TRANSACTIONS of the AMERICAN FISHERIES SOCIETY

October 1960

VOLUME 89

NUMBER 4

# Age and Growth of the Whitefish, *Coregonus clupeaformis*, of Munising Bay, Lake Superior[1]

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ABSTRACT

This study is based on a sample of 415 whitefish collected in 1953 from an unexploited population in Munising Bay, Lake Superior. Gill-net and trawl catches had different length-frequency distributions and age compositions, but estimates of growth from the two catches were very similar. The body-scale relation is a straight line with an intercept of 1.5 inches. Weight of Munising Bay whitefish captured in June increased as the 3.17 power of the length. Growth in length and weight of Munising Bay whitefish was the slowest yet reported from Great Lakes waters. Munising Bay whitefish required nearly 8 years to reach a length of 10 inches and a full 13 years to reach 15 inches. Slightly more than 8 years were required to reach a weight of 8 ounces and a little less than 14 years to reach 1 pound. The sex ratio of the Munising Bay whitefish exhibited no systematic change with an increase in age. The entire sample for which ages were determined contained 52 percent males. Munising Bay whitefish matured at much shorter lengths but at a greater age than reported for other Great Lakes whitefish populations. The smallest mature males were in the 11.5- to 11.9-inch length interval (age-group VII) and all males longer than 14.4 inches (age-group XII) were mature. The first mature females appeared at 12.0-12.4 inches (age-group X) and all females longer than 14.9 inches (age-group XII) were mature. The more rapidly growing individuals matured earlier than the slow-growing ones.

## INTRODUCTION

The present paper is a contribution to a continuing study of the U. S. Bureau of Commercial Fisheries designed to determine the extent of the differences in growth rate among local populations of the whitefish, *Coregonus clupeaformis*, of Lake Superior.

The Munising Bay (Figure 1) whitefish population is of special interest because it is unexploited and has an extremely slow growth rate. Lack of exploitation is attributable both to statutes which prohibit commercial fishing in Munising Bay and to the slow growth of individual fish, which prevents migrants from contributing materially to the commercial whitefish fishery immediately outside the bay. No explanation for the slow growth rate can be offered as a result of this study. The Munising Bay whitefish population, however, is apparently much denser than other Lake Superior whitefish populations, because fishing records for the Bureau's vessel *Cisco* indicate that many more whitefish were caught per unit of effort in Munising Bay than elsewhere in Lake Superior. Munising Bay whitefish are also most abundant at greater depths (22-38 fathoms) than are ordinarily frequented by Great Lakes whitefish. The temperatures at these depths are very low; the maximum of 45° F. is reached in late September.[2]

## MATERIALS AND METHODS

Data from the 415 whitefish collected in Munising Bay in June and August 1953 dur-

[1]This study was submitted as a master's thesis in the Department of Fisheries, University of Michigan.

[2]Temperature data taken during the 1953 and 1959 operations of the U. S. Bureau of Commercial Fisheries vessel *Cisco*.

TABLE 1.—*Collections of Munising Bay whitefish, 1953*

| Gear | Date of capture | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | June 17 | June 18 | June 21 | June 22 | August 14 | August 15 | August 16 | |
| Trawl | 82 | 38 | 5 | 0 | 0 | — | — | 125 |
| Gill net | 91 | — | — | 163 | 27 | 8 | 1 | 290 |
| Total | 173 | 38 | 5 | 163 | 27 | 8 | 1 | 415 |

ing the operations of the U. S. Bureau of Commercial Fisheries vessel *Cisco* are the basis for this study (Table 1). Information on length, weight, sex, and state of maturity was recorded for each fish. Scales were taken from 252 fish (all but the 163 fish captured on June 22).

All whitefish were caught by nylon gill nets and otter trawls. Individual gill nets were 250 feet long and 6 feet deep; each net was one in a series of eight mesh sizes ranging from 1 to 4½ inches.[3] Gill nets were fished in gangs with each gang consisting of a group of gill nets of different mesh sizes joined end to end. Gangs were set on the bottom, usually across the contours and left overnight. The trawls were 35 feet wide at the wings and 36 feet long with mesh sizes from 1½ to 2½ inches in the wings and body and ½ inch in the cod ends. Trawl tows were made on the bottom, generally along the contours, and usually lasted 10 minutes.

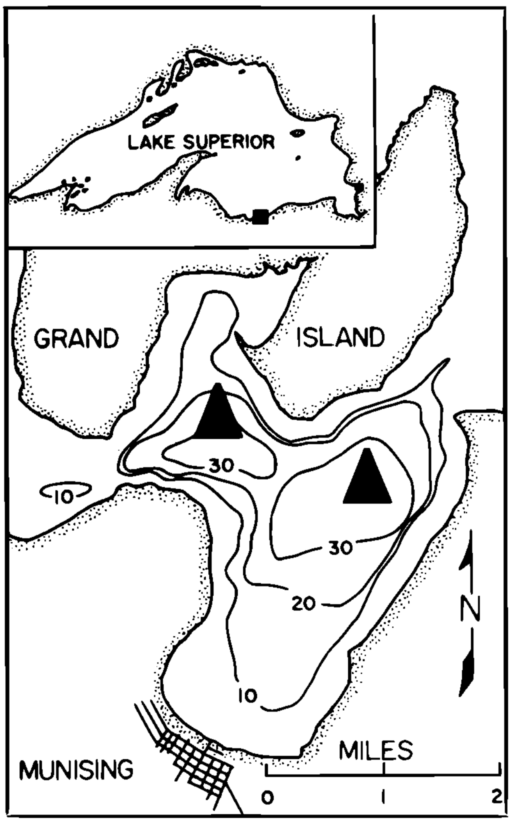


FIGURE 1.—Munising Bay, Lake Superior. Fishing locations shown by shaded triangles; depth contours are in fathoms.

