of only 22,700 kg in 1956-59. However, in Michigan waters alone the catch has since risen to over 900 thousand kilograms annually since 1971.

Intensive exploitation coupled with sea lamprey predation were the major influences on these stocks (Smith 1968; Walter and Hoagman 1971; Christie 1974; Scott 1974; Jensen 1976), the latter having a pronounced effect in the mid-fifties. Since about 1965, the lamprey has been brought under control, lake trout restocking has been substantial so that the remnant lamprey population no doubt resumed pursuit of its preferred prey, and certain management measures were introduced in Michigan to govern the whitefish harvest.

Despite this recent upsurge in harvest there is a persistent concern in the minds of several scientists that the Michigan population, at least, is actually being overfished. Evidence to support this concern stems not only from the age composition of the commercial catch (as opposed to that of the unfished population in nearby Grand Traverse Bay) but also such typical compensatory reactions as an increase in growth rate and a reduced age at first maturity (M. Keller personal communication). Reflecting this concern, Michigan authorities instituted a zone management plan in 1970, together with a limited entry concept designed both to rehabilitate the stocks and assure some profitability to all licensed fishermen. Furthermore, a controversial regulation was to be implemented in 1975 which banned all gill netting in the Michigan waters of Lake Michigan but allowed trap nets and pound nets to be used lawfully to harvest whitefish. The latter ruling was designed primarily to prevent a large incidental loss of lake trout (and some salmon) which are being stocked until natural reproduction is adequate to perpetuate the highly successful sport fishery. Catch quotas for whitefish could be the ultimate step in bringing the harvest under control and thereby stabilizing the fishery of the future. How best to determine the quotas is the subject of this paper. When data are available, a biological basis for setting quotas can provide a sound footing for management decisions although it is recognized that there are important economic, social, and political concerns that must be taken into consideration.

Age composition of commercial catch

Between 1932-1973 the Michigan commercial whitefish catch was sampled for age composition for 15 years in northern Lake Michigan, and 13 years in Green Bay. The resulting age distributions are shown in Figures 2 and 4. These data were compiled either from published papers (Roelofs 1958; DeMuth 1970), graduate theses, or unpublished data from reports and files of the Michigan Department of Natural Resources. By way of contrast, the data in Figure 3 show the age distribution of an unfished population in the lower half of Grand Traverse Bay for 1968-1973, as judged by fall catches in 115-mm mesh gill nets set for population information by fishery biologists. The latter data were summarized in the 1974 Lake Michigan Committee Report to the Great Lakes Fishery Commission.

Commercial fishermen used gill nets, pound nets, and trap nets in the whitefish fishery but most of the scale samples used for age determinations were taken from fish caught in impoundment gear. Gill nets are deemed somewhat more selective as to size of fish caught where mesh size is restricted to one dimension. A minimum mesh size of 115 mm (stretched measure) for all whitefish gear has been in effect for many years. Mraz (1964) indicated that this mesh size captured relatively few whitefish under 432 mm and was relatively ineffective for the largest fish in Green Bay. Cucin and Regier (1966) found almost the same thing for Georgian Bay stocks. Pound nets and trap nets retain a wider range of fish. Only the 1948 and 1949 Lake Michigan data shown in Figure 2 were from gill net catches.

In northern Lake Michigan the information for 1932, 1948-49, and 1960-62 was compiled by Brown (1968) from collections obtained by scientists in the U.S. Bureau of Commercial Fisheries, along with his own collections for 1967. Roelofs (1958) reported on the 1950 stocks. Piehler (1967) analyzed the 1965 (fall) and 1966 catches, and the more recent data (1968-1973) were compiled by biologists in the Michigan Department of Natural Resources.

Whitefish 4 years old and older were prevalent in catches in northern Lake Michigan prior to 1960 (Fig. 2). In 1932, younger fish comprised only 8.5% of the catch, 4-year-olds 77%, and the balance consisted of older fish. A similar situation prevailed in 1948-1950 during which time the strong 1943 year class dominated the population. Since 1960, at least, mortality has been high among whitefish 3 and 4 years old. This is in marked contrast with the age structure of the unfished population in nearby Grand Traverse Bay (Fig. 3) which contains fish up to 10 and 11 years of age.

In discussing the Bay de Noc data for 1949-1954, Roelofs (1958) pointed out that only fish of legal size (432 mm and over) were utilized for those analyses and no samples were from gill nets. Age groups VI and VII dominated the catches in 1949 and 1950, respectively (Fig. 4), because of the presence of the unusually large 1943 year class that produced record catches in the late forties (Hile et al. 1953). However, for at least the next 4 years (1951-54) whitefish from age-group III completely dominated the catches. Mraz (1964) described the same situation for whitefish stocks in the Wisconsin waters of Green Bay during this period. Since 1965, young fish also furnished the bulk of the catch elsewhere in the lake as well as in

Green Bay, as revealed by the work of Piehler (1967), DeMuth (1970), Tyra (1971) and subsequent data compiled by Michigan biologists. Roelofs pointed out the precarious position of a fishery dependent upon a single age group of fish each year, illustrating same by recalling the disastrous results of apparent spawning failure in 1952 and 1953. Only 31,780 kg and 5,000 kg of whitefish were taken in 1955 and 1956 respectively, but these years also were the years of peak abundance for the sea lamprey. In 1948, 1.4 million kilograms were harvested.

Growth and maturity

The references noted in the previous section also provide the source material for this brief resumé of growth history since 1932 (Table 1). Caraway (1951) used a correction factor of 40 mm for back calculation of growth in 1949 and 1950, and this factor also was used by Piehler (1967) and Brown (1968) in their calculations of growth rates for 1932, 1966, and 1967. Other workers used a simple, direct proportion for the body-scale diameter relationship, as reportedly used for other populations by Van Oosten (1939), Dryer (1963), and Mraz (1964). Sexes were combined because there were no differences. The use of a correction factor produces a somewhat larger calculated value than would otherwise be obtained (especially in the first year) but does not affect the subsequent quota and biomass calculations. All scale samples came from fish caught in commercial impoundment gear.

Mean lengths at various ages in different years are shown in Figure 5 for Green Bay and Figure 6 for northern Lake Michigan and Grand Traverse Bay. Because of the relative scarcity of whitefish older than 3 or 4 years, most of the comparisons are confined to the younger age groups. In Figure 5 one can see the pronounced difference in growth between 1949-50 and the more recent years (1966-73) in Green Bay which reflects a faster growth rate in the later years. Populations in northern Lake Michigan (Fig. 6) likewise show this more rapid growth than that which occurred in earlier years (1932, 1949, 1950). The unfished stocks in Grand Traverse Bay fall within the range of growth achieved in former years. Populations of whitefish in recent years attain the legal minimum size of 432 mm nearly one year sooner than some 23 years ago.

Roelofs (1958), Piehler (1967) and Brown (1968) suggested the possibility there were a number of discrete populations along the north shore of Lake Michigan because of apparent differences in growth but these conjectures are debatable. Green Bay stocks, however, are treated as a separate entity. The 1949-50 data came from grounds off St. Helena (St. Helens) Island in the northeastern corner of the lake, in the vicinity of Beaver Island (Garden, High, and Gull islands), and near South Fox Island to the south. The mean calculated lengths of 4-year-old whitefish captured near St. Helena Island were greater at each age than comparable lengths for the other stocks but there was only a sample of 12 fish. Growth appeared to be much slower near South Fox Island but the back calculations were done from whitefish 6-8 years old whereas only 4-year-olds were used for the other computations. Lee's phenomenon might well account for the apparent differences here. There were no real differences in growth among the "Beaver Island" samples.

Piehler demonstrated some differences in growth rate for age-II whitefish between the several samples acquired in 1966. Brown sampled commercial catches at three sites along the north shore in 1967--Seul Choix, Naubinway, and Brevort. Beginning in 1968, the catches were sampled at Seul Choix and Epoufette (midway between Naubinway and Brevort). Brown's calculations suggested that whitefish caught in the vicinity of Seul Choix grow faster than those captured at the other areas to the east, at least during their first 3 years of life, but by the time they were 4 years old there was little difference in average length. On the other hand, a comparison of weighted mean lengths for fish sampled in 1968-73 at Seul Choix and Epoufette showed little difference for the first 3 years of life (Table 1). Other evidence presented by Brown to show that the stocks near Naubinway might be discrete included significant differences in age composition, slope of the length-weight curve and age at maturity. The distances between these adjacent sites are no more than 32 km.

Length-weight relationships were computed for the three major areas using the most recent available data (1971-73) and were as follows:

Green Bay: $\text{Log}_{10}\ W_g = -2.3323 + 3.1780\ (\log_{10} L_{mm})$

Grand Traverse Bay: $\text{Log}_{10}\ W_g = -2.5487 + 3.4552\ (\log_{10} L_{mm})$

North shore: $\text{Log}_{10}\ W_g = -2.4106 + 3.2783\ (\log_{10} L_{mm})$

The relationship for the north shore population is not significantly different from the others for fish longer than 200 mm in Green Bay or 285 mm in Grand Traverse Bay. Also, between the two bays there is no difference for fish 380-457 mm long but for shorter and longer fish the equations for the two bay populations are statistically different. In view of all the above uncertainties, subsequent yield calculations were made under the assumption there is one population along the north shore of Lake Michigan but separate populations in Grand Traverse Bay and Green Bay.

