AGE, GROWTH, AND MATURITY OF ROUND WHITEFISH OF THE APOSTLE ISLANDS AND ISLE ROYALE REGIONS, LAKE SUPERIOR

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ABSTRACT

The round whitefish has been of some commercial importance in the upper Great Lakes but production in Lake Superior has generally been small; the United States average was 26,600 pounds for 1929–59.

This study is based on 1,173 fish collected in the Apostle Islands in 1958–60 and 103 collected at Isle Royale in 1958 and 1960. The average age of 6.0 years at Isle Royale was concluded to be significantly higher than the mean of 4.2 years in the Apostle Islands. The body-scale relation is a straight line with an intercept of 1.1 inches on the length axis. Weight of Apostle Islands round whitefish captured in several months increased as the 3.22 power of the length. Growth in length was relatively slow; nearly or fully 7 years were required to reach an acceptable commercial length of 14 inches in both the Apostle Islands and at Isle Royale. The calculated weights at the end of the seventh year were 12.6 ounces in the Apostle Islands and 13.8 ounces at Isle Royale. Minimum length at maturity of male round whitefish (7.0–7.4 inches) was less than that of females (8.5–8.9 inches). At age-group II, 11.1 percent of male round whitefish, but only 1.5 percent of the females were mature. All males were mature as age-group V and all females as age-group VI. Males dominated the younger age groups but females were more numerous in the older ones. Estimates of the number of eggs in 37 round whitefish ovaries yielded an average of 5,330 eggs for fish 10.5–17.4 inches long.

The round whitefish, *Prosopium cylindraceum*, is found in all the Great Lakes but Lake Erie. The species ranges north from the Great Lakes to the Arctic, is present in the streams and lakes of eastern Canada, and occurs in both the St. Lawrence and Hudson River drainages (Hubbs and Lagler, 1947).

The present study of age and growth is the first for the round whitefish in Great Lakes waters, but growth studies of the species have been made for other waters by Cooper and Fuller (1945), Kennedy (1949), and Rawson (1951). Information on the age and growth of the related pygmy whitefish, *Prosopium coulteri*, in Lake Superior was published by Eschmeyer and Bailey (1955); this species has not been reported from any other of the Great Lakes.

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The round whitefish has some commercial importance. Greatest production has been in Lake Michigan (mostly in the northern part) where the annual catch frequently has approached or exceeded a quarter-million pounds. The U.S. waters of Lake Huron (limited data for Canadian waters) have also produced round whitefish, but the annual catch there has seldom exceeded 100,000 pounds. Production in Lake Superior generally has been small. The catch in U.S. waters of the lake averaged 26,600 pounds in 1929–59. The largest catch most commonly was taken in Michigan waters. The mean landings for the States were: Michigan, 13,600 pounds; Wisconsin, 9,400; Minnesota, 3,700. Production of round whitefish in Canadian (Ontario) waters of Lake Superior averaged 11,000 pounds in 1952–59 (no statistics on the species in earlier years).

Substantial increases in 1959 U.S. landings (to 69,000 pounds), and the estimated 1960 Canadian catch of 58,000 pounds, could mark the beginning of an upward trend in Lake Superior round whitefish production. [1]

Despite the highly palatable flesh, the market value of the round whitefish has been limited because of the relatively small average size and the fluctuating supply. Small catches often are sold as part of shipments of other species. This marketing procedure may contribute to an underestimate of the production since "odd poundages" are not always listed by fishermen on their reports.

A major purpose of the present study was the gathering of information on the size, age composition, and growth of round whitefish in Lake Superior from which to judge the possibilities for increased exploitation.

MATERIALS AND METHODS

This study is based on 1,173 round whitefish collected at various localities in the Apostle Islands (fig. 1) area and 103 specimens captured off the southwestern end of Isle Royale during the operations of the U.S. Bureau of Commercial Fisheries research vessel *Siscowet* (fig. 1). The study is based mainly on the Apostle Islands collections; the small samples from Isle Royale, taken coincidentally to the major work of the *Siscowet* in that area, were collected to obtain information on the possibility of local differences of growth rate. The majority of fish were taken in nylon gill nets 300 feet long and 6 feet deep (table 1). Nine nets of graded mesh sizes (1 to 5 inches, stretched measure, by ½-inch intervals) were joined end to end and fished on the bottom as a standard gang, usually overnight. The remaining gill net samples were collected in shorter gangs of 2- to 3-inch mesh nets.

The sample of April 30, 1959, includes 36 fish of age-group I taken by a semiballoon otter trawl, 30 feet wide at the mouth, with mesh sizes of 2½ inches in the wings and body and ½-inch mesh in the cod end. Tows were made on the bottom in 5–15 fathoms.

The total length of each fish (tip of head to tip of tail, lobes compressed) was determined to the nearest 0.1 inch. Weights of fish 18 ounces or less were recorded to the nearest 0.1 ounce from a spring balance calibrated in 0.2-ounce intervals. Fish heavier than 18 ounces were weighed on a

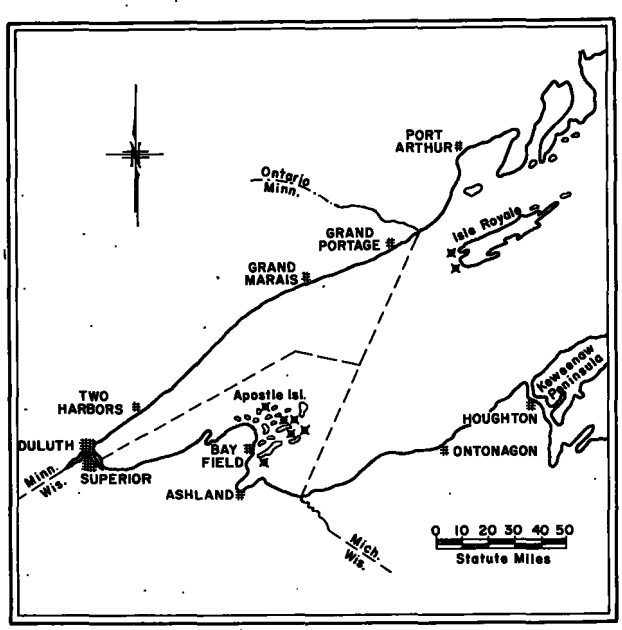

FIGURE 1.—Western Lake Superior. Dots with crosses represent sampling stations.

[1] The statistics for 1929–40 were taken from Gallagher and Van Oosten (1943); U.S. statistics after 1940 appeared in Lake Fisheries, issued by the U.S. Bureau of Commercial Fisheries. Canadian statistics were obtained from records of the Ontario Department of Lands and Forests.

