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BRIEF LIFE HISTORY ACCOUNTS OF FIVE COMMERCIAL SALMONID FISHES IN LAKE SUPERIOR [1]

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ABSTRACT

This report deals with five kinds of fish of commercial importance in Lake Superior, namely: lake whitefish, bloater chub, lake herring, "humper" lake trout, and "siscowet" lake trout. It is a compilation of information on life histories and populations, obtained from published literature and from files at research stations. Parameters covered are: growth, recruitment, mortality, distribution, evidence of discrete populations, interspecific relationships, and information gaps. References cited include 31 published articles and reports.

Contents

[1] A contribution from Dingell-Johnson Project F-32-R, Michigan.

Introduction

Available data on the life histories of important commercial and sport fishes in the Great Lakes are being compiled, from both published and unpublished sources, as background for controlled harvest and other management recommendations. The quantitative data in these summaries include age and growth, recruitment (which includes fecundity and maturity), mortality (including a description of the recent fishery), bathymetric and lateral distribution, and population discreteness. Miscellaneous information on reproduction, food habits, interspecific relationships, etc. also is presented. The last section of each summary lists information gaps for the species. Another objective in compiling these summaries was to identify these gaps so that future research could be directed toward filling them without duplication of effort.

This report covers the five major commercial fishes in Lake Superior: (1) lake whitefish, Coregonus clupeaformis; (2) bloater chub, C. hoyi; (3) lake herring, C. artedii; (4) "humper" lake trout, Salvelinus namaycush; and (5) "siscowet" lake trout, S. namaycush. The last two are of less than species rank (i.e., races or subspecies). The fish are discussed in order of their commercial importance in the contemporary (1970-73) Lake Superior fishery. Fishing ports, fishing grounds and statistical districts referred to in the summaries are shown in Figure 1.

Some of the material in this report appeared earlier, in Fisheries Division Technical Report No. 73-33 (1974) by Peck, Schorfhaar and Wright; see "References Cited."

A word of explanation is in order about the fishing grounds from which fish collections were obtained. Keweenaw Bay and Whitefish Bay are large areas which encompass the sampled grounds, and the collection sites are so cited here. However, the fishing grounds at Marquette, Munising and Grand Marais are outside the respective bays; so collections

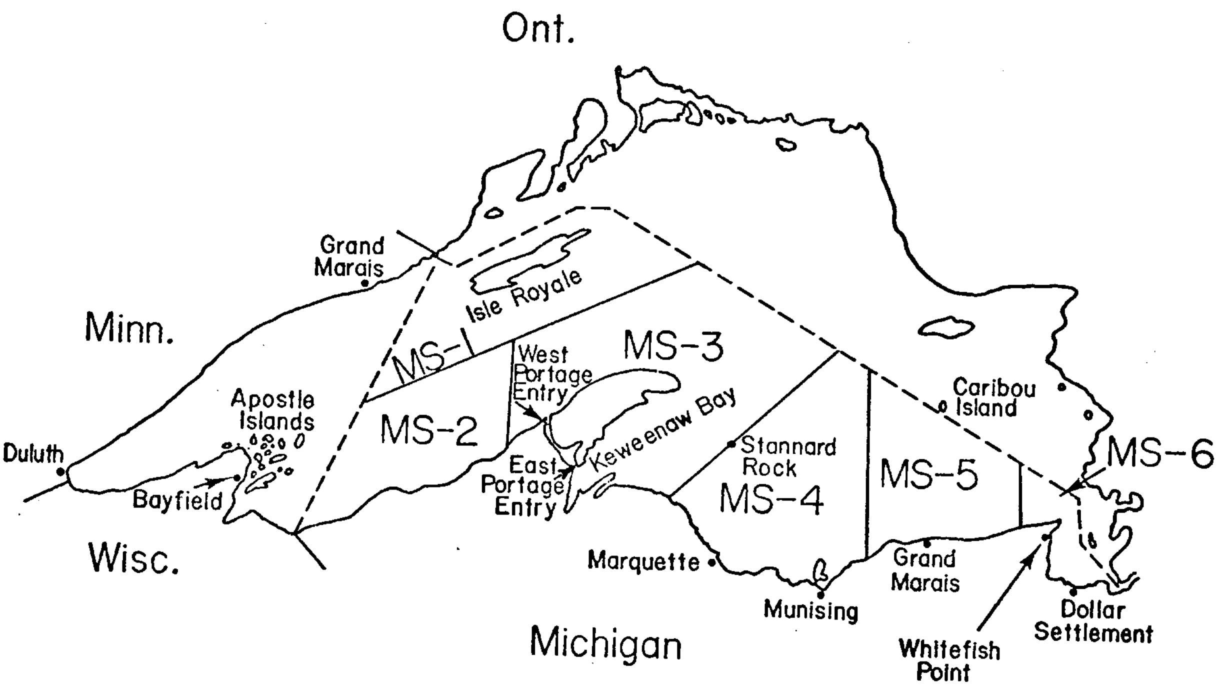

Figure 1.--Lake Superior fishing ports, fishing grounds and Michigan statistical districts.

here are attributed to areas, e.g., Marquette area, Marquette sample, or simply Marquette.

Lake whitefish

The following information on lake whitefish was gleaned from 13 sources. These included three published studies and several unpublished reports for Lake Superior, and studies of whitefish in other waters (see Literature cited).

Growth

Calculated growth of Lake Superior whitefish, sampled during 1957-59, is aptly described by Dryer (1963). He used the following body-scale relationship:

$$L = 0.0443 + 0.5401\ S,$$

where L = total length in inches

S = scale diameter in millimeters times 42

He applied the formula to scale samples collected at three locations in Michigan waters of Lake Superior (Marquette, Whitefish Point and Dollar Settlement). The intercept at 0.04 inch on the length axis was ignored and lengths were calculated by direct proportion. Edsall (1960) calculated growth of the slow-growing population of lake whitefish in Munising Bay which was sampled in 1953. He based his calculations on the following body-scale relationship for that stock:

$$L = 1.486 + 1.222\ S$$

where L = total length in inches

S = scale diameter in inches times 43

Computations of growth in length calculated by Dryer (1963) for Bayfield, Marquette, Whitefish Point, and Dollar Settlement, and those by Edsall (1960) for Munising Bay, are in Table 1.

The largest size attained by the Munising Bay population was 16.7 inches after 16 years of life. Edsall (1960) could offer no explanation of the slow growth rate, except that population density was high in Munising Bay.

Differences in growth between samples at the four other Lake Superior ports, especially that between Whitefish Point and Dollar Settlement (which are only 30 miles apart), indicated to Dryer that a number of distinct stocks may be present in Lake Superior.

Recent growth information (Table 2) consists of empirical growth from the Apostle Islands in Wisconsin waters (Great Lakes Fishery Commission, 1969) and from three locations in Michigan waters (Peck et al., 1974). There were no appreciable growth differences among the Michigan samples. However, average lengths of lake whitefish age groups in the Apostle Islands were less than for corresponding age groups in Michigan waters by about 1 year's growth. The Michigan samples were obtained from the fall fishery and age groups were designated by number of annuli, not seasons of growth. Perhaps the Wisconsin age groups were based on seasons of growth rather than number of annuli, which could account for the difference.

Length-weight relationship.--Dryer (1963) computed the length-weight relationship of lake whitefish sampled at four locations along the south shore of Lake Superior during 1957-59 to be:

$$W \text{ (pounds)} = 0.0001663\ L^{3.2408} \text{ (inches)}$$

and Edsall (1960) calculated the relationship for Munising Bay lake whitefish to be:

$$W \text{ (ounces)} = 0.0074788\ L^{3.712} \text{ (inches)}$$

Table 1.--Calculated total length (inches) at each age for lake whitefish taken at Bayfield, Wisconsin; Marquette, Michigan; Whitefish Point, Michigan; Dollar Settlement, Michigan (Dryer, 1963); and Munising Bay, Michigan (Edsall, 1960)

Age	Bay-field	Marquette	Whitefish Point	Dollar Settlement	Munising Bay
I	5.1	5.6	6.6	5.9	5.5
II	8.0	9.0	11.2	9.5	7.2
III	10.9	12.4	14.7	12.7	8.4
IV	13.3	15.6	17.6	14.8	9.4
V	15.0	18.2	20.4	16.9	10.1
VI	16.7	20.0	21.7	18.6	10.8
VII	18.3	21.5	23.3	20.3	11.5
VIII	20.0	22.9	....	21.4	12.1
IX	21.4	25.2	....	22.4	12.9
X	22.1	26.8	....	23.8	13.6
XI	....	....	....	....	14.4
XII	....	....	....	....	15.4

Table 2.--Average total length (inches) for age groups of lake whitefish in commercial landings from Wisconsin (Apostle Islands, 1968) and Michigan (Whitefish Bay, Munising and Marquette, 1972)

Age	Apostle Islands	Whitefish Bay	Munising	Marquette
III	....	16.5	16.4	....
IV	17.9	18.5	18.5	18.6
V	18.7	20.5	20.2	21.5
VI	20.0	23.0	22.9	22.8
VII	20.9	24.2	23.9	....
VIII	21.7	26.7	26.5	26.6
IX	22.3	....	....	....
X	22.9	....	....	....

Recruitment

Fecundity.--No data are available for Lake Superior whitefish. In Georgian Bay, Lake Huron, Cucin and Regier (1966) found the average fecundity to be 8,200 eggs per pound of fish. In Lac la Ronge, Saskatchewan, the average egg production per pound of fish varied from 7,155 to 9,018 (Qadri, 1968).

Age and size at maturity.--Peck et al. (1974) reported that 82% of age-group IV lake whitefish landed at Marquette in 1972 were immature, whereas only 14% of age-group V and 9% of age-group VI were immature. All fish under 18.0 inches were immature but all over 21.0 inches were mature. They also reported that, in Whitefish Bay, males over 22.0 inches and females over 23.0 inches were mature.

Dryer (1963) found the following ages and sizes at maturity for whitefish sampled at Bayfield during 1957-59: All fish shorter than 14.5 inches were immature but all fish longer than 17.4 inches were mature. The first mature male appeared in the 14.5- to 14.9-inch group, most males were mature at 16.0-16.4 inches, and all males were mature at lengths greater than 16.9 inches. The first mature females appeared at 16.0-16.4 inches, and all females longer than 17.4 inches were mature. The youngest mature fish of each sex were of age V, and all fish were mature at age VII. A sample of spawning whitefish from the Apostle Islands in 1969 indicated a younger spawning population, with males being mature at age III and females at age IV (Great Lakes Fishery Commission, 1970); in that sample, males averaged 5.0 years and females 5.6 years old.

The slow-growing whitefish from Munising Bay (Edsall, 1960) were first mature at 11.5 inches, and all were mature at 15.0 inches. The males were first mature at age VII; the females at age X. All were mature at age XII.

Age at recruitment.--Full recruitment to the Michigan trap-net fishery (4 1/2- to 4 3/4-inch stretch mesh) at Marquette, Munising and Whitefish Bay occurs at age V (Peck et al, 1974).

Dryer (1963) sampled commercial catches at four locations in 1957-59 and found that recruitment occurred as young as age II at Marquette. Age III fish were part of the legal catch at all four locations. Full recruitment occurred as young as age V at Whitefish Point in Michigan, and as old as age IX at Bayfield, Wisconsin. Recruitment occurred at age IV in 1968, and at age III in 1969, in the Wisconsin trap-net fishery for whitefish (King and Belonger, 1970), but lack of information on length distribution of age groups precluded assessment of age at full recruitment.

There is no information available for the very limited sport fishery.

Mortality

Total.--Very little data have been documented on total mortality rate for Lake Superior whitefish. Peck et al. (1974) determined an average annual total mortality rate of 60% for ages V-VIII in Whitefish Bay during 1968-72.

Natural.--No natural mortality rates have been reported for lake whitefish in Lake Superior. Whitefish are preyed upon by lake trout and other salmonids, as well as by the sea lamprey (Petromyzon marinus). Sea lamprey may well be the most important natural predator of adult lake whitefish. The sea lamprey scarring rate on the commercial catch in Minnesota waters was 13.9% in 1967, 12.3% in 1968, and 7.8% in 1969 (Great Lakes Fishery Commission, 1969 and 1970). Unfortunately, scarring and mortality have not been associated quantitatively. Cucin and Regier (1966) believed that natural mortality for whitefish in Georgian Bay, Lake Huron, was 34% in the absence of fishing.

Fishing.--No fishing mortality rates are available for lake whitefish in Lake Superior.