A consensus of several studies showed that many males first become mature in Lake Michigan in their third year of life (33-59%) and virtually all are mature in their fourth year (age-group III). Very few females (less than 5%) become mature before their fourth year of life but, by the fall of that year, 89-100% are capable of spawning. Translated into size groups, few whitefish under 380 mm are mature. Brown (1968) found some 330-mm males and 355-mm females that were mature. However, both DeMuth (1970) and Tyra (1971) saw no mature fish under 368-380 mm long. Nearly all 432-mm males are mature (83-99%) whereas only about 70% of the females are mature at this length. Virtually all whitefish 456 mm and longer of both sexes are mature. Mraz (1964) noted essentially the same distribution of mature fish at these ages and sizes in the Wisconsin waters of Green Bay. Piehler (1967) reported the smallest mature male and female he saw in 1966 was 368 mm and 426 mm, respectively, whereas the largest immature male and female fish were 592 mm and 498 mm, respectively. There was a much higher percentage of age-II fish of both sexes mature in Bay de Noc in the fall catches in 1966 than elsewhere.

Mortality rates

These whitefish populations have experienced high mortality rates over the years as has been documented several times and is implied in the previous discussion of age composition of the catches. A summary of the total mortality rates that have been calculated is presented in Table 2. The value shown for Grand Traverse Bay is a geometric mean covering six years of population sampling in the southern half of the bay where no commercial fishing is permitted. Consequently, this rate of 54% represents a natural mortality rate for these older fish, which is considerably less than the mean total mortality of 71% for the 4- and 5-year-old fish in the exploited population in the lake. The latter becomes 80% if the low values of 1968 are omitted. The true difference between the rates for the exploited and unexploited populations is probably more pronounced than shown since all fish in Grand Traverse Bay were caught in 115-mm mesh gill nets. Cucin and Regier (1966) point out that mortality rates estimated from the age composition of fish caught in gill nets of one mesh size are somewhat inflated because of selectivity.

The unexploited population in Grand Traverse Bay offered a valuable source of natural mortality rates that is not commonly available. Between 1968 and 1973, the whitefish population in the bay was sampled annually with gill nets for age composition for comparison with nearby commercially exploited stocks (Great Lakes Fishery Commission 1974). The accompanying table (Table 3) shows the percentage age composition of the catches in the bay, together with survival rates for the several age groups. The latter are the ratios for pairs of adjacent ages. Complements of these mean survival rates (natural mortality) were then plotted against age and a regression line drawn by inspection (Fig. 7). Natural mortality rates for age groups IV and older were read directly from the figure; those for age-groups II and III were obtained by extrapolation. The availability of these estimates for natural mortality was the key to the subsequent calculations of production and yield. It is true that extrapolation of the regression line between age II and 0 would be fictitious since it is well known that mortality is extremely high for very young fish especially fry, but it is also an accepted fact that a year class is established by the end of the first year of life. Extrapolation to age I is not advisable but, for older ages, it should be reasonable. Conversion of natural mortality rates to instantaneous rates produced the following instantaneous rates of natural mortality:

Age-group	Rate
II	0.20
III	0.29
IV	0.30
V	0.45

Survival rates for the exploited populations in 1968-73 along the north shore of Lake Michigan and in Green Bay were calculated by comparing catch-per-unit-of-effort (CPE) values by impoundment gear for year classes in successive years. This method was used by Gulland (1955) for trawl fisheries and illustrated by Ricker (1975). The method can be used where the gear is fairly well standardized and has the advantage of using the most recently available data. Survival (S) is determined by, say, dividing the CPE of a year class in Year 2 by the CPE of the same year class in

Year 1, after which the instantaneous rate of total mortality (Z) is obtained from $\log_e$ (S). Since estimates of natural mortality (M) were available from Grand Traverse Bay populations, an estimate of instantaneous fishing mortality (F) was derived simply by subtracting M from Z . Table 4 contains mortality information for the exploited population in northern Lake Michigan in 1972, using CPE data for 1972 and 1973.

The procedure for computing CPE values involved the following steps. Commercial catches are reported monthly by round weight. Total weight was converted to an estimated total number of fish by dividing the total weight by the mean weight of individuals sampled in the catch. Commercial catches were monitored in June and October, at which time scale samples were taken. The age composition of the spring and fall samples was assumed to be representative of the respective total catches for the first and second halves of the year and was extended to these respective semi-annual total catches. After combining these totals, a CPE for each age group was available for the mortality calculations described above.

Surplus production vs yield

Ricker (1975) described a method for computing equilibrium yield per recruit which utilizes instantaneous rates of growth and mortality. This procedure was adapted, with some modification, for the quota calculations described in this section. The quota recommendations that emerged from this application are based on the premise that the annual harvest of a population should be confined to the weight gained each year by the harvestable portion of that population (surplus production). If this were done the population should maintain a status quo.

The derivation of the exponential mortality rates has been described. Instantaneous growth (G), by definition, is the natural logarithm of the result of dividing the average weight of members of a year class at the end of the year by the initial mean weight at the beginning of the year or growing season. Mean weights obtained in 1969 were used for calculations prior to 1971; the G for 1971-73 periods was computed from weights obtained in May 1972. With one exception, the age at entry was III; age II was used in 1968 for Green Bay. The mean weight of a year class during a calendar year is represented by the symbol $\overline{W}$.

Equilibrium yield calculations were made for harvests in 1968, 1970, 1971 and 1972 in the northern end of Lake Michigan in statistical district MM-3; 1968 and 1972 for Green Bay (MM-1). The boundaries of the statistical districts were described by Smith et al. (1961). The gaps in the sequence resulted from failure for one reason or another, to monitor the fisheries in 1970 and 1974 in Lake Michigan proper; 1970, 1971, and 1974 in Green Bay. An example of the tabulations is presented in Table 5 for the calculations of production ($G\overline{W}$) and yield ($F\overline{W}$) per 1,000 recruits for 1972 in Lake Michigan, using information from the 1972 and 1973 catches.[2] For these computations, the age at entry into the fishery was III and the mean weight of 3-year-old whitefish was 817 g or 817 kg for 1,000 recruits. At the outset, total production and yield values were not the same and several iterations were required to overcome this disparity, using various fractions

[2] See Ricker (1975, pp. 238) for a detailed example of the calculations.

of F (holding M at the same rate) until yield approximated the production value. This can be done with a desk calculator but utilization of a computer program, described by Paulik and Bayliff (1967), will speed up the work considerably. This program computes only yield and biomass values but it could be modified to include production computations. Upon arriving at total $F\overline{W}$ and $G\overline{W}$ values that were approximately equal, the percentage difference between yield per 1,000 recruits ($F\overline{W}$) at the current rate of fishing for the year in question (1972) and the new "equalization" value of yield was noted. The "correct" harvest for the year was the reported total catch times the percent difference.

To illustrate further, yield per 817 kg of 3-year-old recruits was calculated using the F value for the actual fishing conditions in effect in 1972, as shown in Table 5. The result was 841 kg. However, production of new weight by these three age groups was only 432 kg per 817 kg of recruits, 409 kg less than were harvested. Through a series of iterations in which various fractions of F (and concurrently Z) were substituted, it was found that at a rate of 50% F production approximated yield (626 vs 604 kg). This latter yield of 604 kg was 28% below that obtained under the 1972 harvest rates (841 kg). The total reported catch from all gear used in 1972 was 725,640 kg. According to the above calculations this was 28% too high and the catch should have been in the neighborhood of 522,460 kg or a reduction of 203,180 kg in order to keep the population in equilibrium. Eighty-three percent of the 1972 catch was comprised of age-III fish.

The 1973 harvest amounted to 585,600 kg. Since no monitoring was done in 1974, the above procedure could not be used to evaluate this 1973 catch. Another way of estimating the equilibrium yield for 1973 is as follows. In 1973 there was a 64% decline in age-group III fish as judged by comparative CPE's in 1973 vs 1972 (Table 4). Sixty-four percent of the 1972 catch of III's (602,280 kg) is 385,460 kg. Referring to Table 5, at 50% F there should have been a catch of 210 kg for each 817 kg of age-III recruits. Thus 385,460 ÷ 817 = 470 and the 1973 harvest should have been the adjusted harvest of 1972 less 98,700 kg (210 × 470) or 423,760 kg. If satisfactory indices for age-group II were available, a quota for 1974 could have been computed on the basis of variations between the 1972 and 1973 values, allowing for natural mortality and/or some fishing mortality if it occurs. For example, any marked improvement in the population of 2-year-olds in 1973 over 1972 should be reflected in a substantial increase in number of age-III fish available to the fishery in 1974, with a concomitant upward adjustment in the allowable catch--or vice versa.

Computations of equilibrium yields were made on six different occasions, the results of which are presented in Table 6 which shows both the reported harvests and adjusted yields. Percentage differences ranged between -27 and -45, the geometric mean of which was -30%. With such consistent overharvesting it is indeed fortunate that the fishery has survived. Obviously a series of successful recruiting years has supported the fishery and the population.

