AGE, GROWTH, SEX RATIO, AND MATURITY OF THE WHITEFISH IN CENTRAL GREEN BAY AND ADJACENT WATERS OF LAKE MICHIGAN

By Donald Mraz, *Fishery Biologist*
Wisconsin Conservation Department, Madison, Wis.

ABSTRACT

This study is based on 1,023 whitefish, *Coregonus clupeaformis* (Mitchill)—819 in seven samples from five localities in central Green Bay in 1948–49 and 1951–52 and 204 in a single 1948 collection from northwestern Lake Michigan proper.

Records of age indicated unusual strength for only one year class—1943 which strongly dominated the 1948 sample from Lake Michigan and the 1949 sample from Green Bay and was well represented in the 1948 collection from Green Bay. Collections of 1951–52 without exception were dominated by age group III.

Length distributions of samples varied widely according to the age composition. Among fish more than 2 years old, the length distributions of age groups overlapped broadly. Several 1-inch intervals included fish of four age groups.

The length-weight relation varied considerably among central Green Bay samples, but differences among localities were nearly equalled by the year-to-year difference at a single locality. Lake Michigan whitefish were generally lighter than those from Green Bay. Weight increased to the 3.386 power of length in Green Bay (combined samples) and the 3.359 power in Lake Michigan.

Growth in length, calculated by direct proportion from diameter measurements of growth fields on scales, differed among localities in central Green Bay and between samples of different years at a single locality. If permanent locality differences exist they are not large and can be obscured by the evident annual fluctuations of growth. The grand average calculated length of Green Bay whitefish (combined collections) exceeded that of Lake Michigan fish in all years of life. The advantage was greatest (2.2 inches) at 3 years (calculated lengths of 16.0 and 13.8 inches) and subsequently declined to 0.5 inch at 9 years (lengths of 24.6 and 24.1 inches). Both groups reached the minimum legal length of 17 inches during the fourth growing season. Green Bay whitefish also had the larger calculated weights. The advantage reached 9.3 ounces in 3 years (calculated weights of 22.4 and 13.1 ounces). In years of life 4–9, the weight advantage over Lake Michigan fish ranged from 8.7 ounces, (seventh year; weights of 74.4 and 65.7 ounces) to 12.2 ounces (ninth year; weights of 96.2 and 84.0 ounces).

Comparison of growth of whitefish at four localities in northern Lake Michigan indicates that fastest growth is in central Green Bay and slowest near the Fox Islands. Growth is intermediate and similar in northwestern Lake Michigan proper and northern Green Bay.

Youngest mature male whitefish in Green Bay belonged to age group II and youngest mature females to age group III. All IV-group fish were mature. Shortest mature males were at 14.5–14.9 inches and shortest mature females at 16.5–16.9 inches. All males longer than 17.9 inches and all females longer than 18.4 inches were mature.

The whitefish, *Coregonus clupeaformis* (Mitchill), long has been a major commercial species in the Great Lakes. It occurs in all five lakes. Publications on Great Lakes whitefish include: Hart (1931), Lake Ontario; Van Oosten and Hile (1949), Lake Erie; Van Oosten (1939), Lake Huron; Roelofs (1958), Lake Michigan; and the most recent studies in Lake Superior by Edsall (1960) and Dryer (1963).

Some of these studies revealed the existence of populations with greatly different growth characteristics within the same lake and separated by

Note.—Approved for publication February 12, 1964.

735-722 O—64——9

only relatively short distances. The present paper discloses a similar situation between central Green Bay waters of Lake Michigan and the adjacent area of the lake proper. The knowledge of the existence and location of the various separate populations of whitefish is valuable to the sound management and commercial exploitation of the species.

MATERIALS AND METHODS

This study is based on 1,023 whitefish collected in six areas of central Green Bay and adjacent waters of Lake Michigan from 1948 through 1952 (fig. 1; table 1). The numbers of fish in individual samples ranged from 204 from the Europe Bay area of Lake Michigan to 80 at Peshtigo. The 230 fish at Minneapolis Shoals (131 on July 31, 1952, and 99 on September 16, 1952) had such closely similar growth and size that they were treated as a single collection. All collections were complete catches from the nets.

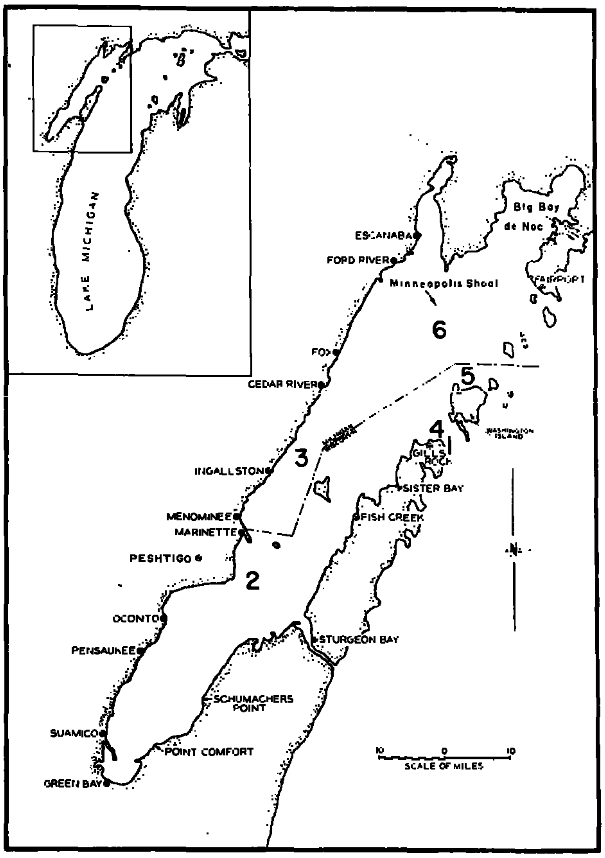

FIGURE 1.—Localities at which whitefish were collected in Lake Michigan proper and central Green Bay. The locality numbers are used in table 1 to identify individual samples.

Several other samples of selected fish, or samples too small to be used effectively for comparison with the larger collections, were employed in the section on the length-weight relation.

TABLE 1.—*Locality, gear, and date of capture of whitefish from Lake Michigan and central Green Bay*

[Figures in parentheses are used to identify localities in figure 1]

Date of capture	Locality	Gear	Number of fish
1948			
Oct. 14	Lake Michigan (1)	4½-inch-mesh pound net	204
Oct. 13	Peshtigo (2)	4¾- to 5-inch mesh gill net	80
1949			
May 18	Cedar River (3)	5-inch-mesh pound net	182
1951			
June 15	Cedar River (3)	4½-inch-mesh pound net	85
June 11	Gills Rock (4)	4½-inch-mesh pound net	129
1952			
Feb. 14	Washington Island (5)	4½-inch-mesh gill net	113
July 31	Minneapolis Shoals (6).	5-inch-mesh pound net	131
Sept. 16	Minneapolis Shoals (6).	5-inch-mesh pound net	99

All available data have been applied to each matter under consideration. As a result, certain discrepancies appear in numbers of fish. For example, a table giving the length-frequency distribution or the length-weight relation for an entire sample may be based on more fish than a table of age composition for the same sample. The latter table, of necessity, excludes those fish for which scales could not be read.

Scales were removed from the left side of the fish between the lateral line and the middle of the base of the dorsal fin. Total lengths (tip of the head to the tip of the tail, lobes compressed) were measured to the nearest 0.1 inch. Weights were determined with spring balances and recorded to the nearest quarter or half ounce. All records were later converted to the nearest 0.1 ounce. The sex was determined for all fish but maturity data were lacking or incomplete for all but the Minneapolis Shoals collections.

Scale impressions were made in cellulose acetate (Smith, 1954) and examined by means of a microprojector at a magnification $\times$ 44 (Moffett, 1952). Diameters of scales and of growth fields within were measured to the nearest 0.1 inch along a line through the focus that approximately bisected the anterior field.

Since the data in this study were not adequate for a precise determination of the body-scale relation all calculations of length were by direct proportion. A plot of the available data did indicate a straight line with an intercept value near zero. This observation disagrees with that of Edsall (1960) who found the relation for Munising Bay (Lake Superior) whitefish to be linear with an intercept of 1.486 inches on the axis of fish length. It agrees, however, with the finding of Van Oosten (1923) for whitefish reared in the New York Aquarium and of Dryer (1963) for Lake Superior whitefish from the Apostle Islands region.

All fish were considered to become a year older on January 1; an annulus was credited at the edge of the scale from that date until the current-season annulus was completed. Age groups are designated by Roman numerals corresponding to the number of annuli.

None of the fish collected in spring or early summer had started growth. At Minneapolis Shoals, growth was in progress in July and September but no difficulty was encountered in locating the outermost annulus.

