AGE AND GROWTH OF THE WHITEFISH IN LAKE SUPERIOR

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ABSTRACT

The average annual commercial production of whitefish in the U.S. waters of Lake Superior dropped from 2,194,000 pounds in 1879–1908 to 504,000 pounds in 1911–59. The modern production, though far below the earlier, has accounted for more than 10 percent of the total value of the fishery in all but one of the last 20 years.

Data are given on growth rate, age and year-class composition, size distribution, and length-weight relation of 1,800 fish collected in 1957–59 at Bayfield, Wis., and Marquette, Whitefish Point, and Dollar Settlement, Mich. Studies of the body-scale relation, sex ratio, and age and size at maturity were limited to fish collected at Bayfield.

The age composition and mean age varied widely by port and year of capture. Oldest fish were those of the 1957 Bayfield samples which were dominated by age-group VII and averaged 5.5 years old. The youngest were from Whitefish Point in 1959; age-group III was dominant, and the mean age was 3.2 years. The evidence on the strength of year classes was not clear-cut, but it was obvious that fluctuations in stocks of different areas were largely independent.

The percentage of legal-size fish (17 inches or longer) in age groups ranged widely; only 8.6 percent of the V group were legal in the 1957 Bayfield collections, whereas 100 percent of fish of the same age were legal in the 1957–59 collections from Whitefish Point. The weight of whitefish in the combined samples increased as the 3.2408 power of the length.

The growth rate from the fastest to the slowest growing stocks ranked as follows: Whitefish Point; Dollar Settlement and Marquette (fish from the two ports reversed ranks after 3 years); Bayfield. The major differences in growth in length among the various stocks occurred during the first years of life. Beyond the fifth year the annual increments were nearly the same in all stocks. The whitefish from Whitefish Point, Dollar Settlement, and Marquette are among the fastest growing in the Great Lakes.

The differences among the Lake Superior stocks in age and year-class composition, and in growth rate offer convincing evidence that populations of different areas are entirely independent.

The sexes were almost equally represented (51.5 percent males) in the combined Bayfield samples, but males were scarce in age groups older than VIII. Whitefish from Bayfield shorter than 14.5 inches were immature and those larger than 17.4 inches were mature. The youngest mature fish belonged to age-group V, and all older than the VII group were mature.

The whitefish, *Coregonus clupeaformis* (Mitchill), is the largest and the most widely known coregonine in the Great Lakes; it occurs in all five lakes. It was the principal species sought in the early Great Lakes fisheries: for the period 1941–54, the whitefish comprised more than 10 percent of the total value of the U.S. catch in the Great Lakes (only exception in 1943 when the value was 9 percent); for the years 1947–50 it ranked first in money value among all Great Lakes species. The 1948 production of whitefish in U.S. waters amounted to 12¼ million pounds, with a value of 3¾ million dollars, which represents 30 percent of the total value of the Great Lakes catch.

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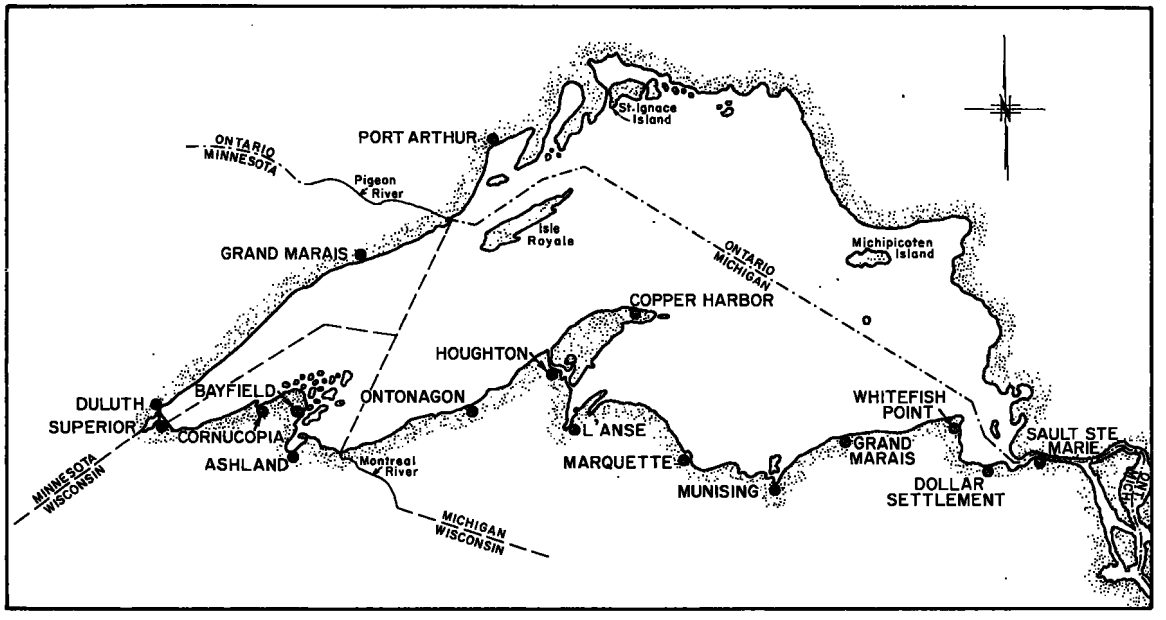

FIGURE 1.—Map of Lake Superior.

The recent production of whitefish in Lake Superior, though far below that of the earlier years, still has been of great economic importance. The species has accounted for more than 10 percent of the total value of the U.S. catch in this lake for the period 1941–59 (exception in 1952 when the whitefish accounted for only 7 percent), and the production in 1956 represented over 26 percent of the value of the U.S. catch. The progressive decline of the lake trout (*Salvelinus namaycush*) makes the high-priced whitefish relatively even more valuable, and greater exploitation of it is to be expected to supplement income from the lower-priced lake herring (*Coregonus artedii*) and chubs (*Coregonus* spp.). Sound management and rational exploitation require knowledge of the species, such as average size composition, growth rate, and maturity. The present paper is a contribution to that knowledge.

Relatively little is known of the whitefish in Lake Superior. The only published study on growth is that of Edsall (1960) on the unexploited stock of dwarf whitefish in Munising Bay.

MATERIALS AND METHODS

The present study is based on 1,800 whitefish captured off four Lake Superior ports (fig. 1) from 1957 through 1959. The number of fish collected at each port (table 1) was: Bayfield, 748; Marquette, 458; Whitefish Point, 340; Dollar Settlement, 254.

More than one-half of the whitefish taken at Bayfield were from commercial pound nets. Most pound nets at Bayfield are 50 to 70 feet deep and have a 4¾-inch-mesh pot. The whitefish collections from the other ports were all from commercial trap nets with a 4½-inch-mesh pot. Net-run samples were taken from commercial pound nets and trap nets by dipping out 150–200 fish without regard to size. When the total number was less than 150–200 fish, the sample included the entire catch.

The remainder of the Bayfield samples came from commercial gill nets of 4½-inch mesh and from experimental gill nets and trawls fished from the Bureau's research vessel *Siscowet*.

All of the fish listed for the *Siscowet* at Bayfield were used in some phase of this study, but they were not employed as part of the materials on age composition and growth since they are not comparable to samples from commercial gear. The small individuals taken with trawls were of particular value in studies of the body-scale regression and length-weight relation. Helpful also were records of calculated lengths that illustrated the effects of gear selection of commercial nets.

The listings in table 1 exclude individuals not used in age and growth analyses because of scale

TABLE 1.—*Locality, gear, and date of capture of Lake Superior whitefish used for the study of age and growth*

Port	Date	Number of fish, by gear				Total
		Trap net [2]	Pound net [3]	Gill nets [1]	*Siscowet* experimental gear [3]	
	1957					
Bayfield, Wis.	June 13	------	135	------	----------	135
	July 22	------	138	------	----------	138
	Aug. 15	------	99	------	----------	99
Marquette, Mich.	June 20	20	---------	------	----------	20
	July 16	51	---------	------	----------	51
	Sept. 30	117	---------	------	----------	117
Whitefish Point, Mich.	June 19	123	---------	------	----------	123
	Sept. 20	61	---------	------	----------	61
Dollar Settlement, Mich.	July 24	96	---------	------	----------	96
	Aug. 13	24	---------	------	----------	24
	1958					
Bayfield, Wis.	June–Nov.	------	---------	------	93	93
Marquette, Mich.	Oct. 2	141	---------	------	----------	141
Whitefish Point, Mich.	Sept. 30	108	---------	------	----------	108
	1959					
Bayfield, Wis.	June–Nov.	------	---------	------	138	138
	June 1	------	106	------	----------	106
	Dec. 18	------	---------	39	----------	39
Marquette, Mich.	Sept. 28	129	---------	------	----------	129
Whitefish Point, Mich.	Sept. 24	48	---------	------	----------	48
Dollar Settlement, Mich.	Sept. 24	134	---------	------	----------	134
	1957–59					
Bayfield, Wis.	All months	------	478	39	231	748
Marquette, Mich.	do	458	---------	------	----------	458
Whitefish Point, Mich.	do	340	---------	------	----------	340
Dollar Settlement, Mich.	do	254	---------	------	----------	254
	1957					
All ports	All months	492	372	------	----------	864
	1958					
Do	do	249	---------	------	93	342
	1959					
Do	do	311	106	39	138	594
Grand total		1,052	478	39	231	1,800

[1] 4½-inch mesh.
[2] 4¾-inch mesh.
[3] Gill nets 1- to 5-inch mesh by ½-inch intervals and 31-foot semiballoon trawls.

regeneration or extreme difficulty in identifying annuli. The number of fish excluded from the total sample was less than 2 percent.

Total lengths (from the tip of the head to the tip of the tail, with the lobes compressed to give the maximum measurement) were read from a measuring board calibrated in 0.1-inch intervals. Weights were determined with a spring balance and were recorded either to the nearest 0.1 ounce or 0.1 pound. All weights given in this paper are in pounds.