[3]Mesh sizes are stretched-mesh measurements.

Length distributions of fish in the June trawl and gill-net catches (Table 2) differ substantially. The trawl sample has a single strong mode in the 11.0- to 11.4-inch length interval, while the length-frequency distribution in the gill-net sample is skewed to the left and lacks the strong mode of the trawl sample at 11.0 to 11.4 inches. The average total lengths of fish in the June trawl and gill-net samples were 11.6 and 12.1 inches, respectively. Growth estimates of fish in catches from the two gears were closely similar, but estimates of age composition differed. A brief discussion of the significance of the difference

TABLE 2.—*Length distribution of Munising Bay whitefish caught by gill nets and trawls*

| Length interval (inches) | Trawl | | Gill net | |
|---|---|---|---|---|
| | Number | Percentage | Number | Percentage |
| 7.0- 7.4 | 2 | 1.6 | — | — |
| 7.5- 7.9 | 1 | 0.8 | — | — |
| 8.0- 8.4 | 2 | 1.6 | — | — |
| 8.5- 8.9 | 3 | 2.4 | — | — |
| 9.0- 9.4 | 4 | 3.2 | 1 | 1.1 |
| 9.5- 9.9 | 10 | 8.0 | 3 | 3.3 |
| 10.0-10.4 | 12 | 9.6 | 8 | 8.8 |
| 10.5-10.9 | 11 | 8.8 | 13 | 14.3 |
| 11.0-11.4 | 21 | 16.8 | 11 | 12.1 |
| 11.5-11.9 | 9 | 7.2 | 9 | 9.9 |
| 12.0-12.4 | 12 | 9.6 | 12 | 13.2 |
| 12.5-12.9 | 11 | 8.8 | 11 | 12.1 |
| 13.0-13.4 | 7 | 5.6 | 9 | 9.9 |
| 13.5-13.9 | 5 | 4.0 | 4 | 4.4 |
| 14.0-14.4 | 7 | 5.6 | 3 | 3.3 |
| 14.5-14.9 | 2 | 1.6 | 1 | 1.1 |
| 15.0-15.4 | 3 | 2.4 | 2 | 2.2 |
| 15.5-15.9 | 2 | 1.6 | 1 | 1.1 |
| 16.0-16.4 | 1 | 0.8 | — | — |
| 16.5-16.9 | — | — | 2 | 2.2 |
| 17.0-17.4 | — | — | 1 | 1.1 |
| Total | 125 | — | 91 | — |
| Average length | 11.6 | — | 12.1 | — |

in length distributions of catches from gill nets and trawls with respect to age is presented in the section on age composition.

The total length (tip of the head to the tip of the tail, with lobes compressed) of each fish was read from a measuring board in the field and recorded to the nearest 0.1 inch. Fresh weights of the smaller whitefish were determined to the nearest 0.1 ounce on a spring scale with an 18-ounce capacity. Fish heavier than 18 ounces were weighed on a larger spring scale to the nearest full ounce. Scale samples were removed from the left side midway between the lateral line and the midpoint of the base of the dorsal fin and were placed in an envelope on which the length, weight, sex, state of gonads, date, gear, and location of capture were recorded.

The sex and state of maturity of the gonads were determined by gross examination. Mature fish were those judged to be ready to spawn in the fall of that same year. Impressions of the scales were made in cellulose acetate (Smith, 1954) and were magnified 43 diameters for study by means of a microprojector similar to that described by Moffett (1952). Measurements of scale diameters were made through the focus along the cephalo-caudal axis from the projected scale image as prescribed by Van Oosten (1923).

The ages of fish were determined from the annuli on their scales. Since each fish was considered to have passed into the next higher age group on January 1 a "virtual" annulus was accredited at the edge of the scale from January 1 to the date the current season's annulus actually was completed (Hile, 1948). Ages are expressed by Roman numerals corresponding to the number of annuli.

Annuli were characterized by a change in the spacing and thickness of the circuli in the anterior and lateral portions of the scale and by crossing over in the posterior-lateral portions. On many scales accessory marks and other odd patterns in the spacing and thickness of the circuli, especially near the margin, prevented age determination with reasonable accuracy. As a result, the scales of many whitefish (17.6 percent of the June catch) were discarded as unreadable.

The average total length of fish in the entire June sample was 11.8 inches, and the average total lengths of the aged and unaged portions of the sample were 11.6 and 12.9 inches, respectively. The greater average length of the unaged portion indicates that many of these fish were members of the older age groups. Although the records of age composition were biased by the rejection of numerous large fish, the calculated lengths gave no evidence of bias to growth estimates through the selective discarding of slow-growing individuals.

The 36 whitefish captured in August were excluded from age analysis because annulus formation was in progress at this time. This fact, and the great irregularity in the growth of individual fish, frequently made it impossible to decide whether marginal growth had been completed in the previous or the current season. Whitefish caught in June presented no such difficulty because growth had not yet started.

