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ESTIMATES OF BIOMASS OF PRINCIPAL FISH SPECIES IN THE GREAT LAKES (First report)

CONTENTS

ABSTRACT

Estimates of biomass of selected fish species were made for specified years and for designated portions of Lakes Michigan and Superior. Estimates for alewives and chubs were based on trawl catches per unit of area, multiplied by total area occupied by the species. For lake trout, herring and whitefish, annual mortality rates were related to known recruitment (lake trout of hatchery origin) or to variable catch per unit of effort of commercial gear over a period of years. Standing crop estimates are:

Lake trout, Michigan waters of Lake Michigan, 1972, 11.2 million pounds, in age-groups II and older.

Whitefish in northern Lake Michigan, 1971 and 1972: Those in age-groups III and older, and subject to commercial exploitation, 4.4 and 6.6 million pounds, respectively. Including age-groups I and II, and all age groups in MM2 (closed to fishing), total biomass was 33 and 55 million pounds, respectively.

Alewives, all of Lake Michigan but limited to the zone of bottom trawling, fall of 1973, 220 million pounds, of age-groups I and older. Expansion of this estimate, to include fish in midwater, gives up to a 10-fold increase in the total figure, i.e., up to 2 billion pounds.

Chubs, all of Lake Michigan, fall of 1973, 15 million pounds, of age-groups I and older.

Lake herring, Michigan waters of Lake Superior, in 1972, for only those herring grounds which were fished commercially during 1972, 4 million pounds of fish in age-groups V-VIII (fish of commercial size).

Confidence limits and other limitations of these estimates are discussed.

Estimates of Biomass of Principal Fish Species in the Great Lakes

Foreword

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In recent reviews of MDNR's fish research program, Fisheries Chief Wayne Tody "prodded" us on the following. The Division has been setting quotas on the commercial catch of certain species of fish in the Great Lakes, but when someone poses the question of just how large is the stock of fish from which the quota is to be taken, no one has a good answer--at least for most species. Rather quickly one is led to the next question, if we don't know the magnitude of the stock, how can one set a quota intelligently? The question is a source of concern to the administrator, and correspondingly a challenge to the research biologist.

An ad hoc committee to pursue the matter was appointed among persons within the Michigan Fisheries Division who work with Great Lakes fisheries statistics (R. W. Rybicki, Myrl Keller, J. W. Peck, M. H. Patriarche, and G. P. Cooper). In an initial meeting at Charlevoix on June 6, 1973, we discussed different approaches to the problem of estimating biomass based on information available and on what others have done. Approaches which seemed to have promise are:

1. For alewives, chubs and other forage species: Use catch-effort data from trawl catches, compute volume of water "screened" by the trawl haul, and extrapolate to total lake volume within depth strata over bottom where each species is known to be concentrated.
2. For lake trout in Lake Michigan: All lake trout in this lake are survivors of hatchery plants, and all are fin-clipped; therefore recruitment each year is a known quantity. Net samples give a series of fish of known ages (from fin-clips), with distribution by year class the same as in the lake if

allowance is made for size selectivity by the gear. Total mortality is then computed for each age interval throughout the life of the species. Starting with the number of fish planted each year, and knowing total annual mortality, one can compute the biomass of the standing crop at any given time.

3. Where recruitment is not known, and where biomass estimates are based just on age distribution, a more involved procedure can be used. Over the years of a commercial fishery, with standardized gear, total annual mortality rate is computed for each year from the age composition of the catches. Total mortality in natural logs is plotted against total fishing effort, and assuming a number of years in which effort is very low, and others in which effort is high, a graph of the relationship shows the point where all of the mortality is from natural causes (i.e., at the ordinate on the graph where fishing effort approaches zero). Secondly, one can read from the graph the amount (rate) of fishing mortality to be associated with any given level of fishing effort; or fishing mortality is computed as the product of the catchability coefficient and fishing effort, less natural mortality. Total biomass can be computed from prior or future catch-effort records, after converting fishing mortality to exploitation rates. This approach seems appropriate for the herring in Lake Superior. For the whitefish in northern Lake Michigan, a somewhat different method was used in computing the necessary mortality and exploitation rates from commercial catches.

We considered the following procedures briefly, and judged them of little merit for present problems:

4. The DeLury method of extrapolating the accumulating catch on a catch/effort graph has little merit here because a population has to be greatly depleted during a short period wherein there is little or no recruitment.
5. Estimating biomass of fish populations at the top of food pyramids, by starting with known bases of plankton and benthos production,

and using established conversion factors, is a more indirect procedure. We are not aware of adequate data on plankton and benthos for the Great Lakes, but this method is perhaps worthy of further consideration.

6. The technique of identifying and counting fish recorded on fathometer tapes would seem to have promise, although no one in our Division has the necessary experience and all the required equipment.

Following the June 6 meeting at Charlevoix, we contacted Dr. Howard D. Tait and solicited help from his staff, some of whom have been involved in estimating fish populations in the Great Lakes. Persons from the United States Bureau of Sport Fisheries and Wildlife, who met with Division personnel in a subsequent meeting in Ann Arbor on December 6, 1973, were: E. H. Brown, J. H. Kutkuhn, R. L. Pycha, LaRue Wells, and H. D. Tait.

Additional Fisheries Division personnel who were present at either the Charlevoix or Ann Arbor meetings were: J. V. Manz, J. D. Bails, A. T. Wright, and T. M. Stauffer.

As a result of meetings, discussions and correspondence, assignments for working up biomass estimates, by a deadline date of February 1, 1974, were accepted as follows:

Lake trout in Lake Michigan	R. W. Rybicki
Whitefish in northern Lake Michigan . .	M. H. Patriarche
Alewife and chubs in Lake Michigan . . .	E. H. Brown, Jr.
Herring in Lake Superior.	J. W. Peck

Estimates for the five species are brought together in this report. At least in most instances, the authors plan to revise and refine the estimates as more information becomes available. Periodic updating will be essential to allow for good management decisions. Finally, this procedure of estimating fish biomass should be extended to other species and other lakes, and perhaps will involve other people depending on who has the information and the time.

This report was typed by Margaret S. McClure.

Biomass of Lake Trout in Michigan's Waters of Lake Michigan in 1972

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Introduction

Since 1965, some 17,000,000 lake trout have been planted in Lake Michigan, of which 8,871,000 were stocked in State-of-Michigan waters of the lake. How many lake trout are there in Michigan's waters of Lake Michigan as the result of these plantings? This report attempts to answer that question.

Knowledge about the density of a fish stock is an indispensable item in the management of a fishery. Although the quality of the results in this report leaves much to be desired, it is a positive step in completing an unknown value in the management equation.

Methods

The expressions used to estimate the standing crop (SC) of lake trout in each of Michigan's statistical districts (SD) of Lake Michigan (Fig. 1) were as follows:

1. SC/sq.mi. = 1.28 + 49.44X

   where X = number per year class/1000' gill net set overnight

2. SC/SD = $(\sum_{k}^{1}$ SC/sq.mi. times sq.mi. per SD)

   where k = number of year classes,

   sq.mi. per SD = surface area of water in the statistical district with depth of 40 fathoms or less.

The regression approach was used because CPE (X in the above equation) is a measure of relative abundance. In order to calculate the regression, the numerical abundance of the population (Y) must be established to regress on the companion CPE.

All catch-per-unit-of-effort data (hereafter referred to as CPE) were from collections made with graded-mesh gill nets. Each net contained eight 300-foot panels with mesh sizes from 2 1/2 to 6 inches (extended measure) at one-half-inch intervals, and the nets were set at established index stations.

Lake trout planted in Lake Michigan since 1965 have been fin clipped, which permitted year class identification. In some cases, where fin clips were duplicated, length frequencies were used to sort year classes. Presently there is little or no natural reproduction of lake trout in Lake Michigan, but significant natural recruitment is expected in future years.

Available data for Statistical District MM1 (see Fig. 1) was by far the best among all districts for computing mean annual survival rate. The number of fish in each year class (1964 to 1969) was determined by multiplying the adjusted number of a year class planted in MM1 by the annual survival rate for each year from the planting year through 1972. The adjusted number planted is the number of individuals per square mile in a specified year class remaining after emigration from MM1 to other statistical districts in Michigan's share of Lake Michigan. This estimate was calculated thusly:

$$\frac{1}{\text{sq. mi.}}\left(\frac{\text{CPE of year class "c" in MM1}}{\text{CPE of year class "c" in MM1} + \ldots \text{MM8}}\right)\left(\begin{matrix}\text{Number of year class}\\ \text{"c" planted in MM1}\end{matrix}\right)$$

The 1970 to 1972 year classes were not included in the present analysis, because these fish were not fully vulnerable to the sampling gear.