The sex and state of gonads were determined for fish from all the *Siscowet* collections and about 75 percent of the Bayfield pound net collections. The remaining 25 percent of the Bayfield pound net collections were omitted from the sex-ratio and maturity studies because of uncertainty as to the sex. Most of these fish were from a single sample collected in June 1957. Data on sex and state of gonads are lacking for samples from commercial gill nets at Bayfield and for collections from all the other ports. The whitefish captured at Marquette, Whitefish Point, and Dollar Settlement were marketed in the round and hence could not be opened. The fish from the commercial gill nets at Bayfield had been dressed before they were examined. A whitefish was considered mature if it would have spawned in the fall of the year of capture.

Scales were removed from the left side of the fish at a point midway between the lateral line and the middle of the base of the dorsal fin.

Scale impressions were made in cellulose acetate (Smith, 1954) and were magnified 42 diameters by means of a microprojector (Moffett, 1952). Diameters of scales and of growth fields within scales were measured through the focus along a line that roughly bisected the anterior field and were recorded to the nearest millimeter.

Age groups are designated by Roman numerals corresponding to the number of completed annuli. All the fish were considered to have passed into the next higher age group on January 1. A virtual annulus was credited, therefore, at the edge of the scale on all fish collected between January 1 and the time an annulus was actually completed.

Among the whitefish collected during the period of annulus formation in mid-June, no difficulties were experienced in separating individuals with a new annulus from those in which the year-mark had not yet been completed. Most of the scale samples were collected before or well after growth had started; for them the interpretation of marginal growth outside the last visible annulus obviously offered no problem.

Statistics on commercial production were obtained from various sources as given in the next section.

PRODUCTION OF WHITEFISH IN LAKE SUPERIOR

The Lake Superior fisheries were the last to be developed in the Great Lakes. As in the other Great Lakes, the whitefish was the principal species sought in the early years of fishing. Seines were the first gear fished along the south shore of Lake Superior, but because of the rough, rocky bottom their usefulness was limited. Gill nets were soon employed; and the pound net,

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introduced in this country from Scotland in 1836, was established in Whitefish Bay about 1860. The pound net was first fished in the Apostle Islands area in 1871, and by 1885 about 125 were in use. Only 40 pound nets were fished in the Apostle Islands in 1960. The trap net, which was invented by Lake Ontario fishermen in 1865, was introduced in Lake Superior during the early 1900's. This net was not adapted for taking whitefish until the 1930's and since then has been important only in Michigan. The use of trap nets is prohibited in Wisconsin and Minnesota waters. The first steamer was introduced in 1871, and the first motor boat appeared at Marquette, Mich., in 1899.

Up to 1890 whitefish were the principal species in the commercial production in United States waters of Lake Superior (Koelz, 1926). Between 1891 and 1899 the lake trout occupied first place, and in the early 1900's large-scale production of lake herring placed them in first rank. The whitefish has held third position behind the lake herring and lake trout up to the recent collapse of the lake trout fishery.

The statistical records of whitefish production in Lake Superior (table 2) came from various sources. The figures through 1940 are from Gallagher and Van Oosten (1943). The U.S. data for 1941–59 are from Lake Fisheries issued by the Bureau of Commercial Fisheries. The later records for Ontario were issued by the Province.

The first published record of whitefish production in Lake Superior is for 1867 in Ontario. The first record of whitefish production in the U.S. waters of Lake Superior is for 1879 (fig. 2).

The catch of whitefish in U.S. Waters of Lake Superior was 2¼ million pounds in 1879 and exceeded 4½ million pounds in 1885—the highest production recorded. Landings fell off drastically during the following 30 years, and by 1913 the catch reached an all-time low of 113,000 pounds.

Koelz (1926) stated pessimistically that from a commercial point of view the whitefish was practically extinct along the United States shore of Lake Superior in 1922 when the total catch in U.S. waters was 319,000 pounds. The production of 144,000 pounds in 1923 marked a still further decline. It was not until the early 1930's that whitefish production in U.S. waters began to improve. An erratic increase in the catch con-

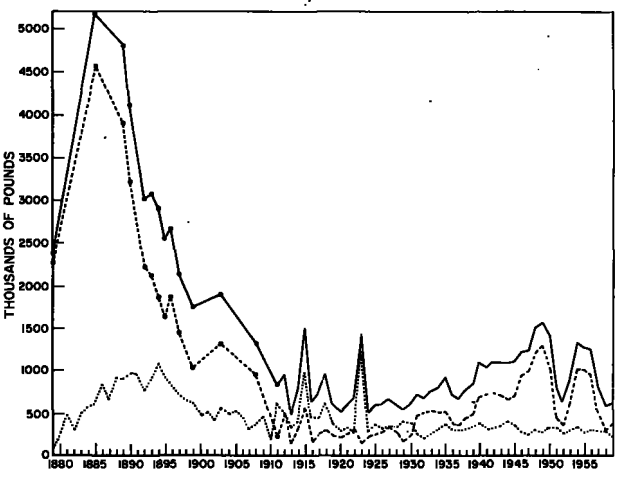

FIGURE 2.—Production of whitefish in Lake Superior, 1879–1959. United States, short dashes; Ontario, dotted lines; entire lake, solid line. Because of the numerous interruptions in the records for U.S. waters, the points for individual years prior to 1912 are shown by dots on the lines for the catch in U.S. waters and in the entire lake.

tinued for about 20 years, and in 1949 the take reached 1,284,000 pounds, the highest since 1903. Since 1949 the catch of whitefish in U.S. waters has fluctuated widely between 1,040,000 pounds in 1950 and 309,000 in 1958. The 1911–59 average production of 508,000 pounds was only 23.2 percent of the 1879–1908 mean of 2,194,000.

The distribution of the yield of whitefish from the different States has not changed greatly during the period for which statistics are available. With the exception of 10 years when Wisconsin had the largest catch (1885, 1925, 1946–50, and 1955–57) Michigan has dominated the yield of whitefish (table 3). For the period 1885–1908 Michigan contributed 70.3 percent of the total U.S. production, Wisconsin 23.8 percent, and Minnesota 5.9 percent. In 1911–59 Michigan continued to occupy first place but with a slightly lower percentage (62.8 percent). Wisconsin's contribution increased to 35.9 percent, and Minnesota's dropped from 5.9 to 1.3 percent.

The production of whitefish in Canadian waters of Lake Superior has not shown the wide fluctuations experienced in U.S. waters. Production exceeded 1,000,000 pounds only in 1894 (1,056,000 pounds) and in 1923 (1,268,000 pounds [1]). On-

[1] A possibility exists that the 1923 statistic may be erroneous. The figure 268,000 pounds would be in better agreement with the production from Ontario in neighboring years. There are no records, however, from which to check this figure.

TABLE 2.—*Production (thousands of pounds) of whitefish in Lake Superior, 1879–1959*

[Totals are given for U.S. waters in all years with records for both Wisconsin and Michigan]

Year	United States				Canada	Grand total
	Minnesota	Wisconsin	Michigan	U.S. total	Ontario	
1879				2,257	99	2,356
1880					245	
1881					466	
1882					320	
1883					509	
1884					565	
1885	628	2,243	1,701	4,572	606	5,178
1886					847	
1887					657	
1888					932	
1889	211	951	2,736	3,899	896	4,795
1890	40	1,109	2,064	3,213	978	4,192
1891			3,848		967	
1892		206	2,015	2,221	784	3,004
1893		251	1,919	2,170	899	3,068
1894		301	1,554	1,855	1,056	2,911
1895		301	1,325	1,626	911	2,538
1896		700	1,162	1,862	796	2,658
1897	31	162	1,246	1,438	686	2,124
1898			1,088		659	
1899	13	62	1,058	1,132	623	1,756
1900			829		462	
1901			794		483	
1902			1,513		417	
1903	8	129	1,200	1,336	564	1,900
1904			630		478	
1905			684		524	
1906			587		452	
1907	7		576		301	
1908	4	174	764	942	363	1,305
1909		24			470	
1910		9			202	
1911		13	202	214	620	834
1912		32	456	488	459	947
1913	(1)	20	93	113	357	470
1914	1	18	335	355	397	752
1915	2	43	522	567	955	1,522
1916	1	44	131	175	462	637
1917	1	36	220	257	452	708
1918	3	66	258	327	628	955
1919	4	62	174	240	366	606
1920	7	16	198	221	303	524
1921	8	56	192	255	329	585
1922	7	52	260	319	287	606
1923	5	60	79	144	1,268	1,412
1924	5	89	142	236	283	519
1925	5	143	99	247	347	594
1926	4	90	185	280	317	597
1927	5	74	249	328	337	665
1928	3	54	229	286	327	613
1929	3	62	101	166	389	555
1930	5	85	161	252	372	623
1931	12	52	410	474	256	730
1932	11	57	417	484	193	678
1933	6	72	442	520	245	765
1934	10	91	388	488	295	784
1935	11	73	429	512	377	890
1936	7	137	230	374	320	694
1937	7	99	258	364	301	665
1938	6	123	327	455	312	767
1939	6	106	385	497	340	837
1940	9	152	532	692	385	1,077
1941	9	273	446	728	315	1,042
1942	9	253	489	751	320	1,071
1943	5	265	461	732	336	1,068
1944	15	263	386	663	403	1,066
1945	11	338	368	717	359	1,076
1946	13	481	421	915	275	1,190
1947	11	619	321	951	246	1,197
1948	11	713	477	1,201	306	1,506
1949	13	767	504	1,284	277	1,561
1950	9	523	508	1,040	341	1,381
1951	14	183	244	442	341	782
1952	13	140	198	351	268	618
1953	5	171	431	607	282	889
1954	8	332	665	1,005	328	1,333
1955	2	501	497	1,000	254	1,255
1956	3	544	374	921	303	1,223
1957	(1)	288	236	525	285	809
1958	(1)	88	221	309	287	596
1959	1	121	260	383	210	593

[1] Less than 500 pounds.

