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HARVEST LEVELS FOR COMMERCIALLY EXPLOITED STOCKS OF LAKE WHITEFISH IN MICHIGAN WATERS OF LAKE SUPERIOR

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Abstract

Harvest levels were calculated for six stocks of Lake Superior lake whitefish using data collected over a 4-year period (1977-1980). Growth rates between stocks did not differ when confidence limits were taken into account. Mean age of the harvested portion of the stocks fluctuated yearly. The only stocks to exhibit a mean age of 1.5 to 2.0 years greater than the mean age of first maturity were in the Keweenaw and Marquette areas. The mean age of first maturity was found to be 5.2 years for all stocks. Total instantaneous mortality rates ranged from 0.37 in the Marquette stock to 0.84 in the Brimley stock. Estimates of optimum yield were made for all stocks utilizing a modified Beverton and Holt model. An optimum instantaneous fishing rate of 0.23 was recommended for all Lake Superior whitefish stocks.

Commercial production of whitefish has averaged over 725,000 pounds during the last 6 years from these stocks. The recommended harvest level for all stocks combined was 573,000 pounds. Decreases in exploitation rates were recommended for the Munising, Whitefish Point, and Brimley stocks while increases were recommended for the Keweenaw, Marquette, and Grand Marais stocks.

Introduction

Lake whitefish (Coregonus clupeaformis) are the most valuable and most sought after commercial species in the upper Great Lakes. This species is not only one of the most sensitive to exploitation but has the reputation of being one of the most resilient after depletion (Smith 1972).

Gill nets, trap nets, and pound nets have all been used extensively to harvest whitefish in the past. Today the bulk of whitefish landings from Michigan waters of Lake Superior come from large mesh trap nets, except in the Whitefish Bay area where an active Indian Treaty fishery utilizes large mesh gill nets.

The objective of this study was to estimate population and fishery statistics for six stocks of Lake Superior whitefish and to use these estimates to develop harvest levels for the individual stocks. Data collected over a 4-year period (1977-1980) on each of six stocks studied were used to calculate the harvest levels.

Methods

Over 7,500 legal-size (17 inches or larger) whitefish from six commercial trap-net locations at Keweenaw, Marquette, Munising, Grand Marais, Whitefish Point, and Brimley were sampled during 1977-1980 (Fig. 1). In 1977 and 1978, total length and scale samples were obtained for 200 fish in the spring and 200 fish in the fall at each location. Also, during 1978 sex and maturity data were obtained from each fish.

In 1979 and 1980 sampling was done by commercial fishermen during two periods, spring through early summer and fall. During each period, at each location, a maximum of 50 net-run fish were scale sampled and all fish were measured from five weekly trap net lifts.

In 1981, graded mesh (1.5- to 6-inch stretch) gill net was used by the Marquette Great Lakes Station crew at

Whitefish Point and Munising to sample age groups not recruited to the trap net fishery. A total of 112 whitefish, ranging in age from one to four, were measured and scale sampled. All scales collected were aged.

Results and Discussion

Commercial production

Commercial landings of whitefish in Michigan waters of Lake Superior over the last 6 years (1976-1981) have averaged over 725,000 pounds. Historical records showed that landings averaged 364,000 pounds from Michigan waters of Lake Superior during the period before heavy lamprey infestation (1929-1943). During the past decade, Michigan's licensed commercial fishermen (non-treaty fishermen) have landed an average of 452,000 pounds each year from Lake Superior. Yield has steadily increased when recent and historical catches are compared.

Most lake whitefish stocks in Lake Superior become fully vulnerable to the trap net fishery (4.5- to 4.7-inch stretch mesh) at age five at a mean total length of 19.8 inches. Eshenroder (1980) found that whitefish in northern Lake Huron were fully vulnerable to the trap net fishery at a length of 19.3 inches.

Catch statistics from the various whitefish stocks studied on Lake Superior are presented in Table 1. Catches have generally increased through the 6-year period on all stocks, except at Marquette which has been fairly stable and at Munising where a decline has taken place.

Negative trends in catch per unit of effort (CPE) through time (Table 2) were noted for the Marquette, Munising, Whitefish Point, and Brimley stocks, but only the trends at Marquette and Munising were significant ($P < 0.05$).

A positive trend in effort through time was noted for Marquette ($P < 0.05$) while effort has remained at a relatively constant level at Munising. The fact that CPE has declined in recent years at Munising while effort has remained stable indicates that abundance has declined. At Marquette, CPE has declined and effort has increased. Therefore, from these data, it is not clear whether stock abundance in the Marquette area is declining or remaining stable.

From 1975 through 1980, CPE generally increased at the Keweenaw. This probably does not reflect an increase in abundance but only that a new fisherman is becoming knowledgeable about his area and more efficient in using his gear. As fishermen enter into a new fishery, such as the trap net fishery, it may take several years for them to become proficient in using the new gear and to locate productive netting sites. Experience has shown that a new fisherman's CPE will increase for a number of years and then level off. The CPE data from the Keweenaw stock are a good example of this.

Catch per unit effort for the Grand Marais stock increased rapidly from 1977 to 1979 then declined through 1981. Part of the increase can be attributed to a new fisherman in a new fishery. However, suspected inaccuracies in daily catch reports for 1979 and 1980 make any conclusions about stock abundance here questionable.

Growth

Mean size at age varied slightly among whitefish collected from trap nets at the six locations (Table 3). Spring data were used to calculate growth at all areas except Munising and Brimley. At these areas some spring samples were not obtained, so fall data were used. Some unknown amount of disparity is created then by comparing mean size at age calculations between areas.

When confidence limits are taken into account, there is little difference between stocks in mean size at age for the fully vulnerable age groups.

Mean length at age data for pre-recruited age groups of lake whitefish are presented in Table 4. These fish were collected from the Munising and Whitefish Point stocks. Due to the small sample size, the data were combined and a weighted mean length was calculated.

Since differences in growth between stocks were slight, weighted lakewide mean lengths for each age group were calculated (Table 3). These mean lengths at age, along with those noted for the pre-recruits, were utilized in a FORTRAN program of the following von Bertalanffy growth equation (Rafail 1973):

$$L = L_{\infty} \, [1.0 - e^{-k(x-x_o)}]$$

where: L = length at age
L_{∞} = theoretical asymptotic length in inches
k = growth coefficient
x_o = theoretical age when length is zero
x = age

The predicted growth curve and the observed mean lengths are very similar for fully vulnerable age groups (Fig. 2). Somewhat larger variation between the predicted and observed occurs with age groups one through four. This variation can probably be attributed to the small sample size of the pre-recruits.

Healey (1975) summarized whitefish growth rates from various exploited and unexploited populations. He found that the rate of growth increased with increased intensity of exploitation. Although some Lake Superior stocks are fished much heavier than others, for example, five times the fishing effort is expended on the Whitefish Point stock than on the Keweenaw stock (Table 2), differences in mean size at age are slight. These slight differences in growth rates could be attributed to other factors such as the availability of suitable habitat for each stock.

Dryer (1963) studied whitefish from the Marquette, Whitefish Point, and Brimley areas during the mid to late 1950's. Differences in mean size at age were slight when

Dryer's data were compared to this study's data for Marquette and Whitefish Point. At Brimley, Dryer's fish were shorter in total length. In addition, Dryer reported that growth rates from the Brimley stock were slower than those at Marquette or Whitefish Point. Dryer did not report confidence limits for his data and therefore these differences may be only apparent.

Mean age and maturity

Mean age of the catch varied by sampling year and stock, ranging from 4.5 to 8.4 years (Table 5). Mean age was calculated by the formula $\bar{A} = (a_1 k_1 + a_2 k_2 + \ldots a_i k_i)/n$. Where $\bar{A}$ is the mean age, $a_1 \ldots a_i$ are the ages of fish in the catch, $k_1 \ldots k_i$ are the numbers of fish in each respective age group and "n" is the total number of fish in the sample. The mean age of the catch generally decreased from west (Keweenaw) to east with the younger ages found in the Whitefish Bay stocks (Whitefish Point and Brimley).

Maturity data were collected during 1978 from all six stocks and were combined into a lakewide sample (Table 6). No between stock analysis was conducted. Sex ratio of the lakewide sample was 49% male and 51% female.

The mean age of first maturity for the sexes combined was 5.2 years. This was calculated utilizing the formula $\bar{M} = (a_1 m_1 + a_2 m_2 + \ldots a_i m_i)/100$. Where $\bar{M}$ is the mean age of first maturity, $a_1 \ldots a_i$ are the ages of fish in the catch and $m_1 \ldots m_i$ are the percentages of newly mature fish in each respective age group.

MacCallum (1980) investigated lake whitefish populations in eastern Lake Superior. He found the mean age of maturity to be 5 years. In addition, MacCallum reported the mean ages of the commercial catch were 5.6 for males and 5.5 for females in 1978 samples taken near Gros Cap, Whitefish Bay. The low mean ages of the Whitefish Point and Brimley stocks are not surprising when one considers that yields have been over 300,000 pounds annually from these areas since 1976. As catch increases, mean ages decrease. This again is probably why mean ages generally decrease from west to east, since catch and effort generally increase in that direction.