Catch data.--Lake whitefish have been harvested from Lake Superior with gill nets, pound nets, and trap nets. Whitefish yields in Michigan waters (Fig. 2) peaked at 3,848,000 pounds in 1891, declined to around 100,000 pounds in 1925, rose to 665,000 pounds in 1954, then declined to 156,000 pounds in 1960 (the latter mainly because of sea lamprey predation--Peck et al., 1974). The period 1960-70 was characterized by a rapid increase in whitefish poundage landed, with Michigan catches reaching 532,800 pounds in 1969 (Great Lakes Fishery Commission, 1970). Catches declined and leveled off at between 400,000 and 450,000 pounds during 1971-73. Wisconsin reported a similar increase in lake whitefish harvest, with pounds per lift of pound net increasing from 58.9 in 1967 to 92.9 in 1969. Minnesota reported a catch of 8,474 pounds in 1969, which they considered high, although it was lower than the 15,112 pounds landed in 1968. Ontario reported a catch of 210,000 pounds of whitefish in 1968 which represented an increase in five of seven statistical districts (Great Lakes Fishery Commission, 1969).

Age composition of the commercial catch in Michigan has been composed mainly of age groups IV-VI, with dominance of any one age group depending on year-class strength. The commercial catch in Wisconsin in 1968 was composed of ages IV-X, with ages IV and V making up more than 80% of the catch. In 1969, the catch included ages III-XI, with ages V and VI contributing 72%. Ages V, VI and VII composed 88% of Minnesota's 1969 commercial catch. Age V alone made up 55% of the catch.

Exploitation of whitefish stocks in Lake Superior is believed heavy, although there is little direct evidence. Dryer (1963) found that the intensive summer pound-net fishery in Wisconsin selected the legal-size fish early in the season, with undersized slower-growing individuals

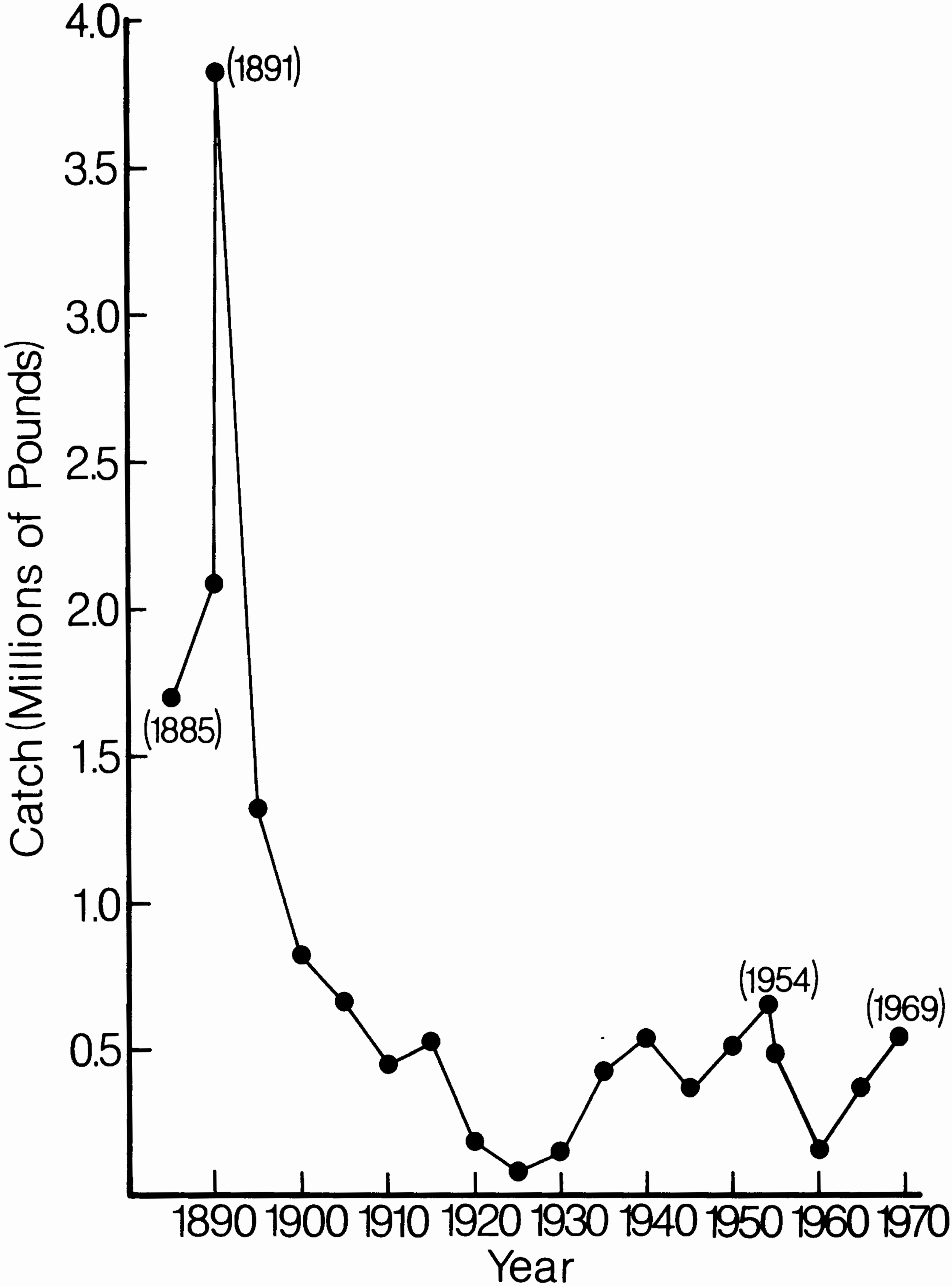

Figure 2.--Commercial harvest of lake whitefish in pounds from Lake Superior, 1885-1969. Data are for individual years.

dominating the catch in the latter part of the season. Exploitation rates of 22.6% for second-year tag returns and 20.5% for first-year tag returns were reported by Dryer (1964) for the Wisconsin fishery. Ninety-two percent of his recaptures appeared in the pound nets. Dryer believed these estimates to be minimal.

Indices of abundance on fishing grounds are provided by commercial catch-per-unit-effort (CPE). These statistics are reported as pounds of legal-sized fish per 1,000 feet of gill net, or per lift of pound net. Because the commercial gear may be fished in different locations from year to year, this index of abundance is not strictly comparable, but it is sufficiently reliable to show trends over a number of years. The following data from the Wisconsin pound-net fishery and the Minnesota gill-net fishery are suggestive of an increase in abundance of lake whitefish in the two areas.

Wisconsin pound net		Minnesota gill net	
Year	Pounds per lift	Year	Pounds per 1000 feet
1956	80.8	1963	16.4
1958	27.7	1964	15.9
1960	30.5	1965	11.1
1967	58.9	1966	11.8
1968	61.6	1967	18.1
1969	92.9	1968	19.0
		1969	18.6

The Bureau of Commercial Fisheries at Ashland, Wisconsin, has been index sampling for a number of years, particularly around the Apostle Islands. The catch of age II-IV lake whitefish in their gill nets in the spring has increased from 58 in 1967 to 535 in 1969 (Great Lakes Fishery Commission, 1970).

There is little information on gear selectivity for lake whitefish in Lake Superior. The Minnesota catch in gill nets with 4.5-inch mesh (extension measure) has averaged between 20.6 and 22.0 inches, total length, from 1963 to 1969, despite year-class fluctuations (Great Lakes Fishery Commission, 1970). The 17-inch size group dominated the gill-net catch in Wisconsin waters during both 1968 and 1969 (King and Belonger, 1970). Evidently, 17-inch lake whitefish are quite vulnerable to the 4.5-inch mesh gill nets. Cucin and Regier (1966) determined the percentage selectivity by 4.5-inch mesh gill nets on lake whitefish in Georgian Bay, Lake Huron, to be as follows:

Inch group (fork length)	Percent selectivity
12.0-12.9	0.0
13.0-13.9	0.0
14.0-14.9	0.0
15.0-15.9	19.1
16.0-16.9	51.6
17.0-17.9	100.0
18.0-18.9	79.8
19.0-19.9	91.0
20.0-20.9	18.5
21.0-21.9	0.0
22.0-22.9	0.0

Selectivity by 3.0-inch mesh pound nets (tarred) ranged from 0 for 12.5-inch fish to 100% at 16.0 inches and longer.

Distribution

Bathymetric.--Dryer (1966) reported that nearly all juvenile lake whitefish were captured at 10-29 fathoms, and none were taken above 10 or below 39 fathoms. Most of the larger whitefish captured by Dryer were also taken between 10 and 29 fathoms. A few were taken above 10 fathoms but none were captured below 39 fathoms. Dryer (1966), quoting from Koelz (1929), reported that most lake whitefish captured in commercial fishing gear were from 20-35 fathoms early in the spring but moved inshore as the season progressed. However, as summer temperatures warmed the inshore water, the lake whitefish moved out and fishermen reportedly caught them in 60-70 fathoms. The fish moved back into shallow water to spawn in the fall and were rarely taken at depths greater than 35 fathoms.

Lateral movements.--Lake whitefish tagged in the Apostle Islands area moved relatively short distances, regardless of time between tagging and recapture (Dryer, 1964). Most (64.5%) small whitefish were recaptured within 5 miles from the tagging site, and the greatest distance traveled was 17 miles. Most (56.5%) of the adult whitefish tagged on the spawning grounds were recaptured within 5 miles, 26.1% traveled more than 10 miles, and the maximum distance traveled was 25 miles. Gill nets were fished along the entire south shore of Lake Superior and, if the tagged fish moved longer distances, some should have been captured.

Evidence of discrete populations

Dryer (1963) suggested that the Lake Superior whitefish population is made up of discrete stocks. This was based on differences in growth of lake whitefish at five locations along the south shore of Lake Superior. Most notable is the extremely slow growth of the Munising Bay stock studied in detail by Edsall (1960). Of whitefish tagged in the Apostle Island area by Dryer (1964) he recovered none outside this area, which supports his suggestion (1963) that these fish are from one of a number of distinct stocks in Lake Superior. Such lack of movement would allow for greater influence by local environmental conditions.

Interspecific relationships

Sea lampreys are believed to be the most serious natural predator on adult lake whitefish. However, sea lamprey wounding has not been quantitatively associated with lake whitefish mortality. Young lake whitefish undoubtedly are preyed upon by most piscivorous fishes in Lake Superior. Although not documented, the lake trout must represent the greatest threat because of its abundance. The bathymetric distribution of juvenile lake whitefish and adult lake trout overlap at all times of the year for which data are available (Dryer, 1966). On the other hand, of 329 lake trout stomachs sampled by King and Belonger (1970), 2 contained lake whitefish.

Additional notes

Lake whitefish spawn in shallow water during fall. Qadri (1968) reported that spawning occurred from late October to mid-November in Lac la Ronge, Saskatchewan in 1953. No definite spawning time is reported for Lake Superior, but King and Belonger (1970) reported sampling whitefish spawners in November. Generally, eggs are broadcast over rocky shoal areas. Information is lacking regarding the Lake Superior spawning grounds and whitefish behavior while on the grounds.

Whitefish feed primarily on bottom organisms. Anderson and Smith (1971a) analyzed the food habits of 62 lake whitefish mostly under 10.0 inches long from western Lake Superior during 1965-68. Crustaceans were the most important food, followed by insects and molluscs. Amphipods were the predominant crustacean food item during most months, followed by *Mysis*, copepods and ostracods. Fish eggs were eaten during February and December. Gross observations by Michigan biologists on some young whitefish captured in 15-34 fathoms showed that their diet was mainly *Mysis relicta*, and included a few amphipods and larval dipterans.

Information gaps

Following are some of the things which need to be done on lake whitefish in Lake Superior:

1. Determine the location and size of stocks. This may be accomplished through tagging and electrophoretic studies of blood protein patterns.

2. When stocks are identified, determine fecundity, mortality rate, exploitation rate, rate of growth, and a yield equation for each stock.

3. Measure recruitment by index sampling the young.

4. If natural mortality is excessive, determine the utilization of lake whitefish as prey by associated predators. With the exception of the sea lamprey, this could be done by examining stomachs of suspected predators which cohabit with lake whitefish. For the sea lamprey, perhaps an association between wounding and actual mortality can be established.

Bloater

The bloater is the most common of five species of chubs (deep-water ciscos) in Lake Superior. Commercial landings of chubs, at least since 1950, are believed to have been mostly bloaters. Distribution, growth and food habits have been documented for chubs in western Lake Superior (Dryer, 1966; Dryer and Beil, 1968; and Anderson and Smith, 1971a and 1971b), but for the Michigan portion of the lake we have information on only age composition and geographical distribution.