## AGE COMPOSITION

The age composition of the trawl and gill-net samples (Table 3) differed both in relative strength of age groups and in average age. Age distributions of both trawl and gill-net samples were unimodal, but of the two the gill-net distribution was the more strongly dominated by a single age group. Age-groups II-XIII were represented in the trawl sample (age-group VI dominant — 19.0 percent) whereas age-groups IV-XVI were represented in the gill-net samples and age-group VII was strongly dominant (31.5 percent). The representation of whitefish in neighboring age groups fluctuated much more widely in the

TABLE 3.—*Age composition of the Munising Bay whitefish caught by gill nets and trawls*

| Age group | Trawl | | Gill net | |
|---|---|---|---|---|
| | Number | Percentage | Number | Percentage |
| II | 2 | 1.9 | — | — |
| III | 5 | 4.8 | — | — |
| IV | 11 | 10.5 | 6 | 8.2 |
| V | 14 | 13.3 | 5 | 6.8 |
| VI | 20 | 19.0 | 11 | 15.1 |
| VII | 14 | 13.3 | 23 | 31.5 |
| VIII | 13 | 12.4 | 9 | 12.3 |
| IX | 9 | 8.6 | 7 | 9.6 |
| X | 6 | 5.7 | 9 | 12.3 |
| XI | 6 | 5.7 | 1 | 1.4 |
| XII | 4 | 3.8 | — | — |
| XIII | 1 | 1.0 | 1 | 1.4 |
| XVI | — | — | 1 | 1.4 |
| Total | 105 | — | 73 | — |
| Average number of annuli | 6.9 | — | 7.4 | — |

gill-net sample and exhibited a less regular trend than in the trawl sample. The average age of fish in the gill-net samples (7.4 years) was 0.5 year greater than in trawl samples (6.9 years). The data of Table 3 do not appear to justify speculation as to the relative strength of the year classes. The differences between the age compositions of the trawl and gill-net samples, especially in view of the exceptionally slow growth rate of this population, are attributed to the differences in the length distributions of the two samples (Table 2).

Although the absence or scarcity of young whitefish in the gill-net sample can be attributed to the difficulty of holding very small fish in gill nets (Hile, 1941), their scarcity in the trawl sample can not. The ½-inch mesh of the cod ends of trawls used was certainly able to retain small whitefish. If small fish had been abundant, they should have been taken in good numbers even though some escaped through the mesh of the trawl body. The scarcity of young whitefish in the trawl sample therefore is believed to be a true reflection of the relative abundance of this segment of the population at the bottom on the deep-water fishing grounds. It is not known, however, whether the absence of young whitefish on the fishing grounds is indicative of a difference in habitat preference or of weak year classes in 1949-51. The decrease in the numbers of Munising Bay whitefish with an increase in age (age-groups VIII-XVI) is typical and undoubtedly reflects mortality.

### LENGTH DISTRIBUTION OF THE AGE GROUPS

There is considerable range in the length of fish in the same age group (Table 4) and extensive overlap between neighboring age groups. Among the better represented age groups the greatest span between the longest and shortest individuals of the group was 3 to 4 inches. The better represented length intervals contained fish from four to seven age groups. The overlapping of the distributions was the result of the considerable range of lengths of most of the age groups in a stock in which the average annual increments of growth were relatively small. As a result, length alone is a poor index of age of Munising Bay whitefish.

### LENGTH-WEIGHT RELATION

The general parabola, $W = cL^n$, where $W$ = weight, $L$ = total length, and $c$ and $n$ are empirically determined constants, has been used satisfactorily to describe the general length-weight relationship of the numerous species and stocks of fish. Determination of the length-weight relation of the Munising Bay whitefish was based on the data from the 379 fish captured in June and may not be ac-

TABLE 4.—*Length distribution of age groups of Munising Bay whitefish*

| Length interval (inches) | Age group | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | XIII | XVI |
| 7.0- 7.4 | 1 | 1 | — | — | — | — | — | — | — | — | — | — | — |
| 7.5- 7.9 | 1 | — | — | — | — | — | — | — | — | — | — | — | — |
| 8.0- 8.4 | — | 1 | — | — | — | — | — | — | — | — | — | — | — |
| 8.5- 8.9 | — | 2 | 1 | — | — | — | — | — | — | — | — | — | — |
| 9.0- 9.4 | — | 1 | 2 | — | 1 | — | — | — | — | — | — | — | — |
| 9.5- 9.9 | — | — | 5 | 6 | 1 | 1 | — | — | — | — | — | — | — |
| 10.0-10.4 | — | — | 6 | 6 | 6 | 2 | — | — | — | — | — | — | — |
| 10.5-10.9 | — | — | 2 | 5 | 6 | 7 | 4 | — | — | — | — | — | — |
| 11.0-11.4 | — | — | 1 | 1 | 12 | 13 | 2 | 2 | — | — | — | — | — |
| 11.5-11.9 | — | — | — | — | 2 | 3 | 8 | 3 | — | — | — | — | — |
| 12.0-12.4 | — | — | — | 1 | 2 | 5 | 1 | 2 | 4 | 1 | — | — | — |
| 12.5-12.9 | — | — | — | — | 1 | 6 | 5 | 1 | — | 1 | — | — | — |
| 13.0-13.4 | — | — | — | — | — | — | 2 | 3 | 5 | 1 | — | — | — |
| 13.5-13.9 | — | — | — | — | — | — | — | 2 | 2 | — | 1 | — | — |
| 14.0-14.4 | — | — | — | — | — | — | — | 2 | 3 | 1 | — | — | — |
| 14.5-14.9 | — | — | — | — | — | — | — | — | — | 1 | — | — | — |
| 15.0-15.4 | — | — | — | — | — | — | — | 1 | — | 1 | 1 | 1 | — |
| 15.5-15.9 | — | — | — | — | — | — | — | — | — | 1 | 1 | 1 | — |
| 16.0-16.4 | — | — | — | — | — | — | — | — | 1 | — | — | — | — |
| 16.5-16.9 | — | — | — | — | — | — | — | — | — | — | 1 | — | 1 |
| Number of fish...... | 2 | 5 | 17 | 19 | 31 | 37 | 22 | 16 | 15 | 7 | 4 | 2 | 1 |
| Percentage of total... | 1.1 | 2.8 | 9.6 | 10.7 | 17.4 | 20.8 | 12.4 | 9.0 | 8.4 | 3.9 | 2.2 | 1.1 | 0.6 |
| Average length.... | 7.4 | 8.5 | 9.9 | 10.4 | 11.0 | 11.4 | 11.9 | 12.8 | 13.4 | 14.0 | 15.5 | 15.6 | 16.7 |

