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Dynamics of Lightly Exploited Populations of the Lake Whitefish, Isle Royale Vicinity, Lake Superior

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DYNAMICS OF LIGHTLY EXPLOITED POPULATIONS OF THE LAKE WHITEFISH, ISLE ROYALE VICINITY, LAKE SUPERIOR*

Ann M. Koziol

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ABSTRACT

Two lightly exploited stocks of lake whitefish (*Coregonus clupeaformis*) near Isle Royale, Lake Superior, were compared in terms of growth, mortality rates, and yield per recruit. The stocks are separated geographically to the north and south of the island.

The ages of 501 lake whitefish from both stocks were determined. Length at age was estimated by conventional back calculation methods. The whitefish from the northern and southern areas were judged to be of different stocks. The southern stock averaged 50 mm longer at a given age than the northern stock. Total mortality rates were calculated for both stocks but they appeared to be high due to gear selectivity.

The Beverton and Holt dynamic pool model was applied to the stocks. Maximum yield per recruit for both stocks was attained at a fishing rate of 2.0 and a size limit of 482 mm (19 inches). The implications of this increase in fishing pressure were viewed in terms of remaining reproductive potential. Potential egg numbers were compared for the stocks at the fishing rate of 2.0 and a fishing rate of 0.7, which approximates that found in northern Lake Michigan. At the 0.7 fishing rate, there were 108% more potential eggs for the southern stock and 46% more for the northern stock than at the higher fishing rate of 2.0. The increase in yield per recruit at the 2.0 fishing rate, however, was only 9% and 7% for the northern and southern stocks, respectively.

The present size limit (432 mm or 17 inches) of the Isle Royale whitefish was hypothetically increased to 482 mm (19 inches) along with the instantaneous fishing mortality to 0.7. With a raised size limit of 482 mm, the decrease in yield per recruit was only 0.001% for the southern stock and 0.04% for the northern stock. The increase in residual egg potential was substantial, however, with 58% more potential eggs for the northern region and 59% for the southern region.

INTRODUCTION

Lake whitefish (*Coregonus clupeaformis*), a schooling fish of the subfamily Coregoninae are classified with salmon and trout, in the family Salmonidae. According to the Michigan Department of Natural Resources, lake whitefish are the most sought after of all Lake Superior commercial species, and their production in recent years has increased (Rakoczy 1982). Their growth is rapid in all of the Great Lakes except Lake Superior (Carlander 1950). However, the largest individual of record was caught in Lake Superior off Isle Royale (Van Oosten 1946). The purpose of this study was to assess two lightly exploited stocks of lake whitefish in the vicinity of Isle Royale, Lake Superior, in terms of growth, mortality, and potential yield per recruit. Growth and mortality data for these stocks were used to predict yields. Hopefully with these figures in hand, a fishery biologist can regulate the exploitation of a fishery to achieve the goal of sustaining the population while maximizing the yield.

Isle Royale parallels the northwestern shores of Lake Superior (Fig. 1) in the MS-1 statistical district of the State of Michigan waters of the upper Great Lakes (Hile 1962). Approximately 45 miles long and 9 miles wide at maximum, the island is a National Park and provides various fish habitats such as open and sheltered shores with variously steep or gently sloping bottoms (Lagler 1982). The commercial fishery of the surrounding waters depends primarily on several members of the whitefish subfamily and on the lake trout (*Salvelinus namaycush*).

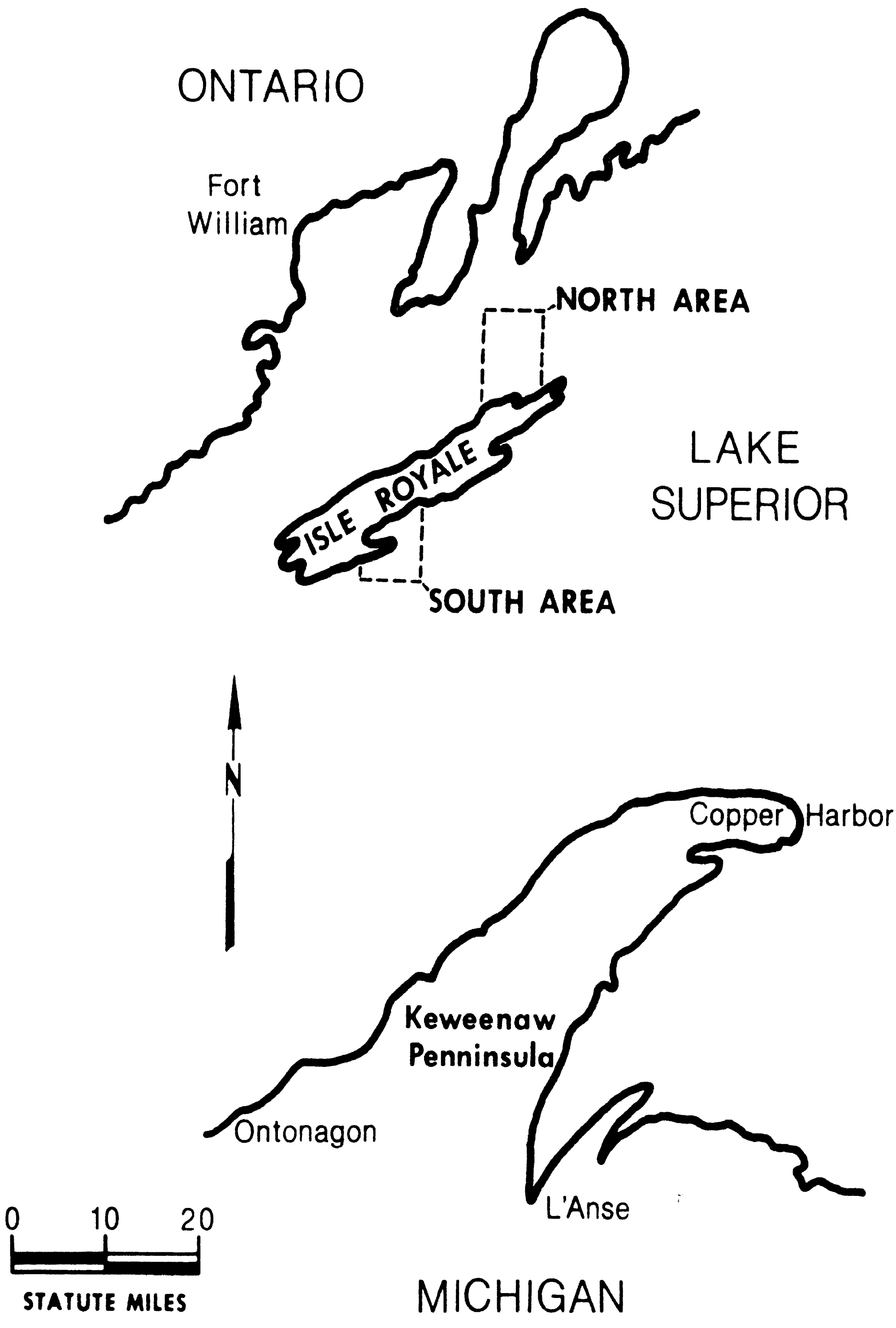

Figure 1.--Isle Royale, Lake Superior, showing the north and south study areas.

