The age, growth and maturity of the haddock (*Melanogrammus aeglefinus* L.) from the inshore Lockeport grounds

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science in Zoology

McGill University, Montreal

August, 1956

Suggested short title:

THE HADDOCK ON THE INSHORE LOCKEPORT GROUNDS

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ACKNOWLEDGEMENTS

The data used in this investigation were collected under the direction of Dr. W. R. Martin, Fisheries Research Board of Canada, St. Andrews, N. B. The author wishes to thank Dr. Martin for making the data available and for his advice concerning the problem. Thanks are also due to Mr. D. N. Fitzgerald who carried out the wharf sampling at Lockeport, N. S., in a very efficient manner.

The author is indebted to his academic supervisor, Dr. M. J. Dunbar, Department of Zoology, McGill University, for suggestions and criticism concerning the text.

I wish also to express my appreciation to Mrs. C. R. Garnett for the typing, to Mr. P. W. G. McMullon for the photographic work and to my wife for her work on the figures.

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INTRODUCTION

The regulation of any fishery depends for its direction upon the knowledge of the biology of the fish involved. As the haddock has been one of the more important marine food fishes even before marine biological investigation was initiated in the fishing areas of the northwest Atlantic, it has periodically received attention from biologists working in these areas. Since the end of World War II with the advent and use of more efficient aids and methods for catching groundfish, the problem of regulation has become more acute.

At the end of the war this problem was foreseen and at that time a program was initiated at the Atlantic Biological Station which would eventually result in a good understanding of the dynamics of the populations of the haddock in Nova Scotian waters. One of the factors entering into a study of this type is a good estimate of the ages of fish making up the population by use of a valid method of age determination. It is also essential to know the rate at which the fish grow. The purpose of this thesis is to examine these two factors in detail and draw some conclusions concerning the haddock in these waters.

The inshore area around Lockeport (Fig. 1) has been selected for study as samples have been taken there at most seasons of the year since September of 1946.

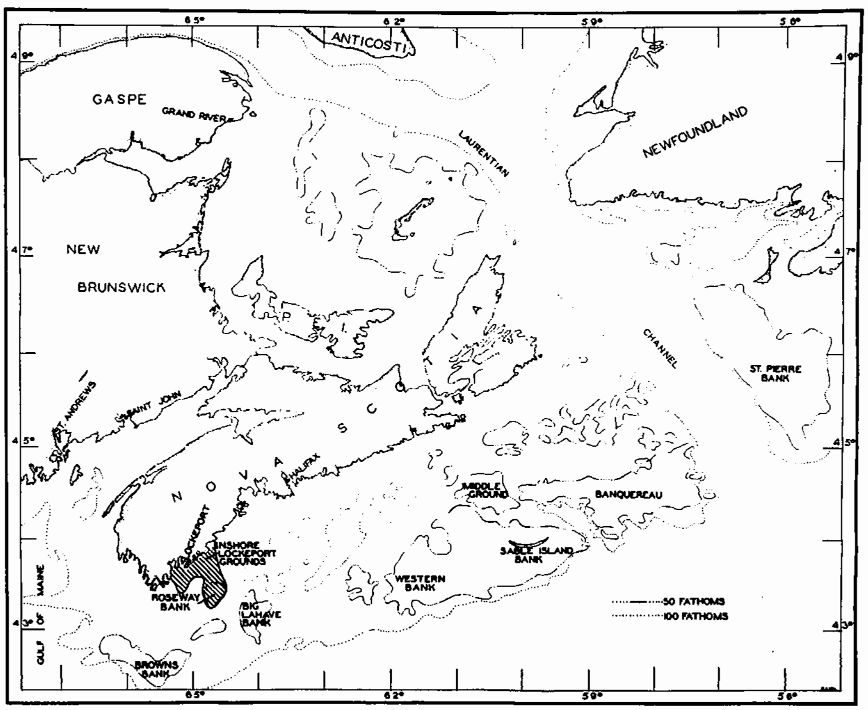

Figure 1. Fishing areas in the Nova Scotian region.

Although the haddock taken there seem to come from a fairly discrete population, it is felt that the results regarding validity of methods used will apply to almost all the Nova Scotian region. This conclusion is based on superficial examination of data collected from several other areas during the same period of time.