TABLE 1.—*Collections of round whitefish from the Apostle Islands and Isle Royale*

Locality and date	Gear			Total
	Gill net		Trawl	
	Standard gang [1]	Other [2]		
Apostle Islands:				
1958:				
June 5	73			73
July 9		32		32
July 23	180			180
Aug. 10–12		157		157
Oct. 24	79			79
Oct. 31	40			40
1959:				
Apr. 30	221		36	257
June 4	4			4
June 9	54			54
July 29	6			6
Oct. 19	40			40
Nov. 10	73			73
1960:				
Dec. 1	[3] 178			178
Isle Royale:				
1958:				
Aug. 20	65			65
1960:				
Aug. 9		38		38
Total:				
Apostle Islands	948	189	36	1,173
Isle Royale	65	38		103
Grand total	1,013	227	36	1,276

[1] Mesh sizes, 1 to 5 inches by ½-inch intervals.
[2] Various combinations of mesh sizes, 2 to 3 inches.
[3] Used only in determination of the length-weight relation (table 5).

similar balance calibrated to 0.1 pound. All weights obtained by this balance were later converted to ounces.

Sex and state of maturity were determined by gross examination of the gonads. A mature fish was one judged to be ready to spawn in the fall of that same year, regardless of whether it had spawned previously.

Scales were removed from the left side of the fish midway between the lateral line and the base of the dorsal fin. The scales were impressed in cellulose-acetate strips by a roller press (Smith, 1954) and were examined at the magnification X43. The diameters and growth fields within annuli of the projected scales were measured in millimeters along the longitudinal axis on a line passing through the focus. Lengths at time of formation of each annulus were determined nomographically from an empirically determined body-scale relation.

Ages were assessed by counting the number of annuli and are expressed in Roman numerals. Fish were moved to the next higher age group on January 1 of each year. A virtual annulus accordingly was assigned to the edge of the scale from that date until growth actually started. Some difficulty was encountered in reading scales of the older fish where the later annuli were indistinct and close together. These annuli were particularly hard to distinguish in the posterior field of the scale. Only a few scales (less than 1 percent) were discarded, however, as totally unreadable.

TIME OF ANNULUS FORMATION

Annulus formation for round whitefish in the Apostle Islands differed slightly in 1958 and 1959. Annulus formation was complete in 1958 for 32 percent of the fish collected on June 5. All fish examined had completed an annulus at the time of next collection on July 9. Fish captured on June 9, 1959, showed no evidence of annulus formation, but all of six fish captured on July 29 had completed the annulus. The period of annulus formation for this stock appears, then, to fall mostly in June but possibly may extend into early July.

With the exception of two individuals caught near Thompson Island on August 9, 1960, both samples from Isle Royale were taken at Rainbow Cove, on the southern shore, one on August 20, 1958, and the other on August 9, 1960. All fish of the 1958 collection but only 32 percent of the fish caught in 1960 had completed the annulus. An annual difference of surface water temperatures (73.4° F. in 1958 but only 62.0° F. in 1960) could explain the difference.[2] Another possible factor could have been the greater proportion of older fish in the 1960 sample. It has been demonstrated (Hile, 1941) that younger fish form annuli earlier than do the older ones. Difficulty in deciding whether or not an individual fish had completed the annulus for the current season did not interfere with age determination.

AGE COMPOSITION

Round whitefish from the Apostle Islands and Isle Royale exhibited pronounced differences in age distribution and average age (table 2). Age-group IV was dominant at both localities, but Isle Royale had much the stronger representation of fish older than the VII group, and, conversely lacked entirely members of age-groups I and II. In the Apostle Islands the fish of age-groups I and II together made up more than 16 percent of the sample. As a result of these differences the mean age at Isle Royale (6.0 years) was 1.8 years greater than the average of 4.2 years for the fish from the Apostle Islands. The oldest fish taken belonged to age-group IX in the Apostle Islands and to age-group XII at Isle Royale.

An under representation of the younger round whitefish was to be expected at Isle Royale in 1960 since the gill nets fished that year had meshes too large to take numbers of age-groups I and II and may have sampled age-group III inefficiently. The standard gangs (mesh sizes 1 to 5 inches by ½-inch intervals) fished in 1958, however, failed to capture any I- or II-group individuals. It is clear, then, that the younger round whitefish were not on the grounds fished at Isle Royale in 1958. This situation could represent a summer segregation by age within round whitefish stocks generally, but more probable, it is peculiar to the Isle Royale locality. A standard gang lifted in the Apostle Islands on July 23, 1958, took 32 II-group individuals—17.8 percent of a total sample of 180. The only sizable August collection from the Apostle Islands—157 fish on August

[2] Temperature data taken during the 1958 and 1960 operations of the U.S Bureau of Commercial Fisheries vessel *Siscowet*.

10–12, 1958—lacked young fish because of the larger mesh sizes, the same as those fished at Isle Royale in 1960. This collection included a single II-group fish. Each of these two summer collections from the Apostle Islands contained representatives of age-groups II–IX, inclusive. The gill nets were fully capable of taking older fish at both the Apostle Islands and Isle Royale.

It is concluded that the difference between the two stocks is real. Even if age-groups I and II were excluded from the Apostle Islands samples, the average age would be increased only to 4.6 years—still 1.4 years below the mean for Isle Royale. No definite explanation is offered for the differences in age distribution and average age of round whitefish in the Apostle Islands and at Isle Royale. Differences in natural mortality and in fishing mortality both may have been factors.

TABLE 2.—*Age composition of round whitefish taken in gill nets in the Apostle Islands and at Isle Royale*

Age group	Apostle Islands		Isle Royale	
	Number	Percentage	Number	Percentage
I	[1] 3	0.3		
II	152	15.8		
III	190	19.8	12	11.7
IV	270	28.2	24	23.3
V	130	13.6	13	12.6
VI	111	11.6	16	15.5
VII	66	6.9	9	8.7
VIII	27	2.8	10	9.7
IX	10	1.0	11	10.7
X			6	5.8
XI			1	1.0
XII			1	1.0
Total	959		103	
Average age	4.2		6.0	

[1] Fish taken in trawls included 36 additional members of age-group I.

The records of age composition for individual years at the two locations (not given here) offered no indication of the occurrence of exceptionally strong or weak year classes.

LENGTH DISTRIBUTION AND AVERAGE LENGTH OF AGE GROUPS

To avoid bias from the capture of fish at various times in the growing season, the data on the length distributions of the age groups (tables 3 and 4) are based on the calculated lengths at the time of formation of the last annulus. All samples for which age was determined have been used in the tables.

The distributions of I- and II-group round whitefish from the Apostle Islands did not overlap, but those of all other successive age groups overlapped from 2 to 4 inches. The range of length in the well-represented age groups was fairly large for fish that do not attain a great size. Among age-groups II–VIII it fell within the limits of 3 to 5 inches. The shortest range (2.5 inches) in age-groups I and IX can be attributed partly to the small numbers of fish.