The populations of these fishes are monitored by the Michigan Department of Natural Resources to record the natural dynamics of fish stocks. This is accomplished through the issuing of research fishing permits only to the three remaining traditional commercial fishermen. Each permit assigns the areas to be fished, and limits of the catch, and requires the taking of annual assessment data on various species of fishes. In this study, two areas were considered. A northern area with many small islands and protected irregular shoreline but, primarily, neighboring Lake Superior; and a southern area with mainly the large Siskiwit Bay and adjacent waters.

Both stocks are considered very lightly exploited, yielding on the average 2,067 kilograms per year from the northern area and 1,159 kilograms from the southern area (Andrew Nuhfer, Michigan Department of Natural Resources, personal communication). These yields are extremely small compared to other Lake Superior stocks such as Keweenaw with 6,925 kilograms per year and Whitefish Point with 65,176 kilograms per year averaged over the same years and approximately the same size area. The Keweenaw stock is regarded as lightly exploited and Whitefish Point stock as heavily exploited (Rakoczy 1982).

MATERIALS AND METHODS

All data reviewed were collected for the Michigan Department of Natural Resources by commercial fishermen as a requirement of the research fishing permit. For the two sample regions, gill nets with mesh sizes ranging from 114 mm to 140 mm (stretched) were used to catch fish. The biological data and scale samples were taken from 100 whitefish from each fisherman's total catch each spring from 1978 through 1981. Data included catch per effort, total length, and occasionally, the weights of the fish. A total of 205 scales (about 52 per year) were aged from the northern site and a total of 284 scales (about 71 per year) were aged from the southern site. Of each available inch group (fish 15.0-15.9 inches, 16.0-16.9 inches, etc.), 10 scale samples were subsampled for age assessment. Scales were mounted in water between two microscope slides and examined on a microprojector with 48 mm magnification. Growth fields were measured to the nearest millimeter from the focus through the anterior portion of the scale. Aging was often difficult due to the condition of the scales, the closeness of circuli of the older fish caused by slow growth, small number of scales taken from each fish, and the possibility of the fishermen not taking the scales from the correct anatomical place on the side of the fish.

The criteria for annulus dermination, as set by Van Oosten (1923) and ranked by Bell et al. (1977) were rigorously applied as follows: (1) cutting over of circuli into the lateral fields; (2) a break in the pattern of circuli indicated by discontinuity; and (3) spacing of the annuli.

Because the samples were taken in the spring, the margin of the scale was taken to represent the most recently laid down annulus.

GROWTH

Age-Length Relationship

Average length at age and annual growth increments were calculated with a FORTRAN program which follows the standard back calculation formula (Lagler 1956).

$$L_n = S_n \frac{(L_c - a)}{S_c} + a$$

where: L_n = length of fish when annulus n was formed

L_c = length of fish at capture

S_n = radius of annulus n

a = intercept from regression of body length on radius

S_c = total scale radius

It was decided not to use the calculated intercept of the body: scale regression (2.0 mm for both the north and south sampling regions). As stressed by Carlander (1981), a calculated intercept can be a misrepresentation due to the gear selectivity of gill nets and subsequent insufficient sample size of the smaller and larger fish. Although the difference from the calculated value was small and probably insignificant a recorded Lake Superior intercept value of 1.0 mm (Carlander 1950) was used.

The lengths at age were estimated for each year (Appendix A-H) and the mean lengths at age for the four years were used in further calculations (Tables 1 and 2). Scale samples from both study sites came from fish ranging from 5 to 14 years of age. The lengths of the southern fish averaged 50 mm longer than the northern fish in the same age class. Taking into account the 95% confidence limits, the mean lengths overlapped through age 3 but proved to be significantly different for fish older than age 3 (Fig. 2).

Table 1.--Estimated mean lengths (mm) at age (years) for the whitefish stock in northern area. The 95% confidence limits are in parenthesis.

Year	Age in years												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1978	104	198	279	351	421	478	525	563	594	613	621	644	668
	(4)	(8)	(10)	(11)	(11)	(11)	(10)	(11)	(16)	(32)	(54)	(84)	(74)
1979	102	198	278	354	420	473	520	555	584	614	608	623	635
	(6)	(11)	(14)	(19)	(19)	(20)	(21)	(23)	(35)	(56)	(24)	(23)	(38)
1980	103	189	270	345	416	470	512	541	573	597	627	649	695
	(6)	(8)	(10)	(10)	(12)	(11)	(11)	(11)	(13)	(16)	(21)	(25)	(12)
1981	111	190	263	332	397	457	507	543	564	602	252	...	...
	(9)	(10)	(12)	(13)	(14)	(14)	(15)	(16)	(16)	(17)	(26)	...	...
Mean	105	194	272	345	413	471	516	550	579	607	627	638	666
	(6)	(9)	(12)	(13)	(12)	(12)	(13)	(15)	(21)	(31)	(31)	(44)	(38)

Table 2.--Estimated mean lengths (mm) at age (years) for the whitefish stock in southern area. The 95% confidence limits are in parenthesis.

Year	Age in years												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1978	100	198	291	381	467	530	577	616	645	666	691	718	...
	(3)	(7)	(11)	(13)	(13)	(12)	(11)	(12)	(12)	(12)	(18)	(27)	...
1979	96	202	298	388	469	537	586	622	647	671	704	727	756
	(4)	(7)	(11)	(13)	(13)	(12)	(11)	(13)	(13)	(14)	(16)	(19)	(24)
1980	97	192	276	352	424	492	549	590	621	642	664	690	706
	(5)	(8)	(13)	(13)	(14)	(12)	(12)	(11)	(11)	(14)	(17)	(22)	(27)
1981	102	214	312	404	483	549	593	628	651	679	696	717	...
	(5)	(8)	(12)	(14)	(14)	(13)	(14)	(15)	(18)	(33)	(9)	(34)	...
Mean	99	201	294	381	460	527	576	614	641	664	689	713	731
	(5)	(8)	(12)	(13)	(14)	(12)	(12)	(13)	(14)	(18)	(22)	(26)	(26)