Abrosov (1969) investigated the relationship between yields, mean age of first maturity, and mean age of the catch. His analysis of several populations of whitefish suggested that a difference of 1.5 to 2.0 years between the two mean ages would be optimal. Cristie and Regier (1972) supported this idea and suggested that lake whitefish be allowed to spawn 1.5 times in order for the population to maintain itself. When Abrosov's (1969) theory is applied to Lake Superior whitefish stocks, the mean age of the catch should range from 6.7 to 7.2 years. Only the Keweenaw and Marquette stocks fall into this range (Table 5).

Although mean ages of the catch are somewhat low for the Munising and Grand Marais stocks, they rebounded during 1980. However, the low mean age statistics for the Whitefish Point and Brimley stocks are cause for concern.

Mortality

Total instantaneous mortality rates (Z) were calculated for the six stocks of lake whitefish from catch curves in which the geometric means of percentage age frequency (y) were related to age (x) (Ricker 1975). A semi-logarithmic relationship was used such that $\ln(y) = a + bx$. The slope (b) represents the total instantaneous mortality (Z) of the fully vulnerable portion of the stock. These instantaneous rates can be converted to annual or seasonal total mortality (A) according to Ricker (1975).

Individual mortality relationships for each stock are contained in the Appendix, Figures 1 through 6. Instantaneous total mortality, annual total mortality rates, and coefficients of determination for the regression for each stock are presented in Table 7.

Annual total mortality for the fully vulnerable portion of the stocks ranged from 31% at Marquette to 57% at Brimley. These rates correspond well with the catch statistics presented in Table 1; where catches are large, the corresponding survival rates are low, and total mortality is high.

Once the total mortality has been determined for a stock, the question arises as to what portion of total annual mortality is due to natural causes and what portion can be attributed to fishing. Conclusive information about natural mortality rates of Lake Superior whitefish does not exist. Rybicki (1980) reported a 36% natural mortality rate for an unexploited stock of lake whitefish in Grand Traverse Bay, Lake Michigan. He used fish obtained from graded mesh gill net samples which ranged in age from six to thirteen. Cucin and Regier (1965) reported a natural mortality rate of 25.4%, in the absence of fishing, for Lake Huron whitefish ranging in age from four through eight. These same authors felt a natural mortality rate of 34% was a more realistic value for Lake Huron whitefish.

The lowest total mortality rate for the Lake Superior stocks studied was noted at Marquette. This rate of 31% total mortality is lower than the 34% or 36% natural mortality rates reported for lakes Huron or Michigan whitefish. The natural mortality rate for the fully vulnerable stocks (age 5 and greater) of Lake Superior whitefish is probably around 20 to 25%. The fact that growth rates are much slower in Lake Superior than Huron or Michigan also lends credence to the belief that natural mortality rates are lower in Lake Superior stocks. Ricker (1949) reported a mean natural mortality rate of 18% for a slow-growing unexploited population of whitefish in Shakespear Island Lake, Ontario.

Estimates of optimum yield

Estimates of optimum yield were made for all stocks utilizing a FORTRAN program of the Beverton and Holt (1957) model. This dynamic pool model weighs the parameters of growth against the instantaneous natural and fishing mortality rates for the purpose of predicting the best level of exploitation.

The model has been slightly modified from the standard Beverton and Holt model in three ways. First, it uses the von Bertalanffy parameters (Fig. 2) of growth in length rather than growth in weight and it converts length to weight for yield computations by using the length-weight regression coefficients. The length-weight relationship reported by Dryer (1963) of:

$$\ln(W) = -8.7 + 3.2408 \ln (L)$$

was used for all stocks. Second, it uses the Baranov catch function to compute catch in numbers by age. And third, it calculates the number of fish by age remaining in the population. These changes were suggested by Tyler and Gallucci (1980) and are described in detail in Clark and Huang (1983).

It was assumed that all whitefish over 17 inches in total length were equally recruited to the fishery. This corresponds to an age of entry of 4.1 years. The combined data of the von Bertalanffy growth curve (Fig. 2) were used as model input because no growth differences were found between the stocks.

Since precise natural mortality rates of Lake Superior whitefish populations are not known, yield estimates were made for three alternative rates. These were rates of 20, 22, and 25% natural mortality. In this way, three alternative yield estimates for each individual stock could be compared with other data, such as historical catches, and recommended harvest levels could be decided upon.

Yield-per-recruit analyses for each of the three alternative natural mortality rates were used to ascertain optimum fishing rates. This was accomplished by plotting yield-per-recruit against the corresponding instantaneous rate of fishing (F). From this, the optimum rate of fishing mortality (F_{opt}) and the maximum rate of fishing mortality (F_{max}) were determined.

F_{max} is the rate of F which corresponds to the peak of the yield-per-recruit curve (Fig. 3). F_{opt} is the rate of F which corresponds to one-tenth of the slope of the yield-per-recruit curve where F equals zero (Fig. 3). This method of determining an optimum fishing rate has been widely used as a target fishing mortality rate for major commercial fisheries of the North Atlantic (Sissenwine 1981, Gulland and Boerema 1973).

There is an economic basis for maintaining the fishing mortality rate below (F_{max}). Fishing mortality corresponds to fishing effort and revenue is related to catch so the additional units of fishing effort when F is near F_{max} produce only very slight increases in revenue. Clearly, from any practical viewpoint, it would be undesirable to increase the amount of fishing beyond the level at which the value of the marginal yield is small compared with the costs of the extra units of effort required to produce that yield (Gulland and Boerema 1973).

Yield-per-recruit curves for the three natural mortality rates are presented in Figures 4 through 6. The resulting optimum instantaneous rates of fishing were 0.23 for the 20 and 22% natural mortality rates and 0.33 for the 25% natural mortality rate (Table 8). F_{opt} was solved for by approximating the tangents to the yield-per-recruit curve (Fig. 3) at F_0 and $F_{0.1}$ using linear regression. Two sets of coordinates near F_0 were arbitrarily chosen and the slope of the line through those points was determined. Then, by trial and error, a tangent to the curve was found that had a slope one-tenth of the slope found at F_0. The point at which that line on tangent ($F_{0.1}$) intercepts the yield-per-recruit curve is equal to F_{opt}.

Biomass and optimum yield estimates were made utilizing the optimum fishing rates for each stock at each alternative natural mortality rate (Table 9).

Average annual biomass ($\bar{B}$) is equal to Y_c/F (Rybicki 1980) where Y_c is the average commercial yield for 1976-1981 and F is the instantaneous fishing rate determined by the relation $Z = M + F$ (Ricker 1975). Optimum yield (Y_{opt}) estimates were determined by substituting F_{opt} for F in the biomass equation.

Optimum yield estimates for all stocks combined ranged from 506,760 pounds for the 20% natural mortality rate (M=0.22) to 1,087,788 pounds for the 25% natural mortality rate (M=0.30) (Table 8). Historical catch records indicate that landings averaged 364,000 pounds from Michigan waters of Lake Superior from 1929-1943, the period before heavy lamprey infestation.

Since 1929, when a catch reporting system was introduced for Michigan licensed commercial fishermen, annual catches only exceeded 600,000 pounds on one occasion. Therefore, the yield estimate of over one million pounds for the 25% natural mortality rate seems unreasonably high.

Very little insight is gained by analyzing historical catches by individual stock. Some stocks, such as those at the Keweenaw, Marquette, and Grand Marais areas, have never been heavily fished consistently. Only the stocks in the Whitefish Bay (Whitefish Point and Brimley stocks) fit this criterion. The historical record indicates that landings for these stocks average 178,000 pounds annually from 1929-1943. This figure is very similar to the optimum yield estimate of 176,609 pounds for the Whitefish Point and Brimley stocks utilizing the 22% natural mortality rate.

Management recommendations

The estimates of optimum yield for the 20 and 22% natural mortality rates are very similar. The yield estimates for the 22% natural mortality alternative are judged to be the most satisfactory.

Recommended harvest levels for the six stocks of whitefish studied are presented in Table 10. Increases in exploitation rates are recommended for the Keweenaw, Marquette, and Grand Marais stocks. Decreases in exploitation are recommended for the Munising, Whitefish Point, and Brimley stocks.

The recommended harvest (Y_r) levels developed from the optimum yields (Y_{opt}) in Table 9 are for the short term. As the average biomass ($\bar{B}$) of the stocks change so will the corresponding optimum yields. Theoretically, with constant rates of fishing and natural mortality, the biomass of each stock will gradually change along with the corresponding optimum yield for that stock until some optimum biomass is reached, assuming constant recruitment.

Taking this into account, the optimum yields or recommended harvest levels over the long term will gradually decrease for the Keweenaw, Marquette, and Grand Marais stocks if F_{opt} is maintained. This will occur because the average biomass of each stock will decrease due to the increase in exploitation.

The opposite will occur over the long term with the Munising, Whitefish Point, and Brimley stocks. Optimum yields for these stocks should increase gradually over time if F_{opt} is maintained. The average biomass of these stocks will increase due to the decrease in exploitation.

Particular attention should be paid to the Whitefish Bay stocks at Brimley and Whitefish Point. The recommended harvest level for the entire bay is 177,000 pounds--91,000 pounds from the Whitefish Point stock and 86,000 pounds from the Brimley stock. These recommended yields are substantially lower than recent harvest levels. Historical catch records indicate that the recommended harvest levels are in line with past yields. Mean age of the commercial catches are depressed in these stocks (Table 5). In addition, data reported by MacCallum (1980) from the Brimley stock, which is thought to be mutually shared by Michigan and Canada, indicates heavy overexploitation. Therefore, all of the evidence indicates that the large recommended reduction in harvest levels in Whitefish Bay, especially in the Brimley stock, is warranted.