curately descriptive for other times of the year. Whitefish collected in August were heavier than fish of the same length that were captured in June but there were too few August specimens to establish clearly the extent of the seasonal fluctuation. The length-weight equation, determined by fitting a straight line to the logarithms of the lengths and weights listed in Table 5, was:

$$\log W = 2.5596 + 3.1712 \log L,$$

where $W$ = weight in ounces and $L$ = total length in inches. This equation may also be written in the form,

$$W = 7.4788 \times 10^{-3} L^{3.1712}.$$

TABLE 5.—*Length-weight relationship of Munising Bay whitefish*

[The lengths are the true averages for fish in 0.5-inch groups]

| Number of fish | Average total length (inches) | Average weight (ounces) | |
|---|---|---|---|
| | | Empirical | Calculated |
| 2 | 7.3 | 1.4 | 1.5 |
| 1 | 7.5 | 1.6 | 1.6 |
| 2 | 8.2 | 2.1 | 2.2 |
| 3 | 8.8 | 2.8 | 2.7 |
| 5 | 9.2 | 3.1 | 3.1 |
| 14 | 9.7 | 3.6 | 3.7 |
| 25 | 10.2 | 4.2 | 4.4 |
| 36 | 10.7 | 5.1 | 5.1 |
| 56 | 11.2 | 6.1 | 5.9 |
| 38 | 11.7 | 6.9 | 6.7 |
| 55 | 12.3 | 7.8 | 7.9 |
| 40 | 12.7 | 8.9 | 8.9 |
| 35 | 13.2 | 10.2 | 9.9 |
| 28 | 13.7 | 11.4 | 11.1 |
| 16 | 14.3 | 12.4 | 12.7 |
| 7 | 14.7 | 14.1 | 13.9 |
| 8 | 15.2 | 16.3 | 15.4 |
| 4 | 15.7 | 16.7 | 17.1 |
| 1 | 16.4 | 16.1 | 19.6 |
| 2 | 16.8 | 20.8 | 21.2 |
| 1 | 17.4 | 26.8 | 23.7 |

The value of $n$ indicates that weight increases more rapidly than the cube of the length.

The data of Table 5 indicate a generally good agreement between empirical and calculated weights. The largest discrepancies were at the greater lengths where numbers of fish were small and actual weights great enough to make relatively modest percentage disagreements seem larger.

The weight of whitefish caught in June varies according to maturity and sex (Table 6). Weights of immature male and female fish of the same length did not differ significantly. The mature fish, however, were usually heavier than immature fish, and the mature females were generally heavier than the mature males.

TABLE 6.—*Weight (ounces) of Munising Bay whitefish by sex and maturity*

[Number of fish in parentheses. Fish shorter than 11.5 inches were immature. Sex and maturity data missing for one fish 14.2 inches long]

| Total length (inches) | Male | | Female | |
|---|---|---|---|---|
| | Immature | Mature | Immature | Mature |
| 11.5-11.9 | 6.6 (12) | 7.3 (5) | 6.9 (19) | 6.5 (2) |
| 12.0-12.4 | 7.7 (23) | 8.0 (7) | 7.6 (18) | 8.4 (7) |
| 12.5-12.9 | 8.7 (17) | 9.2 (7) | 8.9 (15) | 9.9 (1) |
| 13.0-13.4 | 9.7 (9) | 10.3 (9) | 10.3 (14) | 11.0 (3) |
| 13.5-13.9 | 11.3 (9) | 11.4 (7) | 11.2 (7) | 11.8 (5) |
| 14.0-14.4 | — — | 12.1 (7) | 12.5 (5) | 12.8 (3) |
| 14.5-14.9 | — — | 13.6 (2) | 13.8 (3) | 15.2 (2) |
| 15.0-15.4 | — — | 16.3 (5) | — — | 16.3 (3) |
| 15.5-15.9 | — — | 18.8 (1) | — — | 16.0 (3) |
| 16.0-16.4 | — — | 16.1 (1) | — — | — — |
| 16.5-16.9 | — — | 20.8 (2) | — — | — — |
| 17.0-17.4 | — — | — — | — — | 26.8 (1) |
| Number of fish | 70 | 53 | 81 | 30 |

BODY-SCALE RELATIONSHIP

Van Oosten (1923) demonstrated that the ratio of the diameter of the scales of Lake Huron whitefish to the length of fish was nearly constant. A similar body-scale relationship has been demonstrated for the related lake herring *(Coregonus artedi)* by Van Oosten (1929) and by Smith (1956). Largely on the basis of Van Oosten's findings (1923, 1929) most investigators working on coregonids have employed the direct-proportion method for the calculation of growth. The body-scale relationship was, nevertheless, determined for the Munising Bay whitefish stock. "Key" scales were not available, but because the scale samples were taken from a key area, it was felt that average scale diameters based on the measurements of three (sometimes two) scales from each fish would be a reliable substitute for key-scale measurements in the determination of body-scale relationship.