Growth

Dryer and Beil (1968) determined the body-scale relationship for bloaters from the Apostle Island area to be:

$$L = 0.848 + 0.0488\ S$$

where L = total length in inches

S = scale diameter in millimeters times 43

The sexes were combined, as no significant growth differences were noted. Dryer and Beil (1968) calculated the following average total lengths (inches) for different ages and for two time periods, 1958-61 and 1962-65:

	Grand average calculated length (inches) at age									
	I	II	III	IV	V	VI	VII	VIII	IX	X
1958-61	3.8	5.6	6.7	7.6	8.2	8.6	9.2	9.7	10.1	....
1962-65	3.9	5.9	7.2	8.2	8.9	9.4	10.0	10.6	11.2	11.7

The average calculated total length of each age group was greater in 1962-65 than in 1958-61. In addition, they found that the average age of bloaters in their collections increased from 4.6 to 6.0 years for males and 5.6 to 6.7 for females, during 1958 to 1965. The average size of bloaters taken in gill nets with 1.5-inch mesh increased from 8.1 inches in 1953 to 9.6 inches in 1962-63. Bloaters from 2.0-inch mesh averaged 8.8 inches in 1953 to 10.1 inches in 1965. Dryer and Beil could offer no explanation for the increased growth rate of bloaters in Lake Superior. The abundance of bloaters appears to have increased in Lake Superior during the 1960's; however, an increase in abundance generally does not lead to improved growth. The increase in the abundance of bloaters in Lake Michigan during the 1950's and early 1960's also was accompanied by an increase in their growth rate (Smith, 1968).

Annulus formation occurred from mid-May to the end of August during 1965 (Dryer and Beil, 1968) but only 44% had formed an annulus by 24 July. Young bloaters completed their new annulus earlier than older ones. Bloaters completed 30% of their season's growth by the end of July and 80% by the end of August.

Length-weight relationship. --Dryer and Beil (1968) found the relationship to be:

$$\log W = -2.45097 + 3.104 \log L$$

where W = weight in ounces

L = total length in inches

Bloaters taken during 1962-65 were heavier than those collected during 1958-61. Fish taken during 1962-65 were 0.02 ounce heavier at the end of the first year and 1.75 ounces heavier at the end of the 9th year (Dryer and Beil, 1968). The largest annual increment was 1.0 ounce in the 9th year.

Recruitment

Fecundity. --Dryer and Beil (1968) examined 20 female bloaters collected from Apostle Island waters during the falls of 1964 and 1965. The number of eggs increased with fish length from 4,225 for an 8.4-inch bloater to 10,080 for an 11.7-inch fish. The number of eggs per ounce of body weight decreased from 1,408 for an 8.4-inch bloater to 1,050 for a 9.7-inch fish, then fluctuated between 1,121 and 1,292 for bloaters longer than 9.7 inches. The average was 1,241 eggs per ounce of body weight.

Age and size at maturity (Dryer and Beil, 1968). --The youngest mature bloaters of both sexes in the Apostle Island waters were age II. More males than females were mature at age II. Most age-III bloaters were mature (males 91% and females 89%) and all fish older than age III were mature. The smallest mature male was 6.0 inches long and the smallest mature female was 7.0 inches long. All fish longer than 8.4 inches were mature.

Age at recruitment.--Commercial chub fishermen in Michigan waters of Lake Superior used gill nets of 2 5/8- to 2 3/4-inch mesh during 1971-72. Recruitment of chubs to this fishery occurred as early as age IV, with age VI being the most abundant age group.

Mortality

Rates of mortality.--No data are available.

Catch data.--Bloaters generally predominate in the species composition of chub landings from Lake Superior, although some catches could contain some or all of the four other chub species. Dryer and Beil (1968) reported that the 1965 chub landings at Bayfield, Wisconsin, were about 90% bloaters.

Michigan and Wisconsin fishermen have taken the most chubs from Lake Superior since 1940 (Fig. 3). Chub fishing was intensified during the mid- and late 1950's due to a severe decline in lake trout and whitefish abundance. Chub yields subsequently exhibited some wide fluctuations which King and Belonger (1970) attribute to market conditions rather than chub abundance in Wisconsin. However, intensive fishing pressure has been maintained in Michigan waters since 1968. CPE (pounds per 1000 feet of gill net) increased dramatically in Michigan's major chub-producing districts (MS-3 and MS-4) during the mid-1960's but has declined in recent years (Fig. 4). Fishermen subsequently shifted some effort into deeper water and this may change the species composition of their catches to include more kiyi (*Coregonus kiyi*).

There is no information on exploitation rates of bloaters in Lake Superior. Commercial catch statistics provide the only available abundance index for chubs. Chub CPE is subject to many biases that could discredit its use as an abundance index. The substantial increase in CPE during the 1960's (Fig. 4) may reflect an actual increase in chub abundance or an artificial increase caused by a change in fishing operations. Low CPE's for chubs reported during 1959-64 may have resulted from the incidental chub catch in herring nets, as the herring fishery expanded offshore into

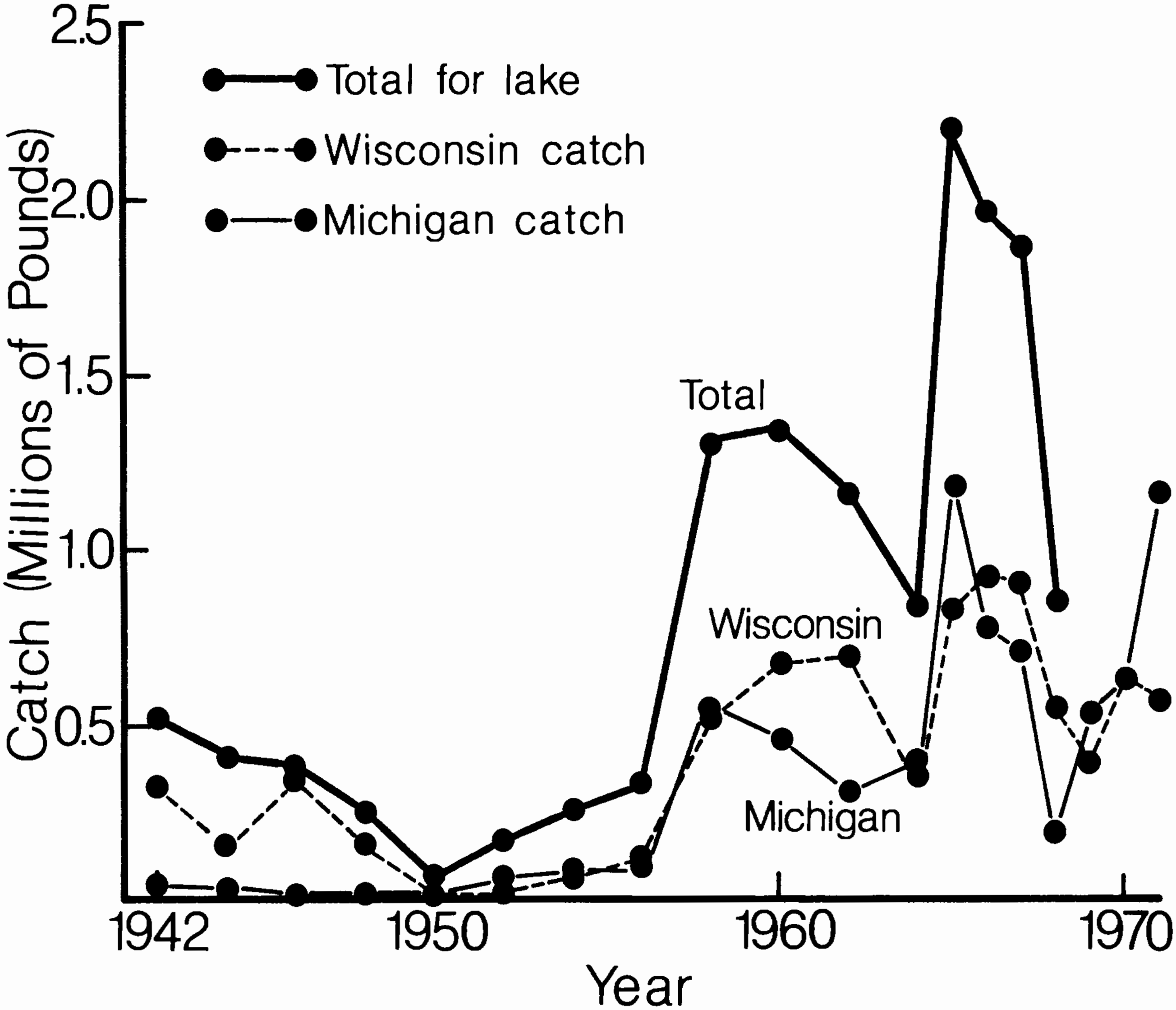

Figure 3.--Chub catches from Lake Superior, 1942-71. (Total for the lake includes Michigan, Minnesota, Wisconsin and Ontario.)

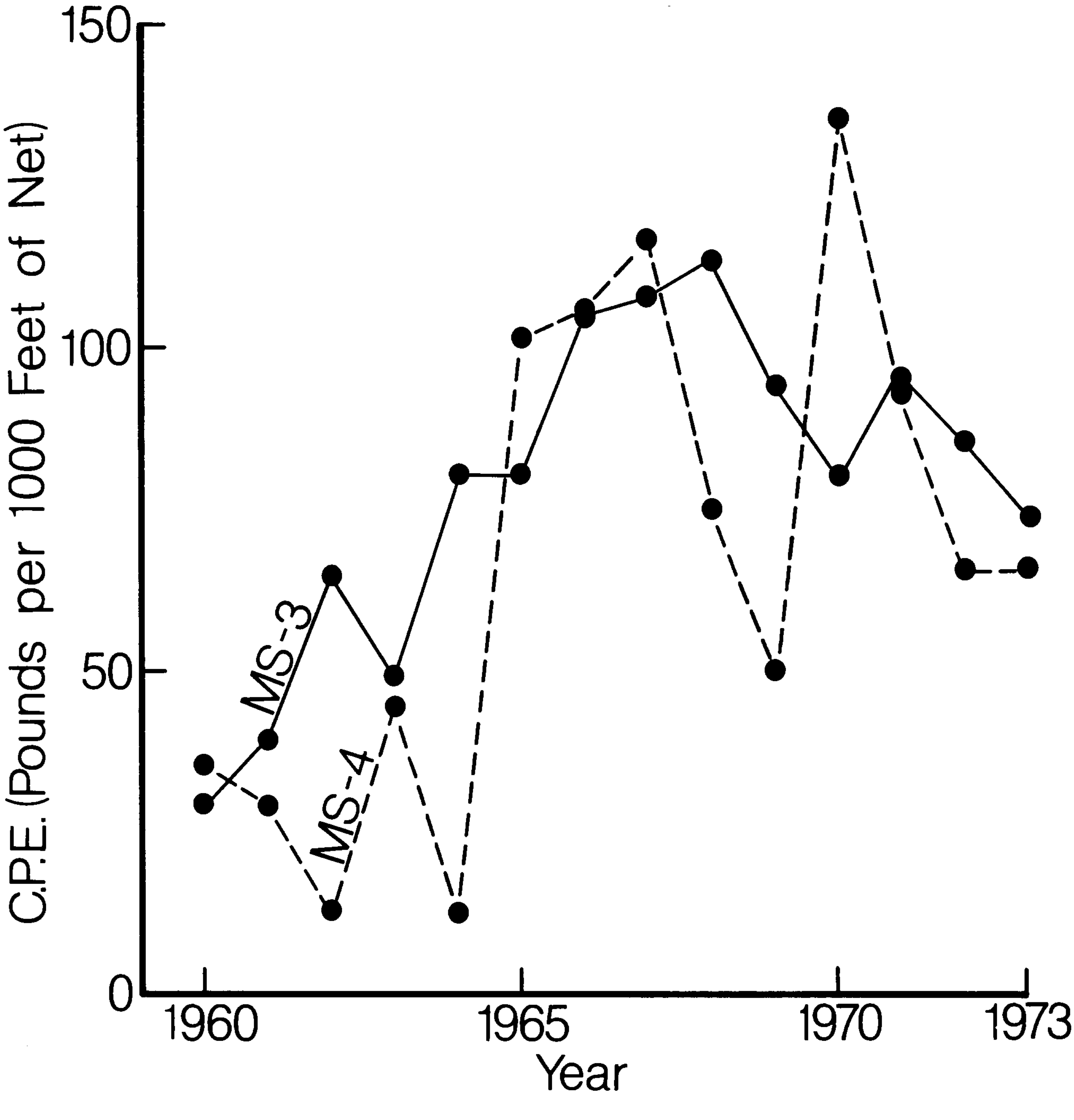

Figure 4.--Catch of chubs, as CPE (pounds per 1,000 feet of gill net), from Michigan statistical districts MS-3 and MS-4, 1960-1973.