Nothing has been published dealing with validity of aging methods used for haddock in Nova Scotian waters. Several growth curves have been presented for the area, all being a combination of age and length data with ages being read from haddock scales. Duff (1915), Huntsman and Needler (1927), Needler (1929, 1930), Vladykov (1934), Thompson (1939), Schuck and Arnold (1951) and Wise (1955) have presented papers dealing with this phase of the haddock's biology. In the present study the use of otoliths as a tool for age analysis and growth calculations will be justified.

Information on age and length at maturity is a further important factor in population management problems. Data concerning this facet of the haddock's life will be presented.

METHODS AND MATERIALS

The fishery for haddock at Lockeport, N. S.

Fishing is carried out almost entirely by hook and line on the inshore grounds as the bottom in the area has been found to be too rough for otter trawling. The boats generally in use in the May to October period are small longliners, with medium longliners joining in from November to April. Small longliners are about 40-45 feet in length while the mediums are 45-55 feet long. In the May to October period of the year small boats and dories also exploit the fishery, usually using handlines.

The approximate area from which the fish used in the present study were taken is outlined in Figure 1. It should be noted that in the years since about 1950, it has been impossible to separate fish taken on the inshore Lockeport grounds from those taken on Roseway Bank , when sampling landings, because many of the boats fish in both places on the same trip.

There are some seasonal differences in depths fished by these craft. The small longliners and handliners tend to fish depths of 20 to 40 fathoms along the inshore grounds and around Roseway Bank in the summer season. In the winter, the medium longliners move inshore usually because of adverse weather conditions and fish the 40 to 60 fathom water.

The stocks exploited in this fishery and sampled at Lockeport are thought to be fairly stable. Martin (1953) separates inshore haddock stocks of southwestern Nova Scotia from those of Browns Bank and offshore Nova Scotia. McCracken (1956) tagged haddock in southwestern Nova Scotia waters in 1953. Conclusions based on returns up to September, 1955, indicated a unit stock of haddock both inshore and offshore in this area. Results from examination of data from inshore Lockeport sampling indicate that samples are taken from a stock that is not noticeably contaminated by fish from other areas.

Sampling

Sampling has been carried out as a routine (from September of 1946 to December of 1954) by D. N. Fitzgerald, a technician attached to the groundfish group of the Atlantic Biological Station. Table I shows the dates on which the samples used in this work were taken, together with number of fish in the sample, type of gear and depth fished. The samples are listed in chronological order with the exception of two small groups at the end of the list.

The first of these small groups contains samples taken at sea by observers on the M. B. "Mallotus" which was engaged in tagging and bait experiments at that time. The second group consists of fish sampled especially for length-weight studies.

As a rule, an attempt was made to measure 200 fish and to remove saccular otoliths from one out of every five of them. Boxes of fish were picked at random as they were landed from the boat and fish were measured until a total of 200 had been examined. Every fifth fish was sampled for otoliths, the fish being taken from the box for measurement in a random manner.

It is the custom in groundfish sampling in this region to measure lengths in centimetres and weight in pounds. Lengths recorded and referred to in this paper are fork lengths, measured from the tip of the snout to the fork of the caudal fin. The length measurements were made on a measuring board with an offset vertical head piece.

When commercial catches are landed at this port they are separated before landing into two size categories, large and scrod. Large haddock are approximately 46 centimetres or more in length while the scrod group contains fish about 40 to 45 centimetres long. Most of the fish below 40 centimetres in length were at this time not acceptable at the Lockeport fish plants and were discarded at sea by the fishermen. A routine method for extracting a random sample from commercial landings was used.

Since it was impossible to measure the whole catch from a boat before processing and since large and scrod haddock were sampled separately as they were landed from the boat, it was necessary to estimate the proportions of large and scrod in the catch and make up a sample approximating the proportions of each. Later, the total weight of large and scrod in the catch and the average weights of large fish and scrod fish were received from the fish plant. Then weighting factors were applied to the sample of large and scrod taken in order to get a combination of data from the two categories which would give an accurate picture of the whole catch.