The harvest estimates presented in this paper could be refined further if a precise natural mortality rate was determined for Lake Superior whitefish populations. Therefore, it is recommended that further study on Lake Superior be targeted in this area.

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Table 1. Landings in pounds of lake whitefish from state-licensed and treaty fisheries, Lake Superior, 1976-81.

Area and fishery	1976	1977	1978	1979	1980	1981	Average
Keweenaw							
State	38,017	34,309	19,203	27,424	55,164	35,623	40,314
Treaty[a]	3,500	4,200	8,400	3,300	4,000	8,745	
Marquette							
State	62,680	60,133	41,236	55,268	64,164	70,634	59,019
Treaty	---	---	---	---	---	---	
Munising							
State	233,848	215,115	203,999	206,961	153,675	108,860	228,925
Treaty	43,700	35,600	36,000	43,800	27,394	64,600	
Grand Marais							
State	1,341	20,017	30,404	50,778	31,591	25,310	46,733
Treaty	4,500	4,000	4,000	4,400	48,358	55,700	
Whitefish Pt.							
State	42,939	21,145	37,003	52,081	89,347	113,953	133,810
Treaty	79,160	40,400	71,400	102,600	78,636	74,200	
Brimley							
State	113,555	79,008	70,340	105,456	107,153	46,463	220,845
Treaty	118,740	60,600	107,100	153,900	117,955	244,800	

[a] Treaty catches for 1976-1978 are estimates based on state wholesale reports; catches for 1979-1981 are from U.S. Department of Interior (1981).

Table 2. Catch per unit of effort (pounds per lift) and effort (number of lifts) for lake whitefish caught in trap nets, Lake Superior, 1975-81.

Area	1975	1976	1977	1978	1979	1980	1981
Keweenaw							
Catch/effort	147	254	295	266	353	364	308
Effort	50	149	111	63	72	185	96
Marquette							
Catch/effort	295	314	212	196	169	194	197
Effort	167	195	270	209	323	337	357
Munising							
Catch/effort	388	276	239	241	232	183	183
Effort	360	568	581	599	642	615	554
Grand Marais							
Catch/effort	---	---	96	100	422	363	159
Effort	---	---	85	131	90	70	158
Whitefish Pt.							
Catch/effort	180	114	87	113	164	120	142
Effort	347	401	420	468	393	774	757
Brimley							
Catch/effort	127	141	105	181	111	94	45
Effort	257	192	359	206	434	462	434

Table 3. Mean total length in inches (with 95% confidence limits in parentheses) and number in sample by age group for lake whitefish collected from trap nets in Lake Superior. (S = spring-summer and F = fall).

Area	Age 5	6	7	8	9	10	11
Keweenaw (S)							
Mean total length	19.40	20.90	22.70	23.90	25.10	25.90	27.20
	(0.17)	(0.15)	(0.13)	(0.21)	(0.21)	(0.29)	(0.49)
Number	69	96	157	130	103	49	17
Marquette (S)							
Mean total length	19.50	21.20	23.30	24.30	25.80	26.90	27.60
	(0.15)	(0.16)	(0.16)	(0.25)	(0.24)	(0.27)	(0.38)
Number	173	180	217	147	87	53	23
Munising (F)							
Mean total length	20.20	21.30	23.80	24.00	25.20	26.80	28.20
	(0.15)	(0.30)	(0.59)	(1.11)	(1.34)	(0.45)	(0.59)
Number	241	97	41	33	45	30	16
Grand Marais (S)							
Mean total length	20.40	22.30	23.80	25.70	27.20	27.70	28.20
	(0.11)	(0.22)	(0.39)	(0.37)	(0.29)	(0.35)	(0.73)
Number	518	567	605	653	690	703	716
Whitefish Pt. (S)							
Mean total length	19.30	21.50	22.80	24.50	25.90	26.40	28.40
	(0.30)	(0.57)	(0.88)	(1.02)	(1.78)	(0.96)	(0.00)
Number	348	103	46	35	16	10	1
Brimley (F)							
Mean total length	20.00	21.50	22.90	23.80	24.80	26.10	27.40
	(0.35)	(0.48)	(0.57)	(0.69)	(1.04)	(0.66)	(0.14)
Number	171	149	103	48	23	10	3
Combined							
Mean total length	19.9	21.8	23.4	25.1	26.7	27.5	28.2
	(0.19)	(0.27)	(0.35)	(0.39)	(0.37)	(0.36)	(0.37)
Number	1,520	1,192	1,169	1,046	964	855	776

Table 4. Mean total length in inches (with 95% confidence limits in parentheses) and number in sample by age group for lake whitefish collected with graded mesh gill nets in Lake Superior, June 1981.

	Age			
	1	2	3	4
Mean total length	5.1 (0.43)	9.1 (1.0)	13.0 (0.32)	16.2 (0.62)
Number	2	2	25	83

Table 5. Mean age of the commercial catch of lake whitefish, Lake Superior, 1977-80.

Area	Year				
	1977	1978	1979	1980	Average
Keweenaw	7.1	8.4	6.2	7.3	7.3
Marquette	6.6	6.5	7.2	6.7	6.8
Munising	7.1	6.5	5.1	6.0	6.2
Grand Marais	--	5.0	5.6	6.3	5.6
Whitefish Pt.	5.0	4.5	5.2	5.1	5.0
Brimley	6.0	4.8	5.7	5.9[a]	5.6

[a] From Williamson, Liston, and Bohr (1981).

Table 6. Percentage of mature lake whitefish by age group, Lake Superior, 1978.

Age	Male	Females	Sexes combined
3	29	19	23
4	31	38	35
5	58	56	57
6	80	81	80
7	91	90	90
8	97	94	95
9	97	95	96
10	93	100	97
11	100	100	100
12	100	100	100

Table 7. Instantaneous total mortality (Z), annual total mortality (A) as a percent and coefficients of determination (R^2) for catch curve analysis of six stocks of lake whitefish, Lake Superior, 1977-80.

Area	Z	A	R^2
Keweenaw	0.428	35	0.94
Marquette	0.368	31	0.91
Munising	0.573	43	0.93
Grand Marais	0.406	34	0.90
Whitefish Pt.	0.586	45	0.96
Brimley	0.839	57	0.98

Table 8. Corresponding natural mortality (m) as a percent and instantaneous rates of natural mortality (M), optimum fishing (F_{opt}) and maximum fishing (F_{max}) for lake whitefish populations in Lake Superior.

m	M	F_{opt}	F_{max}
20	0.22	0.23	0.50
22	0.25	0.23	0.58
25	0.30	0.33	0.60

Table 9. Optimum yield estimates at three levels of natural mortality for lake whitefish stocks in Lake Superior. (Y_c = average catch in pounds 1976-81, Z = total instantaneous mortality, M = instantaneous natural mortality, F = instantaneous fishing mortality, $\bar{B}$ = average biomass in pounds, F_{opt} = optimum instantaneous fishing mortality and Y_{opt} = optimum yield in pounds.)

Area	Y_c	Z	M	F	$\bar{B}$	F_{opt}	Y_{opt}
Natural mortality (m) = 20%							
Keweenaw	40,314	0.43	0.22	0.21	191,971	0.23	44,153
Marquette	59,019	0.37	0.22	0.15	393,460	0.23	90,495
Munising	228,925	0.57	0.22	0.35	654,071	0.23	150,436
Grand Marais	46,733	0.41	0.22	0.19	245,963	0.23	56,571
Whitefish Pt.	133,810	0.59	0.22	0.37	361,648	0.23	83,179
Brimley	220,845	0.84	0.22	0.62	356,201	0.23	81,926
Total							506,760
Natural mortality (m) = 22%							
Keweenaw	40,314	0.43	0.25	0.18	223,966	0.23	51,512
Marquette	59,019	0.37	0.25	0.12	491,825	0.23	113,119
Munising	228,925	0.57	0.25	0.32	715,390	0.23	164,539
Grand Marais	46,733	0.41	0.25	0.16	292,081	0.23	67,178
Whitefish Pt.	133,810	0.59	0.25	0.34	393,558	0.23	90,518
Brimley	220,845	0.84	0.25	0.59	374,313	0.23	86,091
Total							572,957
Natural mortality (m) = 25%							
Keweenaw	40,314	0.43	0.30	0.13	310,107	0.33	102,335
Marquette	59,019	0.37	0.30	0.07	843,128	0.33	278,232
Munising	228,925	0.57	0.30	0.27	847,870	0.33	279,797
Grand Marais	46,733	0.41	0.30	0.11	424,845	0.33	140,198
Whitefish Pt.	133,810	0.59	0.30	0.29	461,413	0.33	152,266
Brimley	220,845	0.84	0.30	0.54	408,972	0.33	134,960
Total							1,087,788

Table 10. Recommended harvest (Y_r) in pounds and current (U_c) and optimum (U_{opt}) exploitation rates in percent for lake whitefish stocks in Lake Superior.