Growth of the Lake Michigan and Peshtigo samples collected in mid-October 1948 has been assumed to be complete for the year. The lengths at capture of age groups in these samples as well as in samples taken in the spring or early summer are therefore treated also as calculated lengths.

On the basis of findings detailed in later text sections it was determined desirable to treat the sample from the Europe Bay area of Lake Michigan separately from the central Green Bay collections; fish from Europe Bay have been designated "Lake Michigan." The collections made within Green Bay are identified by actual locality of capture or labeled collectively as "Central Green Bay."

In the presentation of data, the collections are arranged in the order of capture with two exceptions. The Lake Michigan collection always appears first despite its collection a day later than the one from Peshtigo because the fish are distinct from the central Green Bay fish; again in 1951 the Cedar River sample is placed in tables in advance of the Gills Rock collection to take advantage of ready comparisons of the Cedar River collections of 1949 and 1951—the only two collections from the same locality.

AGE COMPOSITION

The records of age composition point clearly to the presence of only one exceptionally strong year class of whitefish—that of 1943 (table 2; fig. 2). It was strongly dominant as the V group in the Lake Michigan sample in 1948 (52.7 percent) and as the VI group at Cedar River (65.2 percent) in 1949. It was also abundant (38.7 percent) at Peshtigo in 1948 although outnumbered by the IV group (49.4 percent). It had disappeared, however, by 1951.

The collections of 1951 and 1952 from Cedar River, Gills Rock, Washington Island, and Minneapolis Shoals were all dominated by age group III (fig. 2). Roelof's (1958) data showed that age group III provided 85 to 90 percent of the annual commercial catch in Big Bay de Noc waters of Lake Michigan in 1951–54. The author believed that mortality was extremely high from age group III to age group IV.

The use of two types of gear (gill and pound nets) to catch fish made it possible to study their effect on age composition in the samples. The gill net is designed to catch fish above a certain size but does not catch the largest fish. The pound net is not so selective, as the effect of its leaders and the mechanical action of lifting the net frequently result in the capture of small fish. Although many more of these smaller fish escape than are actually caught, some do mill around and avoid escape through the larger side meshes until they are trapped during lifting and are retained. It was this fishing action that permitted the capture of six I-group fish by pound nets; no fish of that age appeared in gill net samples. The pound net also can take the larger fish which cannot be caught readily in a gill net.

The Washington Island gill net sample showed that these various gear effects did not alter the basic composition of dominance by III-age fish during 1951–52. The Peshtigo sample did have fewer V-group fish than would be expected on the basis of the strong dominance of the 1943 year class in the Lake Michigan collection of 1948 and the Cedar River collection of 1949. The Peshtigo sample was small (only 80 fish), however,

TABLE 2.—*Age and year-class composition of samples of whitefish from Lake Michigan and central Green Bay*

Locality, year of capture, and item	Year class												Average or total [1]
	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	
Lake Michigan, 1948:													
Age group	VIII		VI	V	IV	III	II	I					4.0
Number	1		3	106	20	27	40	4					201
Percentage	0.5		1.5	52.7	10.0	13.3	20.0	2.0					
Peshtigo, 1948:													
Age group				V	IV	III							4.3
Number				29	37	9							75
Percentage				38.7	49.4	11.9							
Cedar River, 1949:													
Age group	IX	VIII	VII	VI	V	IV	III	II					5.2
Number	2	2	2	114	3	15	34	3					175
Percentage	1.1	1.1	1.1	65.2	1.7	8.6	19.5	1.7					
Cedar River, 1951:													
Age group						V	IV	III					3.1
Number						I	7	70					78
Percentage						1.3	8.9	89.8					
Gills Rock, 1951:													
Age group							IV	III	II	I			2.7
Number							5	78	41	1			125
Percentage							4.0	62.4	32.8	0.8			
Washington Island, 1952:													
Age group									IV	III			3.2
Number									21	89			110
Percentage									19.1	80.9			
Minneapolis Shoals, 1952:													
Age group									IV	III	II	I	2.8
Number									5	162	59	1	227
Percentage									2.2	71.4	26.0	0.4	

[1] The first of each pair of figures is the average number of annuli.

and may not have been fully representative of the local stock.

The average number of annuli in the 1948–49 samples ranged from 4.0 to 5.2 as compared to 2.7 to 3.2 in the 1951–52 samples (table 2). This difference in average age is traceable to the great strength of the 1943 year class at ages V and VI.

The 1943 year class of whitefish was abundant in Lake Huron as well as in Lake Michigan. Saginaw Bay of Lake Huron, for example, showed an average commercial production of 26,000 pounds during 1938–45, an increase to an average of 807,000 pounds during 1946–48, and a decline to an average of 17,000 pounds during 1949–56 (Hile and Buettner, 1959).

The effect of the 1943 year class of whitefish on the commercial production from the Wisconsin waters of Lake Michigan and the Michigan waters of Lakes Michigan and Huron is shown by the records of catch for 1940–51 (table 3—data from Baldwin and Saalfeld, 1962).

Production in all three areas showed a marked increase in 1946, reached peaks in 1947 or 1948 and thereafter declined to the level of the early 1940's. A feature of the record is the longer period of high catch in Michigan waters of Lake Michigan than in the other two waters; the bulk of this production came from Green Bay.

The same year also saw a strong year class of another coregonine, the lake herring, *Coregonus artedi*, in Green Bay. Following low production over the period 1939–44 (high of 697,000 pounds in 1939 and a low of 285,000 pounds in 1942) the commercial take of lake herring in State of Michigan waters of Green Bay rose to 2,668,000 pounds in 1948 (Hile, Lunger, and Buettner, 1953).

TABLE 3.—*Production (thousands of pounds) of whitefish in Wisconsin and Michigan waters of Lake Michigan and Michigan waters of Lake Huron, 1940–51*

Year	Lake Michigan		Lake Huron, Michigan
	Wisconsin	Michigan	
1940	197	754	188
1941	401	896	114
1942	279	1,061	95
1943	254	1,152	149
1944	343	1,403	185
1945	331	1,326	181
1946	735	1,822	545
1947	1,807	4,018	3,023
1948	985	4,263	2,972
1949	485	3,007	530
1950	259	2,102	114
1951	242	971	143

Coregonines were not alone in the production of strong 1943 year classes in Lakes Michigan and Huron, as the commercial production of walleye, *Stizostedion vitreum*, likewise rose impressively. This increase was most dramatic in State of Michigan waters of Green Bay, where it rose from

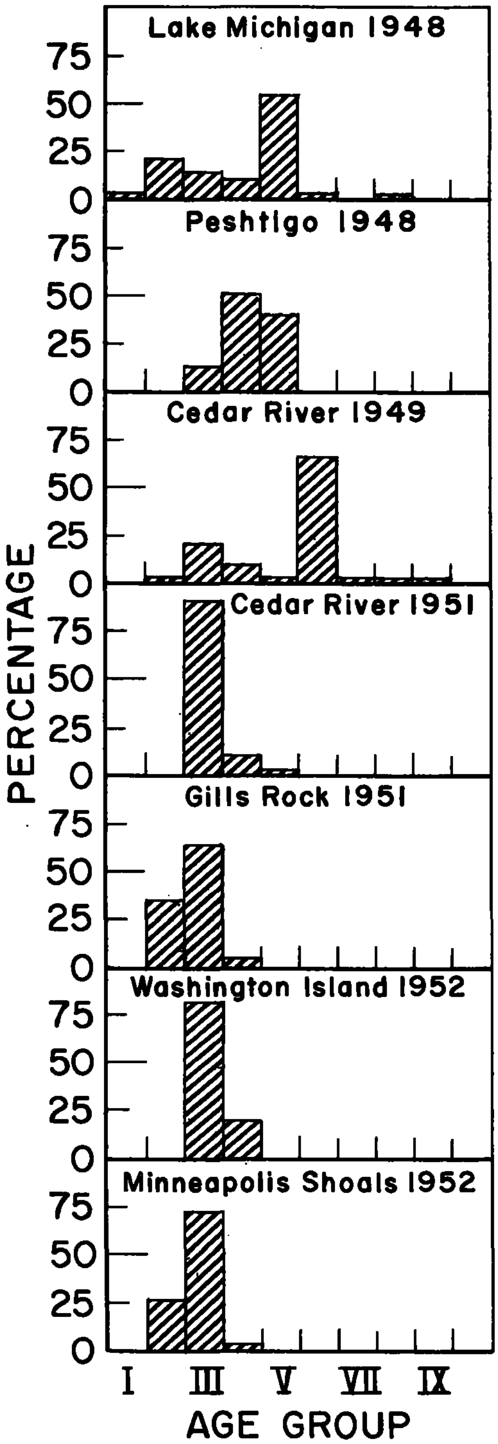

FIGURE 2.—Age composition of whitefish from Lake Michigan and central Green Bay.

the 1929–43 mean of 51,000 pounds to 1,063,000 pounds in 1949 (Hile, Lunger, and Buettner, 1953). Hile (1950) showed that 93.6 percent of a sample of 109 fish taken in the spring of 1949 were 6 years old, and Pycha (1961) gave a complete history of the 1943 year class.