TABLE 3.—*Average annual production (pounds) of whitefish in different States and percentage contribution of each State to the total U.S. catch in Lake Superior in 1885–1908 and 1911–59*

Period and item	Minnesota	Wisconsin	Michigan	Total [1]
1885–1908:				
Average production	117,695	472,899	1,394,964	1,985,558
Percentage	5.9	23.8	70.3	
Number of years of record	8	14	21	
1911–59:				
Average production	6,510	182,449	318,591	507,550
Percentage	1.3	35.9	62.8	
Number of years of record	47	49	49	

[1] Sum of the average annual contribution of the States.

tario's average annual production for the period 1879–1908 was 618,000 pounds which was 22.0 percent of the total for Lake Superior. Ontario's average annual production dropped to 368,000 pounds in 1911–59; yet this figure represented 42.0 percent of the mean annual take for the entire lake.

Little or no correlation exists between annual fluctuations in production of whitefish in U.S. and Ontario waters. The lack of correlation suggests that U.S. and Canadian fishermen are exploiting different stocks and that conditions controlling fluctuations of the take are not the same over the entire lake.

AGE AND SIZE AT CAPTURE

AGE AND YEAR-CLASS COMPOSITION

The age and year-class composition of Lake Superior whitefish in net-run samples (table 4) varied considerably from port to port and year to year. Although the data are not sufficient for a dependable ranking, certain year classes clearly were of greater or less than average strength.

The interpretation of data on age composition for judging the strength of year classes can be made uncertain by a variety of disturbing factors. Port-to-port differences or annual fluctuations of cropping rate and differences of natural mortality have a strong influence on the representation of age groups. The age at which a year class appears in the sample also must affect judgment as to the original strength. For example, a year class that makes up 20 percent of the sample as age-group VIII must have been originally much stronger than one that contributes 20 percent as age-group IV.

The 1957 Bayfield samples included 10 age groups (I–X). The percentage representation

TABLE 4.—*Age and year-class composition of whitefish caught in commercial trap nets, pound nets, and gill nets*

[Asterisks indicate dominant year classes in different collections]

Port, year of capture, and item	Age group										Total or average [1]
	I	II	III	IV	V	VI	VII	VIII	IX	X	
Bayfield, 1957:											
Year class	1956	1955	1954	1953	1952	1951	*1950	1949	1948	1947	
Number	2	22	73	6	70	55	81	59	3	1	372
Percentage	0.5	5.9	19.5	1.6	18.8	14.8	21.8	15.9	0.8	0.3	5.5
Bayfield, 1959:											
Year class			1956	*1955	1954						
Number			6	117	22						145
Percentage			4.1	80.7	15.2						4.1
Marquette, 1957:											
Year class			1954	1953	*1952	1951	1950	1949	1948	1947	
Number			18	63	74	20	7	4	1	1	188
Percentage			9.1	33.9	39.9	10.7	3.2	2.2	0.5	0.5	4.8
Marquette, 1958:											
Year class		1956	*1955	1954	1953	1952	1951	1950		1948	
Number		3	78	29	17	9	3	1		1	141
Percentage		2.1	55.3	20.6	12.1	6.4	2.1	0.7		0.7	3.8
Marquette, 1959:											
Year class		1957	1956	*1955	1954	1953	1952			1949	
Number		13	19	61	24	9	2			1	129
Percentage		10.1	14.7	47.3	18.6	7.0	1.6			0.8	4.1
Whitefish Point, 1957:											
Year class		1955	*1954	1953	1952	1951	1950				
Number		5	92	61	20	5	1				184
Percentage		2.7	50.0	33.2	10.9	2.7	0.5				3.6
Whitefish Point, 1958:											
Year class		1956	*1955	1954	1953	1952					
Number		13	62	21	11	1					108
Percentage		12.0	57.4	19.4	10.2	0.9					3.3
Whitefish Point, 1959:											
Year class	1958	1957	*1956	1955		1953	1952				
Number	1	9	24	12		1	1				48
Percentage	2.1	18.8	50.0	25.0		2.1	2.1				3.2
Dollar Settlement, 1957:											
Year class			1954	1953	*1952	1951	1950	1949		1947	
Number			14	38	54	9	3	1		1	120
Percentage			11.4	31.7	45.0	7.5	2.5	0.8		0.8	4.6
Dollar Settlement, 1959:											
Year class	1958	1957	*1956	1955	1954	1953	1952				
Number	1	40	81	9	1	1	1				134
Percentage	0.7	29.9	60.4	7.3	0.7	0.7	0.7				2.8

[1] Average number of annuli.

was 14.8 percent or higher for age-groups III and V–VIII. The high representation (21.8 percent) of age-group VII and the substantial representation of age-group VIII (15.9 percent) indicate that the 1950 and the 1949 year classes were originally strong. The 1953 year class, represented as age-group IV, was obviously weak since it contributed only 1.6 percent to the catch. The average age of 5.5 for the 1957 Bayfield fish was the highest at any port in any year.

Only three age groups (III–V) were represented in the 1959 samples from Bayfield. The 1955 year class as age-group IV was overwhelmingly dominant (80.7 percent). The absence of age groups above V is difficult to explain. The strong 1949 and 1950 year class probably had largely disappeared by reason of advanced age and continued exposure to exploitation, but some representation of the moderately good 1951 and 1952 year classes (age-groups V and VI in 1957; VII and VIII in 1959) should have been expected. The mean age of 4.1 for the whitefish in the 1959 Bayfield samples was 1.4 years younger than that of the 1957 collections.

The age composition of the Marquette samples also varied with year of collection. The 1952 year class as age-group V was dominant (39.9 percent) in 1957 but failed to show strength in 1958 and 1959. The clear dominance of the 1955 year class as age-group III in 1958 (55.3 percent) and as age-group IV in 1959 (47.3 percent) gives good evidence of strength. The 1954 class, in contrast, was moderately weak. Even though it contributed 20.6 percent to the catch in 1958 its percentage representation was the lowest recorded for both age-groups III and IV and the next to lowest as age-group V. The average ages of the Marquette samples were 4.8 in 1957, 3.8 in 1958 (this low value reflected the strong 1955 year class as age-group III), and 4.1 in 1959 (also dominated by the 1955 year class).

The Whitefish Point collections were unique in that they were persistently dominated by age-group III (50.0 to 57.4 percent) in each year. This situation well may be the result of small

fluctuations in year-class strength and a high mortality rate due to the intensive trap net fishery in the area. Most of the whitefish at Whitefish Point attain legal size during their fourth year of growth (age-group III) and consequently become vulnerable to the fishery. Few individuals may survive to represent the older age groups in subsequent years. Large percentages of the fish in age groups younger than III undoubtedly escape from the 4½-inch-mesh trap nets. Because of persistent dominance by a single age group, judgments of year-class strength at Whitefish Point are not considered possible. The mean age of the Whitefish Point samples varied little from year to year—3.6 in 1957, 3.3 in 1958, and 3.2 in 1959.

The 1952 year class dominated (45.0 percent) the trap net samples at Dollar Settlement as age-group V in 1957. No samples were collected in 1958, but in 1959 the 1956 year class dominated strongly (60.4 percent) as age-group III. Undoubtedly both the 1952 and 1956 year classes were strong, but lack of data from 1958 makes evaluation of relative strength difficult. The 1954 and 1955 year classes appear to have been weak at Dollar Settlement. The mean age of the Dollar Settlement whitefish was 4.6 in 1957 and 2.8 in 1959.

Little evidence exists for lakewide similarity of fluctuations of year-class strength. The 1955 year class was strong at Bayfield and Marquette but weak at Dollar Settlement. The 1952 year class was strong at Marquette and Dollar Settlement but only moderate at Bayfield. The 1949 and 1950 year classes. which were strong at Bayfield, seemingly were too old to be represented in catches at the other ports. The 1956 year class exhibited strength at Dollar Settlement only. No two ports agreed in the appearance of a weak year class.

LENGTH AND WEIGHT OF THE AGE GROUPS

Comments on the sizes of age groups in samples from commercial gear are kept brief since more discriminating data on growth are offered in later sections. The records of table 5 serve, nevertheless, to establish roughly the differences among the several stocks and provide a general idea of the relation between size and age in catches of commercial gear.

The average lengths and weights of the age groups at capture were determined from the combined samples for each locality with the exception of Bayfield where records for the 1957 and 1959 collections were tabulated separately; the 1958 and 1959 *Siscowet* samples were omitted for reasons made clear in the section on calculated growth. Whitefish collected from the commercial fishery at Bayfield in 1959 showed more rapid growth than those in the 1957 samples. Annual differences at other ports were small and erratically distributed; they can be ascribed to the small numbers of fish

TABLE 5.—*Total length (inches) and weight (pounds) of the age groups of Lake Superior whitefish and percentage of legal fish (17 inches or longer) in each age group*

[Net-run samples from commercial gear]

Port, year and item	Age group									
	I	II	III	IV	V	VI	VII	VIII	IX	X
Bayfield, 1957:										
Total length	7.5	11.0	13.3	16.6	15.5	16.7	17.4	17.9	19.7	18.6
Weight	0.1	0.4	0.7	1.5	1.2	1.5	1.8	1.9	2.6	2.2
Number of fish	2	22	73	6	70	55	81	59	3	1
Percentage legal	0.0	0.0	0.0	50.0	8.6	25.5	61.7	83.1	100.0	100.0
Bayfield, 1959:										
Total length			16.4	16.8	17.5					
Weight			1.4	1.6	1.8					
Number of fish			6	117	22					
Percentage legal			33.3	34.2	59.1					
Marquette, 1957–59:										
Total length		14.7	17.1	19.2	20.7	21.8	23.5	24.8	24.2	26.0
Weight		1.0	1.7	2.4	3.0	3.6	4.6	5.5	5.0	6.4
Number of fish		16	115	153	115	38	12	5	1	3
Percentage legal		6.3	58.3	92.8	99.1	100.0	100.0	100.0	100.0	100.0
Whitefish Point, 1957–59:										
Total length	10.5	15.1	17.1	18.8	21.7	22.9	21.9			
Weight	0.4	1.1	1.7	2.3	3.6	4.3	3.7			
Number of fish	1	27	178	94	31	7	2			
Percentage legal	0.0	0.0	53.4	86.2	100.0	100.0	100.0			
Dollar Settlement, 1957, 1959:										
Total length	10.8	14.7	16.6	17.3	18.0	19.9	21.2	19.7		26.1
Weight	0.4	1.0	1.5	1.7	2.0	2.7	3.3	2.6		6.5
Number of fish	1	40	95	47	55	10	4	1		1
Percentage legal	0.0	0.0	37.9	48.9	78.2	90.0	100.0	100.0		100.0

in some age groups. The sexes were also combined in these data. Sex differences in the average lengths and weights at capture were not appreciable in samples for which records of sex were available.