The average annual survival rate of lake trout in MM1 ranged from 0.42 to 0.56 for ages II to VII (Table 1). There was a slight negative correlation (-0.09) between age and survival rate, but the slope (-0.01) was not significantly different from zero ($p < 0.05$; 10 degrees of freedom). Therefore the intercept of 0.5 was used as the mean annual survival rate for age-groups II to VII. This mean value of 0.5 obtained for MM1 was applied to available data for other statistical districts in Lake Michigan because, as stated above, the information for MM1 was more complete and consistent than that collected from the other areas.

Results and Discussion

The estimated standing crop of lake trout in Michigan's waters of Lake Michigan are given in Table 2. These estimates ranged from a low of 74,000 fish in MM1 to a high of 411,000 individuals in MM8; the lake-wide standing crop totaled 2,245,000 lake trout, or about 11.2 million pounds. (Although a figure is given here for pounds of fish, all other figures given for lake trout refer to number of fish.) How realistic are these estimates?

The correlation coefficient of 0.59 obtained for the relationship $\hat{Y} = 1.28 + 49.44X$ accounts for only 35% of the variation about regression, but was nevertheless significant at the 0.05 level.

Confidence intervals on the estimated standing crops of lake trout by year classes ranged from ±14% to ±205% (Table 2), with only 13 out of 48 cases falling within the acceptable range of ±14% to ±29%. Much improved limits result when the individual year-class estimates are summed into statistical district totals, with five out of the eight districts having confidence limits of ±15% or less. The lake-wide estimate of 2,245,000 lake trout has very good limits of only ±5%.

Based on 2,245,000 fish, all of which were considered vulnerable to the sport fishery, there was a standing crop in 1972 of 0.26 lake trout per surface acre in Michigan's waters of Lake Michigan. At an average weight of 5 pounds, the standing crop of lake trout would have been 1.3 pounds per acre. The commercial production of lake trout in Michigan's waters of Lake Michigan during 1929 to 1945 averaged 0.29 pound per acre. If the commercial fishery harvested 10% of the catchable stock, then the standing crop would have been 2.9 pounds per acre; if the commercial fishery removed 20%, then the standing crop would have been 1.5 pounds per acre. If our sport fishery is capable of harvesting on the order of 16% of the vulnerable stock (Table 3), then it seems that the commercial fishery could easily have taken at least 20%. Thus a standing crop of 1.3 pounds per acre in 1972 seems to be a reasonable estimate.

Although there is an intensive sport fishery for lake trout in MM3 (mostly in Charlevoix and Emmet counties), the harvest rate of 32% (Table 3) seems inordinately large. It may be that the standing crop of lake trout in MM3 is underestimated.

Sources of Bias

There are several sources of bias in the population estimates which need some discussion:

1. The expression $\hat{Y} = (\sum_{k}^{1} (1.28 + 49.44X))$ (sq. mi.)

tends to overestimate predicted values. Recall that the regression portion of the expression is based in part on the numbers of planted lake trout remaining in MM1 after emigration. Lake trout will also emigrate into Wisconsin, Indiana and Illinois waters; since the sum of the CPE's for a particular year class is from Michigan waters only, the proportion of fish remaining in MM1 will be positively biased.

2. The catch-per-unit-of-effort statistic is subject to the vagaries of prevailing environmental conditions. Our index fishing scheme was not designed specifically to catch lake trout. Thus the rigid index sampling plan at a particular time and place may have resulted in disproportionately large or small CPE's. This could be a critical factor in the estimates at year-class and statistical-district levels, but less so for the lake-wide estimate because an overestimate in one area probably is counterbalanced by an underestimate in another.

3. Lake trout of yearling or smaller sizes planted one year prior to or in the year of sampling are not fully vulnerable to the gear. Thus fish planted in 1971 and 1972 are not included in the standing crop estimates.

4. The CPE obtained for a statistical district might not be representative of the entire area. In all cases, there were two or more index stations per statistical district, and it was assumed that the average CPE was representative for the area. However, a district is of immense size and the index stations cover only a small fraction of it.

5. Length frequencies of year classes of lake trout bearing the same fin clips overlap. A year class may have a difference of as much as 12.0 inches in its length range. Since lake trout plants possessing duplicate clips were assigned to their respective year classes based on length frequencies, some of the younger fish may have been misplaced in the older age group. This may account for some of the relatively large standing crops of the 1964-1966 year classes.

By and large, the regression approach to estimating the standing crop of lake trout in Lake Michigan appears to produce credible results, and the accuracy should improve as sampling techniques are refined and the data accumulate.

Acknowledgments

M. H. Patriarche and J. R. Ryckman gave helpful advice on this manuscript.

Table 1.--Estimated annual survival rate of lake trout planted in Statistical District MM1

Observation number	Annual survival to age					
	2	3	4	5	6	7
1	0.5617	0.4361	0.6856	0.5611	0.6339	0.2206
2	...	0.5193	0.1539	...	0.1784	0.6550
3	...	...	...	...	0.5979	...
4	...	...	...	...	0.5617	...
Average	0.5617	0.4771	0.4197	0.5611	0.4929	0.4378

Table 2.--Estimated number of lake trout in 1972 in Michigan's statistical districts of Lake Michigan. Estimates were derived from the regression $\hat{Y} = (1.2798 + 49.4355X)$ multiplied by square miles.

Statistical district, and area <40 fathoms	Year class	Number caught per 1000 feet (X)	Estimated population in district	95% confidence limits
MM1	1964	0.0346	1,578	±205%
(528 sq. mi.)	1965	0.4613	12,716	± 58%
	1966	0.0376	1,657	±191%
	1967	0.7614	20,549	± 49%
	1968	0.4045	11,233	± 61%
	1969	0.9772	26,234	± 44%
	Total	...	73,967	± 26%
MM2	1964	1.0714	26,363	± 43%
(486 sq. mi.)	1965	0.2276	6,090	± 66%
	1966	0.3173	8,245	± 64%
	1967	1.7458	42,565	± 34%
	1968	0.5158	13,014	± 56%
	1969	0.0396	1,549	±185%
	Total	...	97,826	± 22%
MM3*	1964	0.0378	4,886	±190%
(1552 sq. mi.)	1965	0.7575	60,104	± 49%
	1966	0.6060	48,480	± 53%
	1967	0.1515	13,609	±153%
	1968	0.2272	19,417	± 66%
	1969	0.7196	57,196	± 50%
	Total	...	203,692	± 25%
MM4	1964	0.4861	6,656	± 57%
(263 sq. mi.)	1965	7.7083	100,556	± 17%
	1966	11.8750	154,729	± 14%
	1967	4.0277	52,702	± 23%
	1968	1.3194	17,490	± 39%
	1969	0.9722	12,976	± 44%
	Total	...	345,109	± 9%