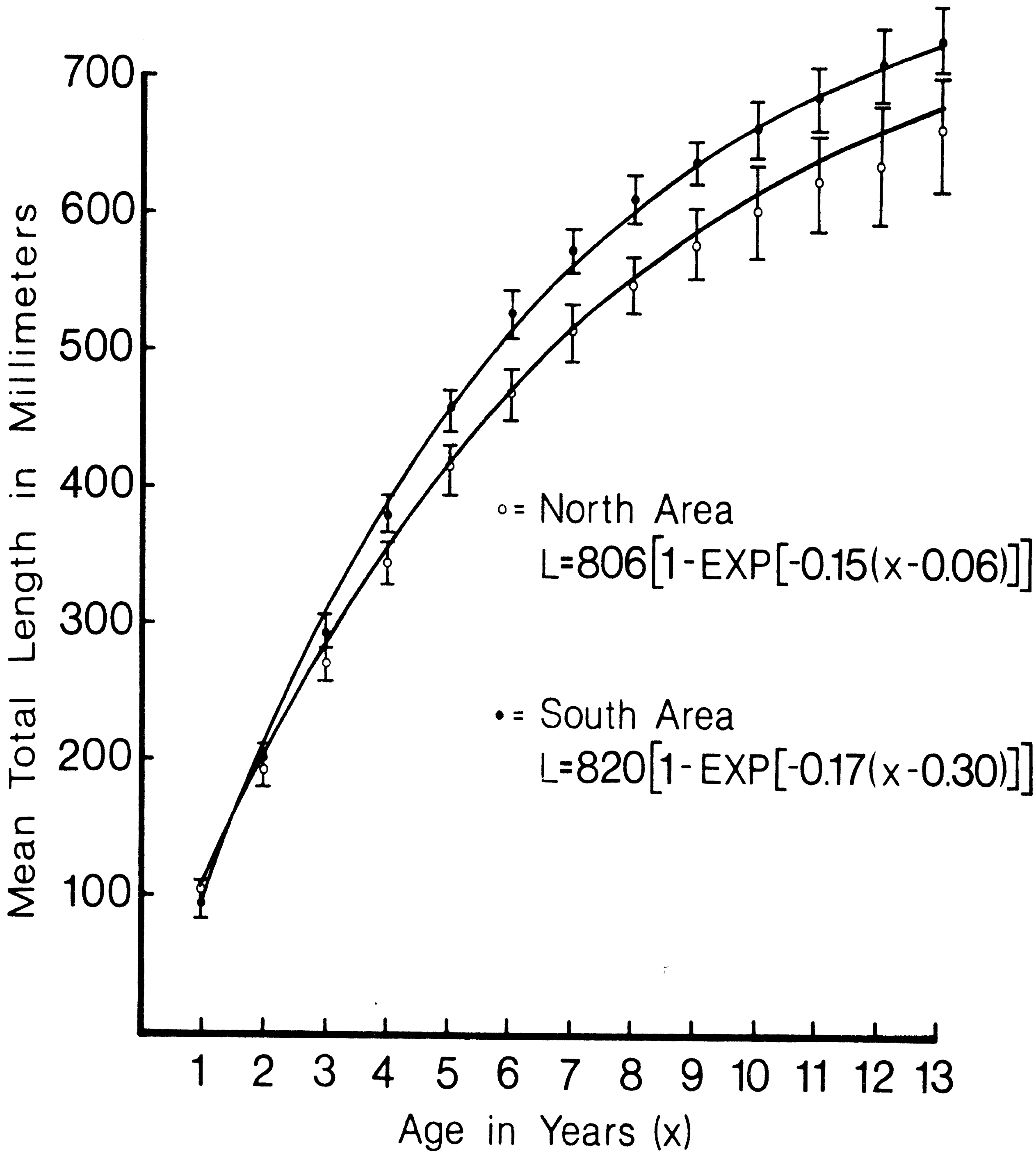

Figure 2.--Fitted von Bertalanffy curve and empirical mean length-age relationship with 95% confidence limits for northern and southern Isle Royale whitefish from 1978 through 1981.

Different size gill nets were used when collecting data, possibly causing the difference in the northern and southern whitefish mean lengths. The southern whitefish were obtained with 114-mm mesh gill nets in 1978 and 140-mm mesh from 1979 through 1981, while gill nets of 133-mm mesh size were used all 4 years in the northern area. Although the greatest dissimilarity in mesh size occurred between the 1978 and remaining southern whitefish data, no difference in their mean lengths was observed (Table 2). Therefore, it was assumed the variation in the mean lengths of the north and south study areas was not due to mesh size difference.

In the back calculated lengths for both the north and south areas, positive Lee's phenomenon was present. The younger the age group of fish used for the back calculations, the greater the mean length for the earlier years of life. Lee's phenomenon is often caused by the size selective mortality of the faster-growing fish which become vulnerable to the fishing gear first and are removed from the year class. In these lightly exploited stocks, however, this selective mortality should not be a major problem. Bias in the sampling of gill nets, which resulted in little representation of the smaller individuals of the younger age groups and the larger individuals of the older age groups, is more likely the major basis for the Lee's phenomenon in this case. The catch curve considered in the mortality estimates below reflected the same selectivity. Using mean lengths at age undoubtedly offsets any effects of Lee's phenomenon on growth.

Rakoczy (1982) suggested that for satisfactory population maintenance, the mean age of a Lake Superior whitefish catch should be at least 6.5 years. This allows the fish to spawn 1.5 times before death, which has been reported to be necessary for a stable whitefish population (Christie and Regier 1973). Both the north and south stocks had mean ages of catch over 8 years as might be expected from very lightly exploited stocks. The mean ages were slightly higher than the lightly exploited Keweenaw stock but almost double the heavily exploited Whitefish Point stock (Table 3).

The mean back calculated lengths were utilized in a FORTRAN program of the following von Bertalanffy growth equation (Rafail 1973):

$$1_x = L_\infty \{1 - \exp[-k(x - x_o)]\}$$

where: 1_x = length at age

L_∞ = theoretical asymtotic length in millimeters

k = growth coefficient

x_o = theoretical time when length is zero

The result for the two stocks of whitefish were as follows, with the 95% confidence limits in parenthesis:

	L_∞	k	x_o
North	806 (0.63)	0.15 (0.07)	0.06 (0.05)
South	820 (0.10)	0.17 (0.01)	0.30 (0.30)

The 95% confidence limits of k and x_o overlapped, while those for L_∞ did not. The difference in the L_∞ parameters means the von Bertalanffy growth curves are statistically different. This provides further support that the northern and southern whitefish are indeed separate stocks.

The predicted growth curves and the observed mean lengths are very close with the northern fish showing more variation in the higher ages (Fig. 2).

Table 3.--Mean ages in years of the annual whitefish catches for the northern and southern Isle Royale, Keweenaw, and Whitefish Point stocks.

Area	Years			
	1978	1979	1980	1981
North	8.6	9.0	8.2	8.8
South	8.4	8.3	9.4	8.8
Keweenaw (Rakoczy 1982)	8.4	6.2	7.3	not available
Whitefish Point (Rakoczy 1982)	4.5	5.2	5.1	not available

Length-Weight Relationship

Individual weights were only available for the southern whitefish population. Least squares regression was used to describe the length-weight relationship as expressed in the conventional equation:

$$W = aL^b$$

where: W = weight

L = length

a and b = constants

For the southern Isle Royale whitefish, this relationship was: $\ln W = -18.7020 + 3.0497 \ln L$. The southern whitefish were heavier at a given length than the northern whitefish (Table 4.).