Some of the differences in the average lengths and weights of whitefish of the same age groups from different localities were striking. The 1957 Bayfield whitefish were the smallest fish, age for age, of all the collections. The average size of the V-group fish, for example, was 6.2 inches shorter and 2.4 pounds lighter than V-group fish from Whitefish Point. Indeed, the weight of the Whitefish Point fish at this age was 3 times that of Bayfield fish. Age-group VII was the youngest at Bayfield in which the average length exceeded the minimum legal size of 17 inches. The mean weight of the 1957 Bayfield whitefish increased less than one-half pound from their fourth to their eighth growing season (from 1.5 to 1.9 pounds).

The 1959 Bayfield whitefish averaged smaller than whitefish from the other ports, but were larger than those in the 1957 Bayfield collections. The average length of the V-group fish, for example, was 17.5 inches, 0.5 inch above the legal minimum and 2 inches longer than the V group in 1957. The weight advantage of the 1959 V group amounted to 0.6 pound.

The available evidence suggests that a temporary improvement in the growth rate of whitefish accounted for the greater size of the age groups in the 1959 samples. Details are not given here since the materials were not suitable for a thorough study of annual fluctuations of growth. They left little doubt, nevertheless, that growth in 1954–57 was substantially more rapid than in the preceding 5 or 6 years (the growth rate dropped sharply in 1958). Since whitefish normally grow much more rapidly in the early than in the late years of life, the relatively young fish of the 1959 samples were in good position to benefit from the 1954–57 period of heightened growth rate. The whitefish caught in 1957 had also lived during most of the period of exceptional growth, but they were of such advanced age that this improved growth did not add materially to their size.

Differences among the average sizes of the fish from other areas of the lake were small at some ages and substantial at others. Among age groups represented by 16 or more fish at each locality, the differences between the largest and smallest fish increased from 0.4 inch and 0.1 pound in age-group II to 3.7 inches and 1.6 pounds in age-group V. Somewhat puzzling is the consistency with which the age groups in samples from Whitefish Point were larger than those from Dollar Settlement. The two collecting localities are barely 30 miles apart (Whitefish Point is at the northwestern entrance to Whitefish Bay and Dollar Settlement at the southern end). The difference appears almost surely to be real, but the true extent of the separation of the two stocks remains to be learned.

The percentage of legal-size whitefish in the age groups was influenced strongly by differences in the growth of fish taken at the various ports (table 5). Not one whitefish in any sample was legal as age-group I, and only one was legal size as age-group II (a 17.1-inch fish captured at Marquette in 1959). At Bayfield in 1957 the first whitefish reached legal size as age-group IV, and age-group IX was the first in which all of the fish were legal size. In 1959 at Bayfield, 33.3 percent of the III-group fish were legal size and 59.1 percent had reached legal size as age-group V.

Much larger percentages of fish reached legal size in the younger age groups at the ports east of Bayfield. More than 50 percent of the III-group fish were legal size at Marquette and Whitefish Point, and all were legal at age-group V at Whitefish Point and at age-group VI at Marquette. It was not until age-group VII was reached that all the fish were legal size at Dollar Settlement.

LENGTH DISTRIBUTION

Data on the length-frequency distribution of the age groups (tables 6, 7, and 8) provide comparisons by age group between the stocks with the slowest and fastest growth and show the length distributions of the combined age groups for the 1957 and 1959 Bayfield samples and the combined collections at Marquette, Whitefish Point, and Dollar Settlement.

The overlap of length distributions of the age groups is influenced strongly by the rate of growth. The range in length of age groups represented by 20 or more fish in the 1957 Bayfield samples (table 6) was 7.9 inches for all age groups except VII where it was 8.9 inches. This wide range in combination with slow growth caused such extensive overlap as to make length an extremely poor index of age. The length interval of 15.0 to 15.9 inches, for example, was represented by seven age

TABLE 6.—*Length distribution of whitefish taken off Bayfield, 1957*

Total length (inches)	Age group									
	I	II	III	IV	V	VI	VII	VIII	IX	X
7.0–7.9	2									
8.0–8.9		1								
9.0–9.9		2	1							
10.0–10.9		9	4							
11.0–11.9		9	4							
12.0–12.9			17		1					
13.0–13.9			21		2	1	1			
14.0–14.9			18		19	4	1			
15.0–15.9		1	6	2	25	13	5	1		
16.0–16.9			2	1	17	23	24	9		
17.0–17.9				2	3	7	24	24		
18.0–18.9				1	2	5	16	13		1
19.0–19.9					1	1	5	9	2	
20.0–20.9						1	3	2	1	
21.0–21.9							2			
22.0–22.9								1		
Total number	2	22	73	6	70	55	81	59	3	1
Average length	7.5	11.0	13.3	16.6	15.5	16.7	17.4	17.9	19.7	18.6

groups (II–VIII). The span of ages was six at 16.0–16.9 inches and several other 1-inch intervals had spans of five age groups. Slow growth and broad length ranges also caused the distributions of five age groups to lie across the legal size limit of 17 inches.

The range in length of the age groups in the 1957–59 Whitefish Point samples (table 7) was also large (9.9 inches at age-group IV and 4.9 to 7.9 inches in other age groups represented by more than 20 fish) but overlapping was reduced by more rapid growth. Because of the good growth and a scarcity of older fish, overlap did not exceed four age groups at any 1-inch interval. The length distributions of only three groups (III–V) fell across the minimum legal size of 17 inches.

The lengths of the 1957 Bayfield samples, age groups combined, ranged from 7.0 to 22.9 inches

TABLE 7.—*Length distribution of whitefish taken off Whitefish Point, 1957–1959*

Total length (inches)	Age group						
	I	II	III	IV	V	VI	VII
10.0–10.9	1						
11.0–11.9							
12.0–12.9		1					
13.0–13.9		5					
14.0–14.9		4	5	2			
15.0–15.9		9	25	2			
16.0–16.9		8	53	9			
17.0–17.9			51	19	1		
18.0–18.9			30	20	3		
19.0–19.9			7	21	1		
20.0–20.9			7	9	5	1	
21.0–21.9				8	7	1	1
22.0–22.9				2	6		1
23.0–23.9				2	4	4	
24.0–24.9					4		
25.0–25.9						1	
Total number	1	27	178	94	31	7	2
Average length	10.5	15.1	17.1	18.8	21.7	22.9	21.9

TABLE 8.—*Length distribution of whitefish caught in commercial pound nets, trap nets, and gill nets*

Total length (inches)	Bayfield		Marquette	Whitefish Point	Dollar Settlement
	1957	1959	1957–59	1957–59	1957, 1959
7.0–7.9	2				
8.0–8.9	1				
9.0–9.9	3				
10.0–10.9	13			1	1
11.0–11.9	13		1		
12.0–12.9	18			1	2
13.0–13.9	25		1	5	5
14.0–14.9	42	3	9	11	24
15.0–15.9	53	23	12	36	65
16.0–16.9	76	64	52	70	40
17.0–17.9	60	36	86	71	59
18.0–18.9	38	11	61	53	31
19.0–19.9	18	5	56	29	11
20.0–20.9	7	3	53	22	5
21.0–21.9	2		53	17	4
22.0–22.9	1		41	9	2
23.0–23.9			14	10	4
24.0–24.9			10	4	
25.0–25.9			4	1	
26.0–26.9			4		1
27.0–27.9			1		
Total number	372	145	458	340	254
Average length	15.8	16.9	19.3	18.0	17.0
Percentage legal	33.9	37.9	83.6	63.5	46.1

and had a mean of only 15.8 inches (table 8). Only 33.9 percent of the fish were legal size. In contrast, the 1959 Bayfield whitefish had a range of only 6.9 inches, from 14.0 to 20.9 inches. The mean length in 1959 was 16.9 inches, and 37.9 percent of the fish were legal size.

The length distributions of the fish from Marquette, Whitefish Point, and Dollar Settlement were similar. The range from the shortest to the longest fish was 15.9 inches at Whitefish Point and 16.9 inches at Marquette and Dollar Settlement. The average lengths of the whitefish from these ports ranged from 17.0 inches at Dollar Settlement to 19.3 inches at Marquette. The percentage of

legal-size fish in the total catches varied considerably—36.1 percent at Dollar Settlement, 63.5 percent at Whitefish Point, and 83.6 percent at Marquette.

LENGTH-WEIGHT RELATION

The general length-weight relation of the Lake Superior whitefish (table 9) was based on the combination of materials regardless of locality, year and season of capture, type of gear, sex, or state of maturity. Undoubtedly the length-weight relation varies during the year and between ripe and recently spent females, as was demonstrated for Lake Erie whitefish by Van Oosten and Hile (1949). The data for this study were not affected by the presence of spawning fish as all fish used were collected in the summer, none later than September 30. Differences among samples from different ports were slight. The lack of small fish from ports east of Bayfield prevented construction of length-weight curves for comparison of localities.