The walleye production in Saginaw Bay, Lake Huron, experienced a rapid decline from an all-time high commercial production of over 2 million pounds in 1942. This decrease was interrupted, however, by a temporary rise in 1946. Hile and Buettner (1959) stated "The recovery of walleyes in 1946 can be attributed to the great strength of the 1943 year class (unpublished records of age)."

LENGTH DISTRIBUTION

No single sample of whitefish in this study is truly suitable for demonstrating a "typical" distribution of the catch of commercial gear. As is common among the coregonines, one age group strongly dominated each sample (see previous section on age composition). This dominance caused individual samples to have a relatively tight length distribution with high modes.

The range of length, mean length, position and relative height of mode, and the percentage of legal-size whitefish varied greatly from collection to collection (table 4), but the seven samples fell clearly into two generally similar groups—the three samples of 1948–49 and the four of 1951–52.

The 1948–49 samples showed high mean lengths (18.9–20.1 inches), high modal lengths (19–21 inches), and high percentages of legal fish (68–96). Dominance or great abundance of the 1943 year class at a time its members had completed 6 growing seasons caused these high values.

The 1951–52 samples were all dominated by III-group fish; consequently the mean lengths (15.6–17.5 inches), the modal lengths (16 or 17 inches), and the percentages of legal fish (41–67) were all lower than in the other group.

The records of table 4 give evidence that pound nets capture more smaller whitefish than do gill nets. Neither of the gill net samples (Peshtigo and Washington Island) included fish shorter than 15.0 inches, whereas four of five pound net samples included smaller fish—some in considerable numbers. Particularly striking is the contrast between the Peshtigo and Lake Michigan samples which were collected on consecutive days.

The individual collections were poorly suited also to show the length distribution of age groups. A single collection usually yielded dependable data on the length distribution of only one age group.

TABLE 4.—*Distribution of total length of whitefish from Lake Michigan and central Green Bay*

[Includes a small number of fish for which ages could not be determined; asterisks indicate modes]

Length interval	Location and year of collection						
	Michigan (1948)	Peshtigo (1948)	Cedar River (1949)	Cedar River (1951)	Gills Rock (1951)	Washington Island (1952)	Minneapolis Shoals (1952)
Inches	*Number of fish*	*Number of fish*	*Number of fish*	*Number of fish*	*Number of fish*	*Number of fish*	*Number of fish*
7.0–7.9					1		
8.0–8.9							
9.0–9.9	1						
10.0–10.9	2				4		
11.0–11.9	1				8		1
12.0–12.9	3		3		13		
13.0–13.9	17		1		14		4
14.0–14.9	17		3		2		25
15.0–15.9	12	1	13	2	5	9	30
16.0–16.9	12	2	16	26	29	*55	35
17.0–17.9	5	9	8	*43	*45	28	*96
18.0–18.9	7	16	10	7	5	10	34
19.0–19.9	8	*20	6	4	2	5	3
20.0–20.9	*52	19	25	1	1	5	2
21.0–21.9	47	13	*58				
22.0–22.9	14		25			1	
23.0–23.9	5		9	1			
24.0–24.9			5	1			
25.0–25.9							
26.0–26.9	1						
Number of fish	204	80	182	85	129	113	230
Percentage at mode	25.5	25.0	31.9	50.6	34.9	48.7	41.7
Average length	18.9	19.4	20.1	17.5	15.6	17.2	16.8
Percentage legal [1]	68.2	96.2	80.2	67.0	41.1	43.4	58.6

[1] Total length, 17 inches or longer; actually, the size limit in State of Michigan waters was not changed from 2 pounds (round) to 17 inches until 1953.

The pooling of length data for fish of corresponding age in different samples, because of annual differences and possible local differences in growth, extends the range somewhat beyond that which would be expected in a single sample of fish of that age and broadens the modal region but does provide a useful idea of the general range and distribution.

Records obtained by the pooling of collections from central Green Bay (table 5) yielded fairly good information on the length distribution of whitefish that had completed 2–6 growing seasons and some data on lengths at other ages. In order to describe the distribution of total lengths in terms of completed growing seasons of the whitefish from central Green Bay, the Minneapolis Shoals collection was not included. Omission of this group, the only one in which growth was in progress when the samples were collected, made it possible to give lengths in terms of completed seasons without the use of any calculated lengths.

If length intervals with only one fish are excluded, length ranges of fish that had completed 2–6 seasons of growth were 5 inches for all but the 6-season fish, which had a range of 6 inches. When all fish are considered, the greatest range was 9 inches (15.0–23.9 inches) for fish that had completed 5 growing seasons. Overlap of lengths for growing seasons 3 through 6 was substantial. Fish 17.0–19.9 inches long could have completed 3, 4, 5, or 6 growing seasons. Every 1-inch length interval above 14 inches included fish of at least 2 ages and usually 3 or 4.

TABLE 5.—*Distribution of total length of whitefish from central Green Bay that had completed one to nine growing seasons*

[Asterisks indicate modes; the lower half of the broad mode at two growing seasons is the one nearer the mean]

Length interval	Completed growing seasons								
	1	2	3	4	5	6	7	8	9
Inches	*Number of fish*	*Number of fish*	*Number of fish*	*Number of fish*	*Number of fish*	*Number of fish*	*Number of fish*	*Number of fish*	*Number of fish*
7.0–7.9	1								
8.0–8.9									
9.0–9.9									
10.0–10.9		4							
11.0–11.9		8							
12.0–12.9		*15							
13.0–13.9		15							
14.0–14.9		2	2						
15.0–15.9			28		1				
16.0–16.9			*120	3	1				
17.0–17.9			109	13	4	1			
18.0–18.9			11	*23	11	2			
19.0–19.9			1	11	*15	5			
20.0–20.9				6	4	37			
21.0–21.9					4	*65			
22.0–22.9				1		24	1		
23.0–23.9					1	9			
24.0–24.9							1	2	2
Number of fish	1	44	271	57	41	143	2	2	2
Average length	7.1	12.4	16.7	18.5	19.2	21.2	23.8	24.6	24.5
Percentage legal [1]	.0	.0	44.7	94.7	95.2	100.0	100.0	100.0	100.0

[1] Total length, 17 inches or longer; actually, the size limit in State of Michigan waters was not changed from 2 pounds (round) to 17 inches until 1953.

LENGTH-WEIGHT RELATION

Whitefish from central Green Bay exhibited considerable sample-to-sample differences in the length-weight relation but the data gave no reason for a conclusion that stocks with different length-weight relations exist in the area (table 6). The Cedar River samples of 1949 and 1951 (both collected in late spring) showed an annual difference as great or nearly as great (3.9 ounces at 17.2 inches; 3.7 ounces at 18.2 inches; and 7.3 ounces at 18.7 inches) as is found between samples from different locations (2.9 ounces at 17.2 inches between Gills Rock and Washington Island; 5.8 ounces at 18.2 and 18.7 inches between Washington Island and Minneapolis Shoals). The pooling of all the central Green Bay samples therefore gives the most useful length-weight information.

The annual weight differences as demonstrated by the Cedar River samples are comparable to fluctuations described for other coregonines (Deason and Hile, 1947, for the kiyi, *Coregonus kiyi*; Van Oosten and Hile, 1949, for the Lake Erie whitefish; Morawa, 1960, whose data showed that adult *Coregonus fera* in Lake Geneva, Switzerland, could lose 25 percent of their weight and 63 percent of their fat between summer and the fall spawning season).