Table 4.--Mean weights at age for the north and south areas calculated with the length-weight regression.

Age	South		North	
	Mean length (mm)	Weight (kg)	Mean length (mm)	Weight (kg)
1	99	0.01	105	0.01
2	201	0.08	192	0.07
3	294	0.30	272	0.20
4	381	0.60	345	0.40
5	460	0.99	413	0.70
6	527	1.50	471	1.10
7	576	2.00	516	1.40
8	614	2.40	550	1.70
9	641	2.71	579	2.00
10	664	3.05	607	2.32
11	689	3.41	627	2.60
12	713	3.79	638	2.70
13	731	4.19	666	3.10

MORTALITY

Total mortality rate (Z) is the sum of the instantaneous natural (M) and fishing (F) mortality rates. The total mortality rate of a very lightly exploited stock should approximate the natural rate. Relatively high mortalities were calculated, however, in both the northern (Z = 0.81) and the southern (Z = 0.71) stocks. These estimates were derived through the regression of the natural logarithm of the catch per effort (catch per 1,000 feet of gill net per day) on age (Figs. 3 and 4). Total mortality (Z) is depicted by the slope of this regression line, but the line can be misleading if the young and old fish are not represented in the catch according to their abundance.

It seems probable that my estimates for total mortality are high due to selectivity of gill nets (Healey 1975). Gill nets of a constant mesh size catch the larger fish in the younger age groups and the smaller fish in the older age groups. The former problem was eliminated by considering in the regression only fish over age 7 for the southern area and age 8 for the northern area; but the latter problem probably exaggerated the steepness of the slope and, thus, overestimated total mortality (Z). Using trap nets to catch whitefish gives a more realistic view of age classes. The more exploited stocks of Keweenaw and Whitefish Point were found to have total mortality rates of 0.43 and 0.59, respectively (Rakoczy 1982). Therefore, an instantaneous natural mortality (M = 0.3) recorded for an unexploited whitefish stock of Grand Traverse Bay (Patriarche 1977) was used in the yield calculations.

A covariance test was conducted for the north and south regressions. No significant difference was found between the regression lines at the 95% level suggesting mortality is probably the same in both areas.

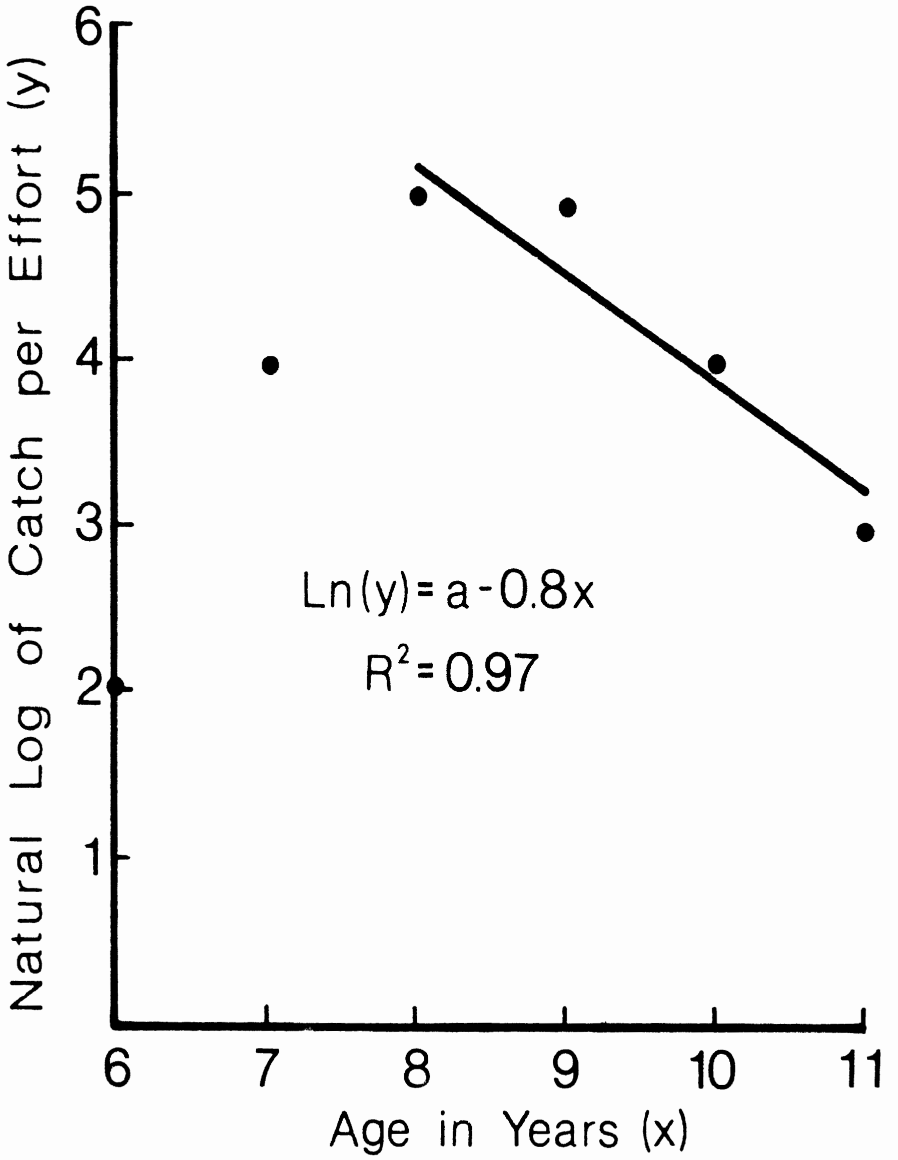

Figure 3.--Catch curve for northern Isle Royale whitefish collected with gill nets.