TABLE 9.—*Length-weight relation of Lake Superior whitefish of the combined collections of 1957–59*

Number of fish	Total length [1] (inches)	Weight (pounds)		Number of fish	Total length [1] (inches)	Weight (pounds)	
		Empirical	Calculated			Empirical	Calculated
1	5.9	0.06	0.05	156	17.3	1.69	1.70
20	6.2	0.06	0.06	142	17.8	1.81	1.86
10	6.7	0.06	0.08	118	18.2	2.01	2.02
4	7.1	0.11	0.10	82	18.7	2.21	2.20
2	7.7	0.15	0.12	68	19.2	2.41	2.40
4	8.2	0.13	0.15	52	19.7	2.54	2.61
14	8.7	0.20	0.19	44	20.2	2.80	2.83
19	9.2	0.25	0.22	33	20.7	3.05	3.06
22	9.7	0.26	0.26	28	21.2	3.42	3.31
13	10.2	0.30	0.31	43	21.7	3.62	3.56
25	10.7	0.38	0.36	21	22.2	3.83	3.87
12	11.2	0.40	0.42	21	22.7	4.18	4.12
15	11.7	0.47	0.48	12	23.1	4.34	4.38
14	12.2	0.54	0.56	16	23.7	4.95	4.75
18	12.7	0.60	0.63	7	24.3	5.14	5.12
19	13.2	0.71	0.72	9	24.7	5.88	5.45
23	13.7	0.80	0.81	2	25.2	6.15	5.79
37	14.2	0.89	0.91	3	25.6	6.80	6.08
55	14.7	1.00	1.01	2	26.2	6.13	6.53
87	15.2	1.12	1.13	1	26.5	5.90	6.82
103	15.8	1.31	1.26	1	27.5	8.00	7.69
120	16.2	1.43	1.39	1	29.2	8.90	9.34
170	16.7	1.53	1.52				

[1] Actual averages for fish grouped by ½-inch intervals.

The empirical weights of whitefish at different lengths are shown graphically by dots in figure 3. The curve is a graph of the following equation obtained by fitting a straight line by least squares to the logarithms of the average lengths and weights:

$$W = 1.6643 \times 10^{-4} L^{3.2408}$$

where W = weight in pounds,

and L = total length in inches.

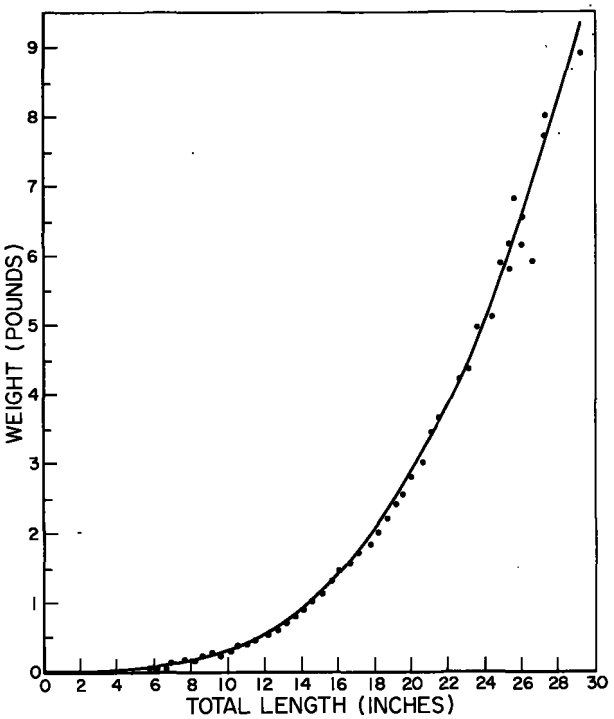

FIGURE 3.—Length-weight relation of Lake Superior whitefish. The curve represents the calculated weights and the dots the empirical weights.

The length of the Lake Superior whitefish increases as the 3.2408 power of the length. The substantial departure of this power above 3 indicates a considerable increase of plumpness with increase of length.

The agreement between the calculated and empirical weights was generally good. The greatest discrepancies were among the larger fish where the numbers of individuals were small. The largest disagreement occurred at 26.5 inches where the empirical weight (5.90 pounds) was 0.92 pound below the calculated weight (6.82 pounds). Other disagreements between the calculated and empirical weights were without trend and did not exceed 0.72 pound among fish above 21.2 inches and 0.07 pound for fish less than 21.2 inches long.

CALCULATED GROWTH

BODY-SCALE RELATION

The body-scale relation of Lake Superior whitefish taken at Bayfield supports the earlier finding of Van Oosten (1923) that direct-proportion calculations of the length of whitefish based on diameter measurements of the scales are satis-

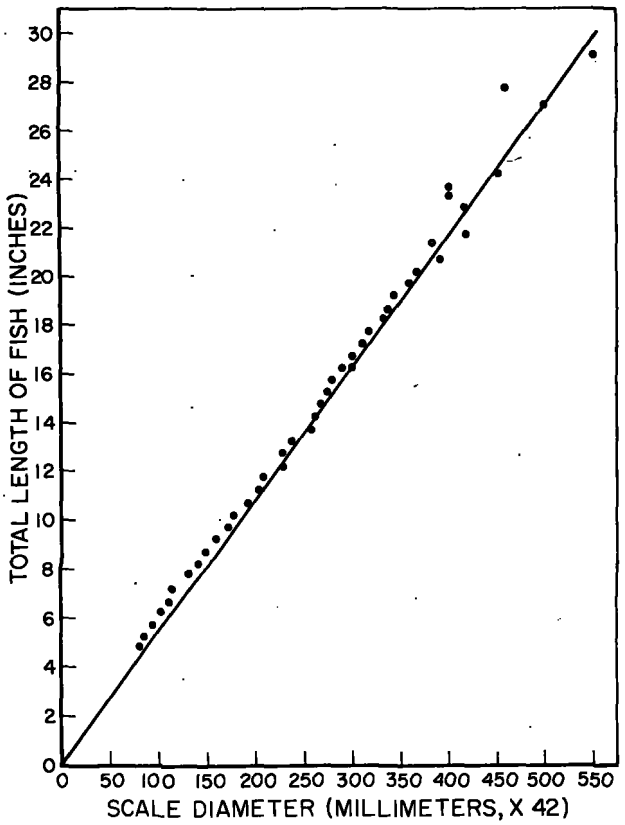

FIGURE 4.—Relation between body length and scale diameter of Lake Superior whitefish taken at Bayfield, 1957–59. The line is a graph of the equation given in the text. The dots show the empirical averages by 0.5-inch intervals of total length.

factory. Key scales, taken from an exactly defined location, were not available, but scale samples removed from the same area of all fish are believed to be reliable for the determination of a body-scale regression.

The body-scale relation (table 10, fig. 4) constructed from records for 694 whitefish collected at Bayfield is obviously linear. A straight line fitted by least squares to the means of scale diameters and lengths of fish had the equation:

$$L=0.04443+0.5401\ S,$$

where L=total length in inches,

and S=scale diameter (×42) in millimeters.

The intercept of 0.04 inch on the length axis is so small it can be ignored; growth, accordingly, may be calculated by direct proportion. This procedure was further justified by the fact that

TABLE 10.—*Relation between body length (L) and the diameter measurement of scales (S) of Bayfield whitefish*

[Scale samples from 54 additional fish were not removed from the key area; these fish were not included in the study of the body-scale relation]

Number of fish	Total length [1] (inches)	Scale diameter (millimeters ×42)	Body-scale ratio [2] (×100)	Number of fish	Total length [1] (inches)	Scale diameter (millimeters ×42)	Body-scale ratio [2] (×100)
1	4.8	85	5.64	32	15.2	276	5.52
4	5.2	87	5.95	46	15.7	281	5.59
3	5.7	95	5.97	75	16.2	294	5.49
20	6.2	103	6.04	70	16.7	301	5.55
10	6.6	113	5.87	43	17.2	313	5.44
6	7.2	115	6.25	45	17.7	318	5.56
3	7.8	133	5.87	23	18.2	336	5.42
5	8.2	141	5.79	17	18.7	338	5.53
17	8.7	148	5.91	15	19.2	345	5.56
20	9.2	160	5.77	11	19.7	360	5.55
23	9.7	174	5.59	6	20.1	368	5.46
14	10.2	177	5.78	5	20.7	382	5.45
22	10.7	192	5.58	5	21.3	369	5.78
12	11.2	205	5.48	4	21.7	418	5.20
13	11.7	208	5.64	2	22.8	418	5.50
12	12.2	228	5.35	1	23.3	401	5.81
18	12.7	230	5.52	1	23.7	401	5.91
23	13.2	241	5.50	1	24.2	453	5.34
13	13.7	258	5.31	1	27.8	460	6.04
28	14.2	263	5.41	1	29.1	553	5.26
21	14.7	270	5.44				

[1] Means for fish within a 0.5-inch interval of total length.
[2] Means of the body-scale ratio computed for individual fish.

the values of the body-scale ratio remained nearly constant regardless of the length of the fish.

Body-scale data were inadequate for whitefish from other parts of Lake Superior because small fish were lacking in the samples. Preliminary observations suggest the possibility of slight differences between the body-scale relation of these fish and those from Bayfield. Because data were insufficient to test this possibility, calculations for all of the samples, regardless of locality, were made by direct proportion. Edsall (1960) described the body-scale relation of Munising Bay whitefish with a straight line that had an intercept of 1.486 inches on the length axis.

GROWTH IN LENGTH OF THE AGE GROUPS

The sexes have been combined for calculated growth of whitefish from the various ports. Sex records were lacking for most collections, but the comparison of the calculated growth of males and females, age group by age group, at Bayfield where sex data were available for most fish, disclosed no differences.