The equation used to obtain the weighting factor for each of the groups was as follows:

$$W_x = \frac{tx}{T} \times \frac{n}{n_x}$$

where
T = total number of fish in catch
t_x = total number of one size category in the catch
n = total number of fish sampled
n_x = total number of the size category in the sample

t_x was estimated by finding the average weight of an individual of the size category in question and dividing the total weight of that size category landed by this average. T was the total $t_x + t_x$ from both sizes. This procedure was initiated by Dr. W. R. Martin of the Atlantic Biological Station in 1946.

Until early in 1954 otoliths were preserved in vials containing a 50% solution of glycerin with a few crystals of thymol added. However, it was decided that haddock otoliths could be examined just as easily if kept dry in envelopes and the labour of sampling was somewhat reduced by this method. Since 1954 they have been kept in this way.

Examination of the condition of gonads of haddock was carried out at sea by observers on the M. B. "Mallotus" in the months January to May, inclusive, in 1953. The data are of a gross nature and the criteria used in classifying the stages found will be dealt with in a later section.

Table I. Haddock samples taken from the inshore Lockeport fishery in the years 1946-1954.

Date	Number of fish	Gear	Depth (fms.)
Sept. 6/46	100	Line	25
Dec. 17/46	200	Line	40-50
Mar. 7/47	80	Line	50
Oct. 17/47	275	Line	40-50
Dec. 2/47	200	Line	...
Feb. 18-19/48	200	Line	...
Mar. 31/48	200	Line	58-70
Apr. 6/48	200	Line	60-70
June 24/48	200	Line	...
July 2/48	200	Line	40
July 13/48	200	Line	...
Oct. 15/48	200	Line	30-35
Dec. 1/48	250	Line	30-35
Dec. 16/48	200	Line	50-65
Feb. 16/49	200	Line	55-60
Mar. 18/49	200	Line	50-55
Mar. 25/49	200	Line	45-55
Aug. 1/49	200	Line	45
Aug. 15/49	225	Line	40-50
Nov. 3/49	600	Line	...
Nov. 17/49	200	Line	50-60
Dec. 10-11/49	200	Line	60-65
Feb. 28/50	250	Line	53
Apr. 25/50	255	Line	58-60

(cont'd)

Table I (cont'd)

Date	Number of fish	Gear	Depth (fms.)
May 22/50	240	Line	...
Nov. 15/50	200	Line	40-50
Nov. 20/50	300	Line	40-60
Dec. 14/50	200	Line	40-55
Jan. 11/51	200	Line	45-60
Jan. 24/51	200	Line	45-55
Apr. 18/51	200	Line	30-40
Sept.18/51	200	Line	40
Nov. 10/51	200	Line	50-60
Dec. 20/51	250	Line	40-60
Jan. 31/52	250	Line	45-60
Mar. 10-11/52	200	Line	45-60
Aug. 20-21/52	300	Line	20-60
Dec. 18/52	200	Line	50-60
Jan. 4/53	200	Line	40-50
Jan. 6/53	200	Longline	40-50
Apr. 30/53	200	Longline	35-55
Aug. 17/53	195	Longline	30-50
Aug. 17/53	200	Longline	30-50
Nov. 17/53	200	Longline	40-50
Dec. 31/53	200	Longline	45-50
Jan. 15/54	200	Longline	45-55
Mar. 3/54	200	Longline	45-55
Apr. 21/54	200	Longline	50-55
May 14/54	200	Longline	30-50
June 15, 18/54	195	Longline	30-40

(cont'd)

Table I (cont'd)

Date	Number of fish	Gear	Depth (fms.)
Sept.28/54	200	Longline	25-45
Dec. 13/54	225	Longline	40-50
Dec. 28/54	400	Longline	45-50
Jan. 23/53	200	Line	48-54
Feb. 24/53	150	Line	42-54
Mar. 23/53	180	Line	...
Apr. 16/53	150	Line	50-62
May 1/53	150	Line	38-48
Aug. 26/49	165	Line	48
Jan. 19/53	150	Line	40-60
Apr. 17/53	150	Line	45-55
Aug. 17/53	150	Line	30-50

Examination of otoliths

Routine examinations of otoliths for age have been made at the Atlantic Biological Station since 1946 for most of the populations of groundfish sampled by the staff. A succession of four people have done this work, the author being the last in line. There has been an overlap of joint examination between each of the people responsible for this work which seems to have resulted in consistent interpretation.