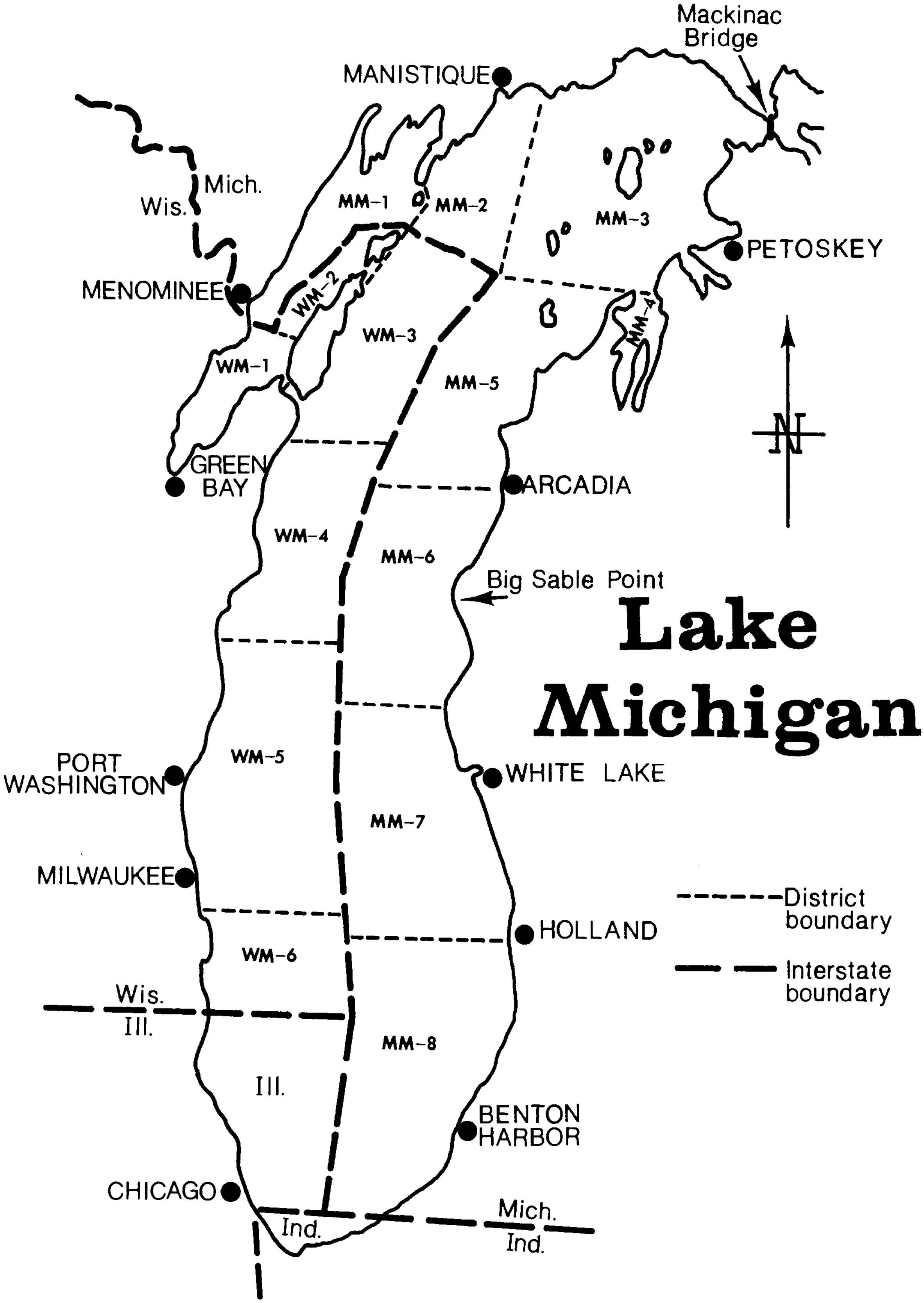
* Excludes commercial fisheries Zone 16.

Table 2.--concluded

Statistical district, and area < 40 fathoms	Year class	Number caught per 1000 feet (X)	Estimated population in district	95% confidence limits
MM5	1964	1.8750	49,616	±33%
(528 sq. mi.)	1965	3.4821	91,565	±25%
	1966	7.1726	187,894	±18%
	1967	1.0714	28,641	±43%
	1968	2.4702	65,152	±29%
	1969	2.1130	55,829	±31%
	Total	...	478,697	±11%
MM6	1964	1.8721	34,153	±33%
(364 sq. mi.)	1965	2.1461	39,083	±31%
	1966	1.3698	25,114	±38%
	1967	0.2283	4,573	±66%
	1968	2.0091	36,618	±32%
	1969	6.1643	111,389	±19%
	Total	...	250,930	±12%
MM7	1964	1.5909	29,892	±36%
(374 sq. mi.)	1965	1.1363	21,487	±42%
	1966	4.2424	78,915	±23%
	1967	6.4015	118,835	±19%
	1968	4.0530	74,935	±23%
	1969	3.1818	59,306	±26%
	Total	...	383,370	±10%
MM8	1964	0.2604	12,567	±66%
(888 sq. mi.)	1965	0.5208	23,998	±56%
	1966	2.7083	120,027	±28%
	1967	4.1145	181,757	±23%
	1968	1.3020	58,292	±39%
	1969	0.3125	14,854	±64%
	Total	...	411,495	±15%
Lake Grand Total		...	2,245,086	± 5%

Table 3.--Estimated number of lake trout in catchable standing crop and sport catch (1964 to 1969 year classes) by statistical district, and the percentages caught by anglers in the Michigan waters of Lake Michigan, 1972

Statistical district	Estimated catchable standing crop	Estimated sport catch	Percentage caught
MM1	73,967	1,020	1
MM2	97,826	1,530	21
MM3	203,692	65,450	32
MM4	345,109	74,290	22
MM5	478,697	51,680	11
MM6	250,930	60,690	24
MM7	383,370	58,480	15
MM8	411,495	34,510	8
Total	2,245,086	347,650	16



Statistical Districts of Lake Michigan

Figure 1

Biomass of Whitefish in Northern Lake Michigan, 1971 and 1972

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Introduction

One of the keys to successful management of the fisheries in the Great Lakes is information on the size of the population being managed. Plausible estimates of the whitefish population in northern Lake Michigan (specifically, in fisheries Statistical Districts MM1 and MM3) were obtained for 1971 by utilizing commercial catches and monitoring data for 1971-1973, together with mortality rates calculated from the estimated age structure of the catches. The computed biomass (in round figures) of whitefish of ages I-VI in these two statistical districts for which there were catch data was 22 million pounds in 1971; 37 million pounds in 1972. Of the 22 and 37 million pounds, only 4.4 and 6.6 million pounds, respectively, were available to commercial exploitation (see below). Statistical District MM2 also has a sizable whitefish population but has been closed to commercial fishing since 1968. In the absence of data on the MM2 stock, I estimate its population at 11 million pounds (the mean of the surrounding MM1 and MM3), bringing the total for the biomass of the three districts to 33 million pounds in 1971, and by the same procedure to 55 million pounds in 1972. The rationale behind the estimates follows.

Methods

The basic data were the commercial catches in pounds reported by month and by gear. A few of the catches were monitored in both June and October, at which time all fish were scale sampled, measured, and weighed. The age structure and mean weight of fish in the monitored catches were assumed to be representative of the period in which the samples were taken. The year was divided into two periods of January-July and August-December. Since catches are reported by weight only, these catches were transformed into estimated numbers of fish caught by each method, using a mean weight. They were then subdivided into inch groups on the basis of the length frequency of the monitored catches. The final step in describing the total seasonal catch each year was to estimate the age structure from the age distribution in the sub-samples. A final estimate of the number of fish caught in each age group (Table 1) was derived by summing the seasonal estimates for each type of gear.

Mortality rates were drawn from several sources. For age-groups I and II, total mortality rate was derived from the age composition of the whitefish catch in small-mesh gill nets set in 1969 at Seul Choix Pt., and averaged out at 0.80 for the two age groups. For age-groups III and IV in MM3, and age-group III in MM1, total mortality (a) was derived by comparing the successive CPE's by trap or pound nets in 1971 and 1972, and was converted to instantaneous rate (i) as described in Ricker (1958, pp. 50-51). It was possible to subdivide this rate into natural mortality (q) and fishing mortality (p) by assuming that the total mortality rate computed for the nearby, unfished whitefish population in Grand Traverse Bay (from survey catches) was equivalent to natural rate applicable to the rest of northern Lake Michigan. The instantaneous natural rate (q) was subtracted from (i) to get (p) (Table 2). A mean annual survival rate of 0.10 for age-groups V and VI in MM3 was obtained from the age composition of the catches in 1971 and 1972; 0.25 for age-groups IV and V in MM1 from the age composition of the 1972 trap-net catches.

The final piece of information needed was exploitation rate for as many age groups as possible. This rate (u) was derived for age-groups III and IV in MM3, and age-group III in MM1, using Ricker's formula:

$$\frac{i}{a} = \frac{p}{u}$$

Thus, for age-group III (MM3) the exploitation rate in 1971 was:

$$u = \frac{ap}{i} = \frac{.71 \times .82}{1.24} = 0.47$$

The exploitation rate for age-group IV in MM3 was 0.76; in MM1, the rate was 0.28 for age-group III.

Estimates for 1971

With estimates of either exploitation rate or mortality and survival rates at hand, along with catches by age group, it was then possible to compute the biomass of whitefish of age-groups I-VI that was present at the beginning of 1971. The procedure is outlined below.

MM1

Age-group III: Total catch (338,998) ÷ exploitation rate (0.28) = an estimated population of 1,210,707 age-III fish.

Age-group IV: The mean survival rate between age III and age IV = 0.25; hence 1,210,707 x 0.25 = 302,677 age-IV fish.