The major difficulties in the estimation of growth lay in the systematic decline in growth rate with increase of age at capture in collections from all four ports (tables 11, 12, 13, and 14). For example, first-year calculated lengths of whitefish taken at Bayfield in 1957 (table 11) decreased from 7.5 inches for age-group I to 4.2

TABLE 11.—*Calculated total length (inches) of whitefish taken at Bayfield in 1957 and 1959 and average calculated lengths for each year's collections and for the combined collections*

[In the bottom section the numbers of fish are in parentheses]

Age and year of capture	Number of fish	Calculated length at end of year of life									
		1	2	3	4	5	6	7	8	9	10
I 1957	2	7.5									
II 1957	22	5.8	10.3								
III 1957	73	5.4	8.8	12.6							
1959	6	5.3	9.9	14.2							
IV 1957	6	5.2	8.4	11.4	15.3						
1959	117	5.6	8.9	12.4	16.1						
V 1957	70	4.2	6.9	9.6	12.2	14.8					
1959	22	5.3	8.2	11.2	14.4	17.0					
VI 1957	55	4.2	6.7	8.9	11.1	13.6	15.9				
VII 1957	81	4.6	6.5	8.3	10.1	12.4	14.8	16.8			
VIII 1957	59	4.6	6.1	7.9	9.6	11.7	13.8	15.8	17.5		
IX 1957	3	4.8	6.9	8.0	9.7	11.8	14.0	16.1	18.3	19.7	
X 1957	1	4.4	6.3	8.2	9.8	11.2	13.2	14.8	16.6	17.9	18.6
Average:											
1957 [1]		4.7	7.3	9.5	10.8	13.1	14.8	16.4	18.1	19.5	20.2
		(372)	(370)	(348)	(275)	(269)	(199)	(144)	(63)	(4)	(1)
1959		5.5	8.8	12.3	15.8	17.0					
		(145)	(145)	(145)	(139)	(22)					
1957, 1959 [2]		5.1	8.0	10.9	13.3	15.0	16.7	18.3	20.0	21.4	22.1

[1] Based on successive addition of grand average increments beyond the seventh year of life.

[2] Unweighted mean average lengths for the 1957 and 1959 samples through the first 5 years of life; lengths for later years obtained by successive addition of annual increments for the fish of the 1957 sample.

inches for age-group V. Second-year calculated lengths decreased from 10.3 inches for the II group to 6.1 inches for VIII group. Similar discrepancies occurred in the data for all of the collections. Second-year calculated lengths, for example, decreased from 11.6 inches for the II group to 7.9 inches for the VI group at Marquette (table 12), from 12.2 inches for the II group to 8.4 inches for the VII group at Whitefish Point (table 13), and from 11.7 inches for the II group to 8.0 inches for the V group at Dollar Settlement (table 14).

The high calculated lengths of the younger age groups and the low values for the older fish can be traced to two major sources: gear selection of the larger fish in the younger age groups, and the progressive destruction of the faster growing fish of a year class as they attain the legal length of 17 inches. Gear selection leads to overestimates of growth of the younger age groups, and the selective destruction of the faster growing fish modifies progressively the growth characteristics of the survivors, and thus leads to successively more severe underestimates of the growth that would occur if the stock were not subjected to this type of exploitation. The selective destruction can end only when the smallest members of the year class reach legal length.

A comparison of calculated lengths of whitefish taken by the *Siscowet* with those taken from commercial gear at Bayfield in 1959 (table 15) illustrates bias through gear selection. The calculated lengths of fish from the commercial samples were nearly always higher than the

TABLE 12.—*Calculated total length (inches) of whitefish taken off Marquette, 1957–59*

[In the bottom section the numbers of fish are in parentheses]

Age group	Number of fish	Calculated length at end of year of life									
		1	2	3	4	5	6	7	8	9	10
II	16	6.0	11.6								
III	115	5.9	9.7	13.9							
IV	153	5.6	9.0	12.6	16.7						
V	115	5.3	8.5	11.5	15.2	18.9					
VI	38	5.2	7.9	10.6	13.7	17.3	20.5				
VII	12	5.6	8.1	10.5	13.2	16.1	19.4	21.8			
VIII	5	5.3	8.0	11.1	14.2	17.8	20.9	23.0	24.3		
IX	1	4.5	6.6	8.6	10.1	11.2	13.2	17.0	18.9	23.1	
X	3	5.5	8.0	9.4	11.9	14.0	16.8	19.2	21.8	23.4	25.0
Grand average [1]		5.6	9.0	12.4	15.6	18.2	20.0	21.5	22.9	25.2	26.8
		(458)	(458)	(442)	(327)	(174)	(59)	(21)	(9)	(4)	(3)

[1] Based on successive addition of mean increments in the 9th and 10th years of life.

TABLE 13.—*Calculated total length (inches) of whitefish taken off Whitefish Point, 1957–59*

[In the bottom section the numbers of fish are in parentheses]

Age group	Number of fish	Calculated length at end of year of life						
		1	2	3	4	5	6	7
I	1	6.8						
II	27	6.8	12.2					
III	178	6.7	11.7	15.1				
IV	94	6.7	10.6	14.3	17.8			
V	31	6.4	10.5	14.2	17.8	20.9		
VI	7	5.5	8.7	12.8	15.9	19.0	22.3	
VII	2	5.1	8.4	11.8	14.9	17.5	19.8	21.4
Grand average [1]		6.6 (340)	11.2 (339)	14.7 (312)	17.6 (134)	20.4 (40)	21.7 (9)	23.3 (2)

[1] Based on addition of the increments in the seventh year of life.

calculated lengths from the *Siscowet* samples. The differences were particularly great for age-groups III and V but were limited in age-group IV. Whitefish collected by the *Siscowet* were taken from small-mesh trawls (2½-inch-mesh body; ½-inch-mesh cod end) and experimental gill nets with mesh sizes ranging from 1 to 5 inches by ½-inch intervals. The commercial samples were taken from 4¾-inch-mesh pound nets and 4½-inch-mesh gill nets. Undoubtedly only the larger members of the younger age groups were retained by the large meshes of the commercial gear, whereas most sizes were retained by the *Siscowet* gear.

The effect of the progressive destruction of the faster growing fish is illustrated by records for whitefish samples collected in 1957 at Bayfield in June, July, and August (table 16). The growth of members of the same age group taken in successive months differed widely. With few exceptions, whitefish at age-groups V to VIII taken earlier in the season had greater lengths at capture and higher calculated lengths than did those taken later. The shift was progressive; the lengths of fish taken in June were greater than for those taken in July; the lengths of fish taken in July were greater than for those taken in August. The length distributions of the age groups (table 17) also show a systematic decrease in size as the summer progressed. With only one exception (August V-group sample) the percentage of legal fish in each of the age groups decreased as the season advanced.

The pound net fishery for whitefish begins at Bayfield about mid-June, and legal-size fish are selected immediately from the population. As the season progresses the number of legal-size whitefish in the commercial catch, despite summer growth, declines until middle and late August when operations cease because production levels make it economically impossible to continue. In 1957, 44.7 percent of the whitefish in the entire June sample were legal size. In July, 37.9 percent were legal, and by August only 16.3 were legal, a reduction of 28.4 in the percentage since June.

Since the growth rate of the Bayfield whitefish is so slow, the number of legal-size fish taken from the fishery far exceeds the number of undersized fish growing to legal size during the early-summer fishing season.

Records on the progress of the season's growth (table 18) suggest that one-third or more of the total growth occurs after August 15 which is about the time that the heavy pound netting ends. This growth, though less than 1 inch, is sufficient to bring a good number of whitefish into legal-size range by the following spring when pound netting is resumed.

TABLE 14.—*Calculated total length (inches) of whitefish taken off Dollar Settlement, 1957–59*

[In the bottom section the numbers of fish are in parentheses]

Age group	Number of fish	Calculated length at end of year of life									
		1	2	3	4	5	6	7	8	9	10
I	1	7.0									
II	40	6.3	11.7								
III	95	6.3	9.9	14.2							
IV	47	6.0	9.1	12.5	16.1						
V	55	5.1	8.0	10.6	14.1	17.2					
VI	10	5.3	8.6	11.3	13.4	16.5	19.1				
VII	4	5.4	8.1	10.4	12.3	14.8	17.7	20.2			
VIII	1	5.5	9.5	11.5	13.1	15.7	17.1	18.7	19.4		
X	1	5.0	8.1	9.9	11.4	14.7	18.1	22.1	23.4	24.4	25.8
Grand average [1]		5.9 (254)	9.5 (253)	12.7 (213)	14.8 (118)	16.9 (71)	18.6 (16)	20.3 (6)	21.4 (2)	22.4 (1)	23.8 (1)

[1] Based on successive addition of the mean increments in the 9th and 10th years of life.

TABLE 15.—*Calculated total lengths (inches) of three age groups of whitefish taken by the M/V* Siscowet *and from Commercial gear at Bayfield, 1959*

Age group and source of sample	Number of fish	Calculated length at end of year of life				
		1	2	3	4	5
III *Siscowet*	14	4.8	8.5	11.5		
Commercial	6	5.3	9.9	14.2		
IV *Siscowet*	21	5.5	9.0	12.3	15.4	
Commercial	117	5.6	8.9	12.4	16.1	
V *Siscowet*	18	5.3	7.7	10.4	13.0	15.4
Commercial	22	5.3	8.2	11.2	14.4	17.0

Discrepancies of calculated length of the type shown by Lake Superior whitefish have been observed repeatedly among fish sorted about a size limit or taken by highly selective gear. Numerous explanations of discrepancies in calculated lengths can be found in the literature. Some have been traced to the use of incorrect formulas for growth calculation, but where the body-scale relation has been determined accurately, investigators generally have agreed that gear selectivity and destruction of the more rapidly growing individuals by the fishery are the two major sources of bias. Discussions of this problem may be found in Deason and Hile (1947) and El-Zarka (1959).

GENERAL GROWTH IN LENGTH

The information on gear selectivity and selective destruction of the rapidly growing fish given in the previous section makes it obvious that any estimate of general growth is of necessity an approximation. Since the two major sources of bias are to an unknown degree compensating, the estimate of general growth for each locality is based on all available fish. The *Siscowet* samples have been omitted from the general growth studies in order to permit comparisons among the net-run collections from commercial gear at the various ports.

The 1957 and 1959 Bayfield samples have been combined even though differences were wide between the sizes at capture and the calculated lengths of the two collections. As was explained in the section on age and size at capture, the differences most probably can be attributed to a period of exceptionally good growth in 1954–57.