Because of the overlap of the length distributions of age groups in the Apostle Islands, most of the 0.5-inch length intervals included fish of several ages. Every length between 7.0 and 15.9 inches was represented by at least two age groups, and five groups were included at 14.0–14.4 inches.

The length distributions of age groups of round whitefish from Isle Royale were similar to those of the Apostle Islands fish, except that the ranges were generally smaller and the overlap correspondingly less extensive. The difference in range can be explained by the small numbers of fish in the Isle Royale collections.

The average lengths of the age groups require little comment since more extensive data on

TABLE 3.—*Length distribution of age groups of round whitefish from the Apostle Islands*

[Based on calculated lengths at last annulus]

Total length (inches)	Age group									Total
	I	II	III	IV	V	VI	VII	VIII	IX	
3.0–3.4	1									1
3.5–3.9	4									4
4.0–4.4	19									19
4.5–4.9	13									13
5.0–5.4	2									2
5.5–5.9										
6.0–6.4		6								6
6.5–6.9		33								33
7.0–7.4		79	3							82
7.5–7.9		29	5							34
8.0–8.4		4	42							46
8.5–8.9		1	46	2						49
9.0–9.4			41	13						54
9.5–9.9			22	30						52
10.0–10.4			21	65						86
10.5–10.9			6	54	13	1				74
11.0–11.4			4	40	22	1				67
11.5–11.9				38	35	3				76
12.0–12.4				21	33	13				67
12.5–12.9				6	18	36	2			62
13.0–13.4				1	5	29	8			43
13.5–13.9					3	20	30			53
14.0–14.4					1	3	18	5	2	29
14.5–14.9						3	6	10		19
15.0–15.4						2	1	7	2	12
15.5–15.9							1	4	2	7
16.0–16.4									4	4
16.5–16.9								1		1
Total number of fish	39	152	190	270	130	111	66	27	10	995
Average length (inches)	4.3	7.1	9.0	10.7	12.0	13.0	14.0	15.0	15.5	[1] 10.4

[1] Grand average length.

TABLE 4.—*Length distribution of age groups of round whitefish from Isle Royale*

[Based on calculated lengths at last annulus]

Total length (inches)	Age group										Total
	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
7.5–7.9	4										4
8.0–8.4	2										2
8.5–8.9	5										5
9.0–9.4	1	3									4
9.5–9.9		5									5
10.0–10.4		5									5
10.5–10.9		7									7
11.0–11.4		4	1								5
11.5–11.9			4								4
12.0–12.4			3								3
12.5–12.9			3	1							4
13.0–13.4				3	1						4
13.5–13.9			2	8	3						13
14.0–14.4				3	4						7
14.5–14.9				1	1	6	1				9
15.0–15.4						3	1	1			5
15.5–15.9						1	2	2			5
16.0–16.4							7	2			9
16.5–16.9								1			1
17.0–17.4										1	1
17.5–17.9									1		1
Total number of fish	12	24	13	16	9	10	11	6	1	1	103
Average length (inches)	8.3	10.4	12.3	13.7	14.0	15.0	15.9	16.0	17.8	17.3	[1] 12.7

[1] Grand average length.

growth are offered in the later section on calculated growth. Attention is called, however, to the relatively slow growth in both stocks. Nearly or fully 5 years were required at each locality for the fish to reach an average length of 1 foot, and the highest average length for any age group was not great (15.5 inches, IX group in the Apostle Islands; 17.8 inches, XI group at Isle Royale). Apostle Islands fish were the longer in age-groups III and IV, but at the higher ages (V–IX) the mean lengths of the Isle Royale stock equalled or exceeded those of fish of corresponding age in the Apostle Islands.

LENGTH-WEIGHT RELATION

The general parabola $W=cL^n$, where W= weight, L=length, and c and n are empirically determined constants, was used to describe the general length-weight relation of round whitefish (table 5). Determination of the length-weight relation was based on data from 755 fish, captured in the Apostle Islands during the 1958–60 collecting seasons, combined without regard to sex, state of maturity, or time of collection. Lengths and empirical weights are averages for 0.5-inch intervals of length. Since some 0.5-inch intervals had large numbers of individuals, not all of the 1,173 Apostle Islands fish were used. The 178 fish captured in the Apostle Islands in December 1, 1960, were included to strengthen the data at the higher length intervals. These fish were not used elsewhere in this study. Limited comparisons according to sex, state of maturity, and date of capture revealed two significant differences. Ripe fish of both sexes were slightly heavier than spent individuals, and fish taken during July and August were generally heavier than those captured in April or November.

TABLE 5.—*Length-weight relation of round whitefish from the Apostle Islands*

[The lengths and empirical weights are averages by 0.5-inch intervals of length. The calculated weights were computed from the equation given in the text]

Number of fish	Total length (inches)	Weight (ounces)		Number of fish	Total length (inches)	Weight (ounces)	
		Empirical	Calculated			Empirical	Calculated
1	4.2	0.3	0.3	37	11.7	6.7	7.0
2	4.8	.4	.4	37	12.2	7.7	8.1
2	5.2	.6	.5	37	12.7	8.8	9.2
3	5.7	.8	.7	37	13.2	10.4	10.4
5	6.3	.9	1.0	37	13.7	11.8	11.7
33	6.8	1.1	1.2	37	14.2	13.3	13.1
37	7.2	1.3	1.5	37	14.7	14.8	14.7
25	7.7	1.7	1.8	37	15.1	17.1	16.0
27	8.2	2.2	2.2	31	15.7	19.6	18.2
37	8.7	2.6	2.7	19	16.1	22.0	19.7
37	9.2	3.0	3.2	21	16.7	22.8	22.2
37	9.7	3.6	3.9	15	17.1	25.6	23.9
37	10.1	4.2	4.4	9	17.7	27.6	26.7
37	10.7	4.9	5.3	7	18.1	29.0	28.7
37	11.2	5.9	6.1				

The length-weight equation, determined by fitting a straight line to the logarithms of the length and weight was:

$$\log W = -3.40468 + 3.2231 \log L,$$

where W=weight in ounces,

and L=total length in inches.

This equation may also be written in the form,

$$W=3.9384\times10^{-4}L^{3.2231}.$$

The weights computed for the mean lengths of fish in each length interval are the basis of the curve in figure 2.