Area	Y_r	U_c	U_{opt}	Percent change
Keweenaw	52,000	15	19	+27
Marquette	113,000	10	19	+90
Munising	165,000	24	18	-25
Grand Marais	67,000	13	19	+46
Whitefish Pt.	91,000	26	17	-35
Brimley	86,000	40	16	-60

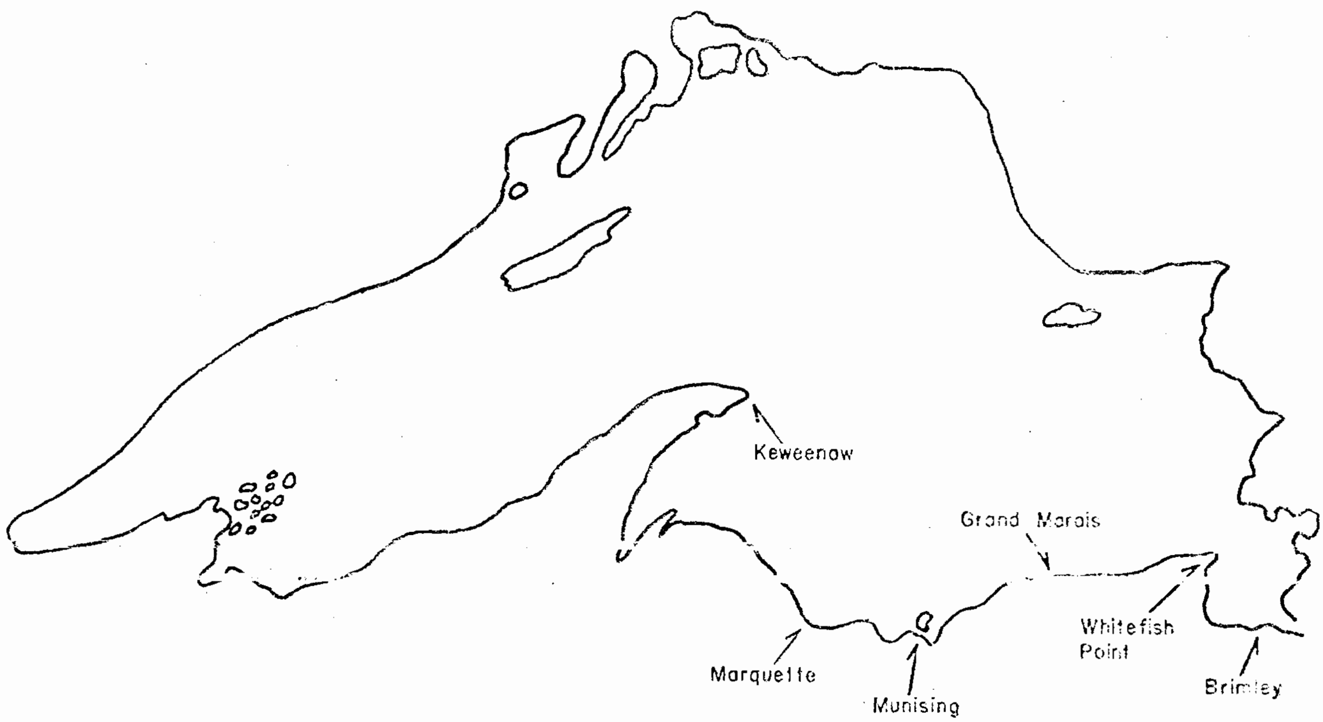

Figure 1.--Lake whitefish sampling areas in Lake Superior.

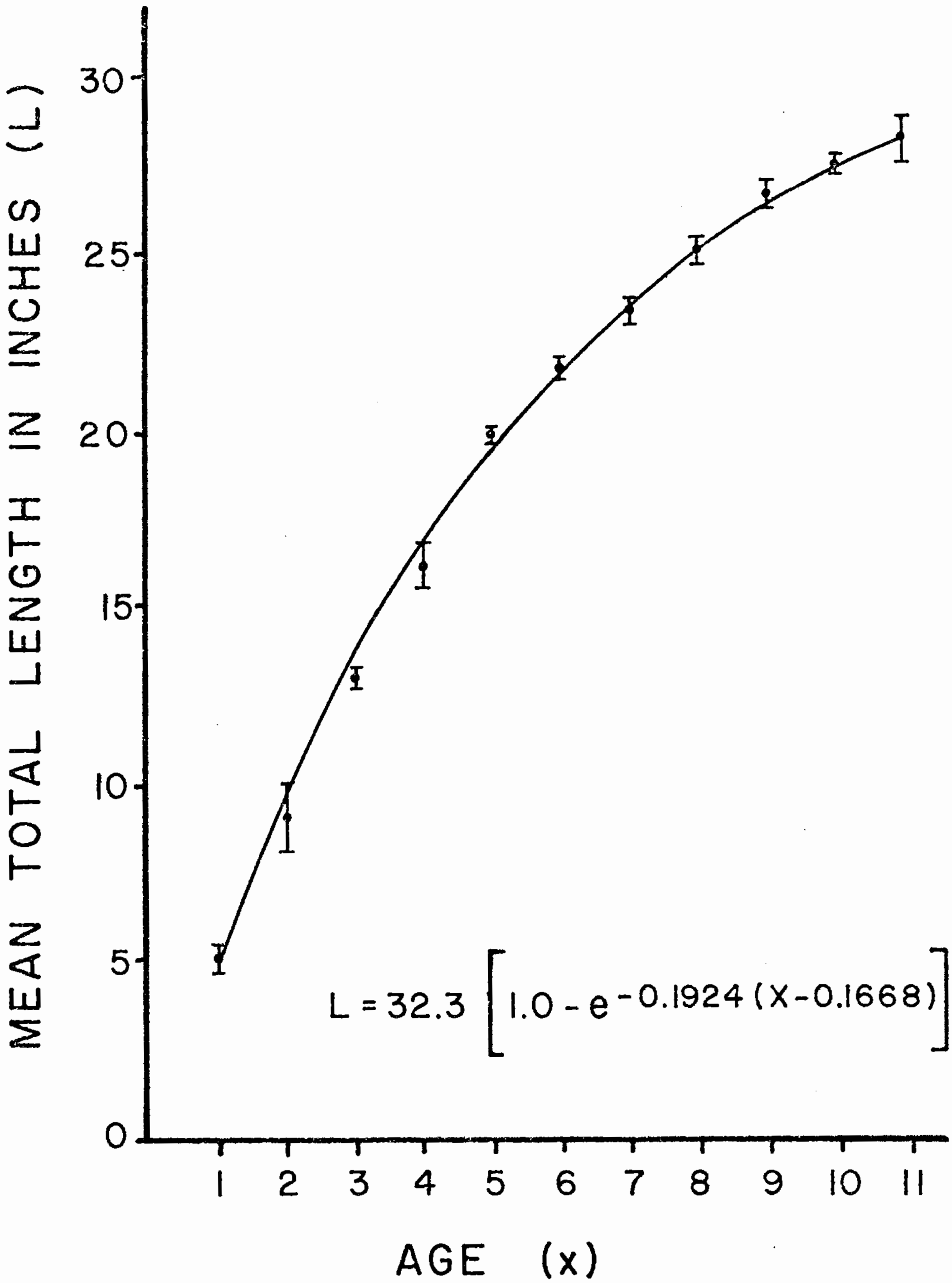

Figure 2.--Fitted von Bertalanffy curve and empirical mean length-age relationship with 95% confidence limits for lake whitefish, Lake Superior, 1977-80.