'chub' water. The chub catch in herring nets was low, but this effort was included in the total chub effort thereby bringing the overall chub CPE down. Collapse of the herring fishery and the shift to full-time chub fishing could explain the increase in chub CPE during 1964-65.

Age of chubs in the 1971-72 commercial landings from Michigan waters ranged from IV to IX, with age VI the most abundant (Table 3). Ages V and VII were also well represented in the 2 5/8- to 2 3/4-inch mesh, with age IV abundant only in the sample from MS-1. Age-group VI was most abundant, or nearly so, in the catch of bloaters from the U.S. Bureau of Commercial Fisheries gill netting and trawling operations in Wisconsin waters during 1958-65. Only slight year class fluctuations occurred. Age-group V was predominant in 1958 and 1962, and age-group VII shared preponderance with VI in 1960. The oldest bloaters reported by Dryer and Beil (1968) were 10 years old.

There is little information on gear selectivity available for gear used in the Lake Superior chub fishery. Eleven inches was the modal length of samples from the 2 5/8- to 2 3/4-inch mesh gill nets utilized by the 1971-72 commercial fishery in Michigan waters. Berst (1961) stated that, for chubs (mostly bloaters) in Lake Huron, the modal fork length captured in 2 1/4-, 2 1/2-, and 2 3/4-inch (stretch mesh) gill nets was 7.0-7.4 inches. These mesh sizes encompass those used in the Lake Superior chub fishery. All three mesh sizes captured about the same bloater size range (6.0-13.4 inches, fork length). No conversion factor for fork length to total length has been documented.

Distribution

Bathymetric.--Dryer (1966) reported that, for the Apostle Island region, bloaters captured in bottom trawls were most abundant at 40-49 fathoms in summer and fall, and were evenly distributed between 30 and 59 fathoms in the spring. Bloaters were most common in gill nets at 40-49 fathoms in the spring and fall, and at 50-59 fathoms in the summer. According to Dryer's records, no bloaters were

Table 3.--Age composition of chubs captured with 2 5/8- to 2 3/4-inch commercial gill nets in Michigan statistical districts and grids of Lake Superior, 1971-72

Statistical district	Grids	Number of fish	Age composition (%) IV	V	VI	VII	VIII	IX
MS-1	718-818	27	22	26	44	8	..	..
MS-2	1021-1119	84	1	29	37	25	6	2
MS-3	1126	44	9	36	34	16	5	..
MS-4	1530	31	6	16	36	36	3	3
MS-5	No sample	..	..	..	..	..	..	..
MS-6	1343	32	9	19	35	25	9	3

collected at less than 10 fathoms, and few between 10 and 19 fathoms. Abundance declined with depth greater than 50 fathoms. Few were taken below 70 fathoms. Reigle (1969) reported that chubs were most abundant at 40-45 fathoms during bottom trawl explorations in U.S. waters of Lake Superior during 1963-65. Only a few chubs were captured at less than 30 fathoms.

Bloaters recently have been found to be abundant at depths greater than 60 fathoms in Michigan waters adjacent to the Keweenaw Peninsula. Bloaters predominated in most commercial catches from 60 to 90 fathoms sampled during May, August and December of 1974. Bloaters were also abundant in samples of commercial catches from 60 to 70 fathoms landed at Marquette but generally ranked second in abundance to kiyi (Marquette Fisheries Research Station, unpublished data).

Lateral.--Reigle (1969) found concentrations of chubs distributed throughout the U.S. waters of Lake Superior. The best concentrations were found in the western half of the lake. Chubs apparently move inshore during the summer according to Dryer (1966); his data indicated an increase in abundance in shallow water and a corresponding decrease in abundance in deeper water.

Evidence of discrete populations

There is no information on the discreteness of bloater populations in Lake Superior.

Interspecific relationships

Coregonids were the major prey fish for lake trout in Lake Superior at depths greater than 35 fathoms, and most of these were chubs (Dryer et al., 1965).

In Lake Michigan the larger chubs and deep-water predators were cropped off by commercial fishing and by sea lamprey predation, allowing the smallest chub (bloater) to become predominant (Smith, 1968). This succession apparently has also occurred in Lake Superior where the larger blackfin cisco (*Coregonus nigripinnis*) and shortjaw cisco (*C. zenithicus*), which were the most abundant chubs in the early fishery, may have been replaced by bloater chubs.

The increase in bloater abundance also has been linked to the decline of lake herring in western Lake Superior. Anderson and Smith (1971b) found that the food of the bloater was very similar to that of lake herring, especially during the larval stage of the two species.

Bloaters may also have hybridized with lake herring in Lake Superior. Some lake herring taken from deep water exhibit certain bloater morphological features such as a projecting lower jaw and symphyseal knob. Smith (1964) suggested hybridization as the possible reason for increasing difficulties in identifying the bloater and lake herring in Lake Michigan.

Additional notes

Dryer and Beil (1968) found some ripe bloaters in Lake Superior during all months of the year, but stated that most spawning occurs in February and March in the Apostle Island region. They concluded that bloaters have no preference as to bottom type over which they spawn.

Food habits of bloaters from this region were examined by Dryer and Beil (1968). They found crustaceans to be the most common food. In order of most frequent occurrence were copepods, *Mysis*, and *Pontoporeia*. In order of greatest volume were *Mysis*, copepods, and *Pontoporeia*. Copepods comprised most (98% by volume) of the diet of small chubs (under 8.0 inches). Insects were found in 17.5% of the Lake Superior samples but contributed less than 1% of the total volume. According to Dryer and Beil, the occurrence of fingernail clams and fish eggs indicated occasional bottom feeding, but most of the food items confirmed that bloaters are mainly pelagic feeders.

Anderson and Smith (1971a) also found crustaceans to be the most important food of bloaters in western Lake Superior. Bloaters less than 8.0 inches ate mostly copepods during all months except September when cladocerans predominated. Mysis, amphipods, ostracods, insects and molluscs also were eaten. Bloaters 8.0 inches and longer also fed predominantly on copepods, but Mysis was most important during May, July, September and November. Bloaters ate amphipods during most months and their diet occasionally included cladocerans, ostracods, isopods, insects, molluscs, and fish eggs.

Information gaps

1. Species composition of commercial chub landings in Michigan waters.

2. Age composition and growth of chubs in important concentrations in Michigan waters of Lake Superior.

3. Exploitation and mortality rates on the major bloater fishing grounds.

4. Commercial gear selectivity for bloaters.

5. Lateral movements and discreteness of bloater populations.

Lake Herring

There are only two published studies specifically on lake herring in Lake Superior (Dryer and Beil, 1964; Anderson and Smith, 1971b). Four other published references (Dryer, 1966; Anderson and Smith, 1971a; Lawrie and Rahrer, 1972; Peck, 1974) contain some information on Lake Superior herring. Other information was found in unpublished reports of the Great Lakes Fishery Commission, Lake Superior Committee; Michigan Fisheries Division (Region I, Great Lakes); and Marquette Fisheries Research Station.

Growth

Lake herring growth in Michigan waters of Lake Superior has increased since growth rates were first determined by Dryer and Beil (1964) in the 1950's. Dryer and Beil calculated growth from samples of herring landed at four ports (Duluth, Minn.; Bayfield, Wisc.; Portage Entry, Mich.; and Marquette, Mich.) during 1950-55 and 1956-59 (Table 4). They did not compute a body-scale relationship, but assumed that it was a direct proportion. Herring landed at Bayfield had the slowest growth, and those landed at Marquette had the fastest growth. According to these authors, there appeared to be a west-to-east increase in the growth rate of herring in Lake Superior. They also noted that, with one exception, growth was faster during 1956-59 than during 1950-55.

Growth in length, calculated from herring taken in Keweenaw Bay and waters near Marquette during the November-December fisheries (Tables 5 and 6), was faster during 1960-71 than during the 1950's. The calculations for 1960-66 are courtesy of the U.S. Fish and Wildlife Service biologists at Ashland, Wisconsin. I calculated herring growth for 1967-71 from samples collected by personnel at the Marquette Great Lakes Station.

In Keweenaw Bay, annual length increments of lake herring, calculated from all age groups, decreased for age I and increased after age IV during 1960-71 (Table 5). Herring abundance declined in Keweenaw Bay during 1960-71, so an increase in the growth rate would not be unusual. However, the decline in first-year growth could not be so readily explained. Since there had been an increase in the average age of herring in the yearly samples, it could be speculated that the declining first-year length was the result of calculating lengths from samples containing progressively more older and slow-growing herring. However, these older herring were surprisingly fast growing, with annual length increments at or near 1 inch. Perhaps the best evidence that the decline was real is that the decline was evident in length

Table 4.--Average calculated total length (inches) at each age for lake herring landed at four Lake Superior locations (Duluth, Minn.; Bayfield, Wisc.; Portage Entry, Mich.; Marquette, Mich.)

Age	Duluth	Bayfield		Portage Entry		Marquette	
	1957-59	1950-54	1956-59	1950-55	1956-59	1950-55	1956-59
I	4.3	4.6	4.7	4.8	4.7	4.8	5.0
II	6.8	7.1	7.4	7.2	7.4	7.6	7.9
III	9.0	8.8	9.4	9.1	9.4	9.5	10.0
IV	10.6	10.5	10.9	10.7	11.1	11.0	11.7
V	11.6	11.2	11.8	11.4	12.1	11.8	12.5
VI	12.5	11.9	12.7	12.2	13.1	12.6	13.5
VII	13.3	12.7	13.6	12.9	13.5	13.3	14.6
VIII	14.0	....	14.1	....	....	....	....

Table 5.--Average calculated total length and increment of length (inches) at each age for lake herring from Keweenaw Bay 1960-71

Year of capture	Age I	II	III	IV	V	VI	VII	VIII	IX	X
					Total length at age					
1960	4.8	7.3	9.3	11.0	11.6	12.1	12.1	....	....	....
1961	4.9	7.5	9.4	11.1	11.9	12.4	12.9	....	....	....
1962	4.8	7.4	9.4	11.2	11.9	12.3	....	....	....	....
1963	4.6	7.8	10.1	11.9	12.6	12.8	13.0	....	....	....
1964	4.8	7.3	9.3	11.0	12.0	12.5	12.6	11.8	....	....
1965	4.7	7.3	9.4	11.1	12.0	12.5	13.1	13.0	....	....
1966	4.8	7.3	9.3	11.0	11.9	12.7	13.0	13.4	15.3	15.9
1967	4.4	6.8	8.4	10.0	11.2	12.4	13.6	14.5	....	....
1968	4.6	7.4	9.6	11.5	12.8	13.5	14.6	16.0	....	....
1969	4.3	7.4	9.9	11.7	12.7	13.4	14.1	14.0	....	....
1970	...	...	...	....	....	....	....	....	....	....
1971	3.9	6.1	8.4	10.4	11.8	12.8	13.7	15.1	....	....
					Increment from next lesser age					
1960	4.8	2.5	2.0	1.7	0.6	0.5	0.0	...	...	...
1961	4.9	2.6	1.9	1.7	0.8	0.5	0.5	...	...	...
1962	4.8	2.6	2.0	1.8	0.7	0.4	...	...	...	...
1963	4.6	3.2	2.3	1.8	0.7	0.2	0.2	...	...	...
1964	4.8	2.5	2.0	1.7	1.0	0.5	0.1	-0.8	...	...
1965	4.7	2.6	2.1	1.7	0.9	0.5	0.6	-0.1	...	...
1966	4.8	2.5	2.0	1.7	0.9	0.8	0.3	0.4	1.9	0.6
1967	4.4	2.4	1.6	1.6	1.2	1.2	1.2	0.9	...	...
1968	4.6	2.8	2.2	1.9	1.3	0.7	1.1	1.4	...	...
1969	4.3	3.1	2.2	1.9	1.3	0.7	0.7	-0.1	...	...
1970	...	...	...	...	...	...	...	...	...	...
1971	3.9	2.2	2.5	1.8	1.0	0.7	0.9	1.4	...	...