Biomass

One of the keys to successful management of a fishery is information on the size of the population being managed. Regulating a fish population can be greatly simplified if plausible estimates of size can be obtained instead of relying on relative changes as indicated above. While direct counts are impossible for populations in a lake as large as Lake Michigan, there are ways of estimating the biomass by indirect means. One such method was used here whereby information on catch and mortality rates were combined to derive estimates of the whitefish biomass in the Michigan waters of Lake Michigan (including Green Bay), in 1972. The basic data were the commercial catches in pounds reported by month and gear for statistical districts MM-1 and MM-3. The rest of the northern waters under discussion lie in MM-2 but it has been closed to fishing since 1968.

Mortality rates were drawn from several sources. For age-groups I and II, total mortality rates were derived from the age composition of the whitefish catch in small-mesh gill nets set in 1969 at Seul Choix Pt. and used for the biomass calculations for MM-1 and MM-3. These averaged 0.80 for the two age groups. Rates for age-groups III, IV, and V were computed for the respective districts by Gulland's method as described previously (pp. 11), and a survival rate of 0.10 was estimated from the age structure of trap net catches in 1971 and 1972 for age-group VI in MM-3.

A final piece of information needed to go along with the other previously calculated parameters was the exploitation rates for as many age groups as possible. This rate (u) was calculated using the following relationship, as described by Ricker (1975):

$$\frac{Z}{A} = \frac{F}{u}$$

With estimates of either exploitation rates or mortality and survival rates at hand, along with total catches by age group, it was then possible to compute the numbers of whitefish of age-groups I-VI present at the beginning of 1972. The procedure is outlined below (estimated numbers rounded off to the nearest 10):

Green Bay

Age-group V: catch (13,280 ÷ exploitation rate (0.28) = an estimated population of 49,360 fish.

Age-group IV: catch (133,388) ÷ exploitation rate (0.77) = an estimated population of 173,230 fish.

Age-group III: catch (441,022) ÷ exploitation rate (0.48) = an estimated population of 918,800 fish.

Age-group II: the mean survival rate between ages II and III was 0.20; therefore, 918,800 age-III fish ÷ 0.20 = 4,593,980 fish.

Age-group I: the mean survival rate for age-group I was 0.20; therefore, 4,593,980 age-II fish ÷ 0.20 = 22,969,900 fish.

Lake Michigan (MM-3)

Age-group III: catch (663,660) ÷ exploitation rate (0.37) = 1,766,650 fish.

Age-group IV; catch (116,190) ÷ exploitation rate (0.60) = 193,650 fish.

Age-group V: catch (12,650) ÷ exploitation rate (0.24) = 52,690 fish.

Age-group VI: estimated number 5-year olds (52,690) ÷ survival rate for age V (0.10) = 5,270 fish.

Age-group II: estimated number 3-year olds (1,766,650) ÷ survival rate for age III (0.20) = 8,833,270 fish.

Age-group I: estimated number 2-year olds (8,833,270) ÷ survival rate for age II (0.20) = 44,166,350 fish.

Biomass (in kilograms) was obtained by multiplying the estimated number in each age group by the mean weight for that age in the 1972 catches. Results of all calculations (number and weight) appear in Table **7.**[3] Jensen (1976) used the logistic surplus production model to compute the biomass for MM-1 and calculated the biomass of the exploited stock (age III+) to be approximately 1 million kilograms using the gill net as standard gear, which agrees closely with the 0.9 million kilograms computed here using the dynamic pool model. Using the pound net as standard gear, however, Jensen's value for exploitable biomass was 4.5 million kilograms.

Statistical district MM-2 lies between Green Bay and MM-3 and is also an important whitefish-producing area. It has been closed to commercial fishing since 1968 and there have been no fishery surveys of consequence here. One could speculate that, with 4.5 million kilograms of whitefish in the Michigan waters of Green Bay and 10.1 million kilograms in MM-3, an intermediate mean biomass value of 7.3 million kilograms might

[3] The values shown here are somewhat lower than those calculated by Patriarche (1974) in Fisheries Research Report No. 1813 of the MDNR because of different natural mortality schedules.

well apply to these waters sandwiched in between the two areas. Thus, the estimated total biomass in 1972 was 21.9 million kilograms for six age groups of whitefish for the entire area.

In Green Bay and MM-3, approximately 18.3% of the 15.6 million kilograms total biomass for these two areas were 3 years old or older and susceptible to exploitation (2.85 million kilograms). The 1972 harvest was 1.29 million kilograms or 45% of the exploitable stock (Table 6). Previously it was determined that, on the basis of equilibrium-yield calculations, the harvest was 28% too high on the north shore (MM-3) and 32% too high for Green Bay (MM-1), so that the "correct" yield in 1972 should have been 30% less, on the average, or 890,000 kg (31% of the exploitable stock). The recommended combined yield for the two areas using the modified dynamic pool (Ricker) method was 903,690 kg (Table 6), a difference of only 1.5%.

Discussion

Up until now the objective was to establish a way to stabilize the fishery at the current population level by matching yield with production. This strategy should be satisfactory as far as it goes but there is no provision for building up a depleted stock. One way to do this is by arbitrarily cutting the equilibrium quota and permitting more spawners to survive for additional egg production. Another approach is to change the minimum size limit so as to allow greater escapement of immature fish. Over the years there has been a 432-mm (17.0-inch) size limit under which most age-III fish were subject to exploitation and many were removed from the population before spawning. If, for example, the minimum size limit were boosted to 482 mm (19.0 inches) this would give a large measure of protection for an additional year, enhance recruitment, increase the mean weight of fish caught, and help stabilize the population at a higher level of abundance.

In 1972, under the 432-mm minimum size limit a residual biomass of 1,675 kg was calculated for each 1,000 recruits at the fishing rates in effect that year for MM-3. If a 482-mm size limit had been imposed, there would have been a biomass of 2,276 kg per 1,000 recruits or a 36% increase in spawning stock. This amounts to an increase of 600 kg. Assuming a 1:1 sex ratio, this is equivalent to 300 kg of additional biomass of females. Fecundity data are not available for Lake Michigan whitefish but Cucin and Regier (1966) found the average fecundity in Georgian Bay to be 8,200 eggs per 454 g of adults, and the mean fecundity per pound in Lac la Ronge, Saskatchewan varied between 7,155 and 9,018 eggs (Qadri 1968). Christie (1963) examined 29 gravid females in Lake Ontario and found them to average 9,900 eggs per 454 g. Lawler (1961) reported fecundity data from 14 females from the 1944 year class in Lake Erie (mean weight was 1,480 g) which indicated a mean of 15,618 eggs per 454 g. Egg complements vary with fish size. A reasonable assumption would be 8,000 eggs per 454 g of age-III females which weigh almost 908 g on the average. Therefore, egg deposition under the 482-mm size limit would increase by an estimated 5.28 million eggs per 1,000 age-IV recruits [8,000 (300 ÷ 0.454)]. Christie and Regier (1972) published data for Lake Ontario whitefish populations that indicated, over a 13-year span, a mean survival from egg to age IV of 0.146 per 1,000 eggs. Assuming a survival rate of 0.00015 from egg to age IV, the boost in size limit would add 792 four-year-old recruits to the fishery for every 1,000 parents--over and above what was recruited under the 432-mm size limit.

One can infer that stock abundance is below carrying capacity in view of the much larger harvests that were formerly made plus the faster growth rate and earlier maturity exhibited in recent years. Hence, it is conceivable this added increment to the stock will promote a build-up within 4 or 5 years, at which time a leveling off will occur. The composition of the catch would change, with increased emphasis on older and larger fish. In 1972, 4- and 5-year-olds were captured at the rate of 469 kg per 1,000 recruits. If the age at entry into the fishery had been approximately IV (482-mm size limit), the catch of 4- and 5-year-olds would have amounted to an estimated 808 kg per 1,000 recruits--an increase of 72% by weight for these larger fish. Eventually more older and larger fish would be available to the fishery under this 482-mm regime.

However, the immediate cost to the fishery would be substantial. In 1972, for example, 78% of the catch in MM-3 consisted of fish 431-480 mm long, 65% in Green Bay (MM-1). In 1973, whitefish of this size comprised an estimated 47 and 52% of the total catch in the respective statistical districts.

There is mounting evidence that whitefish require more than one spawning, on the average, to perpetuate the stock. Abrosov (1969) observed that commercial production of whitefish in some Russian lakes fell off when the difference between age at first maturity and mean age of the catch (designated as 't') was below 1.5-2.0 years. From an analysis of whitefish stocks in Lake Ontario, Christie and Regier (1972) observed that female whitefish should have the opportunity to spawn an average of about 1.5 times in order to maintain the stock. An analysis of the 1973 catch in MM-3 revealed the Abrosov t value was only 0.61 and the mean number of opportunities the captured females had for spawning was only 0.6. If a 482-mm size limit had been imposed, the t value would have risen to 0.75 and the mean number of spawnings per female to 1.1. These calculations were based on 1973 maturity data in which all age-III and older females examined were mature and probably would spawn for the first time in their fourth year of life if not caught. In Green Bay the t value in 1973 was 0.37 and the mean number of spawnings was 0.4, based on 1973 maturity data which indicated 94% of 3-year-old females were mature. If a 482-mm size limit had been imposed, spawning opportunities for each female would have averaged 0.9 and t would have risen to 0.82. In both instances the t values and spawning times would tend to increase somewhat further with the build-up of older fish in the population under the continued imposition of the higher minimum size limit.