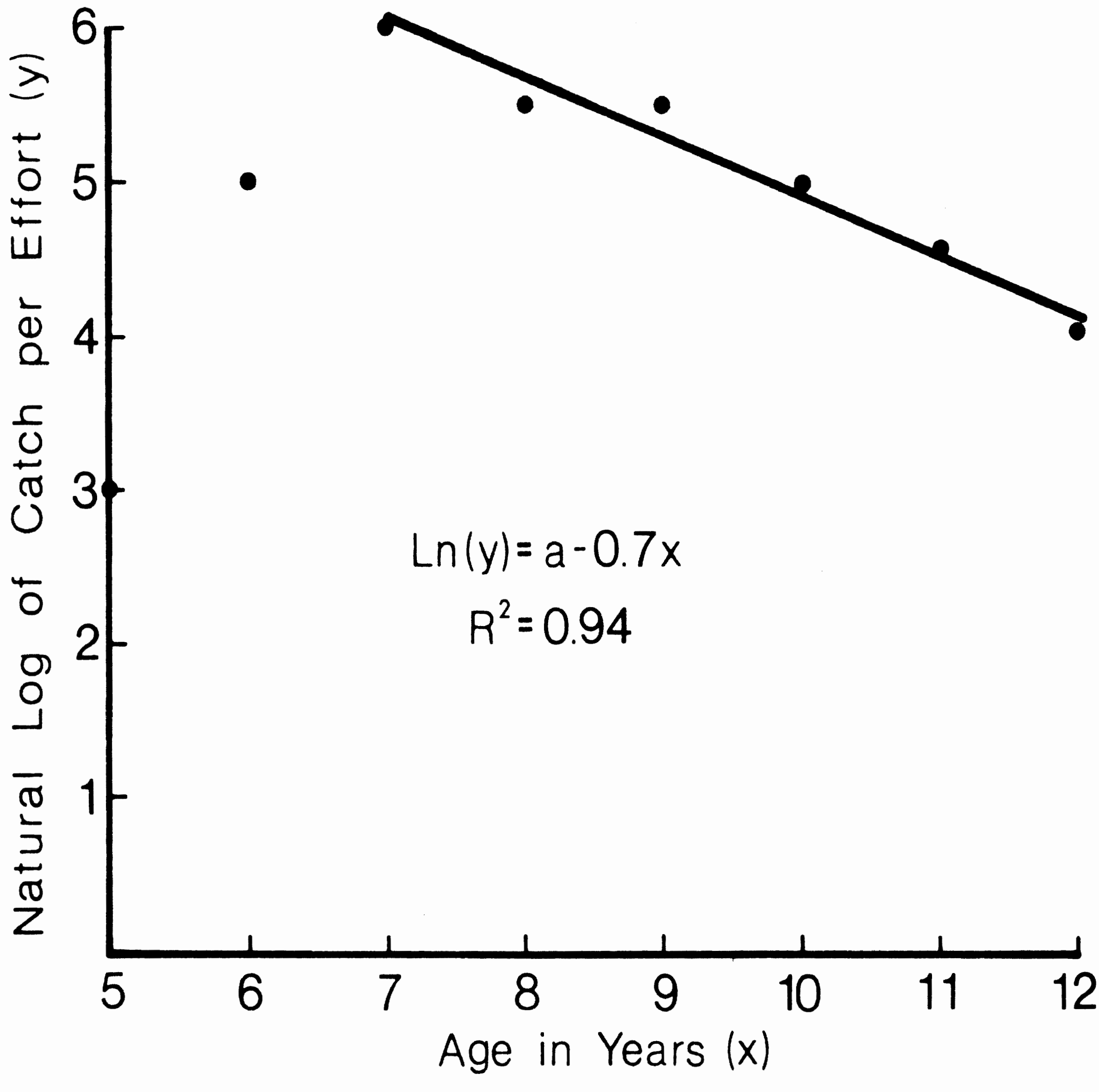

Figure 4.--Catch curve for southern Isle Royale whitefish collected with gill nets.

YIELD PER RECRUIT

The Model

The 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 for fish stocks. Although there is often difficulty in estimating these parameters confidently with available data, this management model is intuitively more appealing to biologists than others such as the surplus production model. The parameters and structure of the dynamic pool model can also be more meaningful in a biological sense.

A FORTRAN program of the Beverton and Holt (1957) model available at the Institute for Fisheries Research, Michigan Department of Natural Resources, was used to make yield computations. This program is slightly changed from the standard Beverton and Holt model in at least three ways. First, it uses the von Bertalanffy parameters 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. 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. All these changes were suggested by Tyler and Gallucci (1980) and are described in more detail in their paper.

The standard procedure of computing the isopleths of yield, as they vary with age of entry (size limit) and fishing mortality rate, was followed. The additional information provided by the program on number of fish at age in the population was used to compare relative egg production potential for selected size limits and fishing rates.

The smallest fish vulnerable to the gill nets of both sample areas was 381 mm (15 inches). Therefore, computations were based on 1,000 recruits of age 3.88 years (381 mm) for the southern stock and age 4.42 years (381 mm) for the northern stock.

Results and Discussion

The results of repetitive model applications with varying instantaneous fishing mortality (F) and age at entry (size limit) are presented in isopleth diagrams (Figs. 5 and 6). The isopleths show yield increasing assymptotically with fishing mortality rate (F) and a maximum yield per recruit is attained at the fishing rate of 2.0 and a size limit of about 482 mm (19 inches) for both stocks. The natural mortality rate used was 0.3. The actual fishing pressure of the Isle Royale populations is unknown, but if similar to the rates recorded for the lightly exploited Keweenaw area (0.14) or even the heavily exploited Whitefish Point (0.30), a substantial increase in exploitation could be sustained by these populations. It seems unlikely, however, that they could sustain a fishing rate of 2.0 with no ill effects on recruitment.

The isopleth diagrams were useful in establishing the maximum yield per recruit and the variations caused by changing size limit or fishing pressure. More information is needed, however, for proper yield predictions as the isopleths ignore the possible impact of fishing on recruitment. Constant recruitment was assumed by the model. Using for comparison a fishing rate of 0.7, which approximates that reported for northern Lake Michigan whitefish (Patriarche 1977), the effects of raising the fishing rate to 2.0 were viewed in terms of residual reproductive potential. Assuming a 1:1 sex ratio, that 56% of Lake Superior whitefish females are mature by age 5 (Rakoczy 1982),