Otolith examinations have been carried out as follows: Along the convex side of the sacculus otolith a shallow groove called the sulcus acusticus runs longitudinally. There is an interruption across this groove near the blunt end of the otolith across which the otolith is fractured. An experienced otolith reader can usually make a clean break by exerting pressure at this point with the thumbs and forefingers. The few poor breaks resulting from this method can be remedied by grinding down the piece that is too long.

The resulting pieces of otolith are then imbedded in a cube of modelling clay, the surfaces of the fractures being set flush with the horizontal upper surface of the clay. They are covered with a few drops of 50% glycerin solution and the rings are examined with the aid of a binocular microscope (9X) and reflected blue light. The examination reveals concentric, consecutive rings of white and blue colouration. The blue rings are considered to be "winter growth" and the white rings "summer growth" for reasons that will be discussed in a later section. For the purpose of clarity, the blue rings will henceforth be referred to as hyaline rings or zones and the white rings as opaque rings or zones, following the procedure suggested by Saetarsdal (1953). These rings are counted one opaque and one hyaline zone making up one year in the life of the fish.

The method of notation of the number of rings observed is as follows:

(a) a central opaque zone followed by a narrow hyaline zone is designated "1 N.H." (narrow hyaline);

(b) a central opaque zone followed by a wide hyaline zone is designated "1";

(c) the zones in (b) followed by a narrow opaque zone are designated "1 + N.O." (narrow opaque);

(d) the zones in (b) followed by a wide opaque zone are designated "1 +";

(e) the zones in (d) followed by a narrow hyaline zone are designated "2 N.H.", and so on (Table II).

The words "followed by" used in the above classifications must be explained. From experience in examining haddock otoliths from the Lockeport area and other areas in the Nova Scotian region, it has been found that zone growth is not always equal or at the same stage in all parts of the edge of the cross section. This has also been found to be the case by other investigators (Saetarsdal, 1953). The area of the cross section which seems to be most easily interpreted and the usual axis on which rings are counted is shown in Figure 2. Therefore, the words "followed by" are taken to refer to zones seen in the pointed end of the cross section of the otolith.

Ring counts were translated to ages by a standard method based on the approximate time of formation of opaque and hyaline rings and the time of the fish's birthday. These factors will be further dealt with in a later section.

For the Nova Scotian region the fish's birthday has been taken to be the first of February. It will be shown that the bulk of the spawning in 1953 occurred in March and April which would make most of the 1953 fish only 10 or 11 months

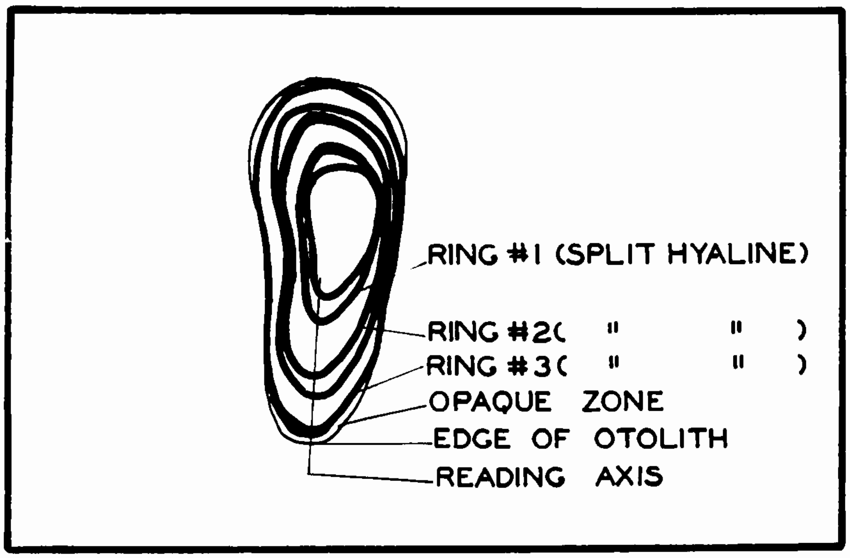

Figure 2. Drawing of a cross-section of a haddock otolith.

old at the time of their first birthday. However, we shall also see that growth is at a minimum during February, March and April, the first quarter of the "fish year", so in order to be able to assign all fish of like age to the same age group in a summary of these three months, we have left February 1 as the birthday.