TABLE 6.—*Length-weight relation of whitefish from Lake Michigan and central Green Bay collections*

Total length [1]	Location and year of collection						
	Michigan (1948)	Peshtigo (1948)	Cedar River (1949)	Cedar River (1951)	Gills Rock (1951)	Washington Island (1952)	Minneapolis Shoals (1952)
Inches	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*
7.2					1.6		
7.7							
8.2							
8.7							
9.2							
9.7	4.0						
10.2	4.0				5.6		
10.7	6.5				6.0		
11.2					7.0		6.5
11.7	8.0				8.2		
12.2	8.5		9.3		9.3		
12.7	9.1				10.6		
13.2	11.6		12.0		12.2		
13.7	12.9				13.5		12.8
14.2	15.2				17.0		14.2
14.7	15.8		18.0		18.0		16.5
15.2	18.0		20.8			25.0	18.2
15.7	19.7	25.0	22.3	22.5	20.3	24.0	20.4
16.2	22.1		25.2	22.7	23.9	26.3	23.0
16.7	26.0	26.5	27.2	24.3	26.8	29.7	24.6
17.2	26.0	34.5	30.7	26.8	29.1	32.0	27.0
17.7	33.4	36.5	34.5	29.9	28.6	32.8	29.8
18.2	32.7	38.8	34.4	30.7	35.7	38.0	32.2
18.7	37.5	43.5	40.8	33.5	42.5	40.5	34.7
19.2	38.8	43.4	38.8	39.5	40.0	40.1	
19.7	42.0	48.0	46.4	42.7	49.0		43.7
20.2	47.7	53.7	48.8	47.5	52.0	48.7	49.0
20.7	52.7	53.6	54.2			53.0	54.0
21.2	56.3	59.1	56.4				
21.7	61.2	65.2	61.5				
22.2	67.7		64.6			70.5	
22.7	65.3		69.6				
23.2	73.8		77.2				
23.7	85.9		79.2	79.5			
24.2			78.0				
24.7			93.1				
25.2							
25.7							
26.2	100.0						

[1] Midpoints of 0.5-inch intervals.

The Lake Michigan sample of 1948 is held to be different from the central Green Bay fish on the basis of mean weights much lighter than those of the Peshtigo fish collected only a day earlier (26.0 and 34.5 ounces at 17.2 inches; 32.7 and 38.8 ounces at 18.2 inches; 38.8 and 43.4 ounces at 19.2 inches); the Lake Michigan fish furthermore were generally lighter than those of other Green Bay samples (table 6).

A length-weight equation, to be most useful, should include fish of both sexes, sampled at various times of the year over a period of years. Bias from annual and seasonal variations, sex differences, and maturity and state of sex organs is minimized by this procedure. The resulting general curve, though not exactly descriptive of fish collected at any given time and considerably different from those of some samples, produces the most usable record.

The samples from central Green Bay meet the above-stated requirements fairly well because both sexes are represented and collection dates covered all seasons—the Peshtigo sample in mid-October 1948; the Cedar River samples in May 1949 and June 1951, the Gills Rock sample in June 1951, the Washington Island sample in February 1952, and the Minneapolis Shoals sample in July and September 1952. Selected fish taken at other times were also used to provide more small individuals. Effects of annual and seasonal fluctuations on determination of the length-weight relation were therefore lessened to a fair degree in central Green Bay. The Lake Michigan data, on the other hand, are based on a single October sample.

Length-weight equations were derived for the Lake Michigan sample and the central Green Bay samples by fitting straight lines by least squares to the logarithms of the lengths and weights. The curves in figure 3 are the graphs of the following equations:

Lake Michigan

$$W=1.9422\times10^{-3}\,L^{3.35903}$$

Central Green Bay

$$W=1.8756\times10^{-3}\,L^{3.38647}$$

where

W=weight in ounces,

and

L=total length in inches.

The weight of the Lake Michigan whitefish increased as the 3.35903 power of the length, and the weight of the central Green Bay fish as the 3.38647 power of the length. The difference between the exponents cannot be considered great. Both equations show a substantial departure from the cube relation; plumpness increasesco nsiderably with increase of length.

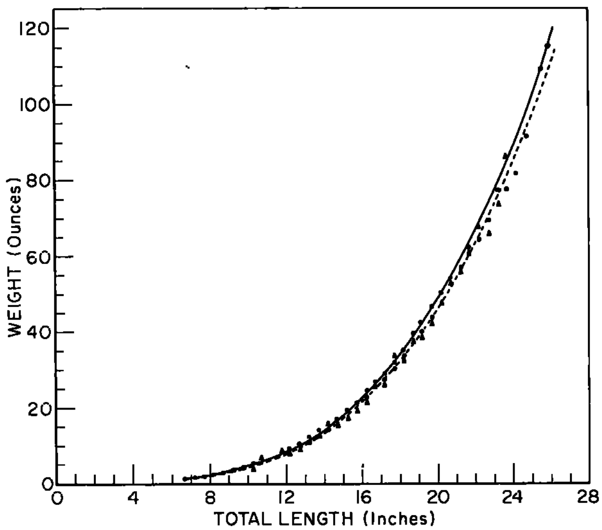

FIGURE 3.—Length-weight relation of whitefish from Lake Michigan and central Green Bay. The broken line represents the calculated weights and the triangles the empirical weights of the Lake Michigan fish; the solid line and dots represent the central Green Bay fish.

Agreement of empirical and calculated weights of the Lake Michigan whitefish (table 7; fig. 3) varied considerably according to length and number of fish. Over the length range, 20.2–22.2 inches, where the fish were most plentiful, the empirical weights were all higher than the calculated weights by 0.6–3.1 ounces. The length range, 9.7–19.7 inches, had empirical weights both greater and smaller than the calculated weights. The maximum deviation of empirical weight below the calculated was 1.4 ounces at 17.2 inches, and the maximum deviation above the calculated weight was 3.1 ounces at the next interval, 17.7 inches. At 11 lengths the empirical weight was less than the calculated, and at 8 it was greater. The greatest disagreement over the entire length range was 12.8 ounces at 26.2 inches (only one fish).

The empirical weights of the Green Bay fish were below the calculated weights at lengths above 21.2 inches; the discrepancies ranged from a low of 1.0 ounce at 21.7 inches to a high of 9.5 ounces at 24.2 inches. Over the remainder of the length range (6.7–20.7 inches) empirical and calculated weights were the same at 4 lengths, differed by only 0.1 or 0.2 ounce at 14 and disagreed by 0.5–1.8 ounces at 10. At 16 of the 24 lengths where the two weights differed, the empirical weight was less than the calculated weight.

TABLE 7.—*Length-weight relation of whitefish from Lake Michigan and in the combined collections from central Green Bay*

[Calculated weights from equations given in text]

Total length [1]	Lake Michigan			Central Green Bay		
	Number of fish	Weight		Number of fish	Weight	
		Calculated	Empirical		Calculated	Empirical
Inches		*Ounces*	*Ounces*		*Ounces*	*Ounces*
6.7	--------	1.1	--------	6	1.1	1.3
7.2	--------	1.4	--------	15	1.6	1.6
7.7	--------	1.9	--------	27	1.9	2.0
8.2	--------	2.2	--------	26	2.3	2.4
8.7	--------	2.8	--------	12	2.8	2.7
9.2	--------	3.3	--------	5	3.5	3.5
9.7	1	4.0	4.0	--------	4.2	--------
10.2	1	4.8	4.0	8	4.9	5.0
10.7	1	5.5	6.5	10	5.8	5.6
11.2	--------	6.4	--------	11	6.7	6.7
11.7	1	7.6	8.0	19	7.7	7.8
12.2	1	8.6	8.5	15	8.9	9.1
12.7	2	9.9	9.1	12	10.3	10.5
13.2	6	11.3	11.6	13	11.6	12.2
13.7	11	12.8	12.9	9	13.3	13.1
14.2	7	14.5	15.2	17	14.9	14.4
14.7	10	16.1	15.8	16	16.9	17.0
15.2	7	18.2	18.0	33	18.8	19.5
15.7	5	20.2	19.7	42	21.1	21.1
16.2	6	22.5	22.1	81	23.4	24.9
16.7	6	24.9	26.0	89	25.9	26.7
17.2	3	27.4	26.0	133	28.7	28.6
17.7	2	30.3	33.4	89	31.6	30.6
18.2	3	33.3	32.7	56	34.7	33.8
18.7	4	36.4	37.5	27	38.0	39.8
19.2	4	39.7	38.8	22	41.6	41.5
19.7	4	43.3	42.0	14	45.4	46.5
20.2	23	47.1	47.7	20	49.3	50.7
20.7	29	51.2	52.7	29	53.7	53.9
21.2	25	55.4	56.3	39	58.2	57.0
21.7	22	59.9	61.2	32	62.9	61.9
22.2	11	64.6	67.7	17	68.0	64.7
22.7	3	69.7	65.3	12	73.3	69.4
23.2	3	74.9	73.8	5	78.9	77.2
23.7	2	80.6	85.9	10	84.9	77.8
24.2	--------	86.5	--------	2	91.0	81.5
24.7	--------	92.6	--------	5	97.6	91.9
25.2	--------	99.0	--------	--------	104.5	--------
25.7	--------	105.7	--------	--------	111.6	--------
26.2	1	112.8	100.0	--------	119.1	--------

[1] Midpoint of 0.5-inch intervals.

CALCULATED GROWTH IN LENGTH

The records of sex for all fish made it possible to study sex difference in growth rate. No difference was found in four of the seven collections; females grew slightly faster in two and males in one. Because sex differences were nil or small, and did not favor either males or females, separation of the sexes was not justified. The growth of whitefish at each locality was described by combining the data for males and females. The mean calculated length at the end of each year of life was determined for each age group of the various samples (tables 8–14).