Age-group V: The mean survival rate from age IV to age V = 0.25; hence 302,677 x 0.25 = 75,669 age-V fish.

Age-group II: The mean survival rate from age II to age III is 0.20; therefore, 1,210,707 age-III fish ÷ 0.20 = 6,053,350 age-II fish.

Age-group I: 6,053,350 age-II fish ÷ 0.20 = 30,266,750 age-I fish.

MM3

Age-group III: Total catch (406,557) ÷ exploitation rate (0.47) = an estimated population of 865,015 age-III fish.

Age-group IV: Total catch (73,994) ÷ exploitation rate (0.76) = an estimated population of 97,360 age-IV fish.

Age-groups V and VI: Computed as shown above for age-group V, using the mean survival of 0.10. Results were 9,735 and 975 fish, respectively.

Age-groups I and II: Computed as shown above. Results were 21,625,375 and 4,325,075 fish, respectively.

Biomass (in pounds) 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 3.

Statistical District MM2 lies between MM1 and MM3 and is also an important whitefish-producing area. It has been closed to commercial fishing since 1968, and there have been no fishery surveys here. One could speculate that, with an estimated 13 million pounds of whitefish in MM1 and 9 million pounds in MM3, there might well be a population intermediate between these two, or 11 million pounds of fish, in MM2. Of the total biomass of 33 million pounds, only 4.4 million pounds were susceptible to the commercial fishery (age-groups III and older, in MM1 and MM3). The total catch in 1971 was 2.1 million pounds or 48% of the exploitable stock.

Estimates for 1972

Using 1972 and 1973 commercial catch data, mortality and exploitation rates also were calculated for 1972 for all age groups except I and II. Following the procedures outlined above for the 1971 calculations, new biomass values were computed for 1972 and are summarized in Table 3. The estimated biomass for whitefish (ages I-VI) at the beginning of 1972 in MM1 and MM3 was 36.7 million pounds (109.7 million fish). No data were available for MM2, but with 11.7 million pounds in MM1 and 24.9 million pounds in MM3, an intermediate value of 18.3 million pounds might well apply to this statistical district, making the total biomass for statistical districts MM1, 2, and 3, an estimated 55 million pounds for the six age groups. Of this 55 million pounds, only 6.6 million pounds were subject to exploitation. The 1972 harvest was 2.8 million pounds, or 42% of the exploitable stock.

There are, of course, whitefish populations in Grand Traverse Bay and in the Grand Haven area; for these, no estimates have been attempted because of insufficient data.

Literature cited

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Bd. Canada, Bull. 119, 300 pp.

Table 1.--Estimated commercial catch of whitefish (numbers) by age group, in MM1 and MM3 of Lake Michigan in 1971 and 1972

Age group	MM1		MM3	
	1971	1972	1971	1972
II	--	12,618	13,809	2,371
III	338,998	441,022	406,557	653,662
IV	33,510	133,388	73,994	116,190
V	2,067	13,820	6,272	12,646
VI	--	--	978	5,533
Totals	374,575	600,848	501,610	790,402

Table 2.--Estimated mortality rates for certain age groups of whitefish in MM1 and MM3 of Lake Michigan in 1971

Age group	CPE (1971)	s	a	CPE (1972)	q	p	i
MM1							
III	94.7						
		.44	.56		.41	.40	.81
IV				41.7			
MM3							
III	95.2						
		.29	.71		.42	.82	1.24
IV	21.0			27.2			
		.14	.86		.24	1.72	1.96
V				2.9			

Table 3.--Estimated number and weight (pounds) of whitefish of ages I-VI in MM1 and MM3 of Lake Michigan at the beginning of 1971, and beginning of 1972

Age group	Beginning of 1971		Beginning of 1972	
	Number	Weight	Number	Weight
MM1				
I	30,266,750	6,053,350	27,563,875	5,512,775
II	6,053,350	4,297,878	5,512,775	3,914,070
III	1,210,707	1,840,275	1,102,555	1,675,885
IV	302,677	777,880	168,845	433,930
V	75,669	222,467	76,780	225,730
Totals	37,909,153	13,191,850	34,424,830	11,762,390
MM3				
I	21,625,375	4,325,075	60,524,250	12,104,850
II	4,325,075	3,070,803	12,104,850	8,594,445
III	865,015	1,314,823	2,420,970	3,679,875
IV	97,360	250,215	184,430	473,785
V	9,735	28,620	25,810	75,880
VI	975	4,534	2,580	11,995
Totals	26,923,535	8,994,070	75,262,890	24,941,030

The Estimation of Fishable Biomass of Alewives and Chubs in Lake Michigan

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Introduction

One method used by the Great Lakes Fishery Laboratory to compute pounds of forage fish available to bottom trawls in Lake Michigan involves the projection of estimates of population density derived from trawling to total lake area within a stratified geographical frame. Each lake-wide estimate for a species is a summation, over all strata, of the catch per acre trawled times the total acreage. These estimates give us a "feel" for the large quantities of fish in the lake, but obviously underestimate total biomass because fish at mid-depths are unavailable to the bottom trawl (alewives of all ages are highly pelagic at times), the trawl is not 100% efficient at capturing fish ahead of it, and trawling has generally been limited to maximum depths of 70 fathoms and less. Variations of this method have been used by Reigle (1966 correspondence at Great Lakes Fisheries Laboratory), Smith and Bostock (unpublished files at the laboratory), and Brown (1972).

Methods

To estimate pounds of alewives and chubs (*Coregonus hoyi*) available to trawls in fall 1973, we divided the lake into eight geographical sectors (Fig. 1) representing fishery statistical districts (or combinations of districts and fractions thereof). Boundaries of each sector were drawn so as to contain one each of eight widely distributed sampling transects, and to permit the use of areal estimates (by depth zone) that are available for all statistical districts in Lake Michigan. The sectors (A, B, C . . . H) in turn were divided into strata representing depth zones of 0-20, 21-40, 41-60, and 61-80 fathoms. Estimates of population density (pounds per acre) in each stratum within a sector equaled the mean number or pounds of fish caught per 10-minute trawl tow in that stratum divided by the 1.2 acres covered in a standard tow. These values were multiplied by total acreage in the sector for that stratum; the values were summed for each sector, and then combined by sector for the lake-wide estimates. (The 39-foot trawl, used in routine assessment sampling, fishes a strip of bottom 21 feet wide and has a maximum vertical opening of 7 feet.)

Fall estimates of alewives and chubs, 1973

Application of the method described above, using total weights corresponding to the numbers of fish in Tables 1 and 2, produced estimates of 220 million pounds of alewives and 15 million pounds of chubs (i.e., bloaters), of age I and older, available in the bottom waters of Lake Michigan during October 23 to November 11, 1973. (Conservative estimates of 188 million pounds of alewives and 7 million pounds of chubs were obtained using geometric mean weights.) Comparisons between the 1973 estimates, and gross estimates by Smith and Bostock for all seasons and years of the period 1963-65 (combined), reflect the continued abundance of alewives and the serious drop in abundance of chubs over the last 10 years:

Year	Fish available to bottom trawls (millions of pounds)	
	Alewives	Chubs
1963-65	237	139
1973	220	15

Smith and Bostock used catch data from 30-minute tows with a 52-foot trawl and stratified the lake only by depth; they also had better coverage at greater depths than we had in 1973. The rate of decline in chub abundance, indicated by this comparison, may be positively biased by young chubs entering bottom stocks at greater ages since 1967, and by lower fishing power of the 39-foot trawl.

Statistical limitations

Our method of systematically sampling at index stations along fixed transects (within geographical strata) is perhaps less desirable, statistically speaking, than purely random stratified sampling, although a comparative analysis of the two approaches has yet to be made. Confidence intervals associated with our estimates are therefore tentative and have not been computed for 1973. Brown (1972, Table 16) calculated standard errors for a similar estimate of alewife biomass in spring 1969. Multiplied by a t-value corresponding to the degrees of freedom, they yielded a confidence interval that departed about +88% and -79% from the estimated value at the .95 probability level, indicating the low precision of biomass estimates in general.