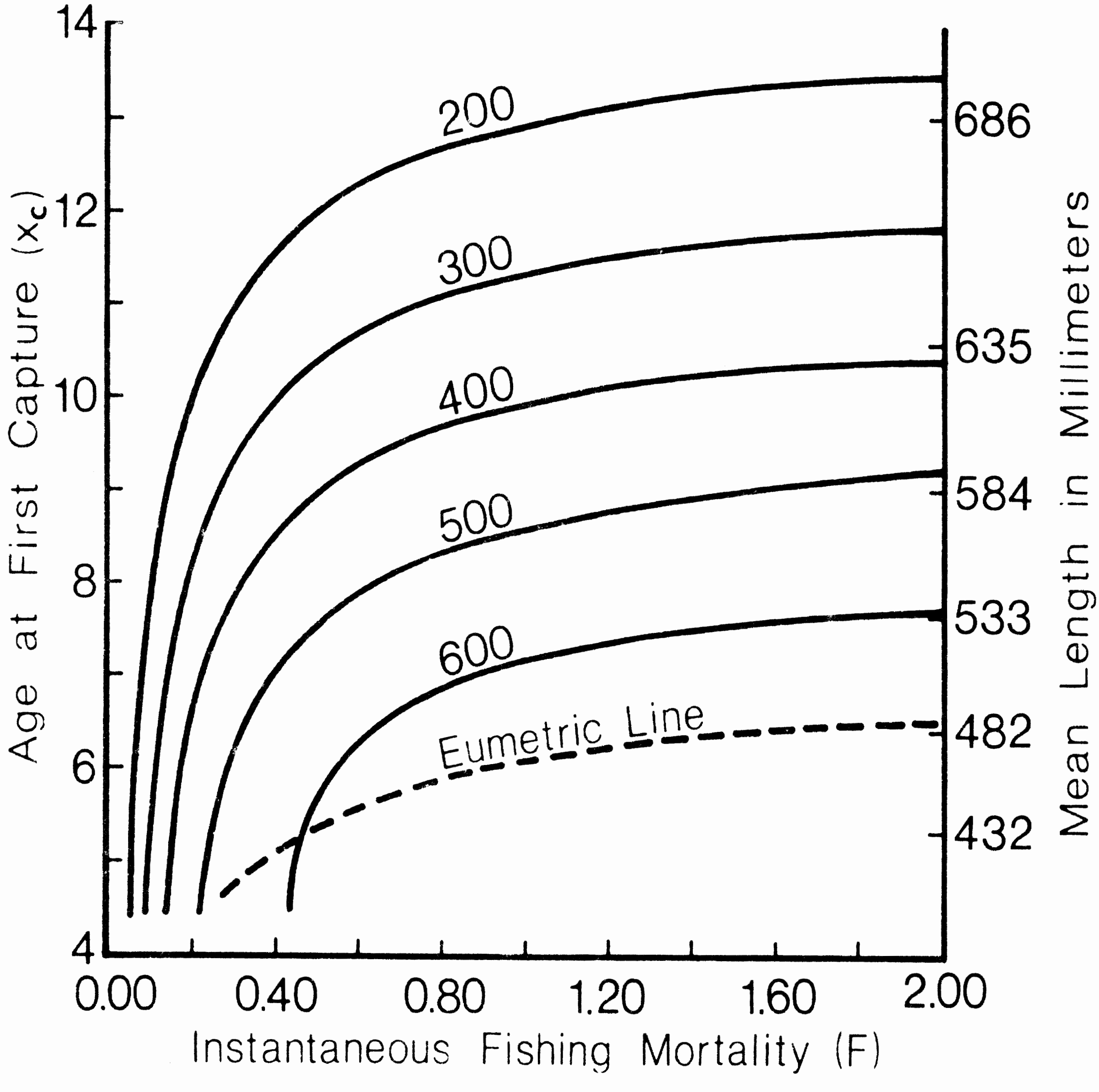

Figure 5.--Yield in kilograms per 1,000 age-4.42 recruits as function of age at entry (x_c) and instantaneous fishing mortality (F) for whitefish of northern area.

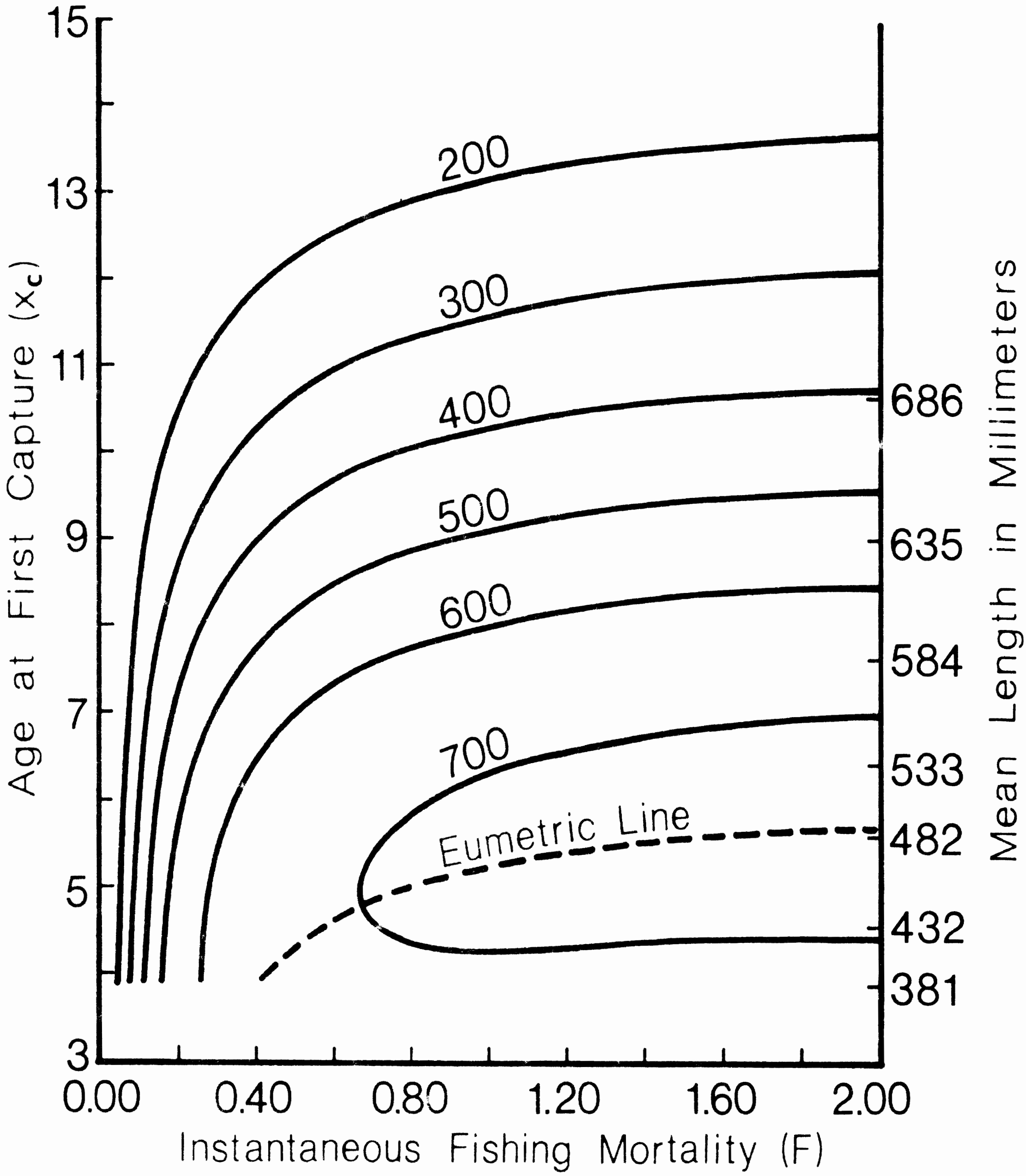

Figure 6.--Yield in kilograms per 1,000 age-3.88 recruits as a function of age at entry (x_c) and instantaneous fishing mortality (F) for whitefish of the southern area.

and an average whitefish fecundity of 18,200 eggs per kilogram per female (Cucin and Regier 1966), potential egg productions of the remaining females were calculated at various size limits and fishing rates (Tables 5 and 6). At the 0.7 fishing rate, there are 108% more potential eggs for the southern stock and 46% more for the northern stock than at the higher fishing rate of 2.0. The increase in yield per recruit at a 2.0 fishing rate is only 9% and 7% for the northern and southern stocks, respectively. This suggests the small increase in yield per recruit in going from 0.7 to 2.0 carries with it a substantial risk in reducing overall recruitment and therefore overall yield.