In summary, it would appear that over-exploitation of these whitefish populations has indeed taken place as indicated both by the above calculations for MM-1 and MM-3 and the computations by Jensen (1976) for MM-1. Relaxing the fishing pressure on these populations, or younger elements of same, would surely improve the fishery. Miller (1947, 1956) described the improvement in two Alberta lakes after fishing pressure was eased, and this management strategy also was advocated by Christie (1974) when he stated that "allowable yields would have to be appreciably lower than heretofore" in order to maintain stability in Great Lakes fisheries. Lake Michigan whitefish are no exception.

Acknowledgments

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Table 1.--Summary of mean, back-calculated lengths (mm) of lake whitefish in the Michigan waters of northern Lake Michigan.

Year	Location	Number of fish	Age I	Age II	Age III	Age IV	Age V
LAKE MICHIGAN (MM-3)							
1932[a]	Naubinway	63	160	254	353	435	508
1949-50[b]	Garden, High and Gull islands	54	137	231	325	432	
1949[b]	S. Fox Island	77	109	178	251	335	
1949[b]	St. Helena Island	12	170	269	376	470	
1966[c]	West of Seul Choix	94	211	373	472		
1966[c]	East of Seul Choix	43	190	333	437	490	
1966[c]	Naubinway	238	185	320	424	490	
1967[a]	Seul Choix	262	241	345	462	523	569
1967[a]	Naubinway & Brevort	496	223	310	424	500	561
1968-73[d]	Seul Choix	179	165	307	429		
1968-73[d]	Epoufette	183	160	305	411		
GREEN BAY (MM-1)							
1949-50[b]	Big Bay de Noc	88	137	241	353	457	
1966[c]	Big Bay de Noc	197	200	358	465		
1969-73[d]	Bay de Noc	174	170	310	419		
1969[e]	Green Bay	725	180	343	455	510	564
1970[f]	Green Bay	197	170	317	414	462	515
GRAND TRAVERSE BAY							
1968-73[d]	South end	183	132	246	406	444	498

[a] Brown (1958) [b] Roelofs (1958) [c] Piehler (1967)

[d] Michigan Department of Natural Resources

[e] DeMuth (1970)

[f] Tyra (1971)

Table 2.--A summary of estimated total mortality rates calculated for several age groups of lake whitefish in Lake Michigan.

Year	Source of fish	Age group	Percent total mortality	Method of computation[a]	Reference
GREEN BAY					
1951-54	Pound net	III	94	Age comp.	Roelofs (1958)
1968	Pound net	II	33	CPE	MDNR[b]
	Pound net	III	57	CPE	MDNR
	Pound net	IV	93	CPE	MDNR
1969	Gill net	III-VII	88	Age comp.	DeMuth (1970)
1971	Pound net	III	56	CPE	MDNR
1972	Trap net	III	66	CPE	MDNR
	Trap net	IV	89	CPE	MDNR
	Trap net	V	55	CPE	MDNR
LAKE MICHIGAN					
1967	Pound and	II	53	Age comp.	Brown (1968)
	trap	III	61	Age comp.	Brown (1968)
	"	IV	94	Age comp.	Brown (1968
1968	Trap net	III	59	CPE	MDNR
	Trap net	IV	42	CPE	MDNR
	Trap net	V	32	CPE	MDNR
1971	Trap net	III	71	CPE	MDNR
	Trap net	IV	86	CPE	MDNR
1972	Trap net	III	56	CPE	MDNR
	Trap net	IV	76	CPE	MDNR
	Trap net	V	55	CPE	MDNR
GRAND TRAVERSE BAY					
1968-73	Gill net	IV-IX	54	Age comp.	MDNR

[a] See text.

[b] Unpublished reports of Michigan Department of Natural Resources.

Table 3.--Percentage age composition of lake whitefish caught in 115-mm mesh gill nets set in the south end of Grand Traverse Bay (1968-1973), and survival rates between age groups.

Year	Number of fish	Age group IV	V	VI	VII	VIII	IX
Percentage age composition:							
1968	266	24	33	20	6	3	1
1969	526	25	19	29	10	4	1
1970	530	46	29	18	15	6	2
1971	228	35	37	13	4	4	4
1972	152	27	23	32	13	4	1
1973	100	10	27	26	14	11	5
Percentage survival:							
1968			61	30	50	33	
1969		76		35	40	25	
1970		63	62	83	40	33	
1971			35	31			
1972		85		41	31	25	
1973			96	54	79	46	
Mean		74	64	46	53	32	

Table 4.--Survival and instantaneous mortality rates calculated from CPE values in 1972 and 1973 for lake whitefish in northern Lake Michigan (MM-3). See text for explanation of symbols.

Age group	CPE 1972	CPE 1973	S	Z	M	F
III	152.9	55.2				
			0.44	0.82	0.29	0.53
IV	27.2	66.9				
			0.24	1.43	0.30	1.13
V	2.9	6.6				
			0.45	0.80	0.45	0.35
VI	1.3	1.3				

Table 5.--Production and yield-per-recruit values (kilograms) for the 1972 lake whitefish fishery in northern Lake Michigan (MM-3), using the illustrated instantaneous rates and the Ricker (1975) model. Empirical values of F were used in Part I; 1/2 F was used in Part II. Mean weight for age-III fish at the beginning of the year was 817 g.

Age group	G	Z	M	F	G-Z	e^{G-Z}	W	$\overline{W}$	Production ($G\overline{W}$)	Yield ($F\overline{W}$)
PART I							817			
III	0.45	0.82	0.29	0.53	-0.37	0.69		690	310	366
							564			
IV	0.32	1.43	0.30	1.13	-1.11	0.33		375	84	424
							186			
V	0.26	0.80	0.45	0.35	-0.54	0.58		147	38	51
							108			
Totals									432	841
PART II (final iteration)										
							817			
III	0.45	0.56	0.29	0.27[a]	-0.11	0.90		776	349	210
							735			
IV	0.32	0.87	0.30	0.57[a]	-0.55	0.58		580	186	331
							425			
V	0.26	0.63	0.45	0.18[a]	-0.43	0.65		350	91	63
							275			
Totals									626	604

[a] 50% F.

Table 6.--Total lake whitefish catches (kilograms) reported for 6 years in northern Lake Michigan (MM-3) and the Michigan waters of Green Bay (MM-1), calculated equilibrium yields (kilograms) and the percentage differences.

Location	Year	Total catch	Calculated equilibrium yield	Percentage difference
Lake Michigan	1968	298,730	218,080	-27
Lake Michigan	1970	483,620	372,390	-23
Lake Michigan	1971	641,750	352,960	-45
Lake Michigan	1972	725,640	522,460	-28
Green Bay	1968	50,740	36,030	-29
Green Bay	1972	560,630	381,230	-32

Table 7.--Estimated number and biomass (kilograms) of lake whitefish between the ages of I and VI at the beginning of 1972 in Green Bay (MM-1) and statistical district MM-3 in Lake Michigan.

Age group	Green Bay		MM-3	
	Number	Biomass	Number	Biomass
I	22,969,900	2,085,670	44,166,350	4,010,300
II	4,593,980	1,480,820	8,833,270	4,371,230
III	918,800	634,040	1,766,650	1,443,710
IV	173,230	202,120	193,650	248,800
V	49,360	65,880	52,690	93,540
VI			5,270	12,150
Totals	28,705,270	4,468,530	55,017,880	10,179,730