Related developments

The midwater trawling capability now being developed at GLFL should enable us to begin to quantify the sizable fractions of forage fish biomass heretofore missed by bottom trawls. We have also made a first indirect attempt to represent proportionally in biomass estimates the large quantities of younger alewives (mainly age groups I, II, and III) in midwater. Hypothetical mortalities of the young, catch-curve estimates of mortalities of the vulnerable adults, and age-weight data are used in what is essentially a backward projection of the catch curve. Relative weights of the projected age groups are then scaled in proportion to the estimated weights of fish available in the bottom zone. An estimate obtained by this procedure for all age groups combined in spring 1972 (Edsall et al., 1974) was more than tenfold greater than the estimate in the present paper of the fishable stock in fall 1973. Although the larger "exploratory" value may be positively biased because of various unproven assumptions, there seems little question now that the true average standing stock of alewives of all ages in Lake Michigan is far greater than 220 million pounds.

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Brown, E. 1972. Population biology of alewives, *Alosa pseudoharengus*, in Lake Michigan, 1949-70. J. Fish. Res. Bd. Canada, 29: 477-500.

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Table 1.--Number of alewives (≥120 mm) per 10-minute tow of a 39-foot bottom trawl at eight index stations in Lake Michigan, October 23 to November 11, 1973

Depth (fathoms)	Benton Harbor	Saugatuck	Ludington	Frankfort	Manistique	Sturgeon Bay	Port Washington	Waukegan
3	0	4	-	-	-	-	-	18
5	0	7	0	-	0	-	-	12
7	8	12	0	-	-	-	-	299
10	1	1	33	2	1	0	51	465
12	18	88	-	-	-	-	-	599
15	64	9	0	209	0	0	41	169
17	13	6	-	-	-	-	-	307
20	161	7	1,769	582	0	4	48	246
25	1,083	114	1,263	1,843	38	3	86	540
30	535	309	991	2,172	171	338	185	413
35	306	593	452	3,860	220	531	125	231
40	569	436	914	2,915	223	374	197	386
45	495	402	684	2,425	-	-	283	416
50	502	312	952	1,245	-	431	272	1,103
60	-	-	632	1,100	-	408	501	-
70	-	-	378	496	-	-	441	-

Table 2.--Number of bloaters (≥140 mm) per 10-minute tow of a 39-foot bottom trawl at eight index stations in Lake Michigan, October 23 to November 11, 1973

Depth (fathoms)	Benton Harbor	Saugatuck	Ludington	Frankfort	Manistique	Sturgeon Bay	Port Washington	Waukegan
3	0	0	-	-	-	-	-	0
5	0	0	0	-	0	-	-	0
7	0	0	0	-	-	-	-	2
10	0	0	0	0	0	0	0	0
12	28	0	-	-	-	-	-	2
15	4	2	0	0	0	0	0	4
17	1	10	-	-	-	-	-	4
20	2	4	0	11	0	0	1	4
25	3	3	0	157	1	0	11	13
30	3	1	117	97	13	0	3	2
35	4	1	91	239	30	2	0	2
40	1	1	56	52	5	5	1	0
45	1	1	7	7	-	-	0	1
50	1	1	0	3	-	0	0	1
60	-	-	0	0	-	0	0	-
70	-	-	0	0	-	-	0	-

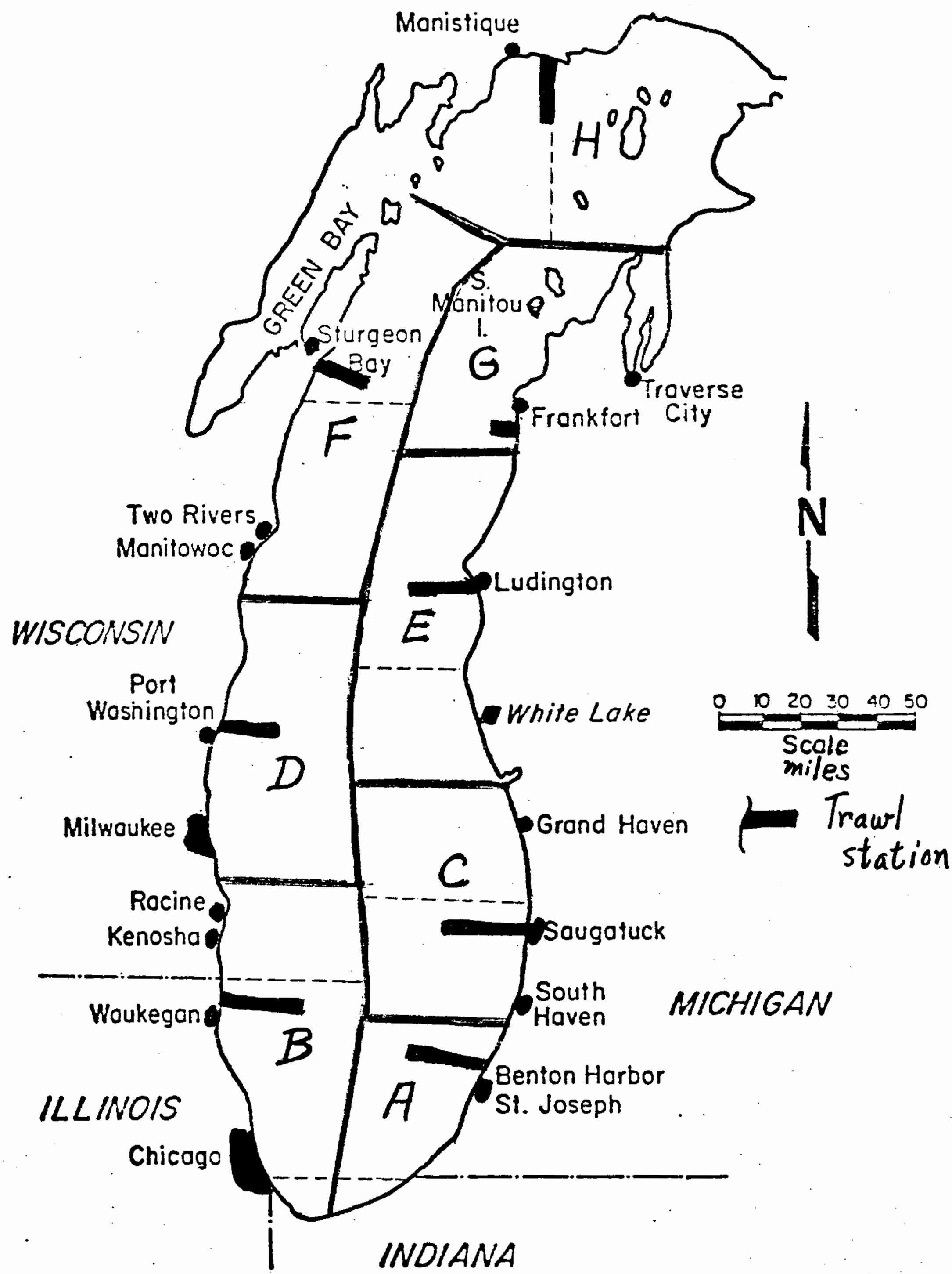

Fig. 1. Trawl index stations on Lake Michigan showing transects fished for alewives and bloaters, Oct. 23-Nov. 11, 1973. (Solid lines are boundaries of sectors A, B, C . . . H used in estimating fish available to trawls; broken lines are boundaries of statistical districts.)

Biomass of Lake Herring in Michigan Waters of Lake Superior

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Introduction

Rehabilitation and sophisticated management of Great Lakes fish stocks to assure greatest possible and continuing yield to fishermen can best be achieved through maintenance of a maximum standing crop of fish. Efforts to obtain data necessary for this sophisticated level of management have been insufficient, in light of the vastness of the Great Lakes. However, a burgeoning sport fishery, and decline in abundance of some important commercial fish stocks, have made it imperative that Great Lakes fisheries biologists utilize existing data for preliminary estimates of biomass now, while gathering data required for more accurate estimates in the future.

Lake herring became the mainstay of the Lake Superior commercial fishery when lake trout and whitefish stocks declined in the 1950's, but herring stocks in Michigan waters of this lake have been declining in abundance since the early 1960's. Fortunately, Michigan biologists have gathered more recent information on lake herring than on any other commercial fish in this lake. Biological data have been collected annually on some lake herring stocks in Michigan waters since 1950, with commercial catch and effort data available back to 1929. In 1973, Michigan biologists prepared stock status reports and made future commercial quota recommendations for important commercial fish stocks. These quotas generally were based on relative abundance trends as determined from commercial catch-effort statistics. My objectives were to determine if the available lake herring data could be used to obtain at least "ball park" estimates of standing crop or biomass, and provide a more accurate basis for establishing commercial quotas.