Patriarche (1977) suggested an elevation of the minimum size limit for the whitefish in northern Lake Michigan from 432 mm (17 inches) to 482 mm (19 inches). He reasoned this would provide greater survival of the spawning stock and, hence, more stable recruitment. My results agree with his recommendation. For the Isle Royale fishery, I calculated the age of a 432-mm southern whitefish to be 4.6 years and a northern whitefish 5.3 years. If fishing pressure became high enough, many immature fish would be harvested at a 432-mm size limit. This may debilitate recruitment and not provide the necessary 1.5 spawnings for stable whitefish population maintenance (Christie and Regier 1973). Because the Isle Royale fishing pressure is so light, however, very few fish under 6 years were noted in the catches and mean ages were over 8 years (Table 3).

Based on the mean fishing mortality rate for the whitefish of northern Lake Michigan of 0.72 (Patriarche 1977), the hypothetical fishing rate 0.70 was considered for the 432-mm and 482-mm size limits.

Table 5.--Number of fish remaining at age, potential egg number (millions), and yield per 1,000 age-4.42 recruits (Y/R) with varying instantaneous fishing mortality (F) and size limit (x_c) in millimeters for whitefish of northern Isle Royale.

Fishing mortality F	Size limit x_c (mm)	Number of fish remaining at age 4.42	5	6	7	8	9	10	11	12	13	Yield per 1,000 recruits Y/R (kg)	Potential number of eggs (millions)
Unexploited		1,000	839	622	460	341	253	187	139	102	76	...	36.8
0.7	432	1,000	839	377	139	51	19	7	2	0.9	0.3	637	9.9
0.7	482	1,000	839	622	275	101	37	14	5	2	0.7	613	15.7
2.0	482	1,000	839	622	105	11	1.1	0.1	...	...	...	670	10.7

Table 6.--Number of fish remaining at age, potential egg number (millions), and yield per 1,000 age-3.88 recruits (Y/R) with varying instantaneous fishing mortality (F) and size limits (x_c) in millimeters for whitefish of southern Isle Royale.

Fishing mortality F	Size limit x_c (mm)	Number of fish remaining at age											Yield per 1,000 recruits Y/R (kg)	Potential number of eggs (millions)
		3.88	4	5	6	7	8	9	10	11	12	13		
Unexploited		1,000	964	714	529	392	290	215	159	118	87	65	...	43.1
0.7	432	1,000	964	535	197	72	26	10	4	1	0.5	0.2	721	7.9
0.7	482	1,000	964	714	342	126	46	17	6	2	0.8	0.3	720	12.3
2.0	482	1,000	964	714	151	15	1.5	0.2	...	...	...	...	766	5.9

For both stocks, the difference in size limit produced little change in the yield per recruit (Tables 5 and 6). In fact, the raising of the size limit from 432 mm to 482 mm resulted in only a 0.001% decrease in the yield per recruit for the southern stock and 0.04% for the northern stock. The major change was in the number of remaining fish available for spawning and consequent egg production (Tables 5 and 6). With a higher size limit for the southern fishery, the increase in reproducing females and potential egg production was 59% from 7.9 to 12.3 million eggs. The increase for the northern stock was 58% from 9.9 to 15.7 million eggs. This large residual egg potential would probably lead to increased stability in year-class strength while not affecting the yield of the fishermen.

The survival rate of the eggs is difficult to ascertain as density dependent mortality must be considered. Heretofore, the spawner-recruitment relationship of whitefish has not been adequately researched to be able to predict the level of egg production needed for a sound recruitment. I recommend such studies be conducted as an additional useful tool for the setting of size limits and fishing pressures for maximum sustainable yield.

SUMMARY

Northern and southern populations of lightly exploited whitefish of Isle Royale, Lake Superior, were assessed in terms of growth and found to be different stocks. The difference in the mean lengths at age of the stocks was obvious with the southern fish averaging 50 mm longer at a given age than the northern whitefish. The difference in the mean lengths was judged not to be caused by the sampling with different sized gill nets by comparison of the mean lengths among the southern stock which was fished with the most variable mesh sizes. Lee's phenomenon was observed but it was not believed to bias the calculations of average growth in length of the two stocks.

The von Bertalanffy growth coefficients (k) and theoretical time of length zero (x_0) were found to be similar in the stocks but the theoretical asymptotic lengths (L_∞) were statistically different, supporting the assumption that northern and southern whitefish were of different stocks.

Evidence of stable population maintenance for both stocks was found in the mean age of the catches. The recommended age of catch for Lake Superior whitefish is 6.5 years. Both stocks had mean ages over 8 years.

The total mortality rates of 0.71 for the southern fish and 0.81 for the northern fish were determined to be overestimates. The lack of representation of the larger, older and smaller, younger fish of the populations, due to the gear selectivity, was most likely the cause.

Yield per recruit from the application of the Beverton and Holt dynamic pool model was depicted in isopleth diagrams for which a fishing

rate of 2.0 and size limit to 482 mm were demonstrated to produce maximum yield per recruit for both stocks.

Number of fish remaining at various levels of fishing pressure and different size limits was used to establish the potential increase or decrease in egg number. For the northern stock it was found that if the size limit was 482 mm and the instantaneous fishing mortality was 2.0, a decrease to the approximate mean fishing rate of the Lake Michigan whitefish (0.7) would result in 108% more residual reproducing females with only a 6% decrease in yield per recruit. Under identical conditions the northern stock had 46% remaining females and a 9% decrease in yield. Although survival rate of the eggs is unknown, a conservative fishing rate of 0.7 with little change in the fishermen's yield but a probable increase in stability of year-class strength would be prudent management.

The size limit at the fishing pressure of 0.7 was reviewed. Presently the size limit for whitefish is 432 mm (17 inches). Again, the change in yield per recruit with a raise in size limit to 482 mm (19 inches) for both stocks was small and again there was a substantial preservation of potential egg numbers implying a raise in size limit would be beneficial for recruitment and overall yield.

Appendix A.--Back calculated lengths (mm) at age (years) for lake whitefish of southern Isle Royale for the spring of 1978.

Age group	Number of fish	Mean total length at capture	Age in years 1	2	3	4	5	6	7	8	9	10	11	12
V	3	563	107	243	365	467	563	...	...	...	...	...	...	...
VI	10	565	97	204	304	405	490	565	...	...	...	...	...	...
VII	20	581	96	202	297	382	466	529	581	...	...	...	...	...
VIII	11	624	106	200	289	379	461	537	585	624	...	...	...	...
IX	11	663	99	202	294	388	474	534	589	632	662	...	...	...
X	8	666	95	187	277	362	446	510	557	600	631	666	...	...
XI	10	688	107	183	266	354	440	509	564	602	635	662	688	...
XII	5	718	100	185	269	357	454	517	576	617	649	676	697	718
Weighted means			100	198	291	381	467	530	577	616	645	666	691	718

Appendix B.--Back calculated lengths (mm) at age (years) for lake whitefish of southern Isle Royale for the spring of 1979.