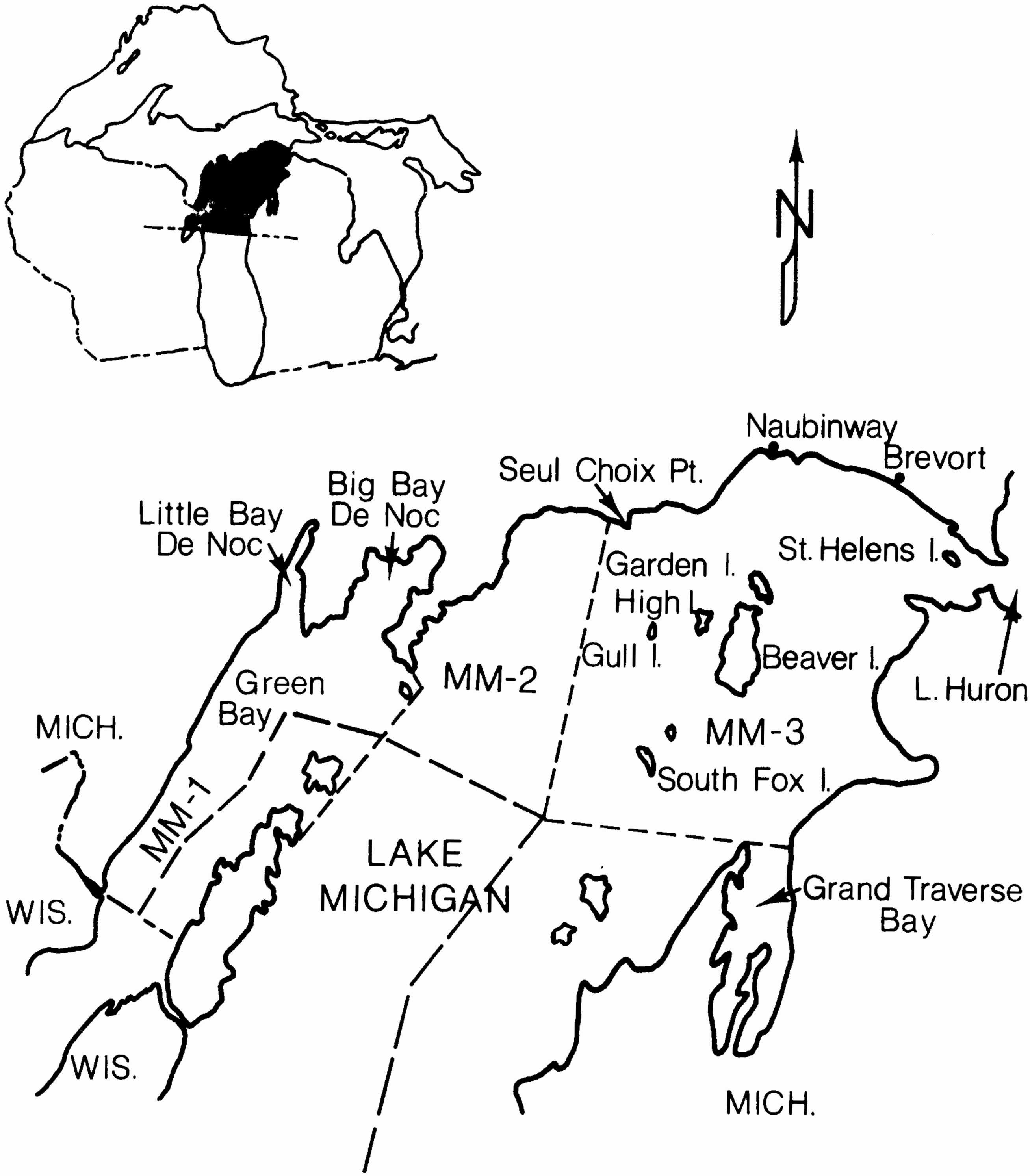


Figure 1.--Map of northern Lake Michigan upon which is shown the statistical districts and various sites mentioned in the text.

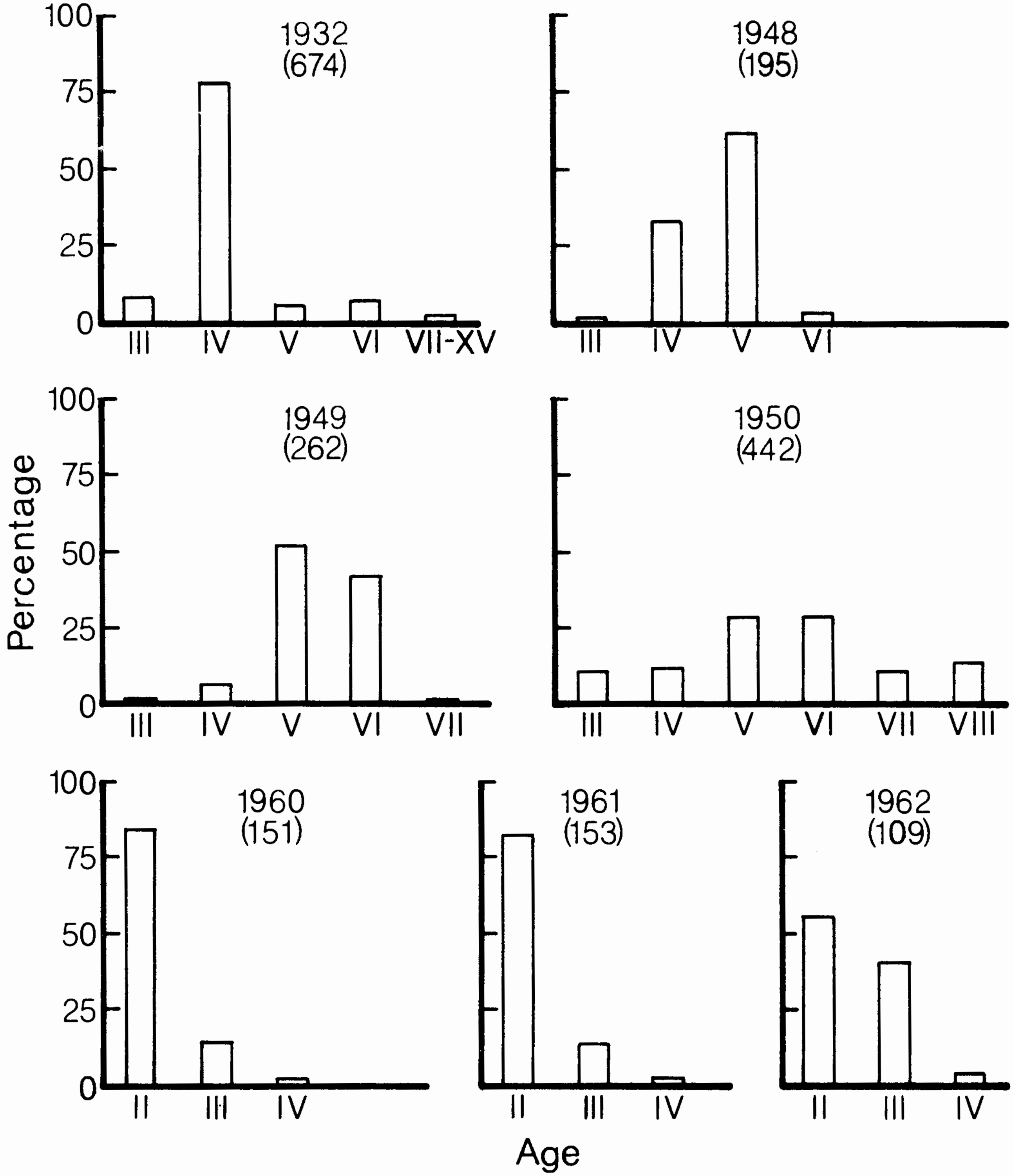


Figure 2.--Percentage age composition of lake whitefish sampled in commercial catches from northern Lake Michigan (Statistical District MM-3) in 1932-1973. Sample sizes in parentheses.