Methods

I calculated standing crop (number per square mile) and biomass (pounds per square mile) of lake herring in Michigan waters of Lake Superior (Fig. 1) based on an analysis of the July-December lake herring fishery in MS3 (Keweenaw Bay) during 1960-1971. Paloheimo's (1961) linear method was used to obtain estimates of the rates of instantaneous fishing mortality (p) and natural mortality (q) (Table 1). This method assumes that: (1) a linear relationship exists between total mortality and fishing effort for age groups that are fully vulnerable to the fishery; (2) the slope represents catchability; and (3) the Y-intercept (zero fishing effort) gives an estimate of instantaneous natural mortality.

Lake herring in MS3 were fully vulnerable to the July-December fishery (gill nets with 2 1/2- to 2 3/4-inch stretch mesh) at age V. Younger fish were not fully vulnerable to the fishery so were not included in standing crop and biomass estimates. Although ages III and IV dominated commercial catches during the 1950's, ages V, VI and VII have dominated since 1964. The linear relationship of total mortality to fishing effort was significant for ages V, VI and VIII but not for VII; so I used the means of the catchability and natural mortality rates of ages VI and VIII for these respective values for age VII. Natural mortality rates for ages V and VI were negative. Since this would be impossible, I assumed natural mortality to be zero for ages V and VI (improbable but not impossible). The catchability coefficient for each age was multiplied by annual fishing effort (thousands of feet of gill net) during 1965-1971 to estimate instantaneous fishing mortality.

An example of the calculated data is shown in Table 1 for 1972. I assumed that catchability and natural mortality remained constant throughout the year. Exploitation rates for each age were computed using Ricker's (1958) formula: $u = ap \div i$. The annual catches in MS3 were divided by the exploitation rates, to estimate total population on the fishing grounds in MS3 (Table 2). I determined total annual standing crop (number per square mile) of age V-VIII herring in MS3 for each year during 1965-1972 by dividing the calculated total number of age V-VIII herring by the estimated area fished. Biomass (pounds per square mile) was derived by multiplying standing crop by the annual average weight of individual herring in the MS3 catch (Table 2).

Standing crops of lake herring in other statistical districts during 1968-1972 (Table 4) were computed from the highly significant relationship of standing crop (Y) to annual CPE (X) in MS3 during 1965-1972 (Fig. 2). The linear relationship ($Y = 37X-852$) was highly correlated ($r = .95$), but linearity would not be expected at very low or very high population densities. CPE should reach zero before the last herring is captured, and with only small numbers of herring, the relationship could overestimate herring abundance by sequential exploitation of the remaining stocks, especially if sophisticated detection gear were used to locate the schools of fish. At high densities, nets could become saturated and a linear relationship would underestimate the actual abundance.

Discussion

I made the estimate that in 1972 there were 5 million lake herring of age-groups V-VIII, or 4 million pounds, on the commercial fishing grounds in Michigan waters of Lake Superior. Ages V-VIII include fish of commercial size. The herring "fishing grounds" constitute a small part of Lake Superior.

The estimate is the sum of the products of the 1972 standing crop (except that I used the 1971 figure for MS2) in each statistical district (Tables 2 and 4) multiplied by the area in square miles which was fished commercially in that district during 1972; these districts and area figures are: MS1, 360; MS2, 20; MS3, 490; MS4, 325; MS5, 100; and MS6, 400.

The validity of the point estimate of 5 million fish is questionable first on the basis of rather wide variation associated with the estimates of fishing mortality and natural mortality (Table 1), and secondly because my estimates of area fished quite likely are overestimates. The July-December 1960-1971 fishery in Keweenaw Bay provided the most complete set of long-term data on catch-effort and on age composition. I assumed that estimates based on the Keweenaw Bay data should exhibit the least variation. Since 1968, fishermen have been reporting their catch by 92-square-mile grids

(8 x 11.5 miles). Total area fished in each statistical district was determined to be the area of all grids fished, regardless of fishing effort expended in each grid, less any land area and water area from shore out 2 miles. These inshore waters were omitted because herring generally are no longer fished there. Area fished in each statistical district during 1968-72 was the summed area of grids in the district that were fished. Area fished during 1965-67 in MS3 was estimated to be more or less than the area fished during 1965-71, based on relative amounts of fishing effort.

The standing crop in MS3 exhibited a significant decline during 1966-1972 (Fig 3) which averaged 10% per year. The trend projects to a zero standing crop by 1980. The decline probably started back in the mid-1950's, because herring year-class strength in MS3 has declined 16% annually from the 1953 year class to the 1965 year class (Fig. 4), and the overall herring CPE in MS3 has declined since a record high in 1954. Biomass has declined less than has numbers of fish, because lake herring growth rate has increased; average weight of individual fish increased by approximately 0.5 pound since the 1950's. Herring standing crops in MS4 and MS6 (Table 3), based on CPE, appear to have increased slightly since 1968. This may be due to the greatly reduced fishing effort either not reflecting actual abundance or permitting an actual increase in herring numbers. Lake herring standing crop in MS1 declined an average of 38% per year during 1970-1972.

The life span of lake herring in Michigan waters of Lake Superior has increased since 1950. Decreased fishing pressure has certainly allowed more herring to live longer; an additional factor may be a physiological response to declining abundance and to declining competition with other species, probably from smelt.

Standing crop or biomass estimates of lake herring not yet fully vulnerable to the fishery would facilitate prediction of future commercial quotas with greater accuracy. Ages 0-IV are considered not fully vulnerable. Unfortunately, survival (mortality) data are presently not available for these age groups because of lack of adequate sampling. These small herring are taken most effectively with surface and midwater trawls, after first being located with an acoustical fish finding device. Even if successful methods of capture were initiated, separating the lake herring from cohabiting young of other coregonids (chubs) would present problems of identification especially for young-of-the-year. Anderson and Smith (1971) found lake herring larvae to be indistinguishable from the larvae of bloaters and other chubs.

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Acknowledgment

Alan D. Sutton drafted Figures 2-4.

Table 1.--Mortality, exploitation and total population of lake herring (ages V-VIII) on the MS3 fishing grounds in 1972, with 95% confidence limits on catchability and instantaneous natural mortality rate

	V	VI	VII*	VIII
Catchability coefficient (x 10^{-4})	.37	.64	1.12	1.60
	±.07	±2.50		±4.70
Effort (ft x 10^3)	1238	1238	1238	1238
Mortality rate				
Instantaneous fishing (p)	.05	.08	.14	.20
Instantaneous natural (q)**	0	0	.29	.58
	±.05	±1.45		±2.07
Instantaneous total (i)	.05	.08	.43	.78
Annual total (a)	.05	.08	.35	.54
Exploitation rate (u)	.05	.08	.11	.14
Catch (thousands)	76.1	28.9	9.9	2.1
Total population on grounds (thousands)	1560.2	376.2	87.0	15.3

* Catchability and natural mortality for age VII are averages of ages VI and VIII. See text for explanation.

** I assumed zero instantaneous natural mortality for ages V and VI. See text.

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Table 2.--Lake herring standing crop and biomass in the MS3 fishing area, with estimated area fished. The latter was not weighted for fishing effort in each grid, but was considered to be total fishable area in each grid fished.

Year	Effort (ft x 10^3)	CPE (number)	Area fished (sq. mi.)	Total number (ages V-VIII)	Standing crop (number /sq. mi.)	Avg. weight (lbs)	Biomass (lbs/ sq. mi.)
1965	12,944	277	650	5,987,744	9,212	0.67	6,172
1966	12,130	276	650	5,955,086	9,162	0.64	5,863
1967	11,349	174	640	3,793,469	5,927	0.77	4,564
1968	11,995	193	630	4,529,318	7,189	0.67	4,817
1969	8,521	134	630	2,449,611	3,888	0.71	2,761
1970	4,533	196	583	2,900,964	4,976	0.71	3,533
1971	1,583	191	493	3,095,181	6,278	0.74	4,646
1972	1,238	147	490	2,038,851	4,161	0.80	3,329

Table 3.--Lake herring catch per unit of effort (pounds per 1,000 feet of gill net) for certain grids in MS3 and MS4, 1968-1971

Grids	Year			
	1968	1969	1970	1971
MS3				
1022	---	112	---	---
1020	---	125	---	---
1026	---	118	---	---
1027	---	75	---	---
1028	---	70	---	---
1125	126	64	44	87
1126	142	145	162	159
1127	160	127	172	120
1128	---	67	40	---
1224	118	59	---	---
1225	117	70	57	110
1226	211	103	111	144
MS4				
1530	---	---	262	---
1430	---	---	298	---
1534	47	42	---	---
1434	47	26	---	---
1334	114	---	---	---
1535	35	40	---	---
1435	---	34	---	---
1335	92	21	---	---

Table 4.--Lake herring standing crop (number per square mile) in Lake Superior statistical districts MS1, MS2, MS4, MS5 and MS6, determined from the regression of standing crop on CPE in MS3 (1965-1972) [1]

Year	MS1		MS2		MS4		MS5		MS6	
	CPE (number)	Standing crop	CPE (number)	Standing crop	CPE (number)	Standing crop	CPE (number)	Standing crop	CPE (number)	Standing crop
1968	---	---	394	13,580	101	2,723	86	2,168	51	873
1969	---	---	203	6,497	103	2,797	69	1,539	46	688
1970	279	9,309	235	7,681	64	1,354	57	1,095	43	577
1971	178	5,572	271	9,013	115	3,214	--	---	60	1,206
1972	69	1,539	---	---	144	4,314	49	799	65	1,391

[1] MS1 CPE from grids adjacent to Isle Royale.