Age group	Number of fish	Mean total length at capture	Age in years												
			1	2	3	4	5	6	7	8	9	10	11	12	13
V	1	521	73	216	342	431	521	...	...	...	...	...	...	...	...
VI	9	581	95	216	331	423	505	581	...	...	...	...	...	...	...
VII	22	598	92	203	300	395	479	545	598	...	...	...	...	...	...
VIII	6	635	96	205	307	394	461	524	589	635	...	...	...	...	...
IX	12	650	102	209	304	400	473	540	588	626	650	...	...	...	...
X	9	658	104	185	250	323	397	475	540	592	627	658	...	...	...
XI	2	686	109	197	286	357	480	527	586	626	645	669	686	...	...
XII	5	725	95	189	282	380	478	550	606	642	666	686	707	725	...
XIII	2	756	84	197	303	387	472	524	599	639	666	692	717	732	756
Weighted means			96	202	298	388	469	537	586	622	647	671	704	727	756

Appendix C.--Back calculated lengths (mm) at age (years) for lake whitefish of southern Isle Royale for the spring of 1980.

Age group	Number of fish	Mean total length at capture	Age in years												
			1	2	3	4	5	6	7	8	9	10	11	12	13
V	1	582	180	313	433	519	582	...	...	...	...	...	...	...	...
VI	3	537	88	197	293	366	460	537	...	...	...	...	...	...	...
VII	9	582	92	203	308	389	459	526	582	...	...	...	...	...	...
VIII	16	601	96	187	264	341	424	497	556	601	...	...	...	...	...
IX	16	636	98	188	273	357	424	499	558	601	636	...	...	...	...
X	9	644	95	191	275	343	399	466	520	580	613	644	...	...	...
XI	11	662	98	194	274	340	408	472	538	580	613	637	662	...	...
XII	4	701	106	181	233	328	407	476	543	597	625	654	677	701	
XIII	4	731	95	182	278	363	437	512	552	595	631	664	685	710	731
XIV	4	708	89	181	257	309	387	451	506	549	588	615	638	660	681
Weighted means			97	192	276	352	424	492	549	590	621	642	664	690	706

Appendix D.--Back calculated lengths (mm) at age (years) for lake whitefish of southern Isle Royale for the spring of 1981.

Age group	Number of fish	Mean total length at capture	Age in years											
			1	2	3	4	5	6	7	8	9	10	11	12
VI	12	582	107	223	336	436	516	582	...	...	...	...	...	...
VII	13	619	104	220	315	413	492	563	620	...	...	...	...	...
VIII	16	648	103	216	322	411	487	552	601	648	...	...	...	...
IX	11	671	96	202	284	376	465	530	578	618	659	...	...	...
X	3	686	109	219	319	415	480	542	586	619	646	686	...	...
XI	3	708	91	210	295	368	444	494	558	612	651	686	703	...
XII	3	717	94	189	261	337	401	473	532	582	627	664	689	717
Weighted means			102	214	312	404	483	549	593	628	651	679	696	717

Appendix E.--Back calculated lengths (mm) at age (years) for lake whitefish of northern Isle Royale for the spring of 1978.

Age group	Number of fish	Mean total length at capture	Age in years												
			1	2	3	4	5	6	7	8	9	10	11	12	13
VI	1	513	129	239	348	403	458	513	...	...	...	...	...	...	...
VII	14	529	103	194	279	352	426	481	529	...	...	...	...	...	...
VIII	20	567	107	203	280	353	420	470	522	567	...	...	...	...	...
IX	16	600	101	200	284	363	433	491	537	568	600	...	...	...	...
X	7	635	101	196	273	337	412	480	526	566	604	635	...	...	...
XI	2	633	118	191	261	344	409	472	518	555	587	609	633	...	...
XIII	2	617	87	173	225	259	311	362	414	466	490	517	558	586	617
XIV	2	739	98	194	283	354	429	515	558	593	619	640	671	702	718
Weighted means			104	198	279	351	421	478	525	563	594	613	621	644	668

Appendix F.--Back calculated lengths (mm) at age (years) for lake whitefish of northern Isle Royale for the spring of 1979.

Age group	Number of fish	Mean total length at capture	Age in years											
			1	2	3	4	5	6	7	8	9	10	11	12
VI	1	531	132	238	325	491	511	531	...	...	...	...	...	...
VII	7	528	101	205	290	378	440	489	528	...	...	...	...	...
VIII	17	554	102	195	278	344	415	464	514	554	...	...	...	...
IX	8	571	109	208	283	361	420	468	513	546	575	...	...	...
X	9	594	107	205	280	353	430	496	555	593	617	643	...	...
XI	3	633	82	154	244	315	375	447	510	542	578	605	633	...
XII	3	641	94	181	253	326	402	456	492	531	557	583	610	641
XIII	3	635	91	188	269	329	393	439	474	505	535	555	580	604
Weighted means			102	198	278	352	419	472	519	555	583	612	608	623

Appendix G.--Back calculated lengths (mm) at age (years) for lake whitefish of northern Isle Royale for the spring of 1980.

Age group	Number of fish	Mean total length at capture	Age in years											
			1	2	3	4	5	6	7	8	9	10	11	12
V	2	498	75	170	257	344	480	...	...	...	...	...	...	...
VI	3	535	135	236	308	382	469	535	...	...	...	...	...	...
VII	11	549	113	207	301	375	452	501	549	...	...	...	...	...
VIII	12	560	97	187	268	344	410	471	514	556	...	...	...	...
IX	12	575	100	185	270	339	406	457	502	535	575	...	...	...
X	7	592	97	163	232	321	393	461	511	541	569	592	...	...
XI	4	638	105	193	264	339	401	446	487	533	577	604	638	...
XII	5	640	98	181	253	310	371	429	481	527	563	588	611	640
XIII	1	696	137	204	279	371	442	489	510	543	591	628	652	672
XIV	1	732	90	152	221	296	344	403	447	530	584	619	636	670
Weighted means			103	189	270	345	416	470	512	541	573	597	627	649

Appendix H.--Back calculated lengths (mm) at age (years) for lake whitefish of northern Isle Royale for the spring of 1981.

Age group	Number of fish	Mean total length at capture	Age in years										
			1	2	3	4	5	6	7	8	9	10	11
VII	7	552	134	215	300	362	430	494	552	...	...	...	...
VIII	11	580	114	185	261	335	410	470	527	580	...	...	...
IX	12	560	102	183	250	322	380	437	483	525	560	...	...
X	11	601	102	186	259	325	386	446	492	530	567	601	...
XI	3	652	110	198	252	313	373	434	483	525	569	608	652
Weighted means			111	190	263	332	397	457	507	543	564	602	652

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