The calculated lengths of the whitefish in the various collections give little evidence of "Lee's phenomenon" of decrease of growth rate with increase in the age of the fish for which lengths are computed. Among the collections in which

Table 8.—*Calculated total length of whitefish taken from Europe Bay area of Lake Michigan, October 14, 1948*

[Asterisks indicate length at time of capture]

Age group	Number of fish	Calculated length at end of year of life								
		1	2	3	4	5	6	7	8	9
		Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
I	4	6.5	*10.5							
II	40	6.4	10.6	*14.1						
III	27	5.7	10.2	13.9	*16.5					
IV	20	5.9	9.7	14.7	18.0	*20.1				
V	106	5.1	9.5	13.4	17.0	19.4	*21.1			
VI	3	6.3	10.1	14.9	18.5	20.6	22.2	*23.2		
VIII	1	5.5	12.2	16.3	19.2	21.5	23.1	24.2	25.2	*26.0
Grand average calculated length		5.6	9.8	13.8	17.1	19.5	21.2	23.4	25.2	26.0
Increment of average		5.6	4.2	4.0	3.3	2.4	1.7	2.2	1.8	0.8
Grand average increment of length		5.6	4.2	4.0	3.4	2.4	1.6	1.1	1.0	0.8
Sum of average increments		5.6	9.8	13.8	17.2	19.6	21.2	22.3	23.3	24.1

Table 9.—*Calculated total length of whitefish taken at Peshtigo, October 13, 1948*

[Asterisks indicate length at time of capture]

Age group	Number of fish	Calculated length at end of year of life					
		1	2	3	4	5	6
		Inches	Inches	Inches	Inches	Inches	Inches
III	9	5.8	11.5	15.6	*18.0		
IV	37	6.1	10.8	14.8	17.6	*19.0	
V	29	6.4	11.7	15.2	17.7	19.3	*20.5
Grand average calculated length		6.2	11.2	15.0	17.7	19.1	20.5
Increment of average		6.2	5.0	3.8	2.7	1.4	1.4
Grand average increment of length		6.2	5.0	3.8	2.7	1.5	1.2
Sum of average increments		6.2	11.2	15.0	17.7	19.2	20.4

Table 10.—*Calculated total length of whitefish taken at Cedar River, May 18, 1949*

[Asterisks indicate length at time of capture]

Age group	Number of fish	Calculated length at end of year of life								
		1	2	3	4	5	6	7	8	9
		Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
II	2	7.0	*12.6							
III	34	6.5	11.6	*16.1						
IV	15	5.9	10.7	15.3	*18.3					
V	3	5.9	10.7	15.3	17.9	*19.1				
VI	114	5.8	11.0	15.1	18.3	20.2	*21.6			
VII	2	8.3	12.9	17.5	20.1	21.7	22.8	*23.8		
VIII	2	7.8	13.8	17.4	20.3	21.6	22.7	23.1	*24.5	
IX	2	7.7	10.5	15.9	18.9	20.6	21.9	23.1	23.8	*24.5
Grand average calculated length		6.0	11.1	15.4	18.3	20.3	21.7	23.3	24.1	24.5
Increment of average		6.0	5.1	4.3	2.9	2.0	1.4	1.6	0.8	0.4
Grand average increment of length		6.0	5.1	4.3	3.2	1.9	1.4	0.9	1.0	0.7
Sum of average increments		6.0	11.1	15.4	18.6	20.5	21.9	22.8	23.8	24.5

Table 11.—*Calculated total length of whitefish taken at Cedar River, June 15, 1951*

[Asterisks indicate length at time of capture]

Age group	Number of fish	Calculated length at end of year of life				
		1	2	3	4	5
		Inches	Inches	Inches	Inches	Inches
III	70	6.8	12.3	*17.1		
IV	7	5.9	10.7	15.4	*18.5	
V	1	7.5	13.4	17.3	21.2	*23.6
Grand average, calculated length		6.8	12.1	16.9	18.8	23.6
Increment of average		6.8	5.3	4.8	1.9	4.8
Grand average increment of length		6.8	5.3	4.8	3.2	2.4
Sum of average increments		6.8	12.1	16.9	20.1	22.5

Table 12.—*Calculated total length of whitefish taken at Gills Rock, June 11, 1951*

[Asterisks indicate length at time of capture]

Age group	Number of fish	Calculated length at end of year of life			
		1	2	3	4
		Inches	Inches	Inches	Inches
I	1	*7.1			
II	41	7.1	*12.4		
III	78	6.9	12.3	*16.9	
IV	5	7.4	10.9	14.8	*18.2
Grand average calculated length		7.0	12.2	16.7	18.2
Increment of average		7.0	5.2	4.5	1.5
Grand average increment of length		7.0	5.2	4.5	3.4
Sum of average increments		7.0	12.2	16.7	20.1

Table 13.—*Calculated total length of whitefish taken north of Washington Island, February 14, 1952*

[Asterisks indicate length at time of capture]

Age group	Number of fish	Calculated length at end of year of life			
		1	2	3	4
		Inches	*Inches*	*Inches*	*Inches*
III	89	7.4	12.5	*16.6	------
IV	21	6.5	12.0	16.2	*19.1
Grand average calculated length	------	7.3	12.4	16.6	19.1
Increment of average	------	7.3	5.1	4.2	2.5
Grand average increment of length	------	7.3	5.1	4.2	2.9
Sum of average increments	------	7.3	12.4	16.6	19.5

Table 14.—*Calculated total length of Whitefish taken at Minneapolis Shoals, July 31 and September 16, 1952*

Age group	Number of fish	Length at capture	Calculated length at end of year of life			
			1	2	3	4
		Inches	*Inches*	*Inches*	*Inches*	*Inches*
I	1	11.2	7.5	------	------	------
II	59	15.0	7.0	12.1	------	------
III	162	17.4	6.9	11.6	15.5	------
IV	5	20.1	6.0	12.2	16.0	18.8
Grand average calculated length	------	------	7.0	11.8	15.5	18.8
Increment of average	------	------	7.0	4.8	3.7	3.3
Grand average increment of length	------	------	7.0	4.8	3.8	2.8
Sum of average increments	------	------	7.0	11.8	15.6	18.4

few age groups were well represented (Peshtigo, 1948, and the three 1950–51 samples) the discrepancies in calculated length appear to be randomly distributed. The two samples that had fair to good representation of several age groups within the range II–VI (Lake Michigan, 1948; Cedar River, 1949) gave some indication of a progressive decline of calculated lengths with age of the younger fish and then an increase among the older fish.

The lack of a progressive change of growth with increase in age leads to closely similar results in the estimation of general growth by grand average calculated length and by the summation of grand average increments of length (see bottom portions of tables 8–14). The summation of increments does have the decided advantage, however, of smoothing out these irregularities brought about in the data for the later years of life by the successive dropping out of poorly represented age groups. Growth curves based on the annual increments were chosen, therefore, for the comparison of growth of whitefish in the different collections (table 15).

Table 15.—*Calculated total length of whitefish from Lake Michigan and central Green Bay*

[Based on successive addition of grand average increments]

Location and year of capture	Calculated length at end of year of life								
	1	2	3	4	5	6	7	8	9
1948	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
Lake Michigan	5.6	9.8	13.8	17.2	19.6	21.2	22.3	23.3	24.1
Peshtigo	6.2	11.2	15.0	17.7	19.2	20.4	------	------	------
1949									
Cedar River	6.0	11.1	15.4	18.6	20.5	21.9	22.8	23.8	24.5
1951									
Cedar River	6.8	12.1	16.9	20.1	22.5	------	------	------	------
Gills Rock	7.0	12.2	16.7	20.1	------	------	------	------	------
1952									
Washington Island	7.3	12.4	16.6	19.5	------	------	------	------	------
Minneapolis Shoals	7.0	11.8	15.6	18.4	------	------	------	------	------

The general growth data for the seven collections from six localities show considerable differences among calculated lengths for each year of life. The Lake Michigan whitefish stands clearly apart from all others, however, by reason of its poorer growth in the first 3 years of life. In all comparisons during the first 3 years of life the Lake Michigan fish are smaller; the minimum difference was 0.4 inch (1949 Cedar River fish at the end of the first year of life) and the maximum difference was 3.1 inches (1951 Cedar River fish at the end of the third year of life). Improved growth of the Lake Michigan fish in later years reduced the differences from the Green Bay fish to unimportance, but the form of the growth curve in the two areas was decidedly different. The growth of fish from Gills Rock, collected only a few miles from Europe Bay in Lake Michigan proper (fig. 1), differed from growth in Lake Michigan in about the same manner as did the growth of whitefish from other Green Bay localities.