Table 6.--Average calculated total length and increment of length (inches) at each age for lake herring from waters near Marquette 1960-69

Year of capture	Age I	II	III	IV	V	VI	VII	VIII	IX
				Total length at age					
1960	4.9	8.0	10.2	11.5	12.2	12.8	14.8	....	....
1961	5.0	8.1	10.6	11.8	12.3	12.4	....	....	....
1962	4.9	7.9	10.3	11.8	12.5	12.8	13.6	....	....
1963	4.9	7.9	10.4	11.7	11.9	12.1	....	....	....
1964	4.8	7.7	9.9	11.5	12.4	12.7	12.8	....	....
1965	4.8	7.7	10.0	11.6	12.4	12.9	13.2	13.8	....
1966	4.7	7.6	9.8	11.8	12.8	13.2	13.5	13.8	....
1967	...	...	...	....	....	....	....	....	....
1968	5.1	8.8	11.3	13.0	14.2	15.2	16.2	17.1	18.2
1969	4.6	7.5	10.0	12.1	13.4	14.5	15.4	16.2	16.8
				Increment from next lesser age					
1960	4.9	3.1	2.2	1.3	0.7	0.6	2.0	...	...
1961	5.0	3.1	2.5	1.2	0.5	0.1	...	...	...
1962	4.9	3.0	2.4	1.5	0.7	0.3	0.8	...	...
1963	4.9	3.0	2.5	1.3	1.2	0.2	...	...	...
1964	4.8	2.9	2.2	1.6	0.9	0.3	0.1	...	...
1965	4.8	2.9	2.3	1.6	0.8	0.5	0.3	0.6	...
1966	4.7	2.9	2.2	2.0	1.0	0.4	0.3	0.3	...
1967	...	...	...	...	...	...	...	...	...
1968	5.1	3.7	2.5	1.7	1.2	1.0	1.0	0.9	1.1
1969	4.6	2.9	2.5	2.1	1.3	1.1	0.9	0.8	0.6

increments calculated solely from age V (Table 7)--an age group well represented in the yearly samples during 1960-71. A possible explanation for the decline in first-year growth is that young-of-the-year herring may have faced increasing interspecific competition for food. Another possibility is that herring sampled during the latter part of 1960-71 were of a different population, one characterized by slow first-year growth.

Herring growth rate increased also in waters around Marquette during 1960-69. Annual length increments, calculated from all age groups, exhibited a definite increase after age III (Table 6).

Herring from Whitefish Bay generally grew faster than herring from Marquette or Keweenaw Bay waters during 1968-71, except that first-year growth was slower (Table 8). Calculated growth of herring exhibited no trend during 1968-71, but herring from the 1971 sample were decidedly slow growing. Apparently herring in the 1971 sample were from a different stock or population than those sampled during 1968-70.

The following information on annulus formation and inter-seasonal growth is provided by Dryer and Beil (1964): The period of annulus formation exceeds 8 weeks, starting sometime before the first week in May and ending after the last week in July. Young fish start new growth sooner than do old fish. The greatest amount of growth (25%) occurred in June; by the end of August over 80% of the season's growth had been completed, and by the end of September, it was 92.5%.

Length-weight relationship.--Dryer and Beil (1964) determined a length-weight relationship for Lake Superior lake herring sampled in the 1950's as follows:

$$\log W = -2.54688 + 3.17008 \log L$$

Dodge (1970), for Keweenaw Bay, gives:

$$\log W = -2.4705 + 3.118 \log L$$

or

$$W = 2.71 L - 25.06$$

Table 7.--Average length increments (inches) calculated from age-V lake herring in fall fishery, Keweenaw Bay, 1960-71

Year of capture	Age I	II	III	IV	V
1960	4.7	2.2	1.8	1.8	1.4
1961	4.9	2.5	1.7	1.7	1.3
1962	4.7	2.2	1.9	1.8	1.7
1963	4.7	2.8	2.2	1.9	1.4
1964	5.0	2.4	2.0	1.8	1.3
1965	4.7	2.4	2.0	2.1	1.3
1966	4.9	2.5	2.1	1.7	1.3
1967	5.1	2.8	2.3	2.0	1.1
1968	4.5	2.9	2.5	1.8	1.4
1969	4.3	3.0	2.4	2.1	1.4
1971	4.0	2.5	2.3	2.3	1.8

Table 8.--Calculated total length (inches) at each age for lake herring from Whitefish Bay

Age	Date of capture: 25 March 1968	May 1969	13 August 1969	16 June 1970	18 June 1970	March-April 1971
I	4.5	4.5	4.5	4.4	4.7	4.4
II	7.7	7.9	8.1	7.9	7.9	6.5
III	10.0	10.4	10.5	10.5	10.5	8.7
IV	11.7	12.3	12.4	12.5	12.5	10.5
V	12.8	13.7	13.8	13.7	13.9	11.7
VI	13.7	14.7	14.4	14.5	15.0	12.4
VII	14.5	15.7	15.1	15.6	16.1	13.2
VIII	15.8	16.9	15.6	15.1	17.1	14.0
IX	....	18.3	16.0	....	....	14.5
X	....	19.7	16.6	....	....	....
XI	....	....	17.1	....	....	....
Number of fish	67	170	77	83	69	112

and for Whitefish Bay he gives:

$$\log W = -2.8605 + 3.457 \log L$$

or

$$W = 3.59\ L - 37.23$$

where, in all of the above

W = weight in ounces

L = total length in inches.

Dodge (1970) computed length-girth equations for lake herring caught in gill nets with 2 5/8-inch mesh in Keweenaw Bay:

$$Y = 0.29\ L + 1.13$$

and in gill nets (2 3/4- to 3 1/4-inch mesh) in Whitefish Bay:

$$Y = 0.40\ L - 0.45$$

where Y = girth in inches

L = total length in inches.

Herring in Whitefish Bay have a larger girth than those in Keweenaw Bay, which agrees with the difference in their respective length-weight relationships.

Recruitment

Fecundity.--Dryer and Beil (1964) and Anderson and Smith (1971b) provided fecundity data on Lake Superior herring. Dryer and Beil found that the number of eggs increased with fish length, and that the number of eggs per ounce of body weight decreased with increasing fish length. The number of eggs per fish ranged from 4,314 for 10-inch fish to 10,250 for a 14-inch fish. Number of eggs per ounce of fish in 1950-54 averaged 842 and ranged from 746 to 1,006. Anderson and Smith found that the average number of eggs per female was 6,351 during 1966-67. Average number of eggs per ounce of fish was 1,105 at Duluth-Superior and 1,019 at Apostle Islands, during 1966-67. Lake Superior herring typically produced fewer eggs per fish, and fewer eggs per ounce of fish, than was reported by Smith (1956) for lake herring in Green Bay, Lake Michigan. The mean diameter of herring eggs from both Lake Superior and Green Bay was 1.88 mm.

Age and size at maturity.--In Lake Superior some males and females become mature at age II, and all older than age III are mature (Dryer and Beil, 1964). All herring shorter than 8.5 inches were immature and all over 11.9 inches were mature. Females were first mature between 9.5 and 9.9 inches. In Green Bay some males (average, 8.2 inches) and females (average, 8.6 inches) were mature at age I (Smith, 1956).

Age at recruitment.--Recruitment to the fishery is evidently declining every year, causing a steady increase in the average age as the fishery is supported mostly by progressively older fish. Average age of herring caught in Wisconsin waters increased from 3.9 years in 1950-59 to 5.1 years in 1966-68. Similar increases have occurred in the fall herring fisheries of Michigan's Keweenaw Bay and waters around Marquette (Tables 9 and 10). Average age increased at Keweenaw Bay from 3.9 years in 1950-59 to 4.4 years in 1960, and further to 5.7 years in 1971. At Marquette, the average age increased from 3.9 years in 1950-59 to 5.7 in 1969. The increase was greatest in 1964 at both locations. From 1960 to 1964, age-groups IV and V dominated the catch in Keweenaw Bay, but thereafter ages V and VI were most abundant, with age VII making some significant contributions (Table 9). The transition at Marquette was even more drastic in that, within 3 years, a fishery supported by ages III and IV changed to one supported by ages V and VI (Table 10). As herring abundance declined, the average size increased. This is due to the older age composition of the catch, and to an increased growth rate, particularly in the later years of life.

Herring growth rate has increased since the 1950's, and so has gill-net mesh size in the commercial fishery. The most common mesh size in herring gill nets used in western Lake Superior was

Table 9.--Percentage age composition of lake herring in the fall catches from Keweenaw Bay, 1960-71

Year	Age group									Average age, years
	II	III	IV	V	VI	VII	VIII	IX	X	
1960	..	10	52	24	10	4	..	..	..	4.4
1961	3	9	38	38	9	3	..	..	..	4.3
1962	1	8	47	36	8	..	..	..	..	4.4
1963	..	8	40	40	10	2	..	..	..	4.6
1964	..	..	19	38	32	10	1	..	..	5.3
1965	1	4	28	36	21	9	1	..	..	5.0
1966	..	1	21	30	36	10	1	..	1	5.4
1967	..	2	19	42	31	4	2	..	..	5.2
1968	..	2	13	46	29	6	4	..	..	5.3
1969	..	15	29	32	20	2	2	..	..	4.8
1970*	..	..	..	..	..	..	..	..	..	...
1971	..	4	12	28	33	19	3	1	..	5.7

* No sample.

Table 10.--Percentage age composition of lake herring in the fall catches from Marquette Bay, 1960-69

Year	Age group								Average age, years
	II	III	IV	V	VI	VII	VIII	IX	
1960	5	27	48	17	2	1	..	..	3.9
1961	2	34	44	18	2	..	..	..	3.8
1962	1	26	44	24	4	1	..	..	4.1
1963	2	23	59	11	5	..	..	..	3.9
1964	1	7	27	45	17	3	..	..	4.8
1965	..	8	30	37	23	1	1	..	4.8
1966	..	1	23	44	25	5	2	..	5.2
1967*	..	..	..	..	..	..	..	..	...
1968	..	..	4	30	31	20	13	2	6.1
1969	..	..	20	32	23	20	..	5	5.6

* No sample.

2 3/8 inches (extension measure) during the 1950's and 2 5/8 inches during the 1960's. Recently, in Michigan waters, fishermen have been using 2 3/4- to 3 1/4-inch mesh. The limited data available indicate that this increase in mesh size and the shift from bottom sets to floating sets did not cause the increasing preponderance of older herring in commercial catches which occurred in Keweenaw Bay and Marquette waters during the 1960's (Tables 9 and 10). Age-IV fish predominated in catches from both the 2 3/8-inch mesh in 1950-59 and the 2 5/8-inch mesh in 1960-63. Age-groups V and VI were most abundant in catches sampled during 1964-66, although the fishermen were still using 2 5/8-inch mesh. Age VII was the modal age group captured in 2 1/2-, 2 3/4- and 3.0-inch mesh fished in Whitefish Bay during May 1969 (Marquette Great Lakes Station, unpublished data). The change in age composition occurred simultaneously in bottom sets and floating sets fished in the same area of Keweenaw Bay in 1964 (USFWS, unpublished data).

Mortality

Total.--Some total mortality and survival rates for herring in Keweenaw Bay, Marquette, and Whitefish Bay are given in the following text and tables. These are based on a method which compares catch per unit of effort of individual year classes during successive years of vulnerability. Catch per unit effort (CPE) in this case is number of fish per 1,000 feet of commercial gill net. The CPE of a year class must decline during successive years of vulnerability if requirements of this method are met. This method is affected by changes in catchability from year to year and requires a representative measure of effective fishing effort. During some years of vulnerability for some year classes, calculations were prohibited or suspect because of the following: (1) An apparent decline in recruitment has subsequently altered age composition of the commercial catch beginning with the 1964 fall fishery. (2) In some cases, annual age composition of herring in a whole statistical district is based on only one sample of scales from one fisherman's lift on one day. (3) Since the early 1960's, fishing effort has changed from bottom sets to floating sets and from inshore to offshore. The data on hand indicate no effect of these shifts on age composition and growth but, as pointed out in (2) above, the samples may be too small to show a change.

Average rates of annual total mortality were 0.23 and 0.60 for ages V and VI in Keweenaw Bay during 1961-64 (Table 11). After 1964, the change in age composition (Table 9) precluded further determinations for age V, but permitted calculations for ages VII and VIII. Calculations were continued on age VI although they exhibited extreme fluctuations. From 1965-70, the average annual total mortality rate was 0.38 for age VI and 0.75 for age VII.