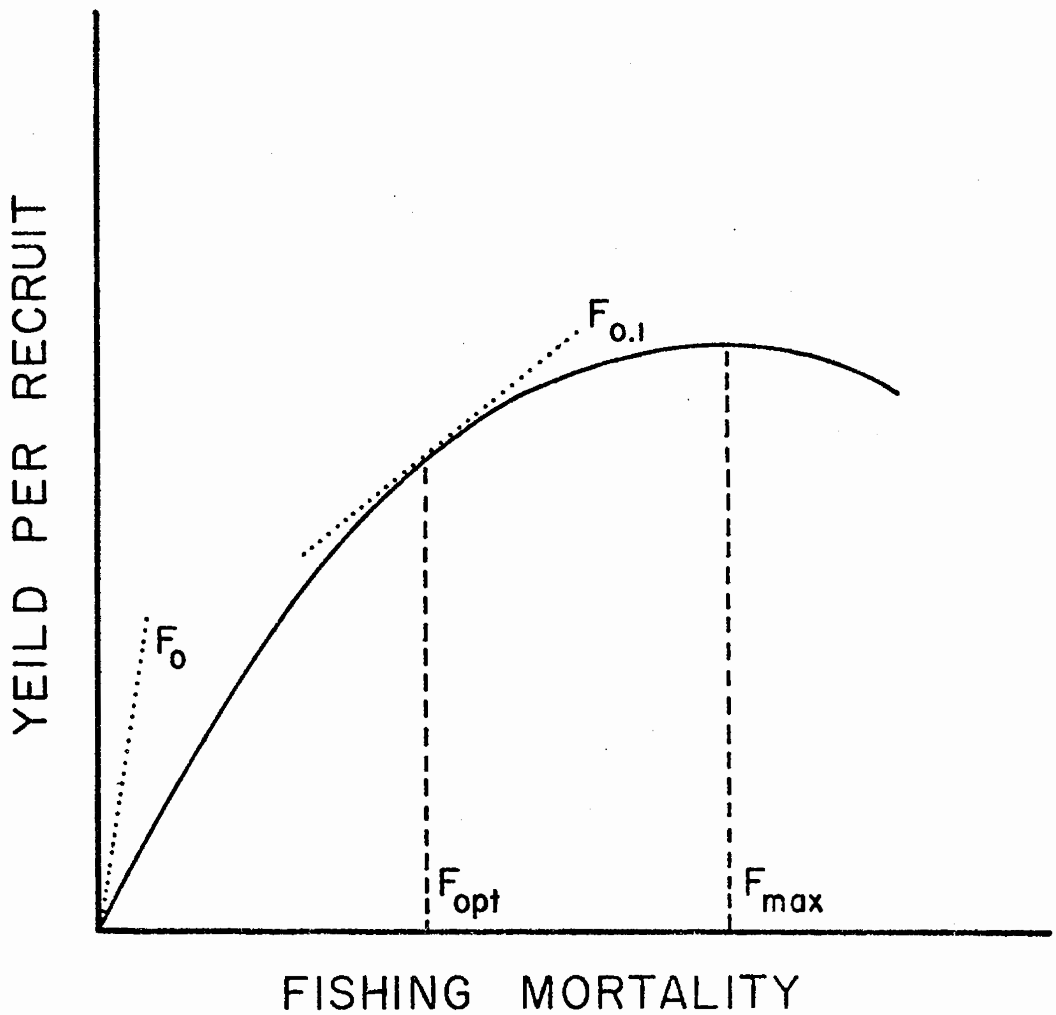

Figure 3.--Example of a yield-per-recruit curve: F_0 is a line tangent to the yield curve at a fishing rate of 0 and $F_{0.1}$ is a line tangent to the curve where the slope is 0.1 at the line F_0. The tangent point of line $F_{0.1}$ indicates optimum yield and rate of fishing F_{opt}. F_{max} indicates maximum yield.

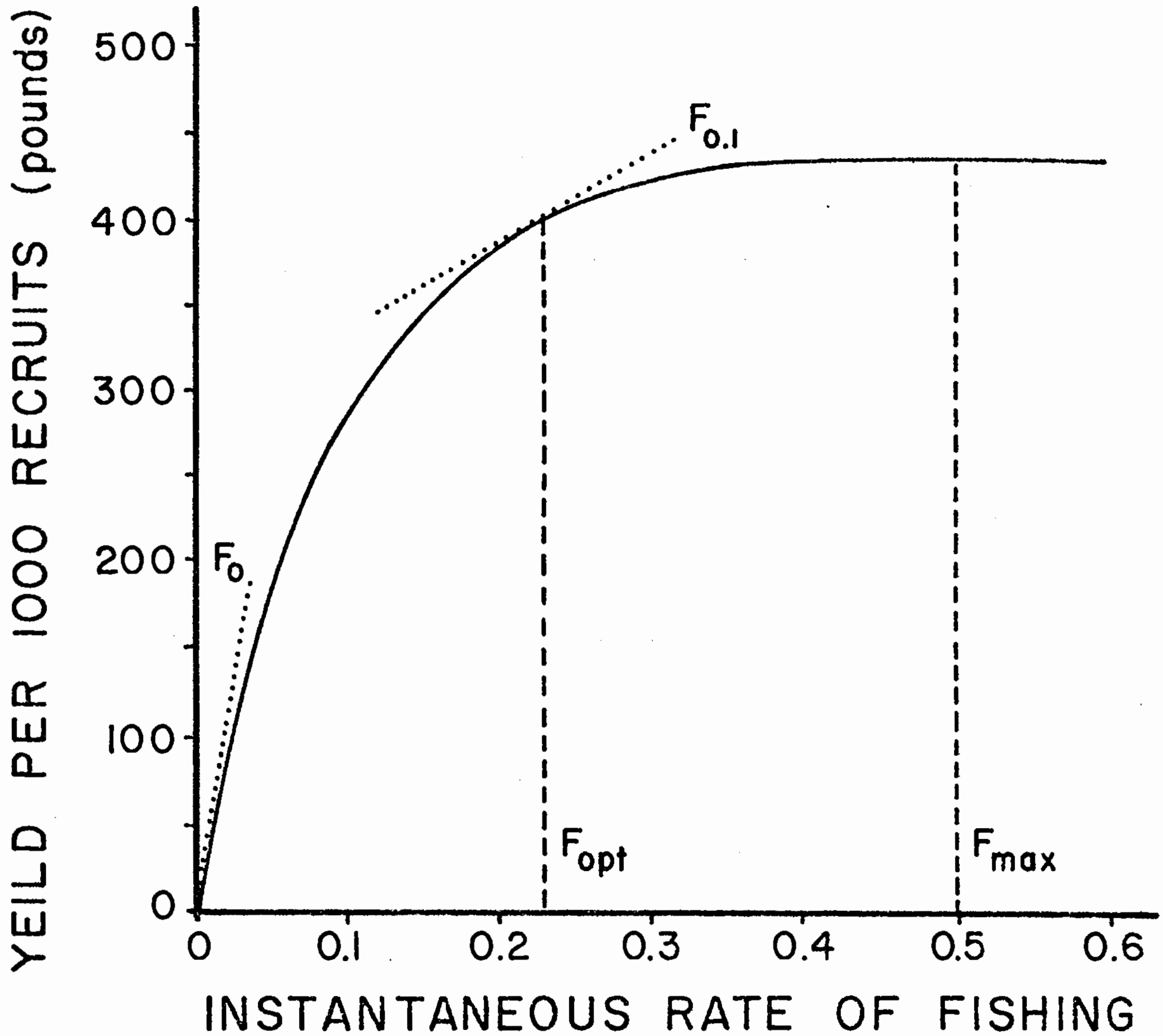

Figure 4.--Yield-per-recruit curve for a lake whitefish population in Lake Superior having a 20% natural mortality rate (M=0.23).

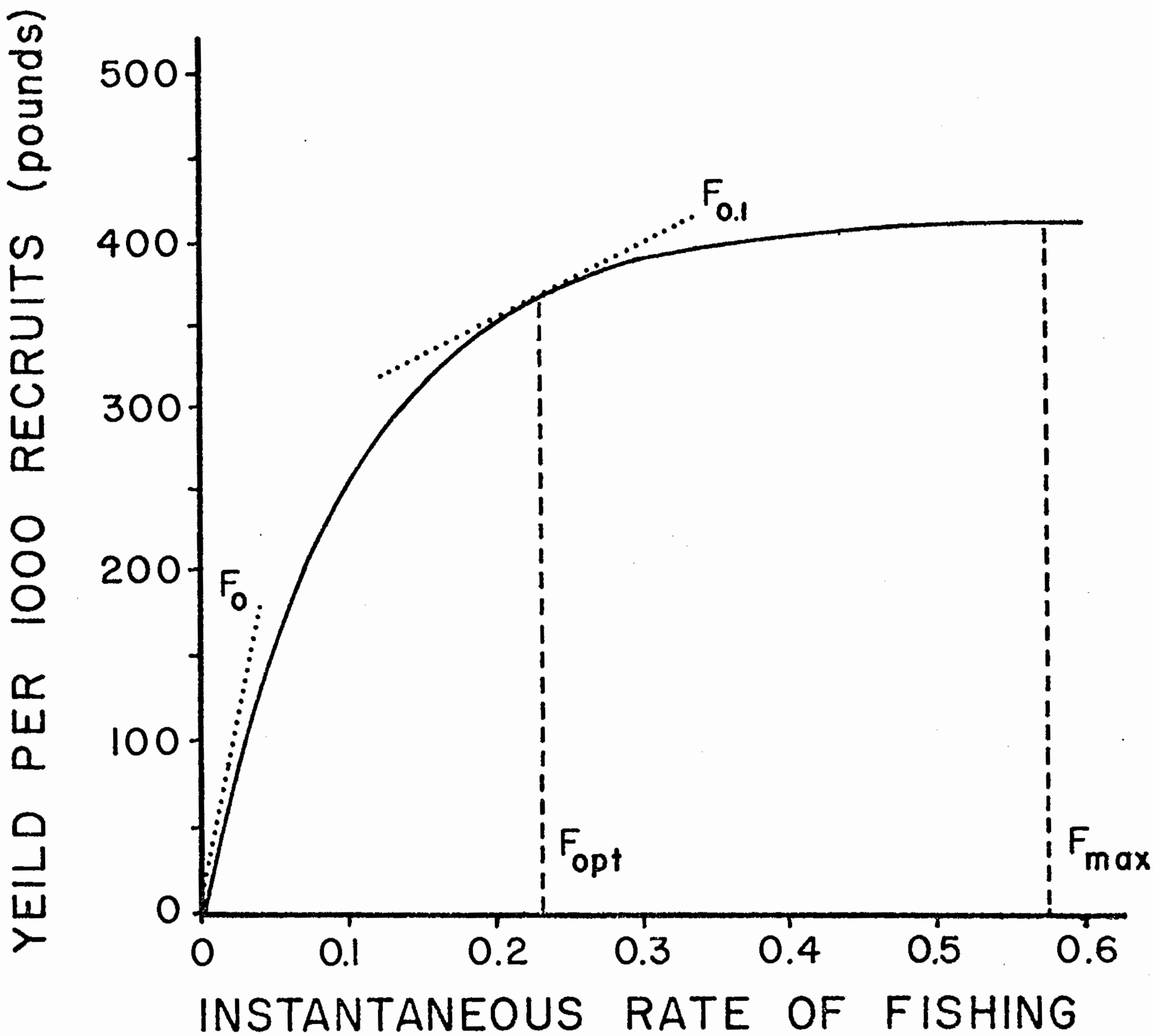

Figure 5.--Yield-per-recruit curve for a lake whitefish population in Lake Superior having a 22% natural mortality rate (M=0.25).