All whitefish captured in June and August, from which scales were collected, were employed for the determination of the body-scale relationship (Table 7). Since a plot of average fish length and scale diameters for 0.5-inch groupings of fish indicated the body-scale relation to be linear, a straight line was fitted to the data by least squares (Figure 2). The equation of the line is:

$$L = 1.486 + 1.222\,S,$$

where $L$ = the total length of the fish (inches), $S$ = the scale diameter (magnified) in inches, and 1.486 is the intercept. Since this value of the intercept differs significantly from zero, it is concluded that the body-scale ratio is not constant in the Munising Bay whitefish population.

The growth in length of the whitefish was calculated by the formula

$$L_n = 1.5 + \frac{L_t - 1.5}{S_t} S_n$$

where $L_n$ equals the length of the fish at the end of the $n^{th}$ year of life, $S_n$ equals the diameter of the scale within the $n^{th}$ annulus, $L_t$ equals the total length of the fish at capture, $S_t$ equals the total diameter of the scale, and 1.5 is the intercept rounded to the nearest 0.1 inch.

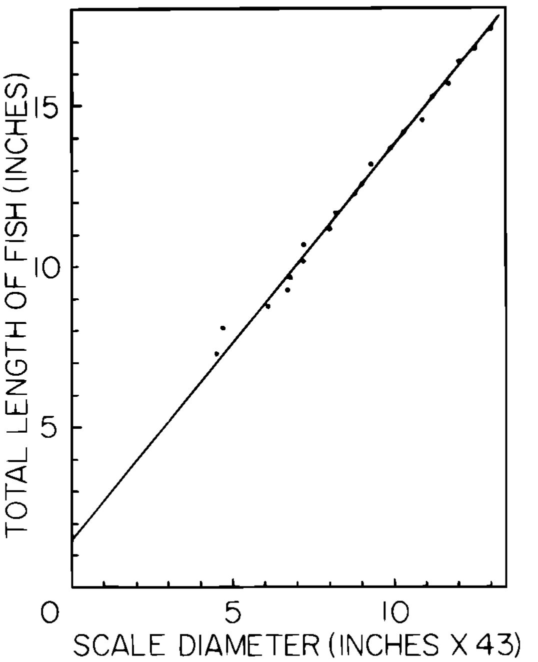


FIGURE 2.—Relation between total length of fish and magnified diameter of scales of Munising Bay whitefish.

### CALCULATED GROWTH IN LENGTH

The average calculated lengths of males and females in different age groups of whitefish gave no evidence of sex differences in the growth rate. Data for males and females therefore were combined (Table 8). The agreement among the calculated growth histories of the different age groups was very close, particularly in view of the small number of fish in several groups and the great difficulty with which the scales were read. No clear trends are to be seen toward a systematic change of calculated lengths with increase of age, and discrepancies that do occur probably can be attributed to small samples or annual fluctuations of growth. Especially reassuring is the agreement between length at capture (the last length for each age group) and the calculated lengths for the same year of life as determined by measurements of scales of fish of greater age. The data of Table 8 appear to justify fully the conclusions that (1) the samples of the age groups were little biased by gear selection or other selective influence, (2) estimates of growth were little affected by the rejection of numerous fish that had unreadable scales, and (3) the empirically determined body-scale relation was highly satisfactory for the calculation of growth.

TABLE 7.—*Relation between total length of fish and magnified scale diameter of Munising Bay whitefish*

[Scales were taken from a key area; scale diameter in inches x 43]

| Length interval (inches) | Number of fish | Average length (inches) | Average magnified scale diameter |
|---|---|---|---|
| 7.0- 7.4 | 2 | 7.3 | 4.5 |
| 7.5- 7.9 | 1 | 7.5 | 5.9 |
| 8.0- 8.4 | 2 | 8.1 | 4.7 |
| 8.5- 8.9 | 3 | 8.8 | 6.1 |
| 9.0- 9.4 | 8 | 9.3 | 6.7 |
| 9.5- 9.9 | 17 | 9.7 | 6.8 |
| 10.0-10.4 | 27 | 10.2 | 7.2 |
| 10.5-10.9 | 28 | 10.7 | 7.2 |
| 11.0-11.4 | 37 | 11.2 | 8.0 |
| 11.5-11.9 | 23 | 11.7 | 8.2 |
| 12.0-12.4 | 24 | 12.3 | 8.8 |
| 12.5-12.9 | 28 | 12.6 | 9.0 |
| 13.0-13.4 | 16 | 13.2 | 9.3 |
| 13.5-13.9 | 10 | 13.7 | 9.9 |
| 14.0-14.4 | 11 | 14.2 | 10.3 |
| 14.5-14.9 | 3 | 14.6 | 10.9 |
| 15.0-15.4 | 5 | 15.3 | 11.2 |
| 15.5-15.9 | 3 | 15.7 | 11.7 |
| 16.0-16.4 | 1 | 16.4 | 12.0 |
| 16.5-16.9 | 2 | 16.8 | 12.5 |
| 17.0-17.4 | 1 | 17.4 | 13.0 |

The estimates of the general growth in length at the bottom of Table 8 are based on the grand average calculated lengths and on the successive summation of the grand average increments of calculated length. Both procedures are basically valid and for the Munising Bay fish they give closely similar

TABLE 8.—*Calculated total length at end of each year of life of each age group of Munising Bay whitefish and average growth for the combined age groups*