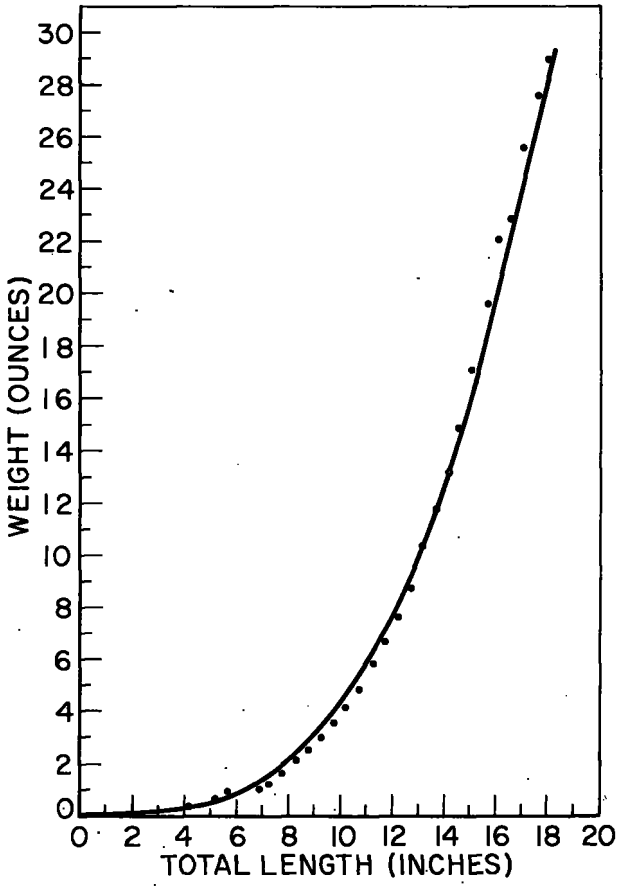

FIGURE 2.—Length-weight relation of round whitefish from the Apostle Islands. The curve represents the calculated weights and the dots, the empirical weights.

A direct comparison of empirical weights of Isle Royale and Apostle Islands round whitefish captured in August (details not given here) demonstrated almost no differences. It is suspected that the condition of the species is at its peak in August, as has been established for other coregonids—*Leucichthys kiyi* (Deason and Hile, 1947) and *Coregonus clupeaformis* (Van Oosten and Hile, 1949). The agreement between Apostle Islands and Isle Royale fish caught in the same month suggests that the length-weight equation derived for Apostle Islands fish may hold reasonably well for both stocks. The equation based on Apostle Islands fish caught in various months may be more suitable for the Isle Royale stock than one based on limited data for a single month in the latter area. The equation is accordingly applied to calculated lengths of both stocks in a later section on calculated growth in weight.

CALCULATED GROWTH

BODY-SCALE RELATION

The body-scale relation for round whitefish of the Apostle Islands area was determined from 429 specimens collected in 1958 and 1959 (table 6). Scale diameters were recorded only from the scale used in age determination. Care was taken, however, to read and measure a scale of average size after all scales on the slide were examined. A plot of the average fish lengths for 0.5-inch groupings, against the average scale diameters, indicated that a straight line best fitted the data (fig. 3).

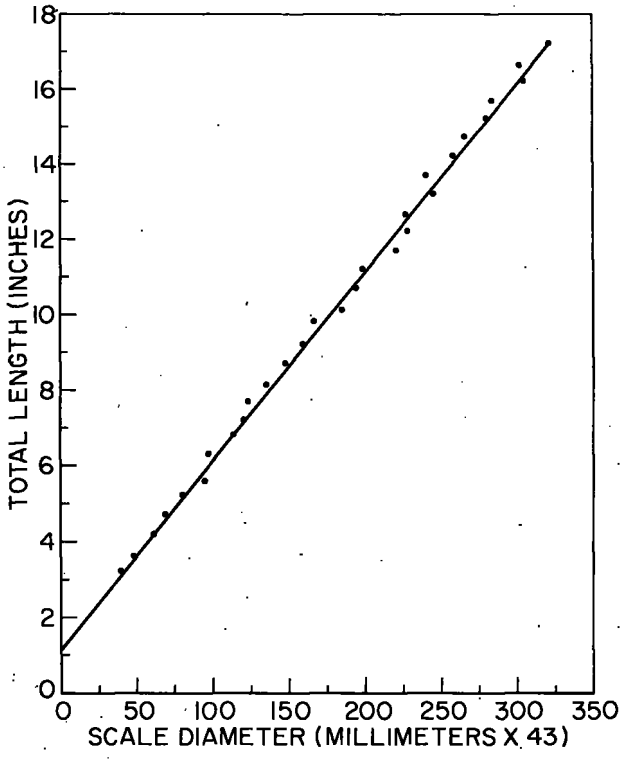

FIGURE 3.—Relation between total length of fish and magnified (X43) scale diameter for round whitefish from the Apostle Islands. [The dots represent the empirical data; the line is a graph of the equation given in the text.]

The equation for the line, fitted by least squares, is:

$$L = 1.1049 + 0.050\ S,$$

where L = total length of the fish (inches),
and S = scale diameter (X43, in millimeters).

For practical purposes the intercept was taken to be 1.1 inches. Lengths at formation of each annulus were calculated nomographically.

GROWTH IN LENGTH

The average calculated lengths of round whitefish gave no evidence of differences according to sex or date of capture. Consequently all collections were combined at each locality in the preparation of tables 7 and 8.

The calculated growth histories of the age groups reveal both random and systematic discrepancies. Some of the randomly distributed discrepancies may reflect true differences of growth, but many of them can be attributed to the small numbers of fish in certain age groups, especially at Isle Royale. The systematic discrepancies are in the form of a progressive decrease of calculated lengths with increase in the age of the fish on which the calculations were based.

In the Apostle Islands samples (table 7) it is difficult to find a trend in the first-year calculated lengths. True, the oldest fish (IX group) had the shortest calculated length (3.7 inches) but this average was based on only 10 fish. The first-year length of the better-represented VIII group (4.4 inches; 27 fish) exceeded that of the younger age-groups I, VI, and VII, and equaled the value for age-group V. Only age-groups II, III, and IV had higher first-year lengths (all 4.8 inches). The second- and third-year calculated lengths, on the other hand, showed pronounced, though irregular downward trends with increase of age. All second-year lengths, for example, were above 7.0 inches (7.2 to 7.4 in age-groups II–V) but were under 7.0 inches (6.1 to 6.8) in age-groups VI–IX. Similarly, third-year lengths exceeded 9.0 inches (9.1 to 9.3) in age-groups III–V, but were lower (8.2 to 8.9 inches) in age-groups VI–IX. Beyond the third year of life no clear trends of calculated length with increase of age can be established.