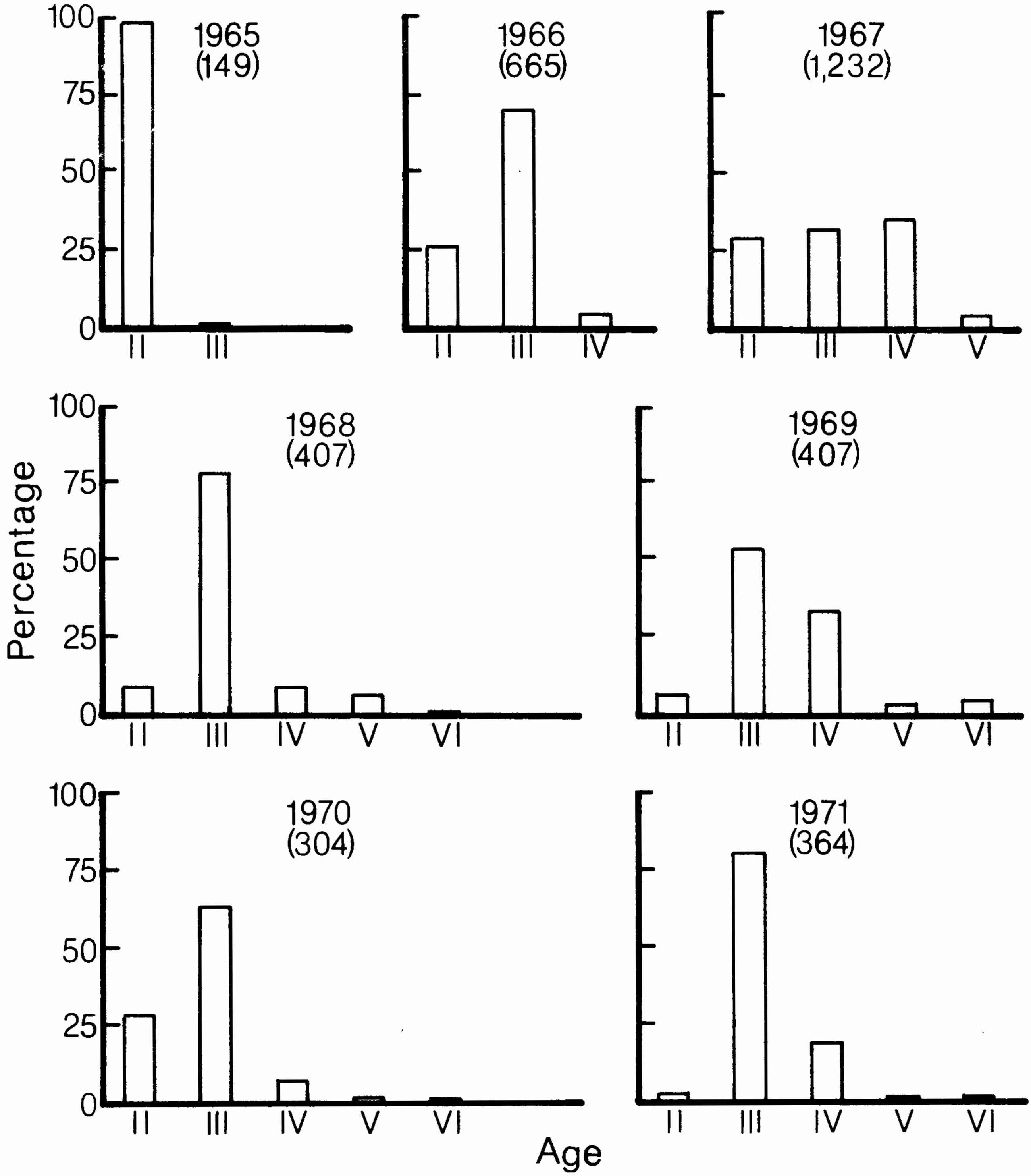


Figure 2. --continued

Figure 2.--concluded

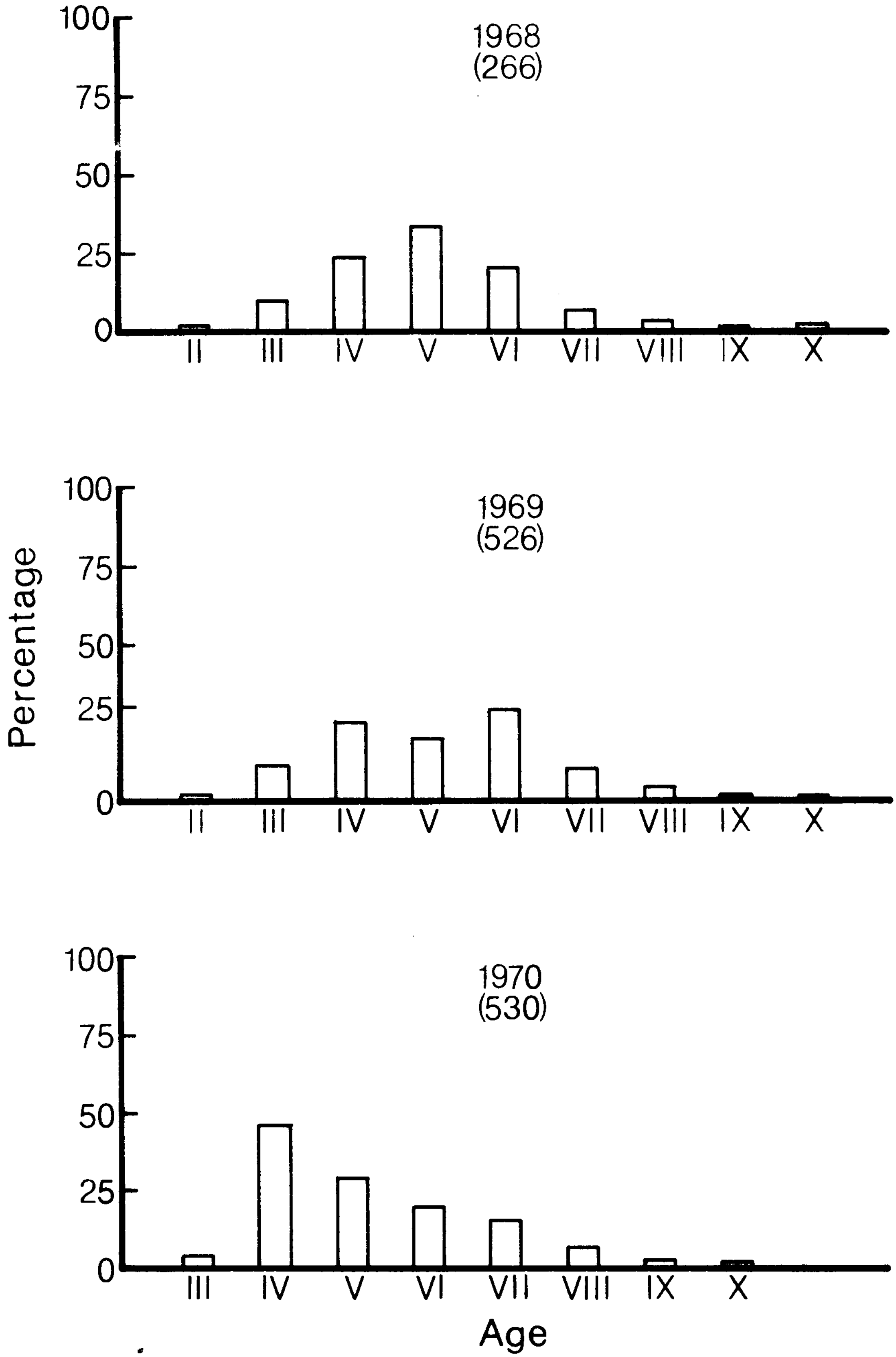
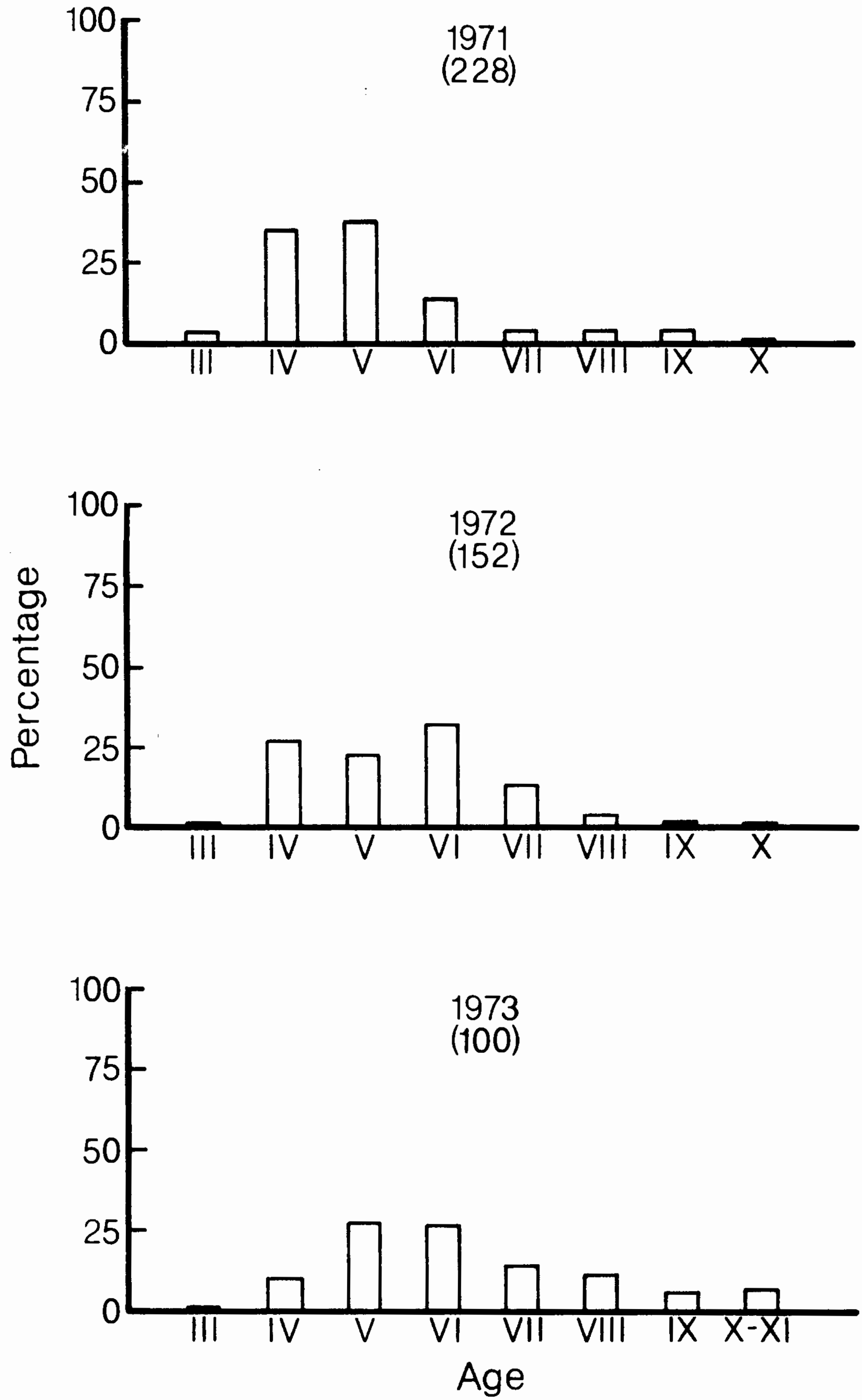


Figure 3.--Percentage age composition of lake whitefish caught in 115-mm gill nets in lower Grand Traverse Bay (1968-1973). Sample sizes in parentheses.