Average rates of annual total mortality for ages V-VII at Marquette during 1961-66 (Table 12) are similar to those for Keweenaw Bay. Since 1966, only two samples of scales from the Marquette fall fishery have been collected, and this was deemed insufficient for calculation of mortality rate.

Data from the Whitefish Bay spring herring fishery were sufficient to calculate survival (s), annual total mortality (a), and instantaneous total mortality (i) only for age VII during 1968, 1969 and 1970:

	s	a	i
1968	0.53	0.47	0.64
1969	0.15	0.85	1.88
1970	0.20	0.80	1.61

Natural and fishing mortality.--I used Paloheimo's (1961) linear method to estimate rates of instantaneous natural mortality (q) and fishing mortality (p) from the July-December herring fishery in MS-3 (Keweenaw Bay) during 1960-71 (Peck, 1974). 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;

Table 11.--Survival rate (s), annual total mortality rate (a), and instantaneous total mortality rate (i) for herring of ages V to VIII from Keweenaw Bay fall fishery, 1961-70

Year	Age V			Age VI		
	s	a	i	s	a	i
1961	0.72	0.28	0.33	0.39	0.61	0.95
1962	0.68	0.32	0.39	0.15	0.85	1.91
1963	0.82	0.18	0.19	0.28	0.72	1.26
1964	0.85	0.15	0.16	0.79	0.21	0.24
1965	....	....	....	0.47	0.53	0.75
1966	....	....	....	0.94	0.06	0.06
1967	....	....	....	0.50	0.50	0.69
1968*	....	....	....	....	....	....
1969	....	....	....	0.36	0.64	1.02
1970	....	....	....	0.85	0.15	0.16
Average	0.77	0.23	0.26	0.53	0.47	0.78

Year	Age VII			Age VIII		
	s	a	i	s	a	i
1964	....	....	....	0.25	0.75	1.37
1965	0.21	0.79	1.55	0.06	0.94	2.85
1966	0.44	0.56	0.83	0.15	0.85	1.90
1967	0.07	0.93	2.69	0.03	0.97	3.41
1968*	....	....	....	....	....	....
1969	0.18	0.82	1.72	0.42	0.58	0.87
1970	0.36	0.64	1.03	0.26	0.74	1.33
Average	0.25	0.75	1.39	0.20	0.80	1.61

* No sample.

Table 12.--Survival rate (s), annual total mortality rate (a), and instantaneous total mortality rate (i) for herring from Marquette fall fishery, 1961-66

Year	Age V			Age VI			Age VII		
	s	a	i	s	a	i	s	a	i
1961	0.47	0.53	0.76	0.16	0.84	1.83	....	....	....
1962	0.45	0.55	0.80	0.20	0.80	1.61	0.24	0.76	1.43
1963	0.25	0.75	1.39	0.21	0.79	1.56	....	....	....
1964	0.95	0.05	0.05	....	....	....	0.65	0.35	0.43
1965	0.94	0.06	0.06	0.35	0.65	1.05	0.05	0.95	3.00
1966	....	....	....	0.61	0.39	0.49	0.21	0.79	1.56
Average	0.61	0.39	0.50	0.31	0.69	1.17	0.29	0.71	1.24

(2) the slope of this linear relationship represents catchability; and (3) the Y-intercept (zero fishing effort) gives an estimate of instantaneous natural mortality.

Lake herring in MS-3 were fully vulnerable at age V to the July-December fishery (gill nets with 2 1/2- to 2 3/4-inch stretch mesh). Younger fish were not fully vulnerable to the fishery, so they were not included in mortality rate estimates. The linear relationship of total mortality to fishing effort during 1960-71 was significant for ages V, VI and VIII but not for VII: therefore, I used the means for catchability and natural mortality rate of ages VI and VIII to represent age VII (Table 13). Natural mortality rates for ages V and VI were negative. Since this would be impossible, I assumed natural mortality at zero for ages V and VI (improbable but not impossible). The catchability coefficient for each age was multiplied by the total fishing effort (thousands of feet of gill net) during 1972 to estimate instantaneous fishing mortality for each age group (Table 13).

Exploitation rates for each age were computed using the formula:

$$u = ap \div i$$

The annual catch in MS-3 was divided by the exploitation rate to estimate total population on the fishing grounds in MS-3 during 1972 (Table 13). I was not able to use Paloheimo's method to estimate rates of natural and fishing mortality in other statistical districts because of inadequate information on age composition.

Catch data (recent).--Herring catches declined in U.S. waters of western Lake Superior during the mid-1950's. According to Anderson and Smith (1971b) commercial landings around Duluth decreased from 1,459,211 pounds in 1954 to 181,950 pounds in 1960, and further to 19,641 pounds in 1966. Catch-per-unit-effort (CPE) declined from 556 pounds per 1,000 linear feet of gill net in 1953 to 131 pounds in 1960 and to 14 pounds in 1966. Herring fishing was intensified in Michigan waters

Table 13.--Mortality, exploitation and total population of lake herring in age groups V-VIII on the MS-3 fishing grounds in 1972, with 95% confidence limits on catchability and instantaneous natural mortality rate

	Age group			
	V	VI	VII*	VIII
Catchability coefficient (x 10^{-4})	0.37± 0.07	0.64± 2.50	1.12	1.60± 4.70
Effort (ft x 10^3)	1238	1238	1238	1238
Mortality rate				
Instantaneous fishing (p)	0.05	0.08	0.14	0.20
Instantaneous natural (q) **	0.00± 0.05	0.00± 1.45	0.29	0.58± 2.07
Instantaneous total (i)	0.05	0.08	0.43	0.78
Total (a)	0.05	0.08	0.35	0.54
Exploitation rate (u)	0.05	0.08	0.11	0.14
Catch (thousands of herring)	76.1	28.9	9.9	2.1
Total population on grounds (thousands of herring)	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.

during the mid-1950's because lake trout and whitefish stocks had been depleted by sea lamprey predation and overfishing. The Michigan herring catch increased to a peak of 7.3 million pounds in 1961, but has since declined (Fig. 5). By 1968 the catch dropped to 2 million pounds, and further to 728,000 pounds in 1971. Total herring production in U.S. waters in 1968 was approximately 50% of the annual production in 1950-61.

The decline of herring in western Lake Superior prompted a study by Anderson and Smith (1971b). They found that competition from bloaters and/or smelt for food during the critical larval stage likely caused the decline. Predation and commercial fishing were judged not responsible, although the authors felt that pressure of the fishery on dwindling herring stocks hastened their collapse, and that continued pressure will slow their recovery, assuming that conditions ever again become favorable.

Herring catches in Ontario waters of Lake Superior held at approximately 2 million pounds during 1961-71. However, there is evidence of overfishing on certain herring grounds in eastern Lake Superior. The catch has either remained relatively constant or has increased, because effort has been shifted to new grounds as fishing success declined on old grounds (Rahrer and Elsey, 1972).

Commercial CPE (catch-per-unit-effort) has been the only index of herring abundance available for Michigan waters of Lake Superior. CPE based on number of fish is the preferred index. CPE based on weight per unit of effort is not considered a valid index for comparisons of herring abundance involving more than a few years, because average size has steadily increased since the 1950's. Two factors having the greatest potential for biasing the use of commercial CPE as an abundance index are (1) sequential exploitation and (2) withdrawal of inefficient or ill-equipped fishermen from the fishery. According to Peck et al. (1974), depletion of inshore stocks in Keweenaw Bay forced fishermen to locate fishable stocks progressively farther offshore, thus forcing ill-equipped fishermen out of business. Total annual CPE for a statistical district did not immediately reflect this stock depletion because,

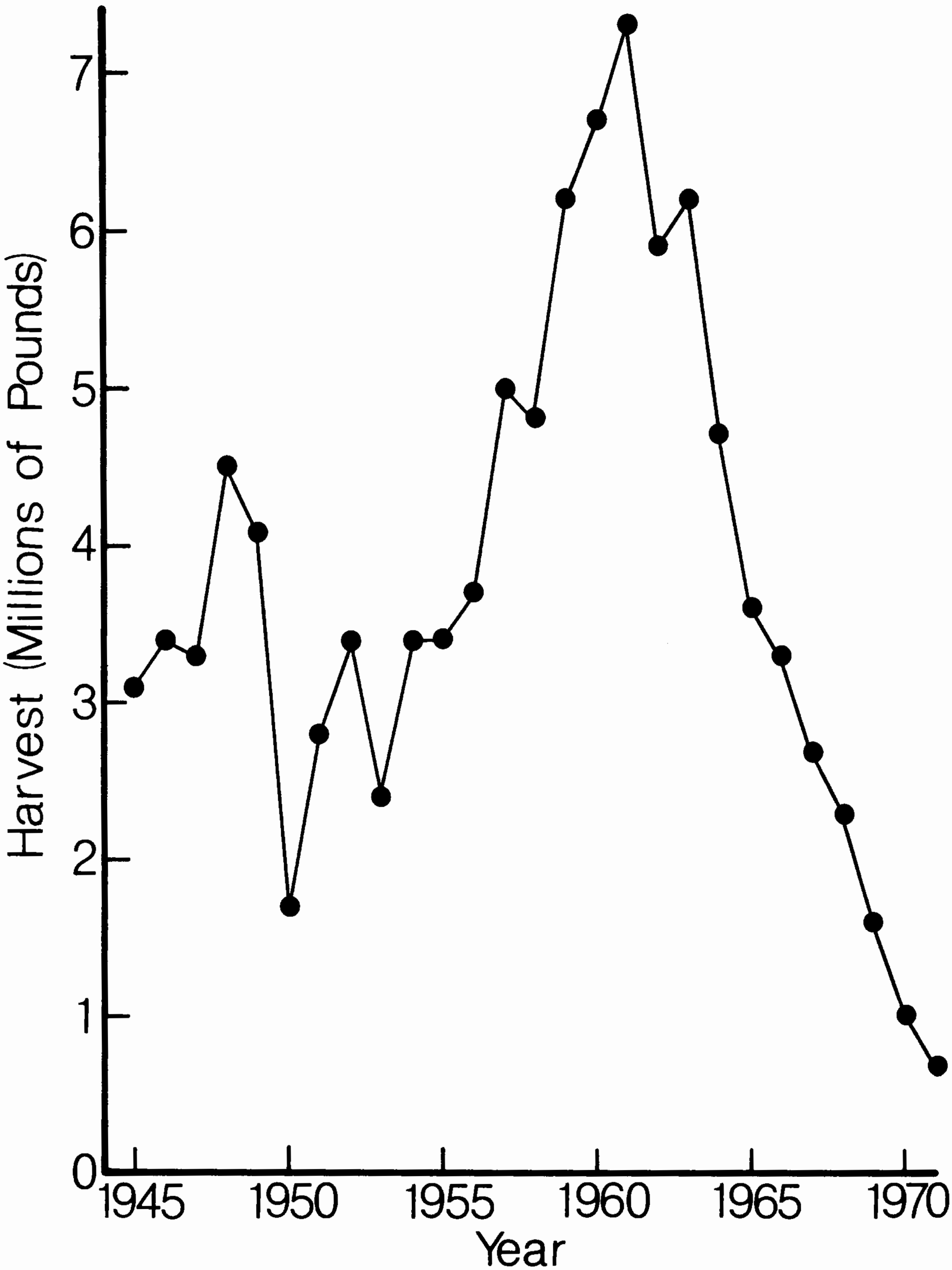

Figure 5.--Lake herring harvest from Michigan waters of Lake Superior, 1945-71.

(1) CPE was kept at a high level by sequential location and the "fishing up" of offshore herring stocks, and (2) the withdrawal of poorer fishermen whose CPE was generally lower than average.

Peck et al. (1974) used commercial CPE to evaluate the herring stock status in Michigan waters of Lake Superior. Anderson and Smith (1971b) presented both commercial CPE and index values based on percentage of 1946-66 mean catch. Both indices showed the steady decline of lake herring in Minnesota and Wisconsin waters.

Dodge (1970) examined the selectivity of commercial herring gill nets. He found that 13 inches, total length, was the modal inch group of fish in 2 5/8-inch mesh nets in Keweenaw Bay. In Whitefish Bay, the modal inch group was 14 inches, total length, in 3.0-inch mesh; and 15.0 inches, total length, in 3 1/4-inch mesh. Some unpublished data from Whitefish Bay show 14 inches, total length, to be the modal inch group in 2 1/2-inch and 2 3/4-inch mesh.