MS2 CPE from grids bordering MS3 (1020, 1021, 1121, 1122).

MS4 CPE from grids adjacent to Marquette and Munising.

MS5 1968 CPE from an inshore grid (1536) bordering MS4, 1969-1972 CPE from Caribou Is. grids.

MS6 CPE mainly from grid 1444.

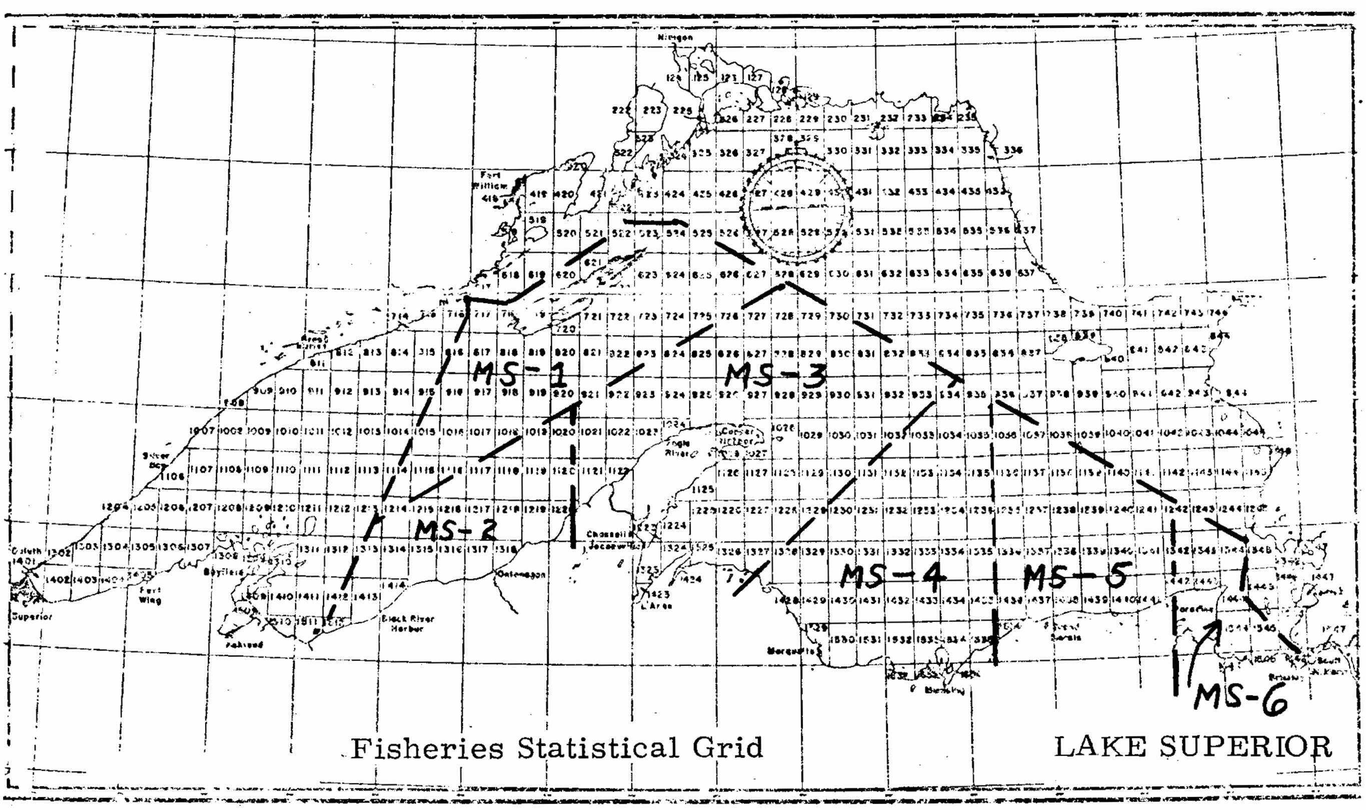

Figure 1. --Statistical grid map of Lake Superior

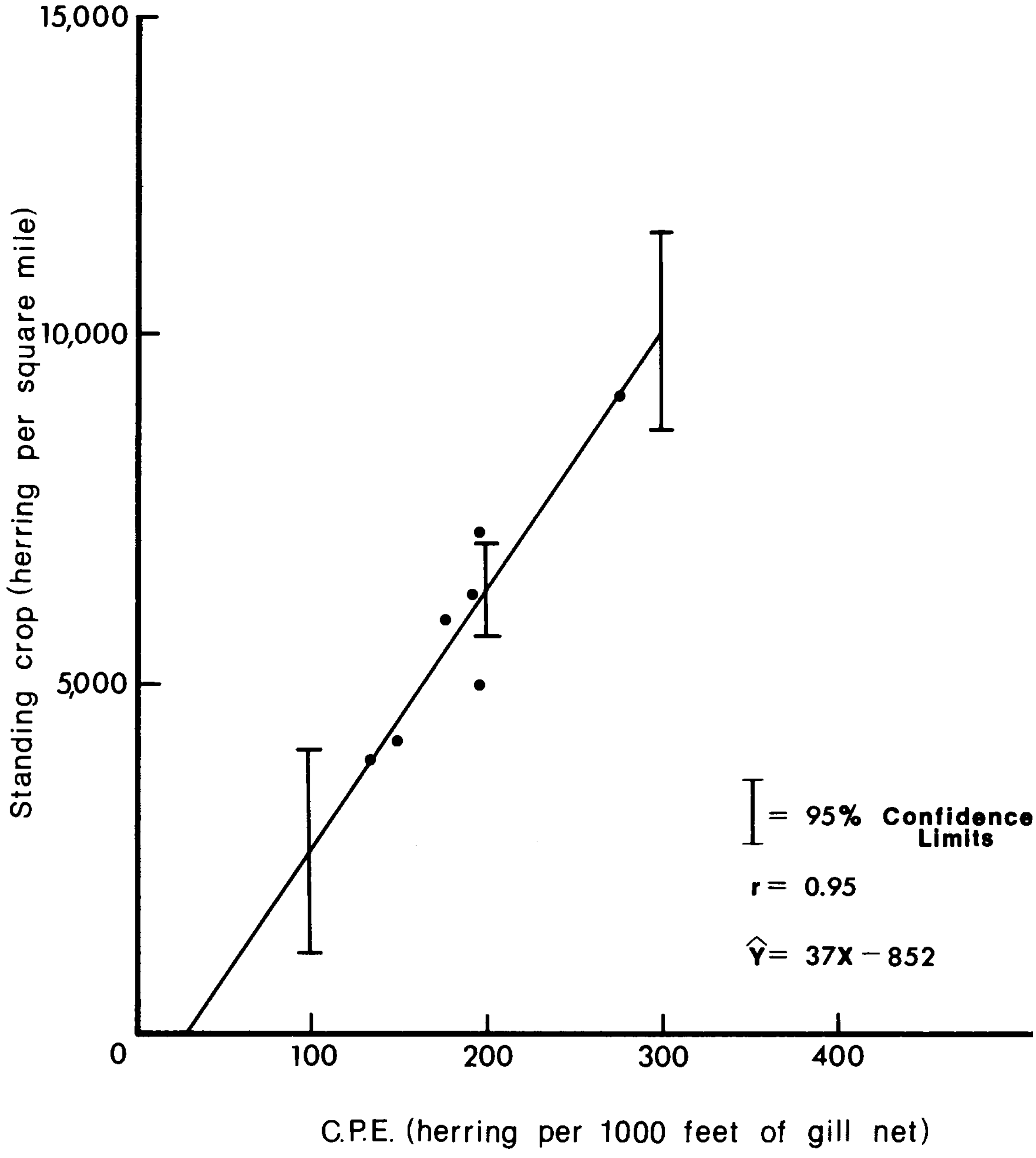

Figure 2.--Relationship of lake herring standing crop to commercial catch per unit of effort (CPE) in MS3 during 1965-1972.