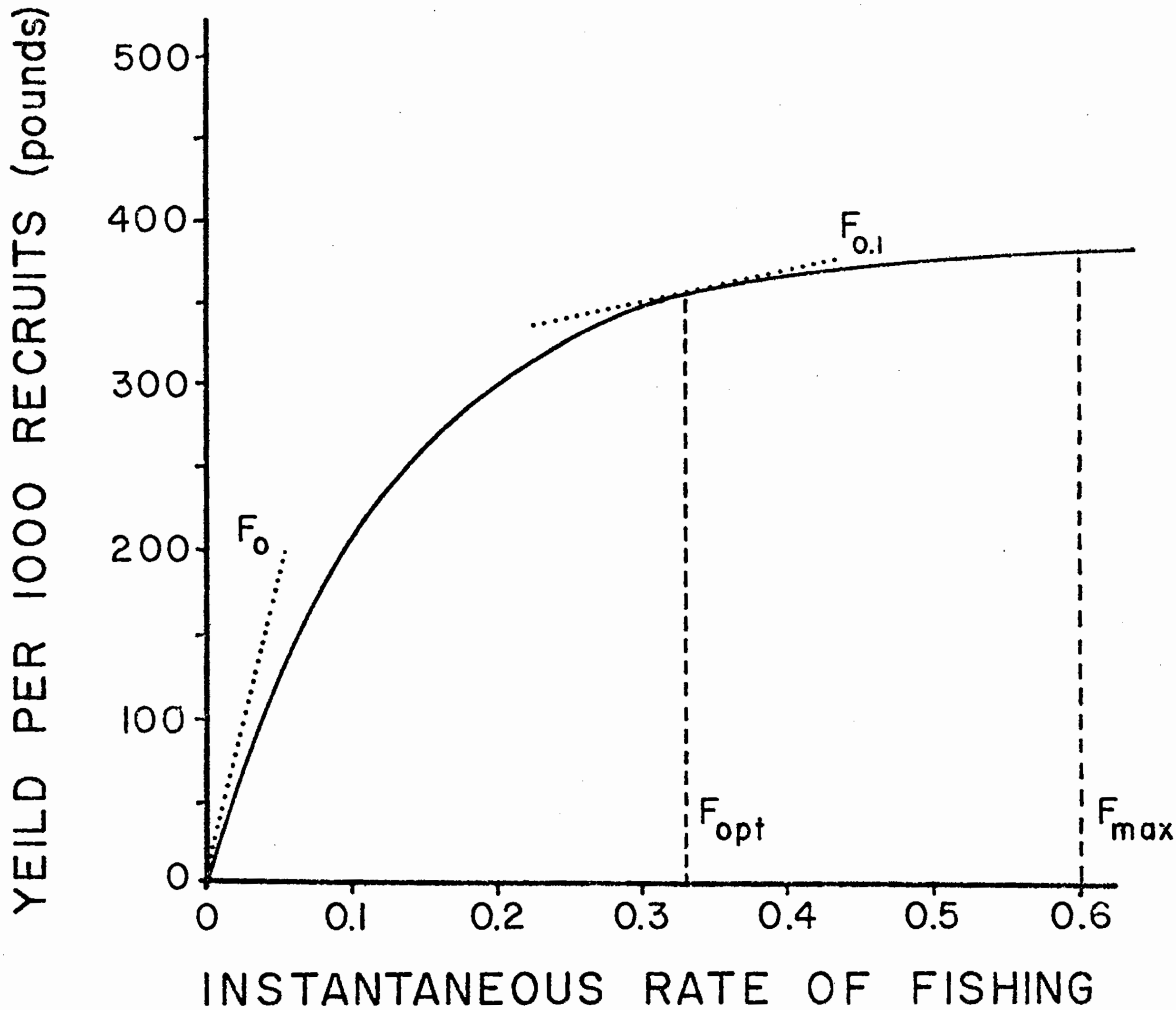

Figure 6.--Yield-per-recruit curve for a lake whitefish population in Lake Superior having a 25% natural mortality rate (M=0.30).

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Report approved by W. C. Latta

Typed by G. M. Zurek

APPENDIX

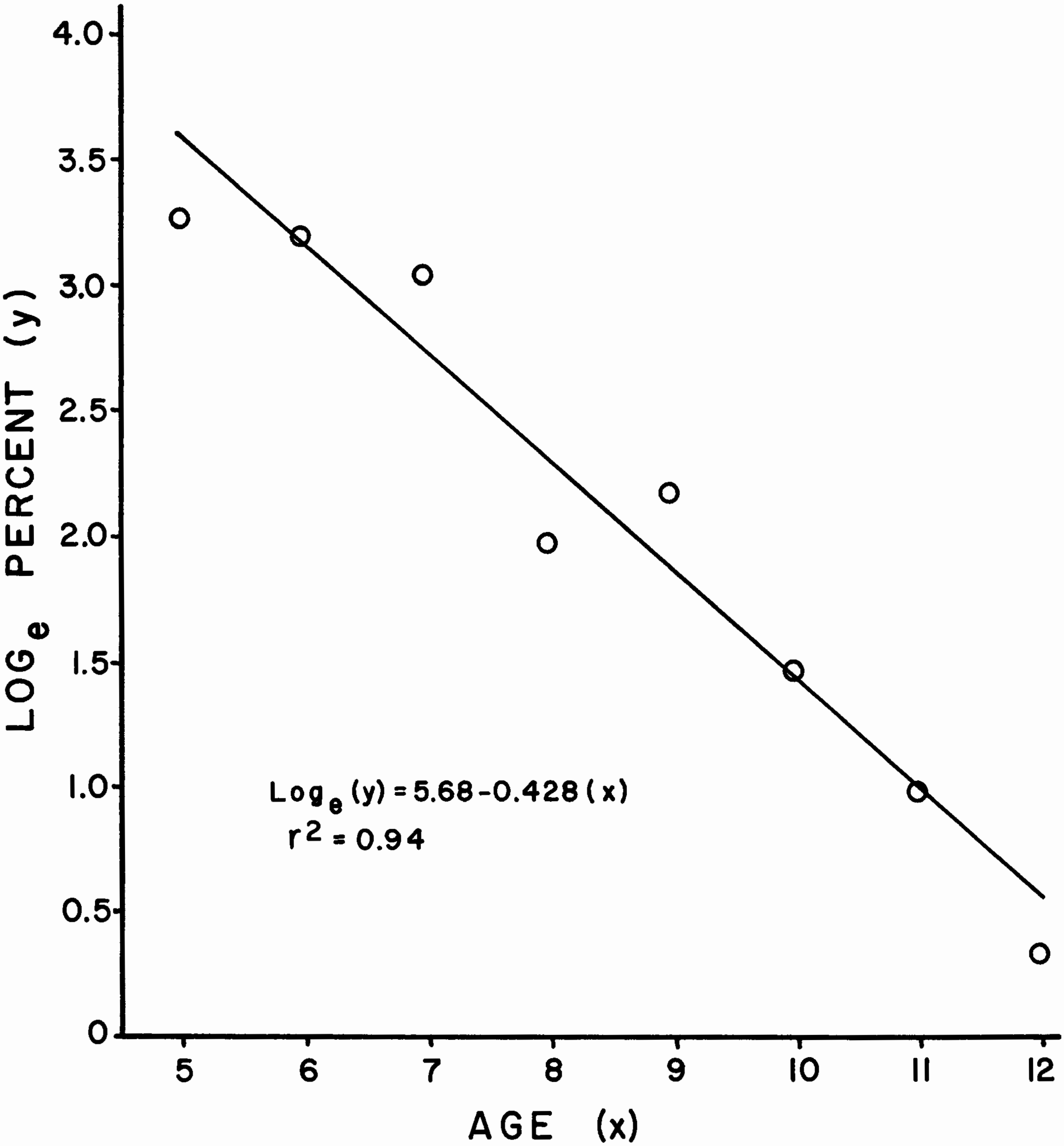

Figure 1.--Natural logarithm of percent age composition of lake whitefish (17 inches or larger) in trap nets at Keweenaw, 1979-80. Each point is a geometric mean of two observations.