The tendency for calculated lengths to decline with increase in the age of the fish on which the calculations were based is much clearer in the records for round whitefish from Isle Royale and extends to a greater number of years of life (table 8). As was true for Apostle Islands fish, no clear trend is apparent in the first-year calculated lengths. The calculated lengths for years 2–7, on the contrary, exhibited a clear, though frequently

TABLE 6.—*Relation between total length of fish and magnified (X43) scale diameter for round whitefish from the Apostle Islands*

Number of fish	Average length [1] (inches)	Average scale diameter (millimeters)	Number of fish	Average length [1] (inches)	Average scale diameter (millimeters)
1	3.2	39	19	11.2	198
5	3.6	48	19	11.7	232
19	4.2	61	19	12.2	228
12	4.7	69	19	12.6	228
4	5.2	81	19	13.2	245
4	5.6	95	19	13.7	241
6	6.3	98	19	14.2	259
19	6.8	114	19	14.7	266
19	7.2	121	19	15.2	281
19	7.7	124	15	15.7	284
15	8.1	136	8	16.2	305
19	8.7	149	8	16.6	302
19	9.2	160	3	17.2	321
19	9.8	167	1	17.6	290
19	10.1	185	3	18.1	320
19	10.7	194	2	18.6	303

[1] Mean for fish within a 0.5-inch length interval.

TABLE 7.—*Calculated total length at end of each year of life of each age group of round whitefish from the Apostle Islands and average growth for the combined age groups*

[Collections of 1958 and 1959 combined]

Age group	Number of fish	Length (inches) at end of year								
		1	2	3	4	5	6	7	8	9
I	39	4.3								
II	152	4.8	7.2							
III	190	4.8	7.3	9.1						
IV	270	4.8	7.4	9.3	10.8					
V	130	4.4	7.2	9.2	10.9	12.1				
VI	111	4.2	6.8	8.9	10.8	12.2	13.1			
VII	66	4.0	6.5	8.6	10.6	12.0	13.2	14.0		
VIII	27	4.4	6.7	8.8	10.6	12.1	13.3	14.2	15.0	
IX	10	3.7	6.1	8.2	10.2	11.9	12.9	14.0	14.8	15.5
Grand average calculated length		4.6	7.2	9.1	10.8	12.1	13.1	14.1	14.9	15.5
Increment of average		4.6	2.6	1.9	1.7	1.3	1.0	1.0	0.8	0.6
Grand average increment of length		4.6	2.6	1.9	1.7	1.3	1.0	0.9	0.8	0.7
Sum of average increment		4.6	7.2	9.1	10.8	12.1	13.1	14.0	14.8	15.5

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

[Collections of 1958 and 1960 combined]

Age group	Number of fish	Length (inches) at end of year											
		1	2	3	4	5	6	7	8	9	10	11	12
III	12	3.6	6.1	8.4									
IV	24	3.4	6.3	8.7	10.5								
V	13	3.6	6.3	8.7	10.7	12.3							
VI	16	3.3	6.0	8.6	10.8	12.7	13.8						
VII	9	3.3	6.0	8.1	9.9	11.7	12.9	14.0					
VIII	10	3.3	5.5	7.8	9.9	12.0	13.4	14.3	15.1				
IX	11	3.5	6.0	8.2	10.3	12.0	13.4	14.3	15.2	15.9			
X	6	3.0	5.3	7.5	9.2	11.2	12.7	13.8	14.7	15.3	16.0		
XI	1	3.3	5.1	7.3	9.0	11.1	12.7	13.9	15.4	16.5	17.3	17.8	
XII	1	3.5	5.6	7.3	9.0	10.4	11.6	12.6	13.9	14.8	16.1	16.6	17.3
Grand average calculated length		3.4	6.0	8.4	10.3	12.1	13.3	14.1	15.0	15.7	16.2	17.2	17.3
Increment of average		3.4	2.6	2.4	1.9	1.8	1.2	0.8	0.9	0.7	0.5	1.0	0.1
Grand average increment of length		3.4	2.6	2.3	2.0	1.8	1.3	1.0	0.9	0.7	0.8	0.5	0.7
Sum of average increment		3.4	6.0	8.3	10.3	12.1	13.4	14.4	15.3	16.0	16.8	17.3	18.0

interrupted, tendency to decrease with increase of age. Beyond the seventh year, trends cannot be established—partly, perhaps, because of the small numbers of fish in the older age groups.

Systematic discrepancies in the calculated growth histories of different age groups are common in data on growth of fish. The most likely contributing factors for these discrepancies for Apostle Islands and Isle Royale round whitefish are: biased samples from gear selection; selective destruction of the faster growing fish in the fishery; higher natural mortality for fish with rapid growth than for those with slow growth.

Certain samples almost surely were biased from gear selection. As was recorded in table 1: 189 fish from the Apostle Islands and 38 from Isle Royale were taken in gangs of gill nets that included no mesh sizes under 2 inches. This gear would select only the larger, faster growing fish of the younger age groups. The higher calculated lengths of these selected fish may account for much of the disagreement in calculated lengths for the first few years. Again, these gangs of nets that had meshes only between 2 and 3 inches possibly took the smaller fish of the older age groups. The selection may explain their slow calculated growth during their early years of life.

The selective destruction of the faster growing fish in the fishery probably contributed little, if at all, to the systematic discrepancies in calculated length of round whitefish at either the Apostle Islands or Isle Royale. Commercial exploitation of the species in Lake Superior (see Introduction) is extremely limited.

Higher natural mortality rate among fast growing fish than among slow growing was demonstrated by Hile (1936) in the cisco population of Silver Lake, Wis., but he found no evidence of similar mortality in three other cisco stocks. The possibility that differential natural mortality accounted for some of the discrepancies in the calculated growth of round whitefish does exist, but materials for verifying or disproving this possibility are not available.

The estimates of the general growth in length have been based on all age groups because of insufficient evidence of bias to exclude any one of them. Although some younger age groups may give overestimates of calculated growth, due to gear selection, their inclusion tends to compensate any underestimates from the older age groups, which, too, may have suffered gear selection or may have lost their faster growing members either to the fishery or through higher natural mortality.

Two basically valid approaches to the estimation of general growth are given—the grand average calculated lengths and the summation of the grand average annual increments of length (bottom sections, tables 7 and 8). Apostle Islands round whitefish gave closely similar results by both methods, but at Isle Royale the sums of the increments yielded the higher calculated lengths in the later years of life. The summation of increments has been used for the preparation of table 9 and figure 4 since it avoids the irregularities caused by successive dropping out of age groups.