The records for central Green Bay collections leave little doubt of the existence of real differences in the growth of whitefish of the various samples, but do not warrant any general conclusion on the presence of stocks with permanent and significant differences of growth. The substantial differences in growth (15.4 and 16.9 inches at the end of 3 years, and 18.6 and 20.1 inches at the end of 4 years) of fish in the two collections from Cedar River are much the same as the difference (15.0 and 16.6 inches at 3 years and 17.7 and 19.5 inches at 4 years) of fish from Peshtigo and Washington Island, or the difference (15.6 and 16.9 inches at 3 years and 18.4 and 20.1 inches at 4 years) of fish from Minneapolis Shoals and Cedar River, 1951.

Although the effects of such factors as random variability, gear selection, and segregation by size should not be discounted entirely, a major cause of variation in estimates of growth has been found by many investigators to be annual fluctuations of growth rate in combination with sample differences of year-class composition. The samples of the present study as a group are poorly suited for studies of fluctuations in growth—lack of collections in consecutive years from any locality, small numbers of well-represented age groups in the majority of samples. Two, however (Lake Michigan, 1948; Cedar River, 1949), do lend themselves to the type of analysis described by Hile (1941) and subsequently employed by numerous investigators.

Growth fluctuated from roughly 16 percent above to 13 percent below average (total range, 29 percent) in Lake Michigan and from 4 percent above to 3 percent below (total range, 7 percent) for Cedar River within the 6-year period 1943–48 (table 16). Fluctuations of this magnitude, especially those in Lake Michigan, can affect estimates of growth materially. Even wider year-to-year changes in growth of Lake Erie whitefish were reported by Van Oosten and Hile, 1947, who recorded a change from 15 percent above the 1924–30 average in 1927 to 25 percent below in 1930.

A feature of the data on fluctuations of growth is the close agreement between Lake Michigan and Cedar River collections. Without exception the direction of the annual change was the same in the two localities and the annual percentage deviations were also all on the same side of the mean. So close was the agreement that the coefficient of correlation (r) between the two series was 0.824, a value that is significant at the probability level $0.05 > p > 0.02$. Evidence is strong therefore that the factors that brought about changes in growth rate in the two areas were closely similar or had similar fluctuations.

If the differences among growth curves for the whitefish in the various samples from Green Bay were attributable primarily to fluctuations in growth rate, the calculated lengths of members of the same year class from different localities should agree very closely. The selected comparisons of table 17 do not lead to a clear conclusion. The three year classes collected at both Peshtigo and Cedar River (1943, 1944, and 1945) give evidence of a difference in the style of growth at the two localities. The calculated lengths for Peshtigo whitefish were greater than those of whitefish from Cedar River in 7 of 9 comparisons (exceptions 5.8 and 5.9 inches at the end of the first year for the 1945 year class; and 14.8 and 15.3 inches at 3 years for the 1944 year class) over the first 3 years of life, but the Peshtigo fish had the shorter calculated lengths in all of six comparisons beyond the third year.

TABLE 16.—*Annual fluctuations in the growth of whitefish in two samples expressed as percentage deviations from the 1943–48 mean*

[Estimates based on annual increments of length of age groups II–V of the 1948 collection from Lake Michigan and age groups III–VI of the 1949 collection from Cedar River; analysis followed procedure described by Hile (1941)]

Year	Percentage deviation from mean	
	Lake Michigan	Cedar River
1943	−7.8	−1.0
1944	6.7	.7
1945	−1.4	−3.0
1946	15.7	4.2
1947	.1	1.8
1948	−13.5	−2.6

TABLE 17.—*Comparisons of growth of whitefish of the same year class collected at different localities in central Green Bay*

[Data from tables 9–14]

Year class and locality	Year of capture	Age group	Number of fish	Calculated length at end of year of life					
				1	2	3	4	5	6
1943				*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Peshtigo	1948	V	29	6.4	11.7	15.2	17.7	19.3	20.5
Cedar River	1949	VI	114	5.8	11.0	15.1	18.3	20.2	21.6
1944									
Peshtigo	1948	IV	37	6.1	10.8	14.8	17.6	19.0	------
Cedar River	1949	V	3	5.9	10.7	15.3	17.9	19.1	------
1945									
Peshtigo	1948	III	9	5.8	11.5	15.6	18.0	------	------
Cedar River	1949	IV	15	5.9	10.7	15.3	18.3	------	------
1948									
Cedar River	1951	III	70	6.8	12.3	17.1	------	------	------
Gills Rock	1951	III	78	6.9	12.3	16.9	------	------	------
Washington Island.	1952	IV	21	6.5	12.0	16.2	19.1	------	------
Minneapolis Shoals.	1952	IV	5	6.0	12.2	16.0	18.8	------	------
1949									
Gills Rock	1951	II	41	7.1	12.4	------	------	------	------
Washington Island.	1952	III	89	7.4	12.5	16.6	------	------	------
Minneapolis Shoals.	1952	III	162	6.9	11.6	15.5	------	------	------

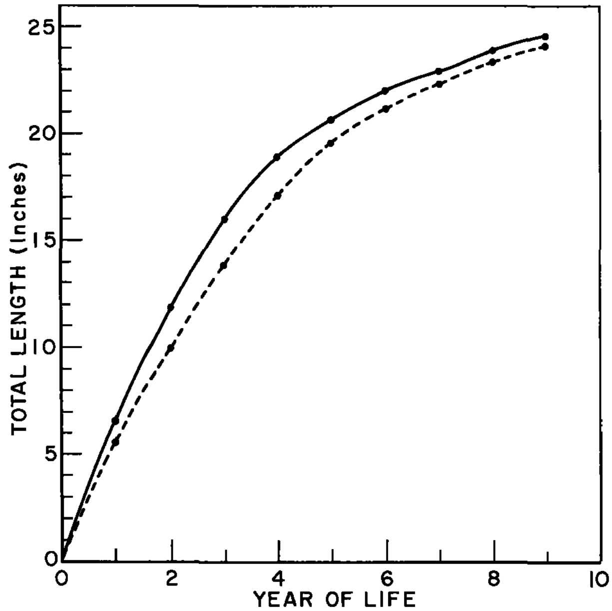

FIGURE 4.—Calculated length of whitefish from Lake Michigan (broken line) and central Green Bay (solid line).

The calculated lengths of members of the 1948 year class from Cedar River and Gills Rock agreed very well; the lengths were shorter at Washington Island than at the former localities and still shorter at Minneapolis Shoals (exception in second year of life).

Whitefish of the 1949 year class had slightly lower calculated lengths at Gills Rock than at Washington Island, a situation directly opposite that shown by the 1948 year class. No explanation can be offered for this disagreement between the data for two year classes from the same collections.

The data for whitefish from Minneapolis Shoals were consistent in that calculated lengths for both the 1948 and 1949 year classes ran lower than at other locations.

The general conclusion seems warranted that some real growth differences may exist among whitefish in different localities within central Green Bay. These differences probably are not large and most likely can be exceeded by year-to-year differences at a single locality. It appears valid, therefore, to combine the data for all Green Bay samples to describe the general character of growth in the area (table 18).

The calculated lengths of table 18, like those of the component samples, lack a trend toward systematic change with age, except for a slight tendency for the calculated lengths for the first 3 or 4 years of life first to decrease and then to increase with the age of the fish on which calculations were based. The agreement between estimates of general growth from grand average calculated lengths and from the summation of the grand average increments was good. The latter estimate was selected for the comparison of the growth of whitefish in Lake Michigan and central Green Bay (table 19; fig. 4).

The outstanding difference between the growth of whitefish in Lake Michigan and central Green Bay was the slower growth of the Lake Michigan fish for the earlier years of life and their more rapid growth in the later years. The situation is seen most clearly in the annual increments.

TABLE 18.—*Calculated total length of whitefish from central Green Bay waters*

[All collections combined]

Age group[1]	Number of fish	Calculated length at end of year of life								
		1	2	3	4	5	6	7	8	9
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
I	2	7.3								
II	100	7.1	12.3							
III	442	6.9	12.0	16.2						
IV	90	6.2	11.1	15.4	18.2					
V	33	6.4	11.7	15.2	17.9	19.1				
VI	114	5.8	11.0	15.1	18.3	20.2	21.6			
VII	2	8.3	12.9	17.5	20.1	21.7	22.8	23.8		
VIII	2	7.8	13.8	17.4	20.3	21.6	22.7	23.1	24.5	
IX	2	7.7	10.5	15.9	18.9	20.6	21.9	23.1	23.8	24.5
Grand average calculated length		6.6	11.8	15.8	18.2	20.0	21.7	23.3	24.1	24.5
Increment of average		6.6	5.2	4.0	2.4	1.8	1.7	1.6	.8	.4
Grand average increment of length		6.6	5.2	4.2	2.9	1.7	1.4	.9	1.0	.7
Sum of average increments		6.6	11.8	16.0	18.9	20.6	22.0	22.9	23.9	24.6

[1] Age groups of late-autumn samples have been combined with the next higher age groups of spring and summer samples.