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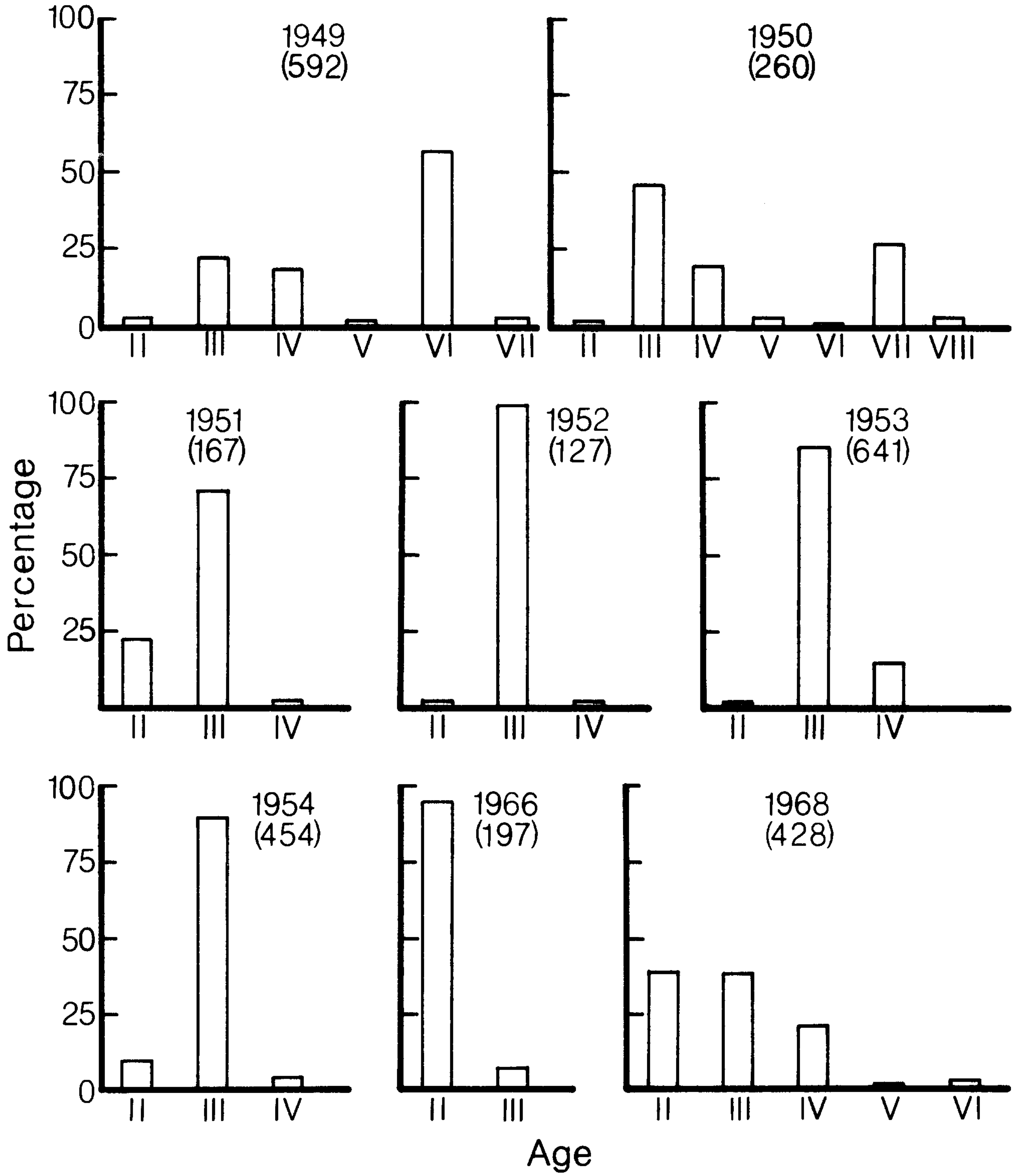

Figure 4.--Percentage age composition of lake whitefish sampled in commercial catches from the Michigan waters of Green Bay (Statistical District MM-1) in 1949-1973. Sample sizes in parentheses.