The trends in growth of round whitefish were noticeably different in the Apostle Islands and at Isle Royale. The calculated length at the end of the first year at Isle Royale (3.4 inches) was 1.2 inches shorter than that of round whitefish from the Apostle Islands (4.6 inches). The second-

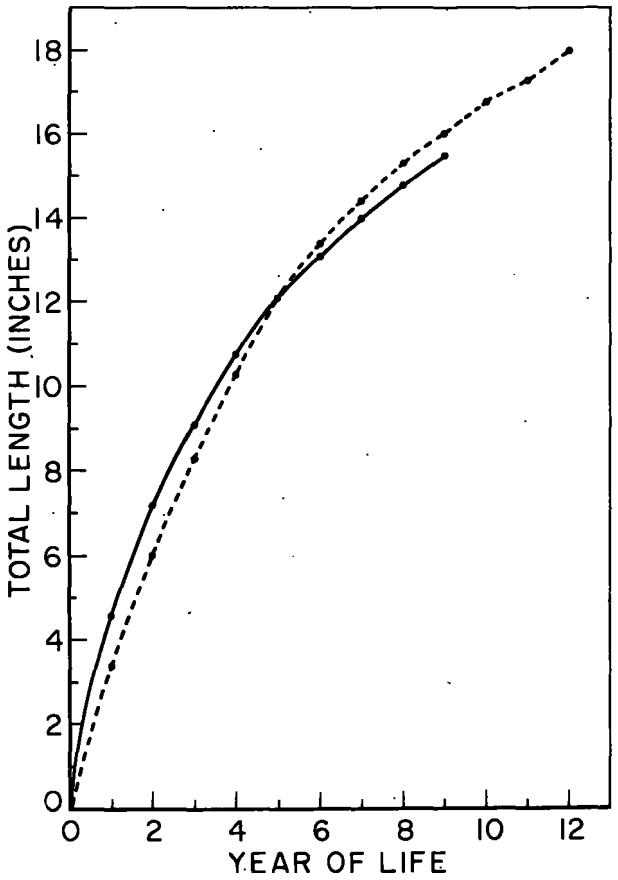

FIGURE 4.—Calculated growth in length of round whitefish from the Apostle Islands (solid line) and Isle Royale (broken line).

year increment was the same in both populations (2.6 inches), but in the third through eighth years, Isle Royale fish grew the faster. (The increments were the same in the ninth year.) The two populations had the same calculated length (12.1 inches) by the end of the fifth year, but thereafter Isle Royale fish were the longer each year through the ninth where further comparisons became impossible. The major difference between the two stocks, then, was the more rapid growth in the Apostle Islands in the first year and equal or better growth at Isle Royale from the second through the ninth years of life.

It is conceivable that the differences in growth rate of round whitefish of the Apostle Islands and Isle Royale, may not be exactly as indicated in table 9. An accurate body-scale relation could not be determined at Isle Royale because no small fish were captured. In consequence, lengths of Isle Royale fish were computed from the body-scale relation determined for round whitefish of the Apostle Islands. Should the body-scale relation actually differ materially between the two stocks apparent differences in growth rate would appear even though the true differences were small.

TABLE 9.—*Calculated growth in length of round whitefish from the Apostle Islands and at Isle Royale as estimated from the data for the combined age groups*

[Based on summation of grand average annual increments; data from bottom of tables 7 and 8]

Year of life	Apostle Islands		Isle Royale	
	Length (inches)	Increment	Length (inches)	Increment
1	4.6	4.6	3.4	3.4
2	7.2	2.6	6.0	2.6
3	9.1	1.9	8.3	2.3
4	10.8	1.7	10.3	2.0
5	12.1	1.3	12.1	1.8
6	13.1	1.0	13.4	1.3
7	14.0	0.9	14.4	1.0
8	14.8	0.8	15.3	0.9
9	15.5	0.7	16.0	0.7
10			16.8	0.8
11			17.3	0.5
12			18.0	0.7

Both stocks of round whitefish made their best growth in length in the first year of life; thereafter the annual increments decreased with few exceptions. The increments beyond the second year were low, and beyond the sixth year were 1 inch or less.

At the present time there is no legal commercial size limit on the round whitefish in any of the Great Lakes. The only factor governing sale is acceptability on the commercial market. Prospects for increased exploitation are dimmed by the fact that nearly or fully 7 years are required for the species to reach a practical commercial size of about 14 inches.

GROWTH IN WEIGHT

Calculated growth in weight of round whitefish from the Apostle Islands and Isle Royale (table 10) was determined by applying calculated lengths (sum of the average increments) of table 9 to the length-weight equation given earlier. The estimates of growth in weight at Isle Royale are subject to possible error since calculated weights were computed from the length-weight equation derived for the Apostle Islands stock. As was explained in the section on the length-weight relation, however, the equation based on Apostle Islands fish, caught in various months, may be more satisfactory for the Isle Royale stock than

one based on limited collections made in a single month in the latter area. In the Apostle Islands the annual increments of calculated weight increased from 0.4 ounce in the first year to 2.5 ounces in the fifth year of life. The weight increments for subsequent years all fell within the range of 2.2 to 2.5 ounces. At Isle Royale yearly weight increments increased progressively from 0.1 ounce in the first year to 3.2 ounces in the fifth year of life. Thereafter the increments fluctuated without trend but all fell within the range of 2.2 to 3.4 ounces. Annual increments of weight for Isle Royale round whitefish were significantly higher than those of the Apostle Islands from the fifth year through the ninth year of life (fig. 5). Conversely, Apostle Islands fish revealed better weight increments in the first 3 years. Relatively slow growth in weight is evident in both populations. Nearly 7 years are required to reach a weight of ¾ pound.

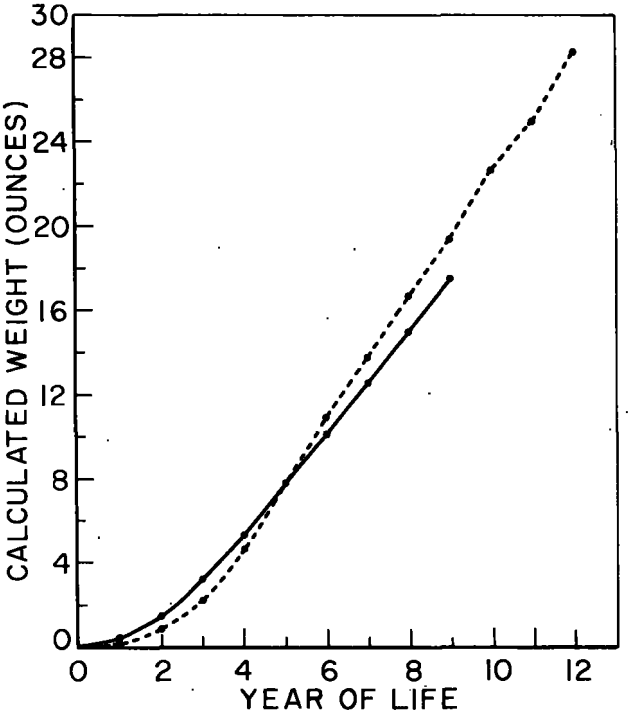

FIGURE 5.—Calculated growth in weight of round whitefish from the Apostle Islands (solid line) and at Isle Royale (broken line).