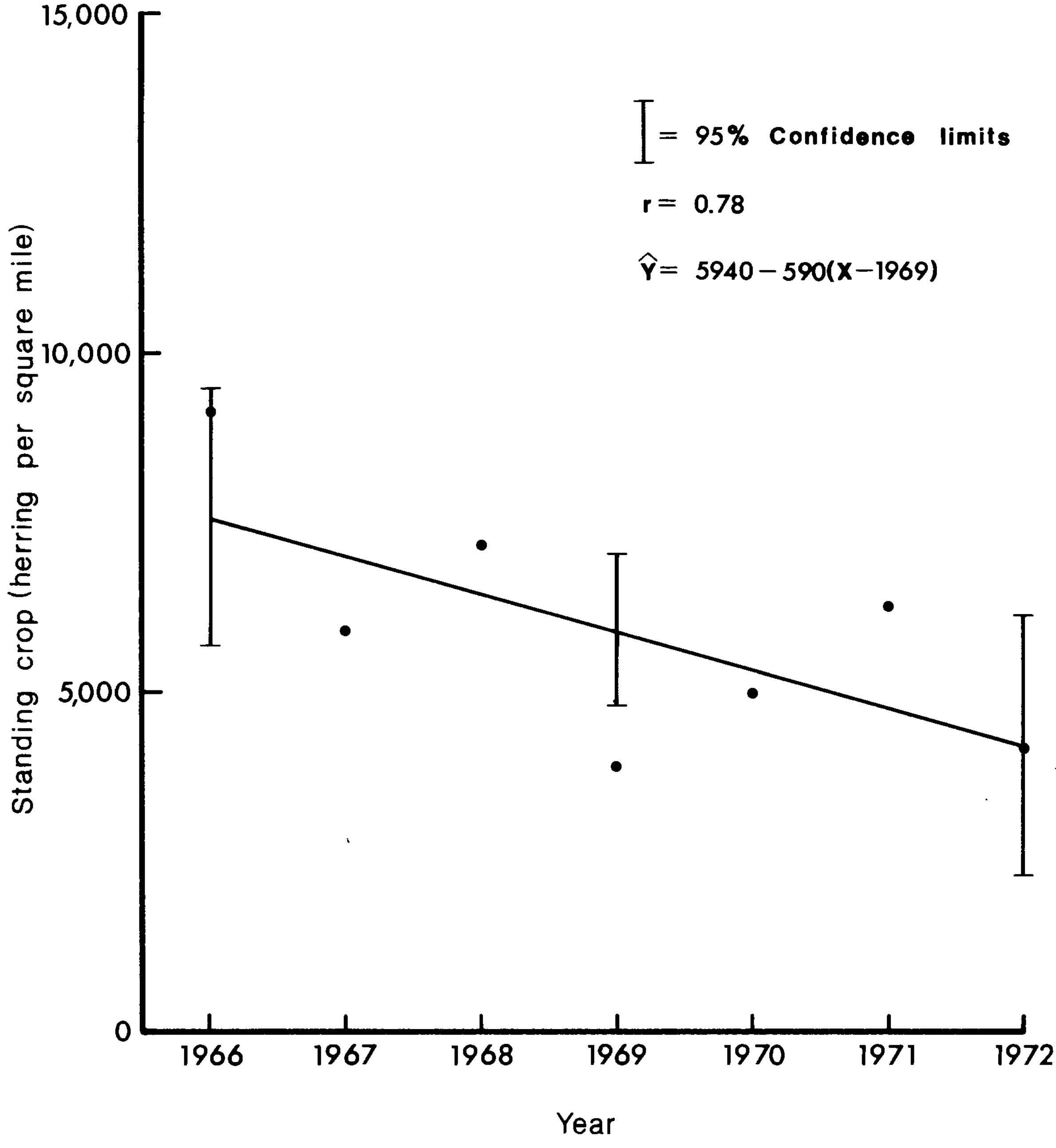

Figure 3.--Size of standing crop of lake herring in MS3 during 1966-1972.

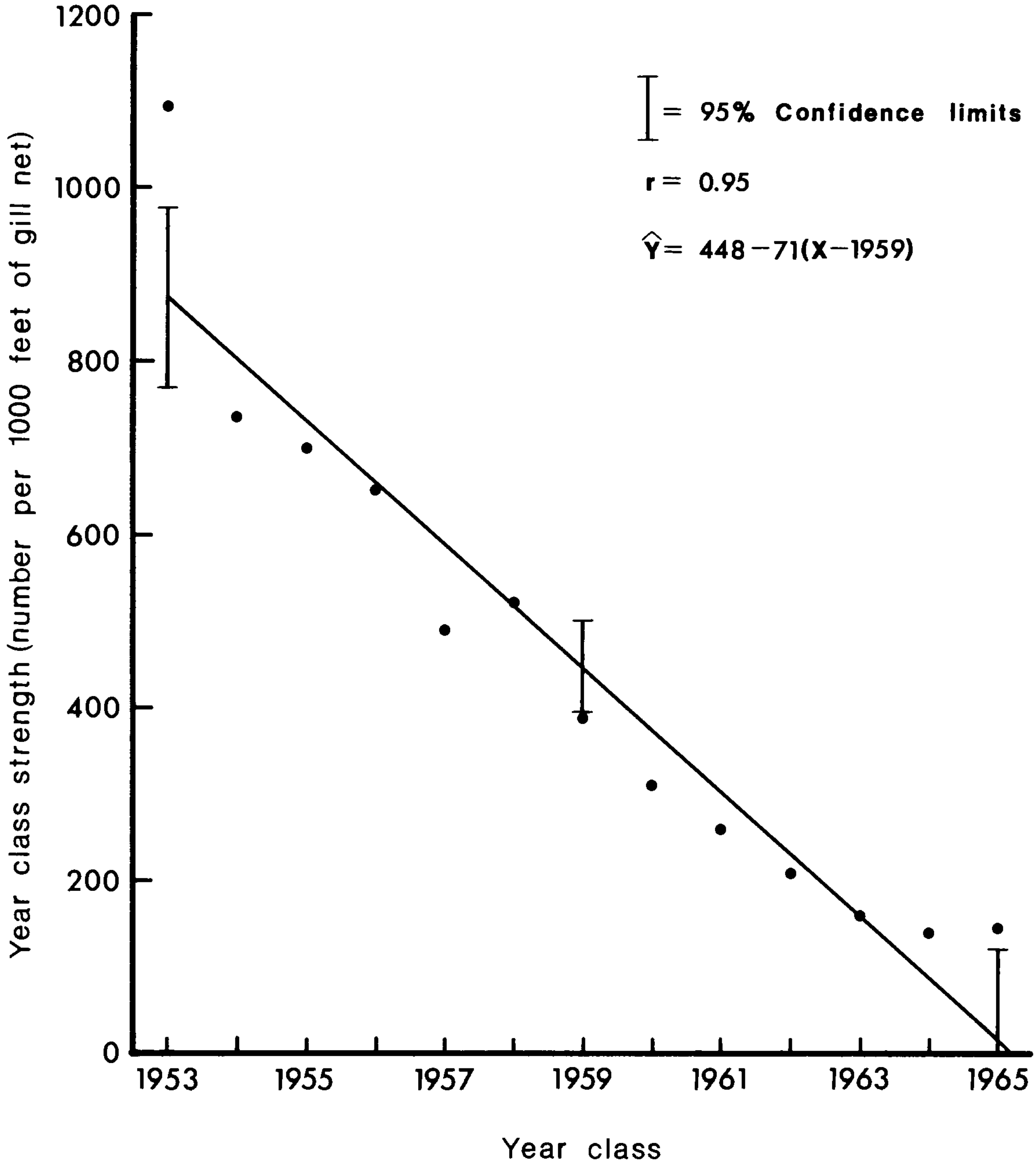

Figure 4.--Decline of lake herring year classes in MS3 as measured by total number in each year class caught per 1,000 feet of gill net during 1956-1972.