TABLE 16.—*Size at capture and calculated total lengths (inches) of four age groups in samples of whitefish collected at Bayfield in different months, 1957*

Age and Date of collection	Number of fish	Average length at capture	Calculated length at end of year of life							
			1	2	3	4	5	6	7	8
V June 13	21	16.4	4.4	7.0	10.0	13.0	16.4			
July 22	32	15.2	4.3	7.0	9.3	12.2	14.4			
Aug. 15	16	15.1	4.2	6.5	8.9	11.1	13.7			
VI June 13	12	17.9	4.6	7.1	9.6	12.5	15.3	17.9		
July 22	28	16.6	4.4	6.9	9.0	11.1	13.6	15.7		
Aug. 15	14	16.0	4.2	6.4	8.1	9.9	12.1	14.7		
VII June 13	24	18.4	4.6	6.7	8.7	10.9	13.4	15.8	18.4	
July 22	41	17.3	4.7	6.6	8.4	10.3	12.3	14.6	16.4	
Aug. 15	16	16.4	4.6	6.1	7.7	9.4	11.4	13.5	15.3	
VIII June 13	21	18.9	4.5	6.3	8.3	10.1	12.3	14.6	16.8	18.9
July 22	27	17.5	4.6	6.1	7.9	9.6	11.6	13.7	15.5	16.9
Aug. 15	11	17.4	4.5	5.9	7.3	9.0	10.7	12.5	14.5	16.4

TABLE 17.—*Length distribution of the age groups of samples of whitefish collected at Bayfield in different months, 1957*

Total length (inches)	V-group			VI-group			VII-group			VIII-group		
	June	July	August	June	July	August	June	July	August	June	July	August
12.0–12.9			1									
13.0–13.9			2						1			
14.0–14.9	2	13	4		1	1		1	2			
15.0–15.9	5	14	5		4	6		3	8		1	
16.0–16.9	9	5	3	3	14	5	2	14	5		5	4
17.0–17.9	2		1	3	7	1	9	10		4	15	5
18.0–18.9	2			4	2	1	5	11		7	5	1
19.0–19.9	1			1			5			7	1	1
20.0–20.9				1			1	2		2		
21.0–21.9							2					
22.0–22.9										1		
Total number	21	32	16	12	28	14	24	41	16	21	27	11
Average length	16.4	15.2	15.1	17.9	16.6	16.0	18.4	17.3	16.4	18.9	17.5	17.4
Percentage, legal size	23.8	0.0	6.3	75.0	32.1	14.3	91.7	56.1	18.8	100.0	77.8	63.6

TABLE 18.—*Amount of season's growth in length (inches) of four age groups of Bayfield whitefish up to and following August 15, 1957*

Age group	Growth to Aug. 15	Full season's growth [1]	Growth after Aug. 15	Percentage of total growth
V	1.4	2.3	0.9	39
VI	1.3	2.0	.7	35
VII	1.1	1.7	.6	35
VIII	1.0	1.4	.4	29

[1] Determined from the next higher age group in the same collection.

Growth in length of Lake Superior whitefish varied considerably according to port (table 19, fig. 5). Bayfield whitefish were by far the slowest growing. The first-year calculated length was 5.1 inches. The annual increments decreased from 2.9 inches in the second and third years to 0.7 inch in the tenth, at which time the fish were 22.1 inches long.

The whitefish from Marquette were considerably faster growing. These fish attained an average length of 5.6 inches in the first year, and fairly rapid growth continued through the fifth year of life when their average calculated length was 18.2 inches. Marquette whitefish were 26.8 inches long at the end of their tenth growing season.

The Whitefish Point whitefish were by far the fastest growing in the four areas studied. At the end of the first year the fish averaged 6.6 inches long. The annual increments decreased slowly from 4.6 inches in the second year to 2.8 inches in the fifth at which time the fish averaged 20.4 inches (compared to 15.0 inches at Bayfield). By the end of the seven growing seasons, the Whitefish Point whitefish were 23.3 inches long. The samples included no fish older than age-group VII.

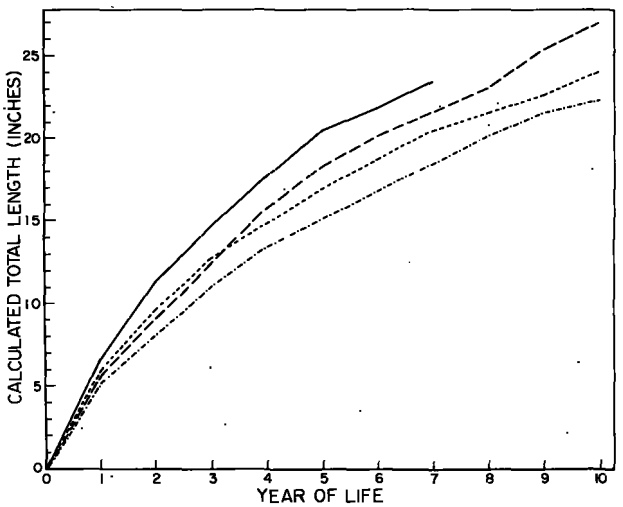

FIGURE 5.—Calculated length of Lake Superior whitefish according to port. Whitefish Point, solid line; Marquette, long dashes; Dollar Settlement, short dashes; Bayfield, dots and dashes.

TABLE 19.—*Calculated total length (inches) of Lake Superior whitefish according to port*

[The collections from the different years have been combined]

Year of life	Bayfield		Marquette		Whitefish Point		Dollar Settlement	
	Length	Increment	Length	Increment	Length	Increment	Length	Increment
1	5.1	5.1	5.6	5.6	6.6	6.6	5.9	5.9
2	8.0	2.9	9.0	3.4	11.2	4.6	9.5	3.6
3	10.9	2.9	12.4	3.4	14.7	3.5	12.7	3.2
4	13.3	2.4	15.6	3.2	17.6	2.9	14.8	2.1
5	15.0	1.7	18.2	2.6	20.4	2.8	16.9	2.1
6	16.7	1.7	20.0	1.8	21.7	2.9	18.6	1.6
7	18.3	1.6	21.5	1.5	*23.3	1.6	20.3	1.7
8	*20.0	1.7	22.9	1.4	-------	------	21.4	1.1
9	*21.4	1.4	*25.2	2.3	-------	------	*22.4	1.0
10	*22.1	0.7	*26.8	1.6	-------	------	*23.8	1.4

Asterisks indicate lengths based on the successive addition of grand average increments.

Dollar Settlement whitefish were longer than the Marquette stocks for the first 3 years, but were the shorter in the subsequent 7 years. Dollar Settlement whitefish attained an average length of 5.9 inches in the first year of life, and 16.9 inches by the end of the fifth year. Their calculated length after 10 growing seasons was 23.8 inches. The growth rate of the Dollar Settlement stock was clearly different from that of the Whitefish Point fish even though the grounds are barely 30 miles apart. Preliminary examination of scale samples collected in 1960 from Dollar Settlement and Whitefish Point further demonstrated faster growth of fish from Whitefish Point; the differences were not as pronounced, however, as in the 1957–59 samples.

The differences in the calculated growth of whitefish taken off different ports, along with the differences in age composition and size at capture of the commercial catch, were sufficiently great and consistent to suggest that a number of distinct stocks of whitefish inhabit Lake Superior. This belief is given further support by the findings of Edsall (1960) on the very slow growth of whitefish in Munising Bay, Lake Superior. The Munising Bay whitefish averaged 5.5 inches long after the first growing season, but second-year growth amounted to only 1.7 inches, and no annual increment exceeded 1.0 inch after the third year or

0.5 inch after the twelfth. The highest calculated length attained was 16.7 inches in 16 years.

The major differences in growth among the four open-lake stocks of Lake Superior whitefish occur during the first few years of life. After the fifth year the annual increments of growth agree reasonably well. It would appear that the factors controlling growth rates are most effective during the first few years of life.

The order of the four stocks with respect to calculated length was the same for all years of life except in the samples from Marquette and Dollar Settlement (fig. 5). The Bayfield fish had the shortest and the Whitefish Point fish the longest calculated lengths in all possible comparisons, but the position of fish from Marquette and Dollar Settlement was reversed as growth proceeded. The differences in calculated lengths between whitefish from Bayfield and Whitefish Point were very large. At the end of 7 years, the calculated length of the Whitefish Point stock was 5.0 inches longer than that of the Bayfield whitefish.

GENERAL GROWTH IN WEIGHT

The weights of table 20 (see also fig. 6) were computed by means of the general length-weight equation given on p. 86 and correspond exactly with lengths of table 19. All questions relating to the reliability of the calculated lengths of table 19 apply, therefore, to the calculated weights.

The calculated weights differed little at the end of the first year, but in subsequent years wide differences developed among fish from the several ports. Since the calculated weights were computed from the calculated lengths, the Bayfield whitefish exhibited the slowest growth in weight.