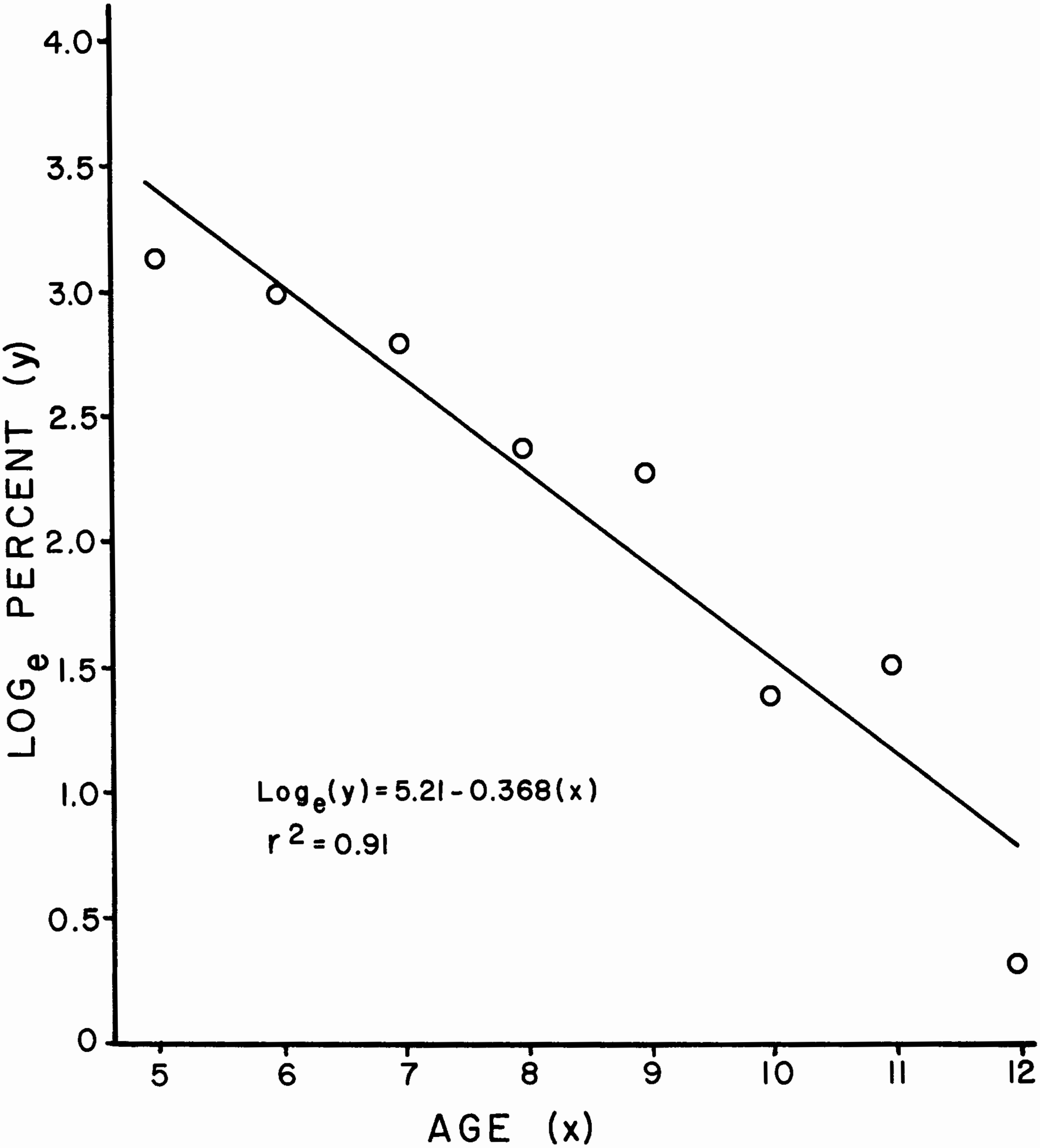

Figure 2.--Natural logarithm of percent age composition of lake whitefish (17 inches or larger) in trap nets at Marquette, 1978-80. Each point is a geometric mean of three observations.

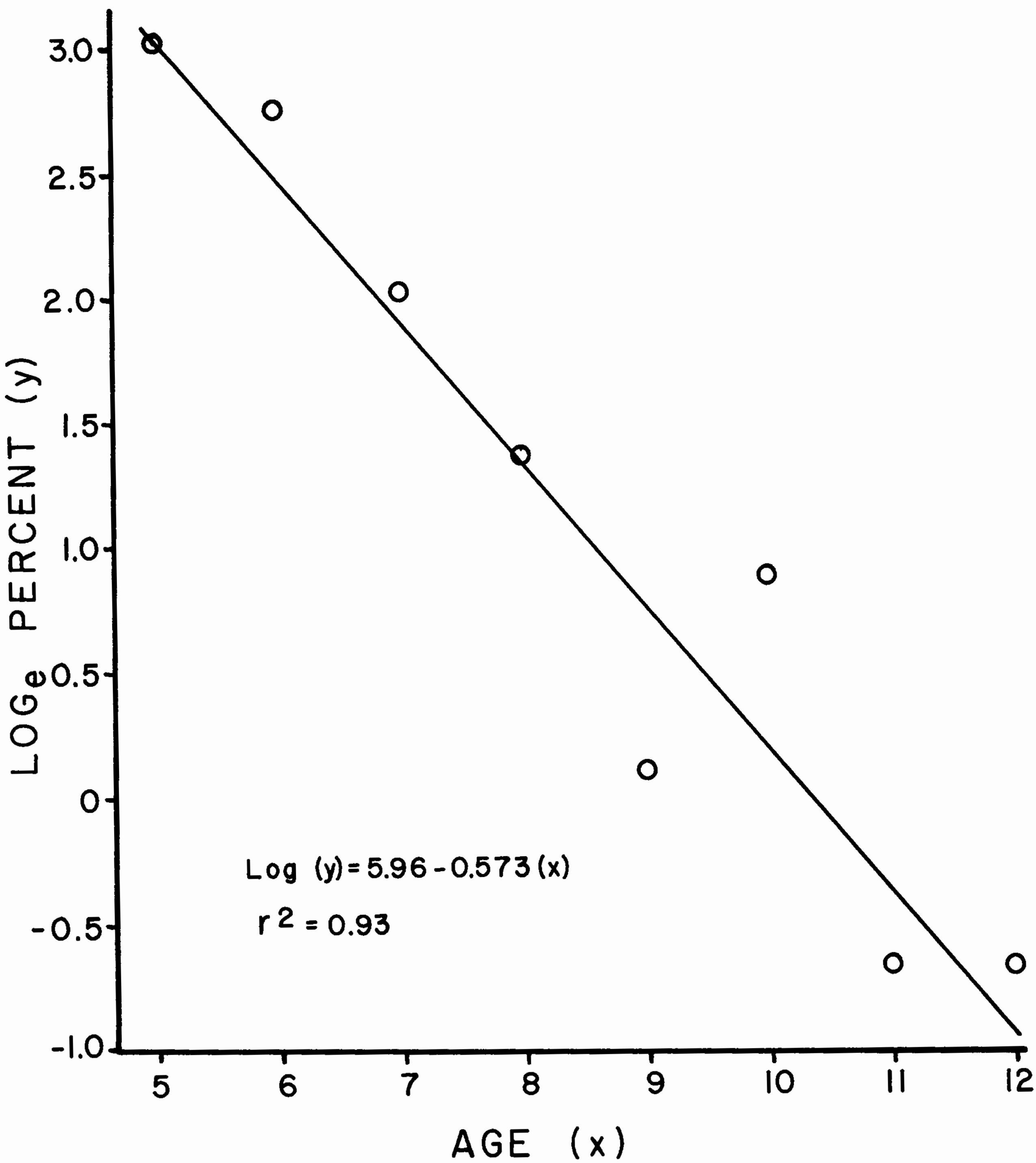

Figure 3.--Natural logarithm of percent age composition of lake whitefish (17 inches or larger) in trap nets at Munising, 1977-79. Each point is a geometric mean of three observations.

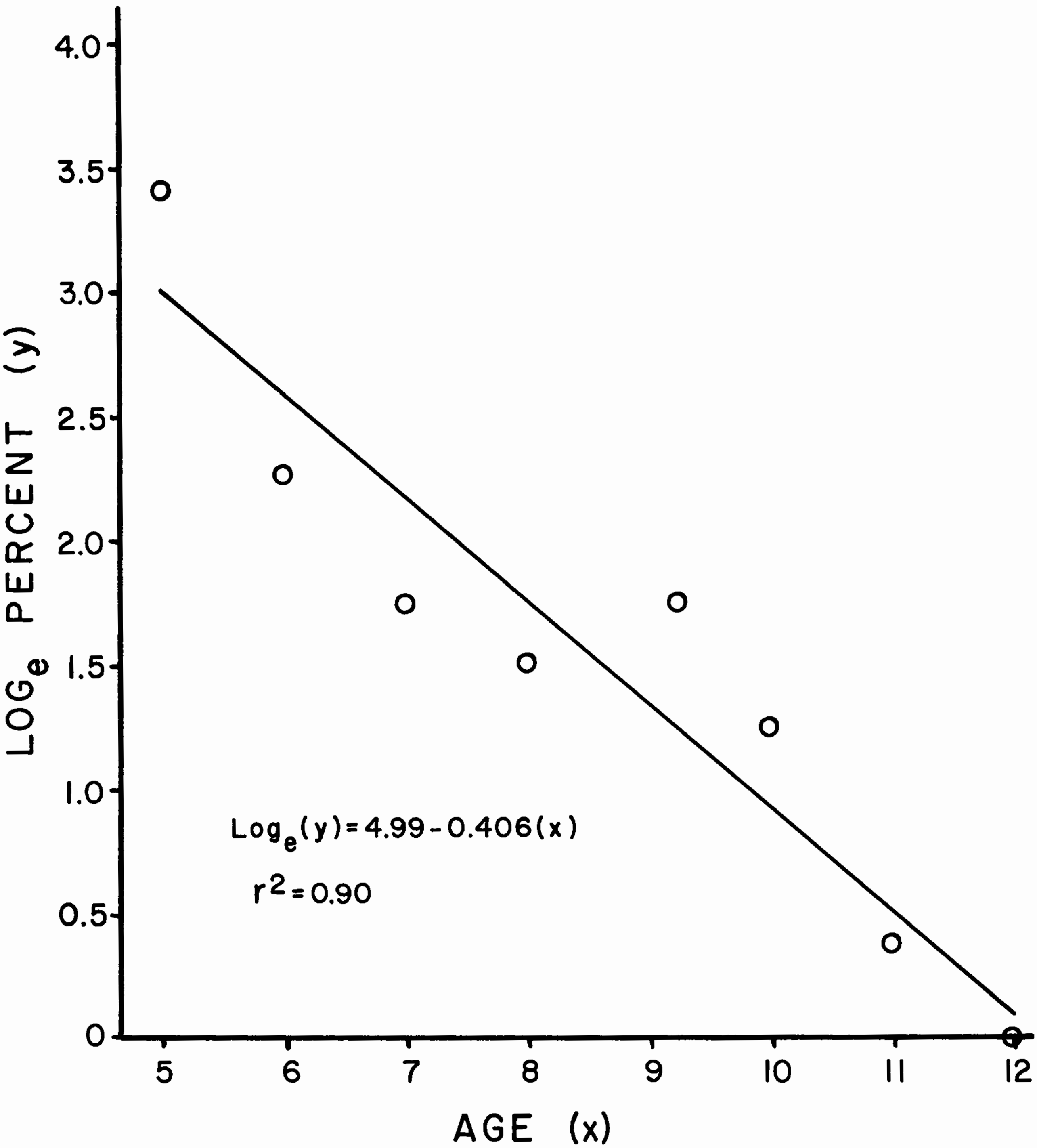

Figure 4.--Natural logarithm of percent age composition of whitefish (17 inches or larger) in trap nets at Grand Marais, 1978-80. Each point is a geometric mean of three observations.