TABLE 19.—*Calculated total length of whitefish from Lake Michigan and central Green Bay*

[Data from tables 8 and 18; based on successive addition of grand average increments]

Year of life	Lake Michigan		Green Bay		Difference of length	Ratio of increments
	Length	Increment	Length	Increment		
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	
1	5.6	5.6	6.6	6.6	1.0	1.1
2	9.8	4.2	11.8	5.2	2.0	1.2
3	13.8	4.0	16.0	4.2	2.2	1.05
4	17.2	3.4	18.9	2.9	1.7	.8
5	19.6	2.4	20.6	1.7	1.0	.7
6	21.2	1.6	22.0	1.4	.8	.8
7	22.3	1.1	22.9	.9	.6	.8
8	23.3	1.0	23.9	1.0	.6	1.0
9	24.1	.8	24.6	.7	.5	.8

The increments for Lake Michigan whitefish were the shorter by 1.0 inch in both the first and second years of life and by 0.2 inch in the third. Subsequently the increments for Lake Michigan fish were greater than those for Green Bay fish with the single exception of the equal values of 1.0 inch for the eighth year. The ratio of the annual increment for Green Bay fish to that of Lake Michigan fish exceeded 1.0 the first 3 years and was 0.7–1.0 the next 6 years. This shift in the relation of the increments causes the growth curves to diverge to a maximum of 2.2 inches at the end of 3 years of life and then to converge until the Green Bay fish were the longer by only 0.5 inch at the end of 9 years.

Whitefish of both stocks attained the minimum legal length of 17 inches in the fourth growing season. Green Bay whitefish reached that length fairly early in the fourth year but those from Lake Michigan were not 17 inches long until near the close of the growing season.

CALCULATED GROWTH IN WEIGHT

The difference between linear growth in Lake Michigan and central Green Bay whitefish and differences in the length-weight relation are reflected in differences in general growth in weight (table 20; fig. 5).

Although the calculated weights were nearly the same at the end of the first year (0.9 ounce, Lake Michigan; 1.0 ounce, Green Bay), the Green Bay fish were the heavier by 3.7 ounces at the end of the second year. This advantage increased rapidly to 12.0 ounces at the end of 4 years, declined to 8.7 ounces at the end of 7, and then rose to the maximum of 12.2 ounces at the end of 9 years.

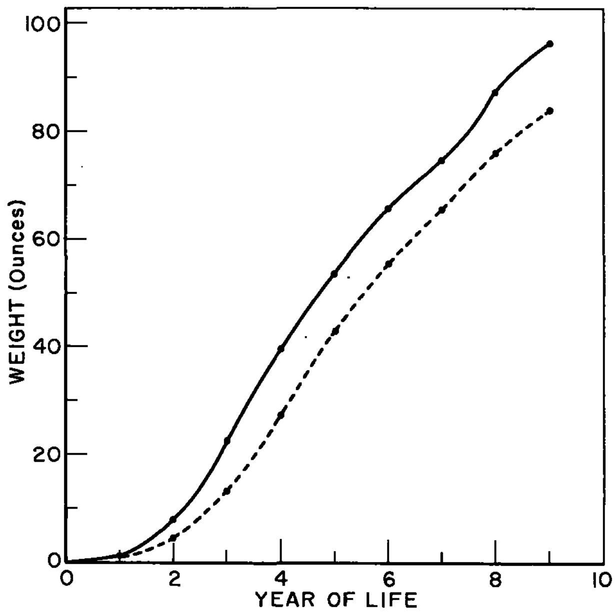

FIGURE 5.—Calculated growth in weight of whitefish from Lake Michigan (broken line) and central Green Bay (solid line).

TABLE 20.—*Calculated weight at the end of each year of life of whitefish from Lake Michigan and central Green Bay*

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

Year of life	Lake Michigan		Green Bay		Difference of weight	Ratio of increments
	Weight	Increment	Weight	Increment		
	Ounces	*Ounces*	*Ounces*	*Ounces*	*Ounces*	
1	0.9	0.9	1.0	1.0	0.1	1.1
2	4.2	3.3	7.9	6.9	3.7	2.1
3	13.1	8.9	22.4	14.5	9.3	1.6
4	27.4	14.3	39.4	17.0	12.0	1.2
5	42.6	15.2	53.7	14.3	11.1	.9
6	55.4	12.8	65.9	12.2	10.5	.95
7	65.7	10.3	74.4	8.5	8.7	.8
8	76.1	10.4	87.3	12.9	11.2	1.2
9	84.0	7.9	96.2	8.9	12.2	1.1

The ratio of increments of weight showed the Green Bay fish to have greater annual growth in weight the first 4 years of life (low of 1.1 the first year and a high of 2.1 the second); the trend was reversed the next 3 years, when the Lake Michigan fish displayed greater annual increases. Increases for the Green Bay fish were again the greater in years 8 and 9. This relation differs from that of linear growth because once the Lake Michigan fish had the greater annual increments their increments continued to be the larger, with a single exception, for years 4 through 9.

The annual increments of weight of the Lake Michigan whitefish increased from 0.9 ounce at the end of the first year to a maximum of 15.2 ounces in the fifth and thereafter declined (except for the eighth) to 7.9 ounces in the ninth year. The increments of central Green Bay fish increased from the first-year value of 1.0 ounce to the fourth-year maximum of 17.0 ounces. The downward trend was then irregular; the lowest value was 8.5 ounces at the seventh year of life.

Without exception the Green Bay fish attained the weights of 1, 2, 3, 4, and 5 pounds in a year earlier than did the Lake Michigan fish (examples, 1 pound during third year in Green Bay and fourth in Lake Michigan; 3 pounds in fifth year in Green Bay and sixth in Lake Michigan; 5 pounds in eighth year in Green Bay and ninth in Lake Michigan).

The 2-pound size limit in effect in the State of Michigan waters of Green Bay at the time of sampling was reached by the Green Bay fish during the fourth year of life.

COMPARISON WITH GROWTH IN OTHER LAKE MICHIGAN WATERS

This section has been limited to the growth of whitefish in Lake Michigan since a full review and comparison of growth in the various Great Lakes waters was recently published by Dryer (1963). The data of table 21 are limited to the first 4 years of life, the period covered in the only previous publication on the growth of whitefish in Lake Michigan (Roelofs, 1958). Among the four areas for which growth data are now available, the South Fox Island fish had by far the poorest growth (only 13.2 inches at the end of 4 years). The central Green Bay fish grew the fastest; they were at least 1.0 inch longer than the others at any of the 4 years of life. Growth was similar in the Lake Michigan and Big Bay de Noc (northern Green Bay) areas. The calculated lengths were equal at 5.6 inches at the end of the first year and at 13.8 inches at the end of the third. The Lake Michigan fish were the longer at the end of 2 years (9.8 as compared to 9.4 inches) but the Bay de Noc fish were the larger (17.9 as compared to 17.2 inches) at 4 years.

The South Fox Island whitefish and the central Green Bay fish are different from each other and from both the Lake Michigan and Big Bay de Noc fish. The data offer no evidence, however, as to whether the growth rates of Lake Michigan and Big Bay de Noc fish are significantly different.

TABLE 21.—*Growth in total length of whitefish in different parts of Lake Michigan*

Area and source of data	Calculated length at end of year of life			
	1	2	3	4
Present study:	*Inches*	*Inches*	*Inches*	*Inches*
Lake Michigan	5.6	9.8	13.8	17.2
Central Green Bay	6.6	11.8	16.0	18.9
Roelofs (1958):				
Big Bay de Noc	5.6	9.4	13.8	17.9
South Fox Island	4.3	7.0	9.9	13.2

SEX RATIO

The sex ratio ranged so widely from sample to sample (36 to 84 percent males—see bottom part of table 22) that it is extremely difficult to judge the possible effects of local and seasonal differences, or gear selectivity.

Data on sex ratio often vary erratically when samples are collected near or during the spawning season. The strong preponderance of males in the October 1948 collections from Lake Michigan (77 percent) and Peshtigo (84 percent) might be attributed to prespawning segregation, but the equally great abundance of males (80 percent) in the June 1951 sample from Gills Rock makes this explanation much less attractive. The two collections made in late spring and early summer at Cedar River (45 and 48 percent males) agreed well. Agreement was good also between the July and September samples from Minneapolis Shoals (combined in table 22); the percentage of males was 59 in July and 60 in September. These two pairs of samples from the same locality, then, offer some evidence of local stability, within certain months at least. The only sample in which males were extremely scarce was taken in February 1952 at Washington Island.