Distribution

Bathymetric.--Dryer and Beil (1964) reported that herring essentially disappeared from the bottom-net fishery during summer. A special effort to determine herring distribution was undertaken by the U.S. Bureau of Commercial Fisheries during their 1958-61 studies of fish populations in western Lake Superior. Although not conclusive, their data suggest a pelagic existence. This pelagic existence has been verified in part by the relatively successful float-net fishery in open waters of Keweenaw Bay and around Marquette. From the experimental netting results it was found that herring were most abundant at water depths of less than 7 fathoms below the surface in spring, and from 7 to 17 fathoms in summer. The summertime decrease in abundance near the surface (less than 7 fathoms) was blamed on the higher temperature of surface water. In the fall, herring were abundant down to 20 fathoms, and especially so at depths less than 7 fathoms. Dryer and Beil suggested that this vertical distribution may be influenced by temperature, abundance of plankton, and spawning. Herring do occur in water much deeper than mentioned above, and many are taken incidentally in bottom nets set for chubs in 50-80 fathoms (commercial fishing records). A careful analysis of depth, date, and catch of herring in the float-net and chub fisheries would certainly improve our knowledge of their bathymetric distribution.

Lateral.--Populations of lake herring appear to be scattered throughout Lake Superior. Their horizontal movements are not well known. Available evidence indicates a random areal distribution in the inshore areas during April-June, a wide scattering in the summer (apparently in the open lake), and an inshore movement in the fall, with the fish widely scattered during the spawning season (Dryer and Beil, 1964).

Evidence of discrete populations

No documented evidence of discrete populations is presented in the literature. Lake herring populations from different areas such as Keweenaw Bay, Marquette and Whitefish Bay exhibit differences in growth, in year-class strength, and in numerical abundance, indicating that they are influenced by local conditions. Discrete populations may exist in specific areas; or also may exist within each area, and separated bathymetrically, or laterally, or ecologically. Wisconsin biologists recognize "reef" and "deep-water" spawning stocks in the Apostle Island area. Reef herring are large, they spawn in shallow water, and they exhibit a 50-50 sex ratio. In contrast, deep-water herring are small, spawn in deep water, and the sex ratio has shown a trend toward a preponderance of females. In Michigan waters, herring mainly are the deep-water type, and few are caught in shallow inshore areas.

The present offshore pelagic nature of Lake Superior herring stocks makes difficult the usual tag-and-recapture method of studying population discreteness. The gill net has been the only practical gear for capturing these pelagic fish, and herring rarely survive being gill netted. Few viable fish would be available for tagging.

Interspecific relationships

Anderson and Smith (1971b) examined the relationships between bloaters, rainbow smelt (Osmerus mordax), and declining herring stocks in western Lake Superior during 1950-68. They studied the food habits of herring and 29 associated fish species during 1965-68 (Anderson and Smith, 1971a) to determine if any were potential predators or competitors; and they compared bloater, smelt and herring abundance trends since 1950 based on indices of abundance derived from commercial fishery statistics.

Predation on herring from larval to adult stages was judged as not sufficient to cause the decline of lake herring. However, most all fish cohabiting with herring fed on eggs of herring and/or chubs during the fall spawning period, as did the herring themselves. Anderson and Smith concluded that, although egg predation apparently did not have a major influence on lake herring abundance, it could have been a contributing factor. Large concentrations of smelt were present on herring spawning grounds during the herring spawning season. Successful spawning could have been impaired by smelt crowding herring off the grounds or eating large quantities of eggs.

Anderson and Smith also found that bloaters and herring had similar food habits. Their larvae depend on copepods for food and occupy the same habitat. Beyond the larval stage, bloaters seek the bottom and herring remain pelagic. That food competition was a factor causing the decline in herring is usggested by the highly significant negative correlation between herring and bloater abundance. Smelt were also found to utilize copepods, and a similarly high negative correlation was found to exist between herring abundance and smelt abundance. Anderson and Smith concluded that smelt were more effective competitors than were bloaters, perhaps because of their greater abundance, but that both were important contributors to the decline of lake herring.

Additional notes

Dryer and Beil (1964) stated that spawning occurs between mid-November and mid-December. Herring are pelagic spawners, with most spawning taking place in water about 20 fathoms deep. The released eggs drift to the bottom. Herring show no preferences as to bottom type over which they spawn. Various investigators have shown that spawning does not occur until water temperature drops below 39 F.

Dryer and Beil also reported that copepods and cladocerans were the most common items in lake herring stomachs; also well represented were Mysis in December and insects in June-July. Fish eggs were eaten by 62% of the herring examined in December.

Anderson and Smith (1971a) studied the food habits of herring in western Lake Superior. Herring larvae were found to feed exclusively on copepods in April-July. Herring shorter than 10.0 inches fed almost exclusively on copepods during April-November, except in September when insects and cladocerans were well represented. Herring longer than 10.0 inches fed mostly on copepods in February, May, June, November and December; cladocerans were important food items in September and November; amphipods in April; insects in June; and fish eggs in November.

Both studies cited above revealed the herring's overwhelming dependence on copepods, particularly the younger fish.

Information gaps

1. Determine if there are discrete stocks of herring, and delimit the lateral boundaries of each stock.

2. Determine exploitation and mortality rates for each important stock.

3. Determine equilibrium yield for each stock.

Humper lake trout

Four published studies involving humper trout are available in the literature. Two of these treat the chemical makeup and taxonomy of the humper (Eschmeyer and Phillips, 1965; Khan and Qadri, 1970), one presents life history data and information on the Isle Royale fishery (Rahrer, 1965), and one describes growth and yield for Caribou Island humper trout (Patriarche and Peck, 1970). Other information on the Caribou Island humpers was obtained from unpublished data at the Marquette Great Lakes Station and Marquette Fisheries Research Station.

Growth

Calculated growth in length for Isle Royale humpers (Rahrer, 1965) and Caribou Island humpers (unpublished data) is presented in Table 14.

Rahrer (1965) determined body-scale relationships for humpers under 9.5 inches:

$$L = 0.0524\ S + 1.93$$

and for humpers over 9.4 inches:

$$L = 0.110\ S - 6.22$$

where L = total length in inches

S = scale diameter in millimeters times 83.

These relationships were used to calculate growth of Caribou Island humper lake trout.

Length-weight relationship.--Rahrer (1965) determined the following length-weight relationship for Isle Royale humper lake trout:

$$W\ (\text{pounds}) = 0.00015332\ L^{3.28243}(\text{inches})$$

Table 14.--Calculated lengths (total length in inches) of humper lake trout from Isle Royale (Rahrer, 1965) and Caribou Island in Lake Superior

Age group	Site	
	Isle Royale 1959, 1963	Caribou Island 1967-1970
I	3.5	3.6
II	5.1	5.2
III	6.9	6.8
IV	8.5	8.4
V	10.4	10.2
VI	13.0	12.8
VII	15.4	15.1
VIII	17.6	17.0
IX	19.8	18.5
X	22.1	19.9
XI	24.3	21.4
XII	....	23.1

Recruitment

Fecundity.--The number of eggs per individual fish ranged from 411 for fish 15.0-15.9 inches long to 2,640 for fish 21.0-21.9 inches long. The number of eggs per pound of fish averaged 516 and ranged from 285 to 687 (Rahrer, 1965).

Age and size at maturity.--On the Isle Royale grounds, all humper lake trout shorter than 12.7 inches were immature and all fish longer than 19.1 inches were mature (Rahrer, 1965). Nearly 50% of the males were mature at 13.0-13.9 inches. The shortest mature female was 14.7 inches, and more than 50% of the females in the 15.0- to 15.9-inch group were mature. The largest immature male was 17.1 inches and the largest immature female was 19.1 inches. In age and size at maturity, the Caribou Island humpers were not significantly different from those at Isle Royale.

Age at recruitment.--Because of the offshore location of the grounds there is no sport fishery for humper trout except in the vicinity of Isle Royale. There is a commercial fishery in Michigan by permit, with gill-net mesh size set at 4.5 inches (extension measure), and a 16.0-inch minimum length on the fish. Isle Royale humper trout enter the commercial fishery at age VII and are fully vulnerable at age VIII. Caribou Island humpers enter the fishery at age VI and are fully vulnerable at age IX.

Mortality

Total.--Annual total mortality rates for Caribou Island humper lake trout of age-groups IX, X and XI were 0.27, 0.70 and 0.95; the corresponding instantaneous rates were 0.32, 1.20 and 2.99 (Patriarche and Peck, 1970). Total mortality was obtained by comparing catch per unit effort for each fully vulnerable year class during successive years.

Fishing.--Instantaneous fishing mortality rates of 0.05, 0.07, and 0.12 were calculated for three fully vulnerable age groups (IX, X and XI) of Caribou Island humper trout (Patriarche and Peck, 1970). The calculations were based on an assumed exploitation rate of 4%, such as reported for Wisconsin "lean" lake trout in the March 1969 Lake Superior Committee report. The actual exploitation rate of humper trout has not been determined.

Natural.--Instantaneous natural mortality rates of 0.27, 1.13 and 2.87 were determined for age-groups IX, X and XI of Caribou Island humper lake trout (Patriarche and Peck, 1970), by subtracting the instantaneous rates of fishing mortality from instantaneous rates of total mortality.

Catch data.--The commercial landings of Caribou Island humper lake trout declined from 12,055 fish in 1967 to 4,653 fish in 1972; the obvious reason was that only one fisherman was fishing in 1972, whereas four fished in 1967. Abundance of humpers has not declined. The catch per unit effort for humpers on seven major Caribou Island banks has risen slightly from 6.73 fish per 1,000 feet of net in 1967 to 8.41 in 1969 (Patriarche and Peck, 1970). Humper trout at Isle Royale have not been heavily exploited in recent years; they were not fished in 1971, and only 4,400 pounds were landed in 1972. Prior to 1969 the minimum size limit on humpers was 1 1/2 pounds dressed weight. In 1969 the minimum size was changed to 16.0 inches total length.

The 1967-69 catch of Caribou Island humpers consisted of age-groups VI-XIII. Age VIII was most numerous in 1967, as was age IX in 1968-69. The average lengths of age-groups VIII and IX in 1969 were 16.8 inches and 17.9 inches. The 1959 and 1963 Isle Royale commercial catch (1 1/2 pounds round weight, minimum size) reported by Rahrer (1965) was composed of age-groups VII-XI, with age-groups VIII (48.1%) and IX (32.7%) making up the bulk of the catch.

No data on exploitation rates are available for either Caribou Island or Isle Royale humper trout fisheries.

Commercial gill nets (4.5-inch mesh, extension measure) captured Isle Royale humpers that were 6.0-25.0 inches total length, spanning age-groups III-XI (Rahrer, 1965). Fish in the commercial catch averaged 17.4 inches long, and were best represented by age-group VIII. Rahrer attributed the lack of age-groups I and II, and the small numbers of age-groups III and IV, to gear selectivity. He believed that the 4.5-inch mesh was large enough to capture the oldest age groups, but these fish were not abundant in the population. Preliminary analysis of the Caribou Island humper fishery indicates gear selectivity similar to that reported for Isle Royale.

Distribution

Bathymetric.--There is little information on the bathymetric distribution of humper lake trout. In Michigan waters of the Caribou Island grounds, humpers are generally not captured below 50 fathoms. Catches from waters deeper than 50 fathoms were almost entirely siscowets and lean trout. Rahrer (1965) indicated 50 fathoms as the humper's lower depth limit, but no data are available on the upper limit.

Lateral.--Humper lake trout are known only from Lake Superior. They exist on offshore reefs such as those surrounding Caribou Island, Isle Royale and possibly Stannard Rock. Rahrer (1965) suspected that lake trout of Canada's Superior Shoal are humpers, and it is likely that populations of humper exist on the reefs around Canada's Michipicoten Island. All humpers may not be confined to offshore reefs. Eschmeyer and Phillips (1965) found that the fat content of flesh of some lake trout from inshore waters at Grand Marais (Minnesota), West Portage Entry (Michigan) and Grand Marais (Michigan) was distinctly different from that of siscowets or lean lake trout and was comparable to the fat content of flesh of humpers.

Evidence of discrete populations

Humper populations on individual offshore reefs might be discrete, especially if intervening deep water prohibits their movement between reefs. Some differences in humper growth rates were noted for Caribou Island reefs (Patriarche and Peck, 1970), which indicates discreteness.