[The last calculated length for each age group is actually the average length at capture in June, as the current season's growth had not begun]

| Age group | Number of fish | Length (inches) at end of year | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| II | 2 | 4.5 | 7.4 | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| III | 5 | 5.6 | 7.2 | 8.5 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| IV | 17 | 5.5 | 7.5 | 8.7 | 9.9 | — | — | — | — | — | — | — | — | — | — | — | — |
| V | 19 | 5.5 | 7.1 | 8.7 | 9.7 | 10.4 | — | — | — | — | — | — | — | — | — | — | — |
| VI | 31 | 5.5 | 7.3 | 8.5 | 9.4 | 10.2 | 11.0 | — | — | — | — | — | — | — | — | — | — |
| VII | 37 | 5.7 | 7.5 | 8.7 | 9.5 | 10.2 | 10.9 | 11.4 | — | — | — | — | — | — | — | — | — |
| VIII | 22 | 5.5 | 7.1 | 8.2 | 9.2 | 10.0 | 10.7 | 11.3 | 11.9 | — | — | — | — | — | — | — | — |
| IX | 16 | 5.5 | 7.1 | 8.2 | 9.2 | 10.0 | 10.9 | 11.6 | 12.2 | 12.8 | — | — | — | — | — | — | — |
| X | 15 | 5.2 | 6.7 | 7.9 | 8.9 | 9.8 | 10.6 | 11.3 | 12.0 | 12.7 | 13.4 | — | — | — | — | — | — |
| XI | 7 | 5.0 | 6.8 | 8.1 | 9.1 | 9.9 | 10.7 | 11.6 | 12.3 | 12.9 | 13.4 | 14.0 | — | — | — | — | — |
| XII | 4 | 5.4 | 6.7 | 8.2 | 9.0 | 9.9 | 10.9 | 12.0 | 13.0 | 13.7 | 14.4 | 15.0 | 15.5 | — | — | — | — |
| XIII | 2 | 5.4 | 6.9 | 8.4 | 9.5 | 10.4 | 11.6 | 12.3 | 12.9 | 13.6 | 14.3 | 14.9 | 15.4 | 15.8 | — | — | — |
| XVI | 1 | 5.0 | 6.3 | 7.9 | 8.8 | 9.6 | 10.2 | 11.1 | 12.0 | 12.6 | 13.2 | 14.5 | 15.2 | 15.5 | 16.0 | 16.3 | 16.7 |
| Grand average calculated length | | 5.5 | 7.2 | 8.4 | 9.4 | 10.1 | 10.8 | 11.5 | 12.1 | 12.9 | 13.6 | 14.4 | 15.4 | 15.7 | 16.0 | 16.3 | 16.7 |
| Increment of average | | 5.5 | 1.7 | 1.2 | 1.0 | 0.7 | 0.7 | 0.7 | 0.6 | 0.8 | 0.7 | 0.8 | 1.0 | 0.3 | 0.3 | 0.3 | 0.4 |
| Grand average increment of length | | 5.5 | 1.7 | 1.2 | 1.0 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.6 | 0.7 | 0.5 | 0.3 | 0.5 | 0.3 | 0.4 |
| Sum of average increment | | 5.5 | 7.2 | 8.4 | 9.4 | 10.2 | 11.0 | 11.7 | 12.3 | 12.9 | 13.5 | 14.2 | 14.7 | 15.0 | 15.5 | 15.8 | 16.2 |

results. The estimate based on the sum of the average increments, however, is preferred (Figure 3). The curve derived from average increments has the advantage of greater smoothness, particularly in the later years of life that are represented by few fish.

The growth of Munising Bay whitefish is similar to that of many coregonids in that the annual increment was by a large margin the greatest in the first year of life and thereafter followed a general (though not perfectly regular) downward trend. The increments beyond the first year were very low. 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 eleventh. As a result of this slow growth, Munising Bay whitefish required almost 5 years to reach a length of 10 inches and a full 13 years to reach 15 inches. The highest calculated length attained (16.2 inches in 16 years) was still 0.8 inch below the Michigan legal minimum length of 17 inches. Exploitation of the Munising Bay stock under the present size limit would not be a rewarding operation.

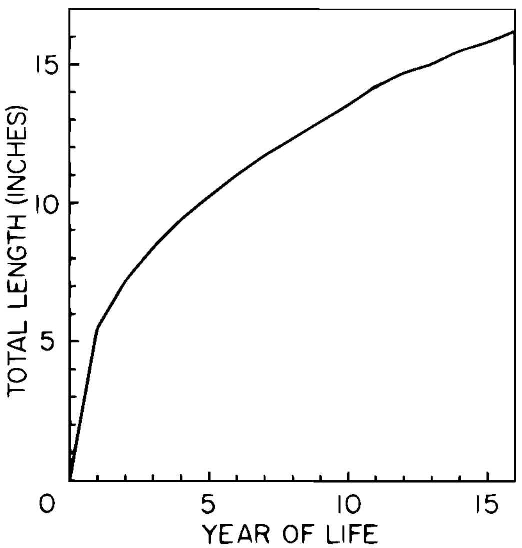


FIGURE 3.—General growth in length of Munising Bay whitefish.

## CALCULATED GROWTH IN WEIGHT

Calculated growth in weight (Table 9) was determined by applying calculated

TABLE 9.—*Calculated weights at the end of each year of life of Munising Bay whitefish*

[Weights are from the general length-weight relation and correspond to lengths at the end of year of life on the general growth curve]

| Year of life | Calculated weight | Increment | Year of life | Calculated weight | Increment |
|---|---|---|---|---|---|
| 1 | 0.6 | 0.6 | 9 | 9.2 | 1.3 |
| 2 | 1.5 | 0.9 | 10 | 10.6 | 1.4 |
| 3 | 2.4 | 0.9 | 11 | 12.4 | 1.8 |
| 4 | 3.3 | 0.9 | 12 | 13.9 | 1.5 |
| 5 | 4.3 | 1.0 | 13 | 14.8 | 0.9 |
| 6 | 5.6 | 1.3 | 14 | 16.4 | 1.6 |
| 7 | 6.7 | 1.1 | 15 | 17.4 | 1.0 |
| 8 | 7.9 | 1.2 | 16 | 18.9 | 1.5 |

lengths (sum of the average increments of length) of Table 8 to the length-weight relation. The annual increments of weight increased irregularly through the first 11 or 12 years and thereafter fluctuated without trend. Increments in individual years of life were small (0.6 ounce in the first year of life to a maximum of 1.8 ounces in the 11th year of life). Because of this slow growth in weight, considerable time was required for the fish to reach even a moderate size. Slightly more than 8 years were needed for fish to reach a weight of 8 ounces and a little less than 14 years to reach 1 pound.