Evidence is lacking for any effect of gear on the sex-ratio data. The two gill net samples had the highest (84 percent, Peshtigo) and the lowest (36 percent, Washington Island) percentages of males. The variation was wide also among the remaining samples, all from pound nets; here the percentage of males ranged from 45 (Cedar River) to 80 (Gills Rock).

It seems to be impossible also to speak of a trend in sex ratio with increase of age. A trend toward decrease in the percentage of males with increased age is clearly apparent in the Lake Michigan data but is lacking in the data for Cedar River, 1949—the other sample that covered a fair range of age groups. No clear trend can be established for the remaining samples.

TABLE 22.—*Sex composition of whitefish from Lake Michigan and central Green Bay*

Age and item	Lake Michigan October 1948	Peshtigo October 1948	Cedar River May 1949	Cedar River June 1951	Gills Rock June 1951	Washington Island February 1952	Minneapolis Shoals July and September 1952
I group:							
Percentage males	100	-------	-------	-------	100	-------	100
Number of fish	(4)	-------	-------	-------	(1)	-------	(1)
II group:							
Percentage males	100	-------	33	-------	100	-------	51
Number of fish	(40)	-------	(3)	-------	(41)	-------	(59)
III group:							
Percentage males	100	100	50	48	70	33	63
Number of fish	(27)	(9)	(34)	(70)	(78)	(89)	(162)
IV group:							
Percentage males	80	87	40	43	60	48	20
Number of fish	(20)	(37)	(15)	(7)	(5)	(21)	(5)
V group:							
Percentage males	61	76	67	0	-------	-------	-------
Number of fish	(106)	(29)	(3)	(1)	-------	-------	-------
VI group:							
Percentage males	33	-------	46	-------	-------	-------	-------
Number of fish	(3)	-------	(114)	-------	-------	-------	-------
VII group:							
Percentage males	-------	-------	50	-------	-------	-------	-------
Number of fish	-------	-------	(2)	-------	-------	-------	-------
VIII group:							
Percentage males	100	-------	0	-------	-------	-------	-------
Number of fish	(1)	-------	(2)	-------	-------	-------	-------
IX group:							
Percentage males	-------	-------	100	-------	-------	-------	-------
Number of fish	-------	-------	(1)	-------	-------	-------	-------
Ages combined:							
Percentage males	77	84	45	48	80	36	60
Number of fish	(201)	(75)	(174)	(79)	(125)	(110)	(227)

The only conclusion warranted by the data of table 22 is that segregation by sex can be pronounced at times other than near the spawning period and/or that local differences in the sex ratio are extremely large.

AGE AND SIZE AT MATURITY

Usable data on both sex and maturity were available only for the Minneapolis Shoals collections of July and September 1952.

The single I-group male and all females of age group II were immature (table 23). Some males (16.7 percent) were mature as age group II and most males (87.3 percent) and a majority of the females (61.0 percent) were mature as age group III. The five IV-group whitefish (one male and four females; no older fish in the sample) all were mature.

All whitefish shorter than 14.5 inches were immature and all longer than 18.4 inches were mature. The first mature males appeared at 14.5–14.9 inches. The percentage of mature males reached 71.5 at 16.0–16.4 inches and was 100 percent above 18 inches (table 24). The first mature female appeared at 16.5–16.9 inches (2 inches longer than for the males); 68.7-percent maturity was reached at 17.0–17.4 inches and 100 percent above 18.4 inches (0.5 inch longer than for males). More than half of all fish of each sex were mature at all lengths, greater than the 17-inch size limit.

TABLE 23.—*Relation of age to maturity of whitefish taken at Minneapolis Shoals in July and September 1952*

[The single I-group male was immature; the 5 IV-group fish (1 male; 4 females) were all mature]

Sex and state of gonads	Age group II	Age group III
Male:		
Mature	5	90
Immature	25	13
Percentage mature	16.7	87.3
Female:		
Mature	0	36
Immature	29	23
Percentage mature	0.0	61.0

TABLE 24.—*Relation of total length (inches) to maturity of whitefish taken at Minneapolis Shoals in July and September 1952*

[All fish shorter than 14.5 inches were immature, and all longer than 18.4 inches were mature]

Length	Males: Number of fish	Males: Percentage mature	Females: Number of fish	Females: Percentage mature
14.5–14.9	6	16.7	4	0.0
15.0–15.4	11	9.0	8	.0
15.5–15.9	6	16.7	5	.0
16.0–16.4	7	71.5	7	.0
16.5–16.9	15	93.3	6	16.7
17.0–17.4	39	79.5	16	68.7
17.5–17.9	20	90.0	21	71.5
18.0–18.4	18	100.0	9	77.7

ACKNOWLEDGMENTS

Among the persons who collected or assisted me in the collection of materials for the present study were: Kenneth G. Flakas, D. John O'Donnell, and Glen Voskuil of the Wisconsin Conservation Department; Ralph Hile and Leonard S. Joeris of the Bureau of Commercial Fisheries. Hile also advised in the preparation of the manuscript. Numerous commercial fishermen permitted the use of their catches.

LITERATURE CITED

BALDWIN, NORMAN S., AND ROBERT W. SAALFELD.
1962. Commercial fish production in the Great Lakes 1867–1960. Great Lakes Fishery Commission, Technical Report No. 3, 166 pp.

DEASON, HILARY J., AND RALPH HILE.
1947. Age and growth of the kiyi, *Leucichthys kiyi* Koelz, in Lake Michigan. Transactions of the American Fisheries Society, vol. 74, for the year 1944, pp. 88–141.

Dryer, William R.
1963. Age and growth of the whitefish in Lake Superior. U.S. Fish and Wildlife Service, Fishery Bulletin, vol. 63, No. 1, pp. 77–95.

Edsall, Thomas A.
1960. Age and growth of the whitefish, *Coregonus clupeaformis*, of Munising Bay, Lake Superior. Transactions of the American Fisheries Society, vol. 89, No. 4, pp. 323–332.

Hart, John Lawson.
1931. The growth of the whitefish, *Coregonus clupeaformis* (Mitchill). Contributions to Canadian Biology and Fisheries, N.S., vol. 6, No. 20, pp. 427–444.

Hile, Ralph
1941. Age and growth of the rock bass, *Ambloplites rupestris* (Rafinesque), in Nebish Lake, Wisconsin. Transactions of the Wisconsin Academy of Science, Arts, and Letters, vol. 33, pp. 189–337.
1950. Green Bay walleyes—a report on the scientific investigation of the marked increase in abundance of walleyes in Green Bay. The Fisherman, vol. 18, No. 3, pp. 5–6. (Grand Haven, Mich.)

Hile, Ralph, and Howard J. Buettner.
1959. Fluctuations in the commercial fisheries of Saginaw Bay 1885–1956. U.S. Fish and Wildlife Service, Research Report No. 51, 38 pp.

Hile, Ralph, George F. Lunger, and Howard J. Buettner.
1953. Fluctuations in the fisheries of State of Michigan waters of Green Bay. U.S. Fish and Wildlife Service, Fishery Bulletin 75, vol. 54, pp. 1–34.

Moffett, James W.
1952. The study and interpretation of fish scales. The Science Counselor, vol. 15, No. 2, pp. 40–42.

Morawa, F.W.F.
1960. Jahreszeitliche Veränderungen der chemischen und gewichtsmässigen Zusammensetzung von *Coregonus fera* Jurine des Genfer Sees. Annales de la Station Centrale d'Hydrobiologie Appliquée, tome 8, pp. 281–306.

Pycha, Richard L.
1961. Recent changes in the walleye fishery of northern Green Bay and history of the 1943 year class. Transactions of the American Fisheries Society, vol. 90, No. 4, pp. 475–488.

Roelofs, Eugene W.
1958. Age and growth of whitefish, *Coregonus clupeaformis* (Mitchill), in Big Bay de Noc and northern Lake Michigan. Transactions of the American Fisheries Society, vol. 87, for the year 1957, pp. 190–199.

Smith, Stanford H.
1954. Method of producing impressions of fish scales without using heat. U.S. Fish and Wildlife Service, Progressive Fish-Culturist, vol. 16, No. 2, pp. 75–78.

Van Oosten, John.
1923. The whitefishes (*Coregonus clupeaformis*). A study of the scales of whitefishes of known ages. Zoologica, Scientific Contributions of the New York Zoological Society, vol. 2, No. 17, pp. 380–412.
1939. The age, growth, sexual maturity, and sex ratio of the common whitefish, *Coregonus clupeaformis* (Mitchill), of Lake Huron. Papers of the Michigan Academy of Science, Arts, and Letters, vol. 24, for the year 1938, part 2, pp. 195–221.

Van Oosten, John, and Ralph Hile.
1949. Age and growth of the lake whitefish, *Coregonus clupeaformis* (Mitchill), in Lake Erie. Transactions of the American Fisheries Society, vol. 77, for the year 1947, pp. 178–249.