Interspecific relationships

Very little is known about the interspecific relationships of these fish. Direct observation is nearly impossible, and the remoteness of offshore grounds makes even commercial fishing difficult. Caribou Island humper trout cohabit with sea lamprey, burbot (Lota lota), lean and siscowet lake trout, lake herring and chubs (unpublished commercial fishing data). Because of the humper's small size, it is rarely preyed upon by sea lamprey. Scarring rates have averaged less than 1%. Predation on humpers by other fishes is not known. Siscowets generally inhabit deeper water, but some are taken at shallower depths with the humpers. The hatchery-reared, lean lake trout has been increasing in abundance on the humper grounds since sampling was undertaken. The CPE (number per thousand feet of gill net) for hatchery lean trout has risen from 0.56 in 1967 to 2.12 in 1969 (Patriarche and Peck, 1970). Burbot are rarely captured on the Caribou Island reefs.

There has been no study of food habits on humper lake trout. Gross observations indicate that Mysis, chubs, smelt and sculpins are the principal food items.

Additional notes

Although the humper lake trout has not been given subspecific status, it is a distinct form recognized by commercial fishermen and by some biologists. Rahrer (1965) described Isle Royale humpers as deep-bodied fish with a thin abdominal wall, a short head, and convex snout. They typically have a bronze-green back and brightly colored fins. Caribou Island humper trout approximate this description, excepting that their head, while shorter than that of the lean variety, is longer than the head of the siscowet and their abdominal wall is not always thin, especially on older fish.

Eschmeyer and Phillips (1965) found the fat content of flesh of humpers to be much less than that of siscowets, but more than that of lean lake trout.

Khan and Qadri (1970) recognized the humper as distinct from siscowets and from lean lake trout, on the basis of morphological differences. However, they hesitated to assign a taxonomic rank to the humper because of a lack of data on biology and distribution.

In addition to morphological differences, recent electrophoretic studies of the blood enzyme LDH (Lacto dehydrogenase) indicate that the humper LDH pattern is distinct from that of siscowets and lean lake trout (Patriarche and Peck, 1970).

What is unique about humper trout is their previously described slow growth rate and small size at maturity. Humpers spawn in the fall, about the same time as siscowets, but generally earlier than lean lake trout. Ripe humpers have been collected in August (personal communication with biologist Richard Schorfhaar). Humpers were spawning during the first week of October in 1973. The exact starting time and duration of spawning is not known.

Information gaps

1. Exploitation and fishing mortality. To provide for an effective quota, the actual exploitation rate for the important humper grounds should be determined.

2. Taxonomic status should be determined and identifying key characteristics documented.

3. Bathymetric distribution. Exact upper and lower limits cannot presently be determined because of depth variance in individual sets by commercial fishermen.

4. Food habits. Samples could be obtained from commercial gear of known depth. Potential predators could be stomach-sampled concurrent with humpers.

5. Duration of spawning. May be done by periodic examination of commercial catch, providing the fishing extends far enough into the fall.

Siscowet

The siscowet is recognized by some biologists as a subspecies (*Salvelinus namaycush siscowet*) of the lake trout, but it has not been given subspecies status by the American Fisheries Society (1970). According to Thurston (1962) it has a smaller head, larger scales, lighter color, and a much higher oil content. Siscowets are called "fat" trout by commercial fishermen, whereas *S. n. namaycush* is called the "lean" trout. Most siscowets are caught at depths greater than is the lean lake trout, although the bathymetric distributions of the two overlap broadly (Eschmeyer and Phillips, 1965). Lake trout that are called "half-breeds" by fishermen are mostly young siscowets. Eschmeyer and Phillips included half-breeds with siscowets in their study of the fat content of lake trout flesh. Khan and Qadri (1970) found that half-breeds resemble siscowets both morphologically and ecologically, and suggested that they be considered as one form. Siscowets and most half-breeds have identical LDH blood enzyme patterns as determined by electrophoresis (Patriarche and Peck, 1970). Occasionally some large humpers are mis-identified as half-breeds by Caribou Island fishermen, but half-breeds are considered to be siscowets in this report.

Growth

In the absence of a valid body-scale relationship, lengths (total length in inches) at various ages of Caribou Island siscowets (unpublished data) were calculated by direct proportion and are summarized below:

Age									
I	II	III	IV	V	VI	VII	VIII	IX	X
3.0	5.8	8.7	11.7	14.4	17.3	19.9	22.0	23.9	24.8

A better sample of siscowets longer than 25.0 inches, and application of a body-scale relationship to the growth calculations, would probably change the above lengths, especially for older age groups.

Length-weight relationship.--Eschmeyer and Phillips (1965) found the length-weight relationship for Lake Superior siscowets to be:

$$\log W \text{ (pounds)} = -3.890 + 3.387 \log L \text{ (inches)}$$

The modal inch group of their lake-wide collections was 19.0-19.9, but several fish were over 30.0 inches long and weighed 20 pounds.

Recruitment

Fecundity.--Eschmeyer (1955) reported the fecundity of 13 siscowets taken from Lake Superior in 1950-54. The number of eggs ranged from 1,207 for a 16.8-inch fish to 10,476 for a 34.2-inch fish. Egg diameters ranged from 3.4 to 5.4 millimeters.

Age and size at maturity.--More information for the siscowet is needed on size and age at maturity. Eschmeyer (1955) collected 6 mature females 16-21 inches long from the Caribou Island grounds on 28 September 1954. In addition, 6 mature males 15-21 inches long were reported from the same locality. This is a much shorter size at maturity than observed for lean lake trout. Mature fish identified as siscowets from the Caribou Island grounds in 1968 were all longer than 20 inches, but mature fish less than 20 inches long of unknown identity (or called humpers) were later identified as siscowets by electrophoresis. One mature siscowet so identified was a female 15.7 inches long, whereas the others were all longer than 18 inches. All siscowets over 25 inches long were mature. The 15.7-inch mature female siscowet was 8 years old, whereas some of the 25-inch siscowets were as young as 6 years old. More data from reliably identified siscowets are needed to confirm or deny such overlap and to accurately establish the age and size at maturity.

Age at recruitment.--The Caribou Island assessment fishery on siscowets operates under a 16-inch minimum size limit and a minimum mesh size of 4 1/2 inches (stretch measure). Siscowets recruit to this fishery at age V, and full recruitment occurs at age VIII (Patriarche and Peck, 1970).

Mortality

The source of total, natural and fishing mortality rates presented below is Patriarche and Peck, 1970.

Total.--Total mortality for fully vulnerable age-groups VIII, IX and X in 1967 was 0.50, 0.76 and 0.94, respectively. The corresponding instantaneous rates were 0.69, 1.43 and 2.81. Total mortality rates were determined by comparing CPE's (catch per unit effort) for each fully vulnerable year class during successive years.

Fishing.--Instantaneous fishing mortality rates of 0.06, 0.08 and 0.12 were calculated for the fully vulnerable Caribou Island age-groups VIII-X. The calculations were based on an assumed exploitation rate of 4%. This rate was calculated from a tagging study of lean trout in Wisconsin waters (Great Lakes Fishery Commission, 1969). The 4% rate is believed applicable to Michigan waters. The actual exploitation rate of Caribou Island siscowets could not be determined because of insufficient data.

Natural.--The instantaneous rates of natural mortality for age-groups VIII-X of Caribou Island siscowets are 0.63, 1.35 and 2.69. These were obtained by subtracting instantaneous fishing mortality from instantaneous total mortality.

Catch data.--The number of siscowets in commercial landings from Caribou Island grounds was 7,327 in 1967; 6,255 in 1968; 5,183 in 1969; 869 in 1970 and 502 in 1972. The siscowet catch dropped sharply after 1969 because two of the three Caribou Island fishermen ceased fishing. Those two fishermen fished mainly for siscowets, whereas the one remaining fished for humpers. Michigan siscowet landings since 1969 have come from incidental captures in the fisheries for humper lake trout and chubs.

The catch of siscowets was composed of age-groups V-XII with age VIII predominant in 1967 and 1969, and age VII most numerous in 1968 (Patriarche and Peck, 1970).

Commercial catch per unit of effort (pounds or numbers of fish per length of gill net) is the only index of abundance available on siscowet fishing grounds. Because of the water depth involved, gill nets are the only practical type of gear. Siscowet catch per unit of effort on the Caribou Island grounds rose slightly from 5.00 in 1967 to 6.73 in 1969. Part of this rise was due to a shift of effort to deeper water where siscowets were more numerous (unpublished data).

There was a steady decrease in calculated lengths, as these were back-calculated from progressively older age groups, indicating that the gill nets with 4 1/2-inch mesh were selecting the faster growing individuals from the younger age groups. Lengths calculated from age-groups VII-IX were noticeably larger than those calculated from age-groups X-XII.

Distribution

Bathymetric.--Eschmeyer (1955) and Eschmeyer and Phillips (1965) stated that siscowets generally inhabit, and are caught at, depths greater than 50 fathoms, but some individuals are occasionally caught in shallower water. Of those taken at depths less than 50 fathoms, Eschmeyer (1955) found nearly all to be half-breeds (young siscowets). Based on 1969 Caribou Island catch data, most siscowets, young and old, were taken at depths greater than 60 fathoms although young siscowets were more abundant than old fish in less than 60 fathoms. Half-breeds studied by Khan and Qadri (1970) were captured in Canadian waters in 21-45 fathoms.

The available information on bathymetric distribution of siscowets is insufficient to state specific upper and lower limits.

Lateral.--Collections made by Eschmeyer (1955), Eschmeyer and Phillips (1965) and Khan and Qadri (1970), and the incidental catch in chub nets, indicate that the siscowet is widely distributed throughout the deeper waters of Lake Superior.

Evidence of discrete populations

There are no data available on the presence or absence of discrete populations of siscowet within Lake Superior. No tagging studies have been undertaken.

Interspecific relationships

There is very little known about relationships between siscowets and other fishes. Predation by sea lamprey on larger siscowets (fats) is believed high. Although actual mortality caused by sea lamprey is not known, 1968 wounding rates of 20-30% have been reported for 25.0- to 28.9-inch fish, and 50%+ for fish longer than 29.0 inches. Wounding on the smaller siscowets (also called half-breeds) has been less than 10%. Predation by fin-fishes is not known.

Additional notes

Eschmeyer (1955) assumed that spawning might begin in late July and extend to late November. He also reported ripe and nearly spent siscowets in early June from a reef near the extreme east end of Isle Royale. These were later confirmed as siscowets on the basis of flesh fat content by Eschmeyer and Phillips (1965). Recent collections indicate that at least some Caribou Island siscowets spawn in September and October. There is no documented information on the early life history of siscowets.

Dryer et al. (1965) studied the food habits of siscowets and lake trout in Lake Superior. They observed only minor differences in the food habits of lake trout and siscowet, which could have been due to sample variation. Therefore, the following (from their study) are the food habits of all lake trout (including siscowets) collected at depths greater than 35 fathoms: *Coregonus* spp. was the most important food item both in volume and frequency of occurrence; cottids were second in importance; smelt was a major food item for shallow-water lake trout, but was rarely encountered in the stomachs of lake trout from deeper water; and insects and *Mysis relicta* were much less frequent than in the stomachs of trout from shallow water.

No other study of food habits of siscowets has been conducted.

Generally siscowets bring a lower price than do lean lake trout, because their high fat content makes them too oily for usual preparation (i.e., frying, broiling, baking, etc.). Most siscowets are smoked or salted for the market. The oil or fat content of flesh has been studied by Thurston (1962) and Eschmeyer and Phillips (1965). Thurston found that the oil content of fillets from 23 lake trout, 35-73 cm long, averaged 9.4% whereas the average for fillets of 29 siscowets, 39-82 cm long, was 48.5%. Eschmeyer and Phillips studied fat content of flesh and found that a 20-inch siscowet contained 64% flesh-fat, whereas a 20-inch lean lake trout had only 23% flesh-fat. Siscowets and lean lake trout, both reared in a hatchery under similar conditions, still differed significantly in fat content of flesh, although their diet was the same. In the size range 15.0-15.9 inches, siscowets had 26.8% flesh-fat, lean lake trout had 12.3%, and their hybrid (lean lake trout x siscowet) had 19.0% flesh-fat. Eschmeyer and Phillips concluded that genetic differences in flesh-fat exist between siscowets and lean lake trout. Khan and Qadri (1970) found significant ecological and morphological differences between the siscowet and lean lake trout; they felt the siscowet should retain a subspecies status.

Information gaps

1. We need characters for field identification of siscowets, particularly the young which are confused with lean lake trout and humpers.

2. Exploitation rate of siscowets on the important fishing grounds.

3. Calculated growth based on more samples of younger and older siscowets, and employing their own body-scale relationship.

4. Age and size at maturity.

5. Food habits of siscowets.

6. Time and duration of spawning, and fecundity by age and size.

7. Upper and lower limits of bathymetric distribution.

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