## COMPARISON OF THE GROWTH OF WHITEFISH IN MUNISING BAY WITH GROWTH IN OTHER WATERS

In order to compare the growth of whitefish from a number of localities (Table 10), the data from various sources have been adapted to permit presentation in terms of total length in inches. A full coverage of published data has not been attempted. All available records for the Great Lakes have been included, but data for other waters have been limited to two inland lakes that have stocks with extremely slow growth.

Growth of the Munising Bay whitefish in the first year of life does not differ greatly from the first-year growth in the other Great Lakes whitefish populations, and the length at the end of 2 years was very similar in Munising Bay and in the Fox Islands area of Lake Michigan. In all other comparisons, however, the Munising Bay whitefish were decidedly shorter than fish of the same age in other Great Lakes stocks. In general, the differences increased with age. Munising Bay fish after 4 years were 2.6 to 8.7 inches shorter than whitefish in other Great Lakes waters and in 12 years were 8.8 to 11.2 inches shorter (Lake Michigan not represented at the higher age).

Whitefish from two small inland lakes, on the contrary, had growth rates similar to or below that of the Munising Bay stock. Whitefish from Trout Lake, Wisconsin, (Hile and Deason, 1934) were shorter than Munising Bay fish in the first 4 years of life, but were longer in the sixth and later years (fifth-year lengths were identical in the two stocks). Slowest growth yet reported for any population is that of a stock of dwarf whitefish discovered by Kennedy (1943) in Lake Opeongo. These dwarf whitefish (Opeongo also contains a stock with more rapid growth) reached a length of 6.0 inches in 5 years as compared with 10.1 inches in Munising Bay.

## SEX RATIO

Although the sex ratio of the Munising Bay whitefish fluctuated widely among the age groups (Table 11), the belief that the data were without trend was supported by a statistical test. Much of the variation probably was a result of the small numbers of fish in several of the age groups. In the entire sample, all ages combined, the sexes were almost equally represented (52 percent males).

The failure of the sex ratio of Munising Bay whitefish to change systematically with

TABLE 10.—*Growth in length of whitefish in Munising Bay and in certain other waters*

[Sources of data: Lake Erie, Van Oosten and Hile (1949); Lake Huron, adapted from Van Oosten (1939); Lake Ontario, adapted from Hart (1931); Lake Michigan, Roelofs (1957); Lake Opeongo (dwarf race), adapted from Kennedy (1943); Trout Lake, adapted from Hile and Deason (1934)]

| Area | Average calculated total length (inches) at end of year of life | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Great Lakes | | | | | | | | | | | | | | | | |
| Lake Erie | 6.9 | 12.7 | 16.1 | 18.1 | 19.6 | 20.7 | 21.4 | 22.1 | 22.8 | 23.2 | 23.7 | 24.2 | 24.6 | 25.0 | 25.3 | 25.6 |
| Lake Huron[1] | 5.0 | 8.9 | 12.3 | 16.1 | 19.2 | 21.4 | 22.9 | 23.9 | 24.8 | 25.3 | 25.9 | 26.6 | — | — | — | — |
| 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 Ontario[1 2] | — | — | 9.4 | 12.0 | 15.4 | 17.9 | 19.1 | 20.4 | 21.0 | 22.3 | — | 25.8 | — | — | — | — |
| Lake Superior | | | | | | | | | | | | | | | | |
| Munising Bay | 5.5 | 7.2 | 8.4 | 9.4 | 10.1 | 10.8 | 11.5 | 12.1 | 12.9 | 13.6 | 14.4 | 15.4 | 15.7 | 16.0 | 16.3 | 16.7 |
| Small inland lakes | | | | | | | | | | | | | | | | |
| Lake Opeongo[3] | 4.4 | 5.3 | 5.6 | 5.8 | 6.0 | — | — | — | — | — | — | — | — | — | — | — |
| Trout Lake[3] | 3.8 | 5.5 | 7.1 | 8.5 | 9.7 | 10.8 | 11.9 | 12.9 | 14.3 | 15.0 | 15.7 | 16.2 | 16.8 | 17.2 | — | — |

[1]Lengths taken directly from a table in Van Oosten and Hile (1949). Methods of adaptation are described by them.
[2]Actual lengths at capture during growing season subsequent to indicated year.
[3]Standard lengths converted to total lengths by means of a factor determined by Hile and Deason (1934).

TABLE 11.—*Sex composition of age groups of Munising Bay whitefish*

| Age group | Number of males | Number of females | Percentage males |
|---|---|---|---|
| II | 2 | — | 100 |
| III | — | 5 | 0 |
| IV | 11 | 6 | 65 |
| V | 12 | 7 | 63 |
| VI | 15 | 16 | 48 |
| VII | 21 | 16 | 57 |
| VIII | 11 | 11 | 50 |
| IX | 6 | 10 | 38 |
| X | 8 | 7 | 53 |
| XI | 5 | 2 | 71 |
| XII | 1 | 3 | 25 |
| XIII | — | 2 | 0 |
| XVI | 1 | — | 100 |
| Total | 93 | 85 | 52 |

increase of age is in contrast to the findings in two other Great Lakes stocks. The percentage of male whitefish in samples from Lakes Huron (Van Oosten, 1939) and Erie (Van Oosten and Hile, 1949) decreased with an increase in age. A decision as to whether this disagreement between the Munising Bay whitefish and the Lake Huron and Lake Erie stocks represents true differences in the biological characteristics of the stocks is reserved because of problems of segregation, biased sampling, and (in exploited stocks) differential exploitation. Indeed the whole question of the accurate determination of the sex ratio and of factors that influence the ratio is too complex to be discussed in this paper. An excellent review of the matter may be found, however, in a recent paper by Alm (1959).