TABLE 10.—*Calculated growth in weight of round whitefish from the Apostle Islands and at Isle Royale*

[Weights were computed from the general length-weight relation and correspond to the lengths in table 9]

Year of life	Apostle Islands		Isle Royale	
	Weight (ounces)	Increment	Weight (ounces)	Increment
1	0.4	0.4	0.1	0.1
2	1.5	1.1	0.8	0.7
3	3.1	1.6	2.3	1.5
4	5.4	2.3	4.7	2.4
5	7.9	2.5	7.9	3.2
6	10.1	2.2	10.9	3.0
7	12.6	2.5	13.8	2.9
8	15.0	2.4	16.7	2.9
9	17.4	2.4	19.3	2.6
10			22.6	3.3
11			24.8	2.2
12			28.2	3.4

SIZE AND AGE AT MATURITY SEX RATIO

No collections made near or during the spawning runs were included in determining the size and age at maturity or sex ratios of round whitefish from the Apostle Islands since segregation by sex and maturity can bias samples obtained at this period.

The shortest mature males were 7.0–7.4 inches long (table 11) and 100-percent maturity was reached at 13.0–13.4 inches. This range of 6 inches seems to be large, particularly for a species of relatively slow growth. One immature male was found at 14.0–14.4 inches, but it is highly probable that the gonads of this fish were undeveloped for other physiological reasons. The shortest mature female was at 6.5–6.9 inches. The suspicion that the single mature specimen at this length may be exceptional is supported by the fact that the next mature female was found at 8.5–8.9 inches. By the 10.0- to 10.4-inch interval, 60 percent of the females were mature, and all were mature at 12.5 inches. Male round whitefish apparently mature at a slightly smaller size than females, but 100-percent maturity is reached by both sexes at about the same length.

The youngest mature fish of both sexes belonged to age-group II (table 12). The single mature female in this age group, however, was the same fish found at 6.5–6.9 inches (see table 11). All males were mature at age-group V (one was immature in the VII group) and all females at age-group VI. In the younger age groups the higher percentage of maturity for males than for females is in agreement with findings for other species.

A commercial fishery for the round whitefish in the Apostle Islands region, based on the acceptable minimum length of about 14 inches (age-group VII), would take few, if any, immature fish.

Male round whitefish outnumbered females in the Apostle Islands (table 13) in the younger age group. The ratio was near 50–50 in age-groups IV and V, and females became progressively more plentiful in age-groups VI through IX. Males constituted only 20 percent of age-group IX.

TABLE 11.—*Relation between length and sexual maturity of round whitefish from the Apostle Islands*

[All fish shorter than 6.5 inches were immature; all fish longer than 14.4 inches were mature]

Total length (inches)	Males			Females		
	Number immature	Number mature	Percentage mature	Number immature	Number mature	Percentage mature
6.5–6.9	11	0	0.0	11	1	8.3
7.0–7.4	41	4	8.9	14	0	0.0
7.5–7.9	9	2	18.2	15	0	0.0
8.0–8.4	10	2	16.7	10	0	0.0
8.5–8.9	21	1	4.5	18	1	5.3
9.0–9.4	21	1	4.5	22	1	4.3
9.5–9.9	11	4	26.7	14	5	26.3
10.0–10.4	5	11	68.8	10	15	60.0
10.5–10.9	9	28	75.7	4	17	81.0
11.0–11.4	6	22	78.6	4	22	84.6
11.5–11.9	2	31	93.9	8	32	80.0
12.0–12.4	1	30	96.8	3	22	88.0
12.5–12.9	1	32	97.0	0	49	100.0
13.0–13.4	0	28	100.0	0	28	100.0
13.5–13.9	0	24	100.0	0	25	100.0
14.0–14.4	1	23	95.8	0	21	100.0

TABLE 12.—*Relation between age and sexual maturity of round whitefish from the Apostle Islands*

[All fish younger than age-group II were immature; all fish older than age-group VII were mature]

Age group	Males			Females		
	Number immature	Number mature	Percentage mature	Number immature	Number mature	Percentage immature
II	72	9	11.1	65	1	1.5
III	66	23	25.8	61	13	17.6
IV	10	78	88.6	6	107	94.7
V	0	67	100.0	3	47	94.0
VI	0	47	100.0	0	54	100.0
VII	1	26	96.3	0	36	100.0

TABLE 13.—*Sex composition of age groups of round whitefish from the Apostle Islands*

[No sex record for 47 fish]

Age group	Number of males	Number of females	Percentage males
I	1	1	50.0
II	82	66	55.4
III	110	78	58.5
IV	135	134	50.2
V	64	66	49.2
VI	51	58	46.8
VII	28	37	43.1
VIII	11	16	40.7
IX	2	8	20.0
Total	484	464	51.1

FECUNDITY

The number of eggs was estimated for 37 round whitefish collected in the Apostle Islands area between September 15 and October 20, 1960. Before estimates of egg numbers were undertaken, a test was made to determine the relative dependability of overnight drying at room temperatures and oven drying as described by Smith (1956).

The testing procedure was first to break up thoroughly the alcohol-preserved ovaries and separate and remove connective tissue and other foreign matter. Eleven random samples of 500 eggs each, all from the same ovary, were dried at room temperature and weighed on a milligram balance. The samples were then further dried in an oven at 60° C. and reweighed. Since further weight loss was found to be nearly constant for all samples after oven drying, this additional step was judged to be unnecessary.

For each of the 37 fish, a random sample of either 500 or 1,000 dried eggs (depending upon the ovary size) was removed from each ovary and weighed. The remainder of the eggs were also weighed and the total number estimated by direct proportion. The accuracy of this method was tested by actually counting the eggs in six ovaries. The errors (all slight overestimates) ranged from 0.02 to 4.9 percent and averaged 1.3 percent.