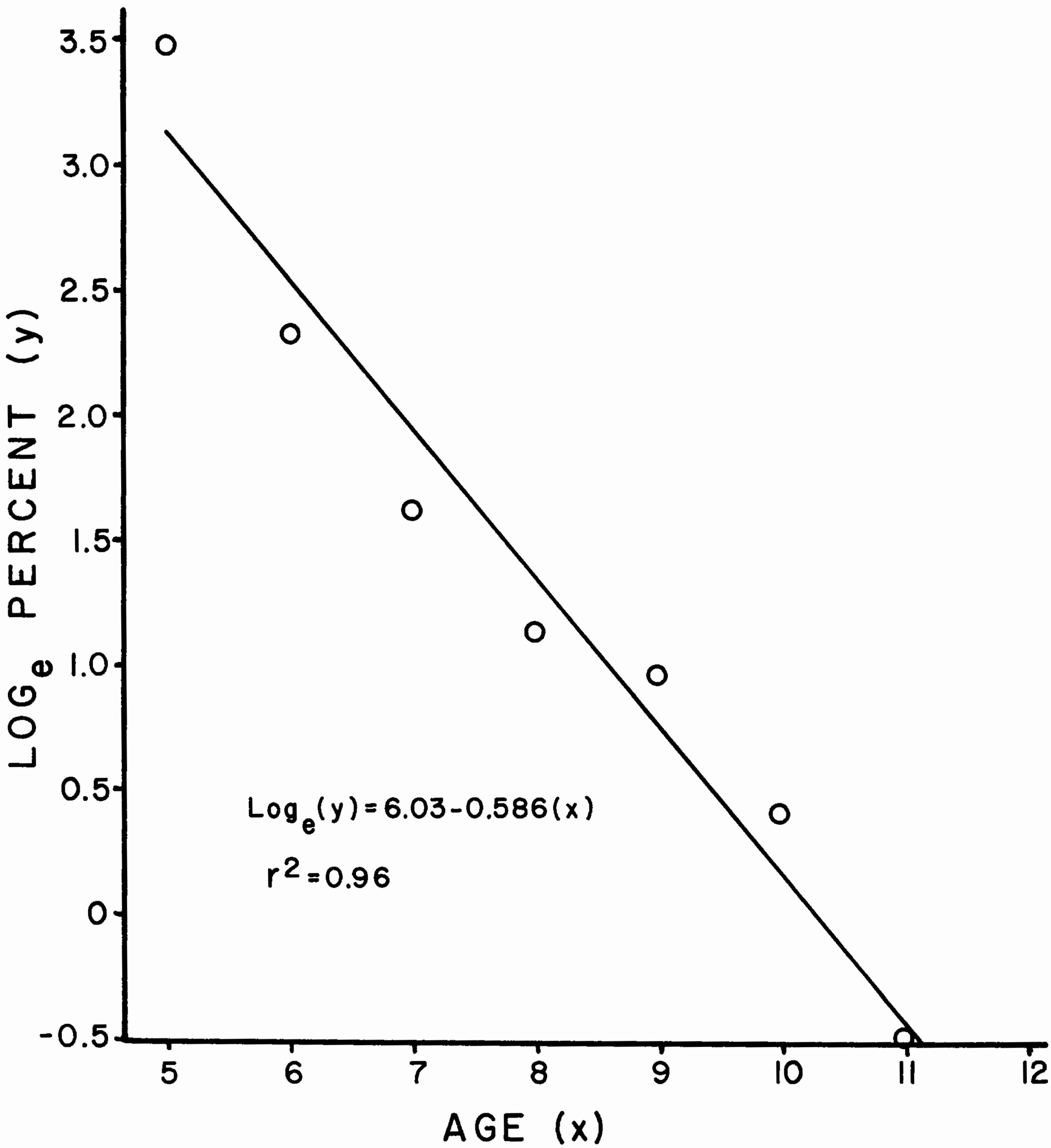

Figure 5.--Natural logarithm of percent age composition of lake whitefish (17 inches or larger) in trap nets at Whitefish Point, 1977-80. Each point is a geometric mean of four observations.

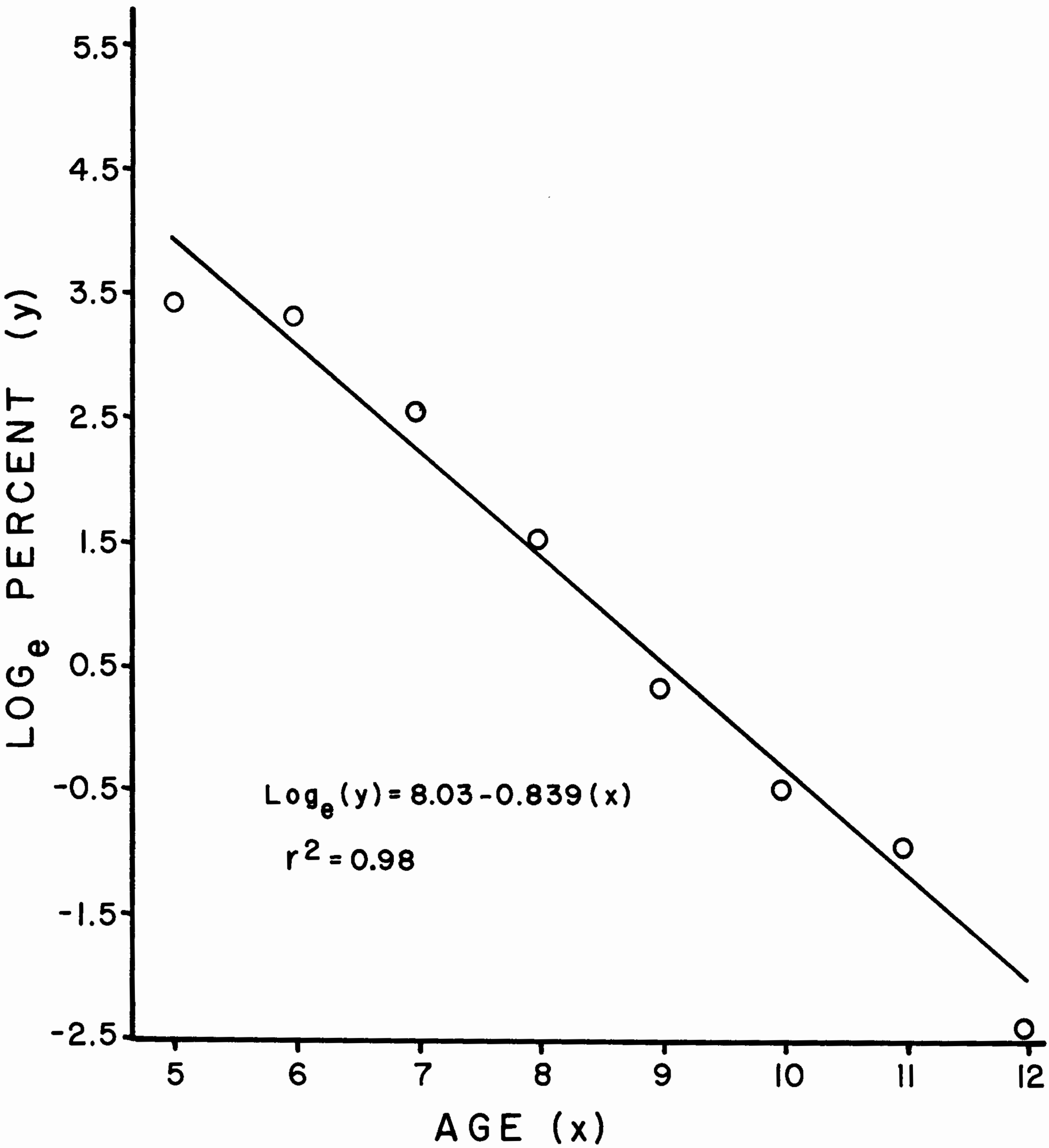

Figure 6.--Natural logarithm of percent age composition of lake whitefish (17 inches or larger) in trap nets at Brimley, 1977-80. Each point is a geometric mean of four observations. The 1979 and 1980 data are from Williamson, Liston, and Bohr (1981).