## MATURITY

The June and August samples of Munising Bay whitefish exhibited such closely similar trends in the relation between length and maturity that the data for the two groups were combined (Table 12). All fish shorter than 11.5 inches were immature. The smallest mature males appeared in the 11.5- to 11.9-inch length interval. Fifty percent of the males were mature at 13.0-13.4 inches and all males (11 fish) longer than 14.4 inches were mature. The first mature females appeared at 12.0-12.4 inches, somewhat fewer than half were mature at 13.5-14.9 inches, and all fish longer than 14.9 inches (7 individuals) were mature. First maturity and 100-percent maturity of males occurred at lengths 0.5 inch shorter than in females.

Whitefish attain maturity at much shorter lengths in Munising Bay than in Lake Huron where Van Oosten (1939) reported first maturity for males at 17.8 inches and of females at 18.3 inches, and 100-percent maturity for males at 20.1 inches and females at 21.5 inches. First maturity was attained in Great Slave Lake at a small size (20 percent mature at an average fork length of 12.1 inches) but average length at 100-percent maturity was 18.0 inches (Kennedy, 1953). Smallest mature whitefish yet reported were from Lake Opeongo where Kennedy (1943) found that the first dwarf whitefish (both males and females) were mature at a standard length of 4.3-4.5 inches.

The slow growth of Munising Bay whitefish in later years of life caused the small differences between the sexes in length at attainment of maturity (Table 12) to become large when the comparison is on the basis of age (Table 13). No female younger than the X group was mature whereas 14 to 50 percent of the males were mature in age-groups VII-IX. All fish of both sexes were mature, however, in the XII age group and older.

The age at first attainment of maturity is much greater in Munising Bay whitefish than in Lake Huron, Lake Erie, and Great Slave Lake stocks. In Lakes Huron (Van Oosten, 1939) and Erie (Van Oosten and Hile, 1949) the first mature whitefish were found in age-groups III and II respectively. The Great

TABLE 12.—*Relation between length and sexual maturity of Munising Bay whitefish*

[All fish shorter than 11.5 inches were immature; all fish longer than 14.9 inches were mature]

| Length interval (inches) | Male | | | Female | | |
|---|---|---|---|---|---|---|
| | Number immature | Number mature | Percentage mature | Number immature | Number mature | Percentage mature |
| 11.5-11.9 | 15 | 5 | 25 | 21 | — | 0 |
| 12.0-12.4 | 25 | 6 | 19 | 23 | 4 | 15 |
| 12.5-12.9 | 20 | 8 | 29 | 15 | 2 | 12 |
| 13.0-13.4 | 9 | 9 | 50 | 14 | 4 | 22 |
| 13.5-13.9 | 9 | 9 | 50 | 7 | 5 | 42 |
| 14.0-14.4 | 1 | 7 | 88 | 5 | 3 | 38 |
| 14.5-14.9 | — | 2 | 100 | 3 | 2 | 40 |

TABLE 13.—*Relation between age and sexual maturity of Munising Bay whitefish*

[In parentheses, number of mature fish at left and immature at right; all fish younger than age-group VII were immature and all in age groups older than XI were mature]

| Age group | Percentage mature | |
|---|---|---|
| | Males | Females |
| VII | 14.3 (3-18) | 0.0 (16-0) |
| VIII | 27.3 (3-8) | 0.0 (11-0) |
| IX | 50.0 (3-3) | 0.0 (10-0) |
| X | 37.5 (5-3) | 42.9 (4-3) |
| XI | 60.0 (2-3) | 50.0 (1-1) |

Slave Lake whitefish (Kennedy, 1953) achieved first maturity in age-group IV. The dwarf whitefish from Lake Opeongo achieved first maturity in age-group II.

The more rapidly growing members of the Munising Bay whitefish stock mature earlier than the slow-growing individuals. The mature fish were longer in six of seven comparisons between the mean lengths of mature and immature fish of the same age and sex (Table 14); the X-group females were the single exception. This finding is in agreement with observations on the relation between growth rate and attainment of maturity in numerous populations (Alm, 1959).

TABLE 14.—*Relation between the average length of immature and mature Munising Bay whitefish of the same age*

[All fish in age-group VI and younger were immature; all fish in age-group XII and older were mature]

| Age group | Male | | Female | |
|---|---|---|---|---|
| | Immature | Mature | Immature | Mature |
| VII | 11.5 | 12.5 | — | — |
| VIII | 11.8 | 12.3 | — | — |
| IX | 12.9 | 14.6 | — | — |
| X | 12.8 | 14.2 | 13.5 | 12.9 |
| XI | 12.5 | 14.0 | 14.2 | 15.5 |

ACKNOWLEDGMENTS

The crew of the M/V *Cisco* collected the field data on which this study is based. Stanford H. Smith and other members of the Ann Arbor Biological Laboratory, Bureau of Commercial Fisheries, U. S. Fish and Wildlife Service, gave advice during the preparation and examination of the data. Ralph Hile assisted in the preparation of the manuscript.

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