The average number of eggs for fish grouped by 0.5-inch intervals increased irregularly with increased fish length (table 14 and fig. 6). The single specimen at 10.5–10.9 inches had 1,076 eggs in its ovary, and the fish at 17.0–17.4 inches

TABLE 14.—*Relation between the length of round whitefish from the Apostle Islands and the number of eggs in the ovaries*

Total length (inches)	Number of fish	Number of eggs per fish		Number of eggs per ounce of fish
		Average	Range	
10.5–10.9	1	1,076		199
11.5–11.9	1	2,688		395
12.0–12.4	3	2,461	1,906– 3,022	300
12.5–12.9	4	2,970	2,211– 4,595	323
13.5–13.9	3	3,623	2,986– 3,951	335
14.0–14.4	2	3,947	3,656– 4,237	290
14.5–14.9	4	4,458	3,381– 5,170	312
15.0–15.4	8	5,438	4,014– 6,601	340
15.5–15.9	2	7,086	6,920– 7,251	369
16.0–16.4	5	7,673	6,020– 9,254	364
16.5–16.9	3	10,459	8,053–11,888	436
17.0–17.4	1	10,187		398
All lengths	37	5,330	1,076–11,888	341

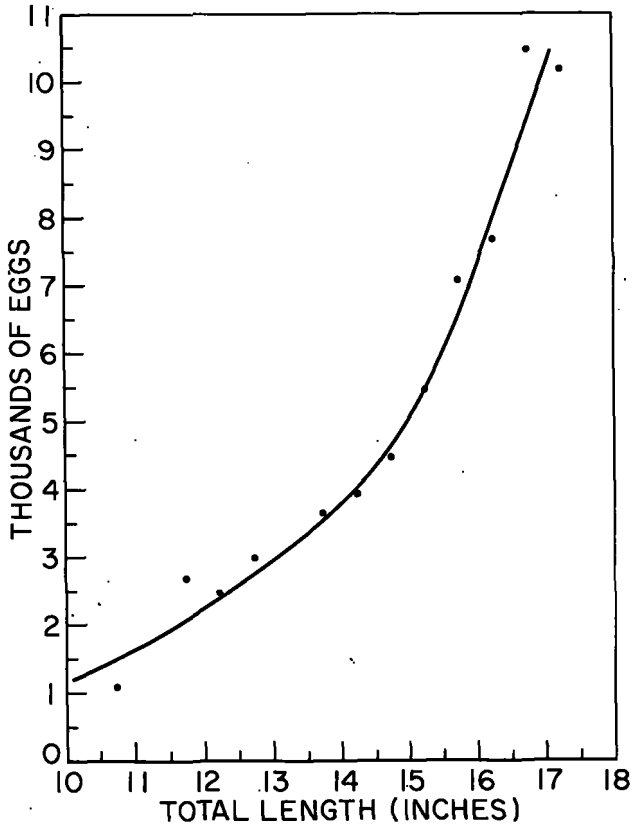

FIGURE 6.—Relation between length of round whitefish from the Apostle Islands and number of eggs per ovary. The dots represent the empirical data for 0.5-inch length groups; the curve was sketched by inspection.

contained 10,187 eggs. The mean number of eggs for all fish was 5,330.

The number of eggs per ounce of fish varied irregularly with length but tended to be higher among the longer than among the shorter fish. The number per ounce was low for the single female at 10.5–10.9 inches (199). The highest number (436) was for fish 16.5–16.9 inches long. The mean number of eggs per ounce of fish for all individuals was 341.

Only one publication could be located that included egg counts for round whitefish. Brice (1898) listed an average of 3,500 eggs per female; a 1.75-pound female produced 12,000 eggs.

SUMMARY

1. The round whitefish is found in all the Great Lakes but Lake Erie. It occurs northward to the Arctic and is common in the streams and lakes of eastern Canada and in the St. Lawrence River and Hudson River drainages.

2. The investigation of round whitefish from Lake Superior was based on data from 1,173 specimens collected in the Apostle Islands area and 103 captured at Isle Royale. This study is the first on the age and growth of the species in the Great Lakes.

3. Round whitefish production for the U.S. waters of Lake Superior generally has been small and averaged only 26,600 pounds in 1929–59. Canadian (Ontario) production averaged 11,000 pounds in 1952–59.

4. Slight year-to-year differences in time of annulus formation were found at both the Apostle Islands and Isle Royale. The period of annulus formation for the Apostle Islands stock appears to fall mostly in June, but 1960 Isle Royale samples suggest a later annulus formation date at this location.

5. The average age of 6.0 years at Isle Royale was concluded to be significantly higher than the mean of 4.2 years in the Apostle Islands. Age-group IV was dominant at both localities and the oldest fish taken belonged to age-group IX in the Apostle Islands and to age-group XII at Isle Royale.

6. Length distributions of the well-represented age groups demonstrate a fairly large range in length at both the Apostle Islands and Isle Royale. The distributions of I- and II-group round whitefish from the Apostle Islands did not overlap, but those of other successive age groups overlapped from 2 to 4 inches.

7. The general length-weight relation of round whitefish from the Apostle Islands is described by the equation: $\log W = -3.40468 + 3.2231 \log L$, where W is weight in ounces, and L is total length in inches. Weight varied according to state of maturity and date of capture. The length-weight equation derived for Apostle Islands fish was accepted for the Isle Royale stock since a comparison of empirical weights of fish captured in August from both areas revealed little difference.

8. The relation between the total body length in inches (L) and the magnified ($\times 43$) scale diameter in millimeters (S) is described by the equation, $L = 1.1049 + 0.050\ S$. The intercept was taken to be 1.1 inches on the length axis and lengths at formation of each annulus were calculated nomographically.

9. The different age groups of both the Apostle Islands and Isle Royale stocks exhibited systematic discrepancies in the form of a progressive

decrease of calculated lengths with increase in the age of the fish on which calculations were based.

10. The most likely contributing factors for the systematic discrepancies are: biased samples from gear selection; selective destruction of the faster growing fish in the fishery; higher natural mortality for fish with rapid growth than for those with slow growth.

11. First-year growth in length in the Apostle Islands (4.6 inches) was greater than at Isle Royale (3.4 inches), but in subsequent years of life growth at Isle Royale exceeded or equaled that in the Apostle Islands. The Apostle Islands fish had the greater calculated lengths (by 1.2 to 0.5 inches) through the first 4 years, the lengths for the two stocks were equal at 12.1 inches in 5 years, and the Isle Royale fish were the longer (by 0.3 to 0.5 inch) in years 6–9. Both stocks required nearly or fully 7 years to reach an acceptable market length of 14 inches.

12. Differences between the two stocks in growth in weight resembled those of growth in length. Both required nearly 7 years to reach three-quarters of a pound.

13. The slow growth of round whitefish from the Apostle Islands and at Isle Royale suggests that possibilities for greatly increased commercial exploitation are small.

14. The percentage of maturity of male round whitefish from the Apostle Islands was higher than that of females at the shorter lengths and younger ages but 100-percent maturity was reached by both sexes at about the same length and age. All fish shorter than 6.5 inches were immature and all longer than 14.4 inches were mature. Youngest immature fish of both sexes belonged to age-group II. Only one male (possibly aberrant) older than the IV group and no females older than the V group were immature.

15. Male round whitefish from the Apostle Islands outnumbered females in the younger age groups (II and III) but females became progressively more plentiful as age increased and dominated the higher ages.

16. Estimates of the number of eggs in 37 round whitefish ovaries ranged from 1,076 to 10,187 and averaged 5,330 eggs for fish 10.5–17.4 inches long. The average numbers of eggs for fish grouped by 0.5-inch intervals increased irregularly with increased fish length. The mean number of eggs per ounce of fish was 341.

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