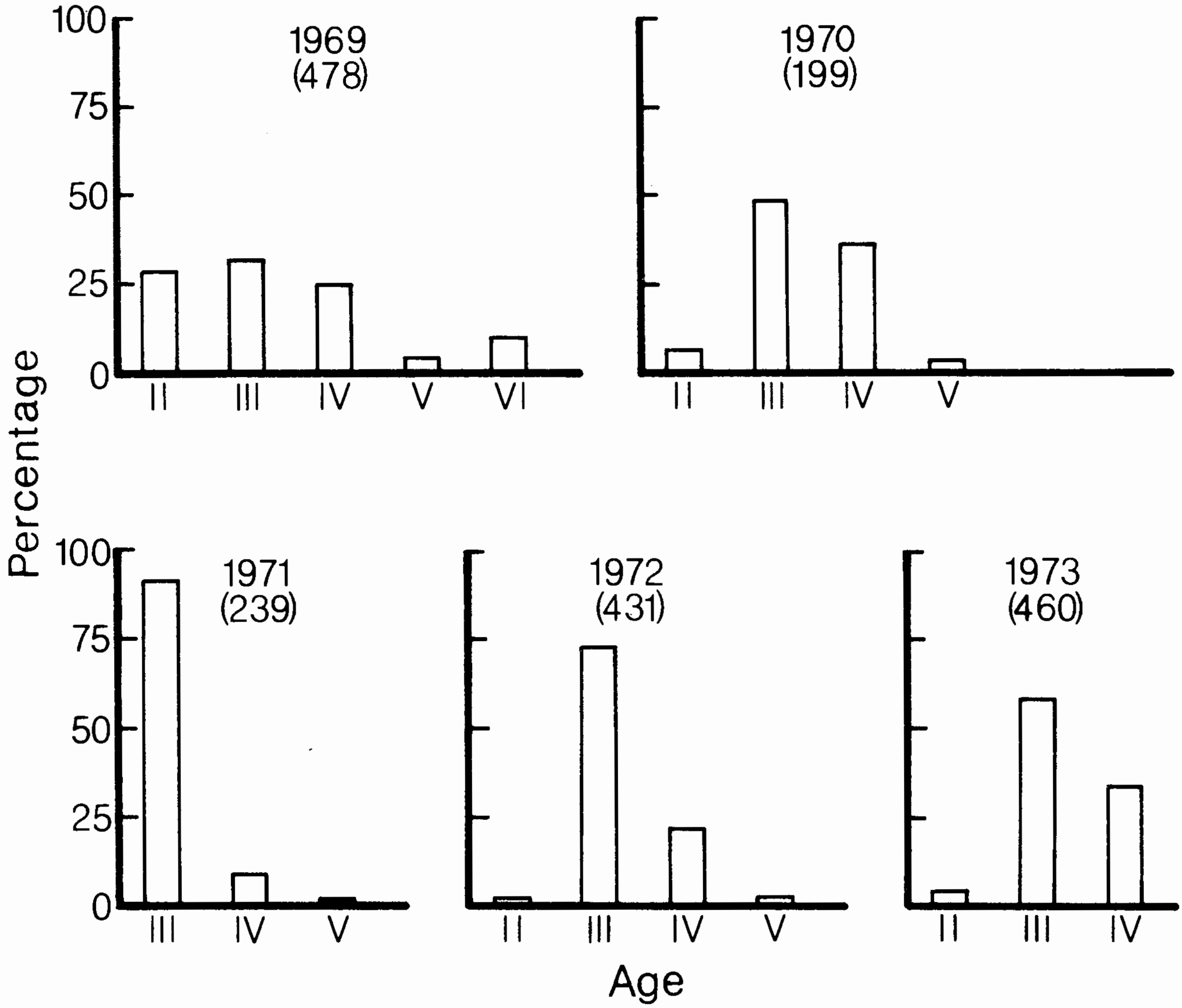

Figure 4.--concluded

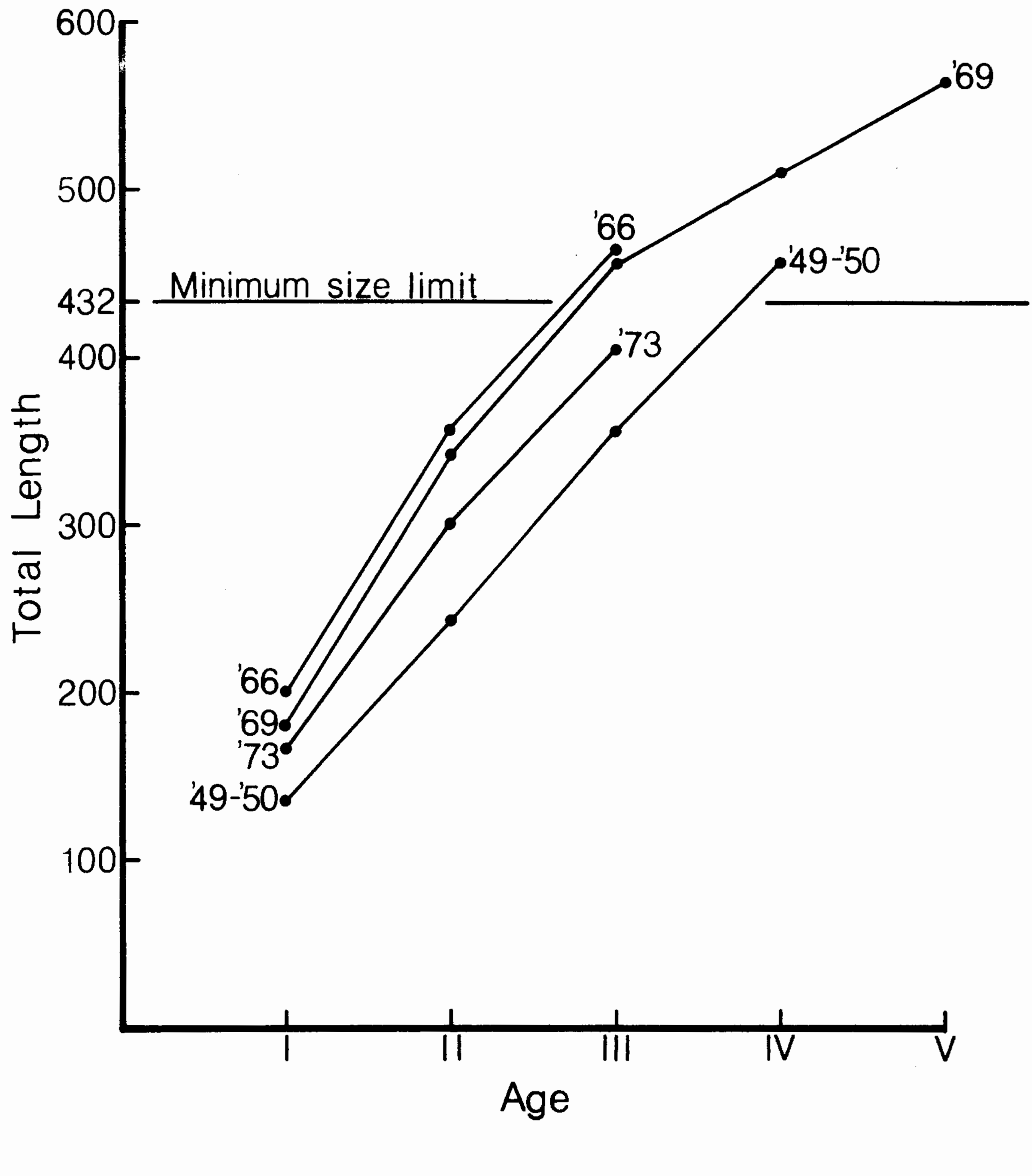

Figure 5.--Mean back-calculated lengths of lake whitefish captured in Michigan waters of Green Bay, 1949-1973.

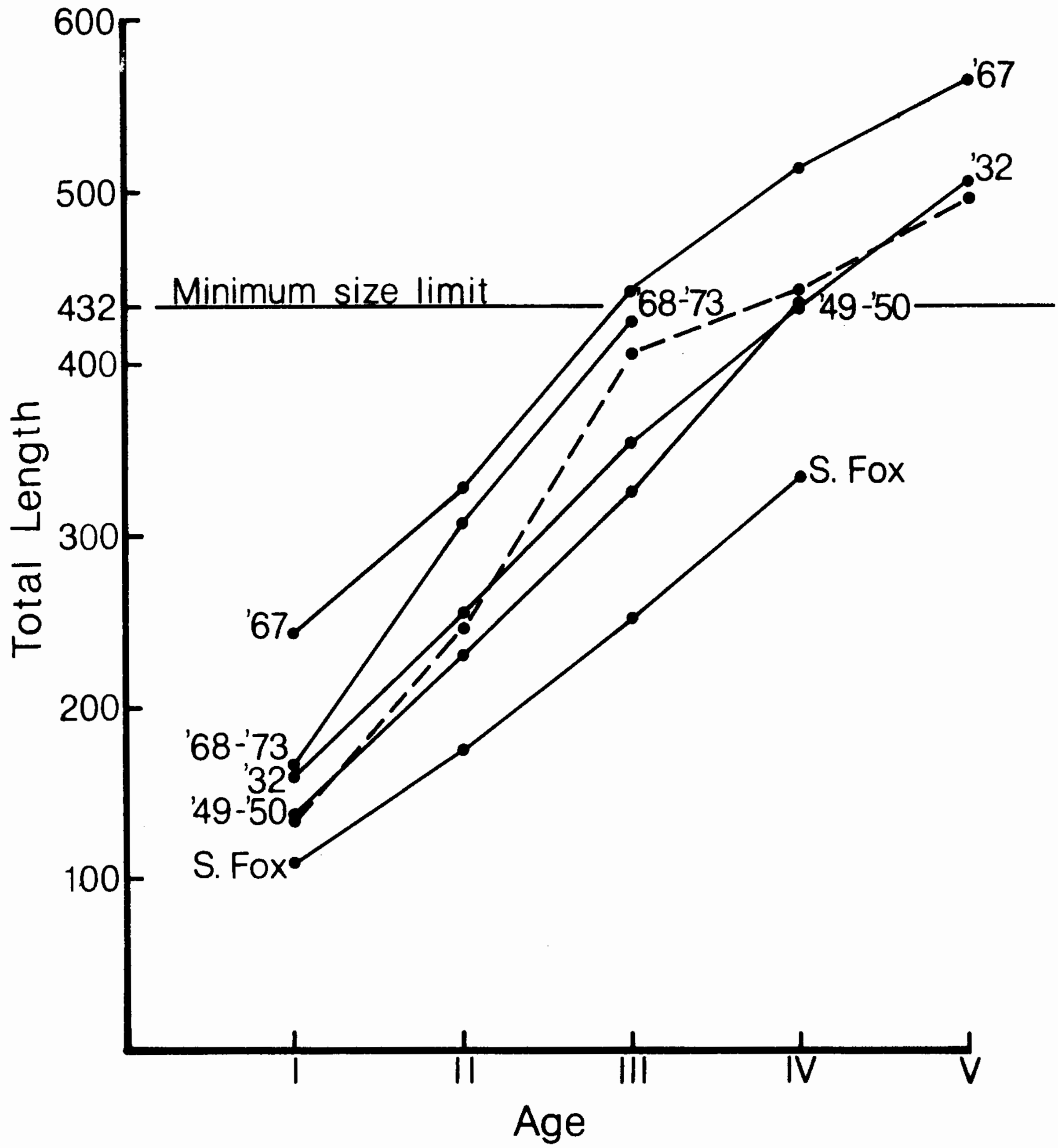

Figure 6.--Mean back-calculated lengths of lake whitefish captured in northern Lake Michigan (——) vs. 6-year mean for lower Grand Traverse Bay (----).

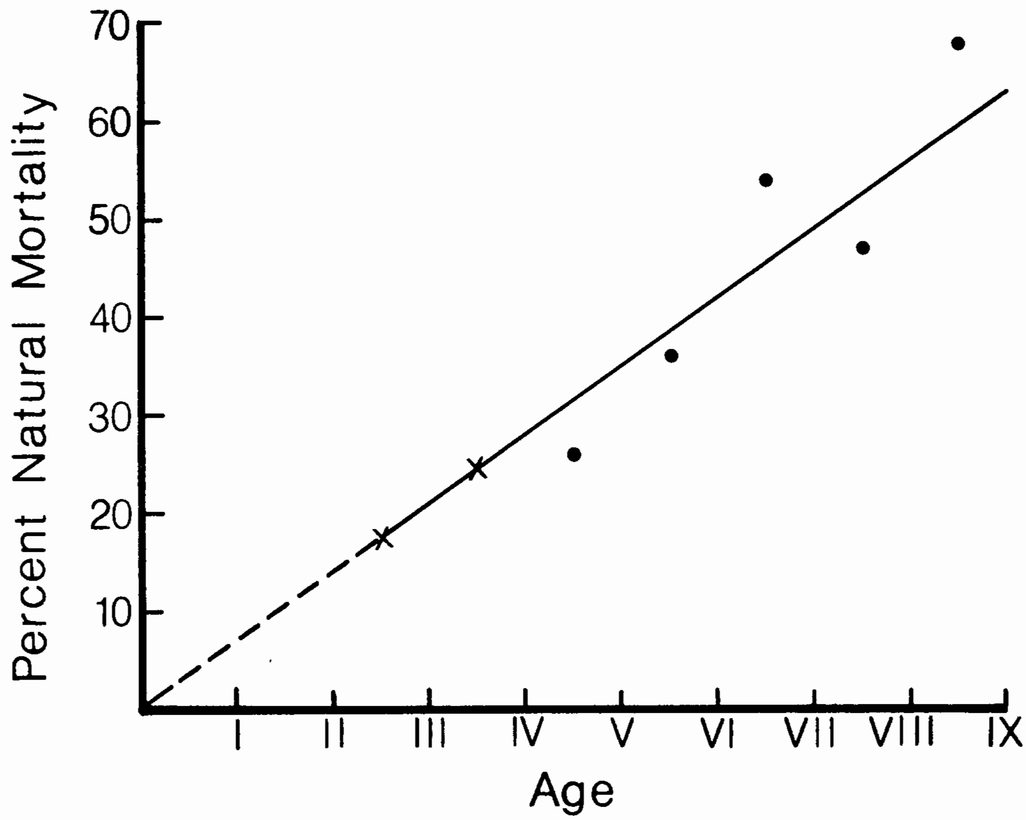

Figure 7.--Estimated mean natural mortality rates for five age groups of lake whitefish in the lower end of Grand Traverse Bay (1968-1973).

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Report approved by W. C. Latta

Typed by M. S. McClure