TABLE 20.—*Calculated weight (pounds) at the end of each year of life of Lake Superior whitefish according to port*

[Weights were computed from the calculated lengths of table 19 by means of the general length-weight equation]

Year of life	Bayfield		Marquette		Whitefish Point		Dollar Settlement	
	Weight	Increment	Weight	Increment	Weight	Increment	Weight	Increment
1	0.04	0.04	0.05	0.05	0.07	0.07	0.05	0.05
2	.14	.10	.20	.15	.42	.35	.25	.20
3	.40	.26	.57	.37	1.01	.59	.63	.38
4	.72	.32	1.20	.63	1.80	.79	1.02	.39
5	1.05	.33	2.00	.80	2.90	1.10	1.57	.55
6	1.52	.47	2.70	.70	3.56	.66	2.13	.56
7	2.02	.50	3.40	.70	4.48	.92	2.88	.75
8	2.70	.68	4.20	.80	------	------	3.37	.49
9	3.40	.70	5.79	1.59	------	------	3.95	.58
10	3.85	.45	7.05	1.26	------	------	4.80	.85

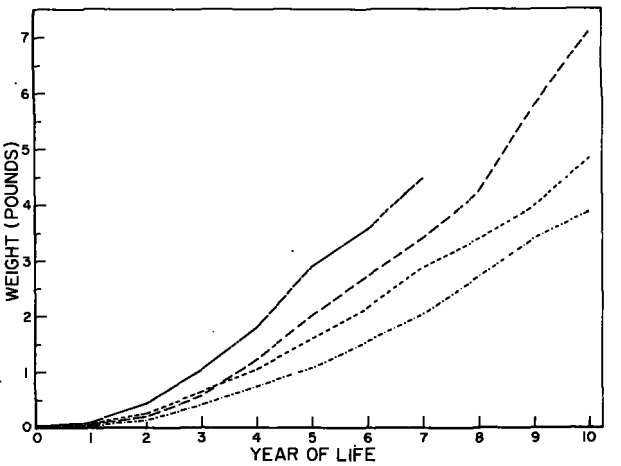

FIGURE 6.—Calculated growth in weight of Lake Superior whitefish according to port. Whitefish Point, solid line; Marquette, long dashes; Dollar Settlement, short dashes; Bayfield, dots and dashes.

Increments in individual years of life were small at Bayfield (0.04 pound the first year to 0.70 pound in the ninth). Bayfield stocks did not reach 1 pound until the fifth year of life and weighed only 3.85 pounds after 10 years.

The Marquette whitefish grew considerably faster in weight than the Bayfield stock. These fish reached 1 pound during the fourth growing season, and by the tenth they had reached 7.05 pounds. The annual increments of weight increased steadily from 0.05 pound in the first year to 0.80 pound in the fifth year. Between the fifth and eighth years the increments varied only from 0.70 to 0.80 pound. During the ninth year the increment was 1.59 pounds, and in the tenth it was 1.26 pounds.

Growth was faster at Whitefish Point, of course, than at any other port. The fish reached 1 pound at the end of the third growing season, and by the seventh year they weighed 4.48 pounds. Annual increments exceeded 0.5 pound in each year after the second.

The growth in weight of Dollar Settlement stocks was better than Bayfield fish but slower than the Marquette (after 3 years) and Whitefish Point stocks. Four years were required for the fish to reach 1 pound, and at the end of 10 years they weighed 4.80 pounds. The annual increments varied from 0.05 pound in the first year to 0.85 pound in the tenth year of life.

TABLE 21.—*Growth in total length (inches) of whitefish in different parts of the Great Lakes*

[Sources of data: Lake Ontario, Hart (1931); Lake Erie, Van Oosten and Hile (1949); Lake Huron, Van Oosten (1939); Lake Michigan, Roelofs (1958); Lake Superior, Munising Bay, Edsall (1960). Records are not carried beyond 10 years]

Area	Calculated length at end of year of life									
	1	2	3	4	5	6	7	8	9	10
Lake Ontario [1]			9.4	12.0	15.4	17.9	19.1	20.4	21.0	22.3
Lake Erie	6.9	12.7	16.1	18.1	19.6	20.7	21.4	22.1	22.8	23.2
Lake Huron	5.0	8.9	12.3	16.1	19.2	21.4	22.9	23.9	24.8	25.3
Lake Michigan:										
Big Bay de Noc	5.6	9.4	13.8	17.9						
South Fox Island	4.3	7.0	9.9	13.2						
Lake Superior:										
Bayfield	5.1	8.0	10.9	13.3	15.0	16.7	18.3	20.0	21.4	22.1
Marquette	5.6	9.0	12.4	15.6	18.2	20.0	21.5	22.9	25.2	26.8
Munising Bay	5.5	7.2	8.4	9.4	10.1	10.8	11.5	12.1	12.9	13.6
Whitefish Point	6.6	11.2	14.7	17.6	20.4	21.7	23.3			
Dollar Settlement	5.9	9.5	12.7	14.8	16.9	18.6	20.3	21.4	22.4	23.8

[1] Actual lengths at capture during growing season subsequent to indicated year.

GROWTH OF WHITEFISH IN LAKE SUPERIOR AND OTHER GREAT LAKES

The records of growth of whitefish in other Great Lakes localities were published originally with various measurements and units, and some presentations included no calculated lengths. Certain adaptations were required and some explanations are needed to permit an instructive study of the data of table 21. The lengths for the Lake Ontario whitefish represent actual lengths at capture for fish collected during the indicated year of life; they have been converted to total length from the standard lengths given by Hart (1931). The data for Lake Huron and Lake Erie are from a table in Van Oosten and Hile (1949).

The differences in growth among the various stocks of Great Lakes whitefish do not allow a clear ranking for individual populations. The relations among the stocks shifted according to age, and not one group was consistently the faster or slower growing population. The whitefish from South Fox Island grew only 4.3 inches during the first year of life but by the end of the fourth year they were 13.2 inches long. Munising Bay whitefish grew 5.5 inches the first year but did not reach 13.0 inches until the tenth year of life. The growth of whitefish from Whitefish Point, Marquette, and Dollar Settlement compared closely with the growth of Lake Erie, Lake Huron, and Big Bay de Noc stocks. Again, the relations shifted according to age, but all of these stocks were among the fastest growing whitefish in the Great Lakes. The growth of the Bayfield whitefish was similar to that of the Lake Ontario stock, faster growing than Munising Bay and South Fox Island fish but slower than the other populatiosn.

SEX RATIO AND MATURITY

SEX RATIO

Usable data on the sex ratio of Lake Superior whitefish are available only for part of the Bayfield samples of 1957 and 1959 (table 22). The data from the samples for the 2 years were so similar that the collections have been combined. Fish of age-group I were omitted from this study because of uncertainties in sex determination. With the exception of age-groups V and VII, the number of males exceeded the number of females in age-groups II–VIII. The advantage of the males over the females was small—not over 58.1 percent males (age-group III). Age-groups IX and X were represented by very small numbers of fish, but males were scarce at these ages—only one male in a total of seven fish. The percentage of male whitefish in samples from Lake Huron (Van Oosten, 1939) and Lake Erie (Van Oosten and Hile, 1949) decreased with increase of age.

In the entire Bayfield sample, all ages combined, the sexes were almost equally represented (51.5 percent males).

SIZE AND AGE AT MATURITY

All whitefish from Bayfield shorter than 14.5 inches were immature, and all fish longer than 17.4 inches were mature. The first mature male appeared in the 14.5- to 14.9-inch group (table 23). The percentage of mature males reached 57.1 percent at 16.0–16.4 inches, and all of the males were mature at lengths greater than 16.9 inches.

TABLE 22.—*Sex ratio of whitefish taken at Bayfield*

[Based on the combined collections of 1957 and 1959]

Age group	Number of males	Number of females	Percentage males
II	35	29	54.7
III	50	36	58.1
IV	54	47	53.5
V	46	47	49.5
VI	25	24	51.0
VII	38	46	45.2
VIII	32	30	51.6
IX		3	0
X	1	3	25.0
All ages	281	265	51.5

TABLE 23.—*Relation of length to maturity of whitefish taken at Bayfield in July and August 1957*

[Data on maturity were not recorded for all individuals. All fish shorter than 14.5 inches were immature, and all longer than 17.4 inches were mature]

Length (inches)	Males			Females		
	Number immature	Number mature	Percentage mature	Number immature	Number mature	Percentage mature
14.5–14.9	5	1	16.7	7	0	0
15.0–15.4	8	2	20.0	6	0	0
15.5–15.9	5	2	28.6	8	0	0
16.0–16.4	6	8	57.1	8	7	46.7
16.5–16.9	1	10	90.9	5	11	68.8
17.0–17.4	0	12	100.0	1	5	83.3

The first mature females appeared at 16.0–16.4 inches, and all females longer than 17.4 inches were mature. First maturity of males occurred at a length 1.0 inch shorter than in females, and 100-percent maturity of males occurred at a length 0.5 inch shorter than in females.

The youngest mature fish of each sex belonged to age-group V (table 24), and all whitefish older than age-group VII were mature. Among age-groups V–VII the percentage maturity of males was consistently higher than for females of corresponding age. The mature fish of each sex without exception were longer than the immature fish of the same age group.

The scanty data on sexual maturity from other ports are inadequate for detailed study, but they suggested that the faster growing whitefish mature at a greater length and a lower age. Alm (1959) held that fish which have particularly slow growth may mature at a higher age but at a length which is below that of faster growing specimens. Comparisons of length and age at maturity of Bayfield whitefish with those of whitefish from other localities support this argument. Munising Bay whitefish (Edsall, 1960), which grow much more slowly than the Bayfield stock, exhibit first maturity at 11.5 inches and 100-percent maturity

TABLE 24.—*Length of mature and immature whitefish of three age groups taken off Bayfield in July and August 1957*

[Number of fish in parentheses. All whitefish younger than age-group V were immature, and all older than age-group VII were mature]

Sex and state of gonads	Calculated length at last annulus		
	V	VI	VII
Male:			
Mature	15.4 (3)	17.0 (15)	17.3 (20)
Immature	15.0 (24)	15.2 (6)	16.4 (2)
Percentage mature	11.1	71.4	90.9
Female:			
Mature	17.2 (1)	16.6 (9)	17.7 (21)
Immature	15.1 (16)	16.0 (11)	15.8 (10)
Percentage mature	5.9	45.0	67.7

at 15.0 inches. All Munising Bay whitefish younger than age-group VII were immature, and some were still immature as age-group XI. In direct contrast, Van Oosten (1939) reported first maturity for males at 17.8 inches and for females at 18.3 inches in Lake Huron. All of the males were mature at 20.1 inches, and all of the females at 21.5 inches. All male whitefish younger than age-group III and females younger than age-group IV were immature, and all males older than age-group V and females older than VI were mature. It appears, then, that among fish of the same length, those from stocks with the slower growth are the more likely to be mature, and among fish of the same age those from stocks with the more rapid growth are the more likely to be mature.

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