Table II shown below has been prepared to show the standard notation used for the various months of the year. "x" is found by counting the number of hyaline rings visible in the otolith. The date of capture of the individual in question is essential to the translation from ring number to age. Fish having otoliths showing only an opaque central core in the first and second quarters of the year and forming the first hyaline zone in the third and fourth quarters of the year are assigned to age group 0 as they have not reached their first birthday. Similarly, a fish in its second year of life, having passed one birthday and showing one completed hyaline zone, is assigned to age group I and so on.

Table II. Standard notation for ring counts on haddock otoliths and age groups to which they belong. Value of "x" must be a constant whole number for any one horizontal line in the table.

Quarter	Months	Number of hyaline zones	Age group
	Feb.	x N.H.	x
I	Mar.	x	x
	Apr.	x + N.O.	x
		x +	x

(cont'd)

Table II (cont'd)

Quarter	Months	Number of hyaline zones	Age group
	May	x N.H.	x
II	June	x	x
	July	x + N.O.	x
		x +	x
	Aug.	x N.H.	x-1
III	Sept.	x	x,(x-1 in Oct.)
	Oct.	x + N.O.	x
		x +	x
	Nov.	x N.H.	x-1
IV	Dec.	x	x-1
	Jan.	x + N.O.	x
		x +	x

VALIDITY OF THE OTOLITH METHOD OF AGE DETERMINATION FOR INSHORE LOCKEPORT HADDOCK

The use of otoliths as a tool for determining age in many marine species of fish has long been recognized. It is generally conceded that Reibisch (1899) introduced the method, using the ear-bones of Pleuronectes platessa as an example. Since that time, the method has been examined and applied to such members of the Gadidae as the cod by Dannevig (1933) and Rollefsen (1933, 1935), the hake by Hickling (1933), and the haddock by Saetarsdal (1953), as well as many other species.

Saetarsdal (1953) points out that scales and otoliths of haddock have been used in many other haddock investigations without their applicability to the material at hand having been questioned. He suggests that results of growth determinations may, in these cases, be quite uncertain. In this statement he is supported by Gulland (1955), who, however, further states that mortality rates calculated from such age distributions may not be seriously affected by mistakes in age determination, provided that the errors do not increase sharply from one age group to the next. Random error in age reading is to be expected in any method of determining age from structures in the fish. We are more concerned with a method valid in the majority of cases in which we can expect most of the fish to exhibit a recognizable annual mark for each year of their life.

In the following sections evidence for the annual periodicity of a hyaline zone plus an opaque zone in the otoliths of haddock from the Lockeport area will be presented. The evidence is based on examinations carried out on 2,479 pairs of haddock otoliths collected in the area from March, 1947, until December, 1954.

The seasonal change in the otolith margin

In a critical review of the validity of aging methods for fish, Graham (1929b) stated that the seasonal change is good evidence that the method is valid if the turnover from one marginal type to another is sharply defined during the year. In his paper on the growth of cod, Graham (1929a) found that the structure at the edge of the scale did not always register this sharp difference and he attributed this to the failure of some scales to follow the seasonal variation of the majority.

However, Hickling (1933), A. Dannevig (1933) and Menon (1950) disagreed with this conclusion after having found that the marginal fluctuation in their material was somewhat the same as that found by Graham. They point out that the unmistakeable yearly fluctuations in the edge growth of their material are convincing proof of the annual formation of these zones even though it is not sharply defined.

In Figure 3 the marginal types found on otoliths collected in the Lockeport region are shown. Sampling times have not been strictly consistent throughout the eight years shown but the pattern of edge turnover is quite evident. The majority of samples have been found to have 100% hyaline edges from the month of January to May. In June the period of opaque growth starts, reaching a peak in the months of August, September and October, then decreasing again to the zero point by the end of December.

This annual rhythm in percentage of opaque and hyaline edges per sample shows clearly that in the great majority of cases one hyaline and one opaque zone per year are formed in the otoliths of these haddock. The small deviations from 100% hyaline edges in the January to May period are probably due in most cases to "secondary zones" (Dannevig, 1933) which would be recognized and ignored if further growth were laid down on the otolith.

The hyaline zone in the otolith and the corresponding zone of narrow sclerites in the scale have been related to "summer" or "winter" growth by many writers. Saetarsdal (1953)

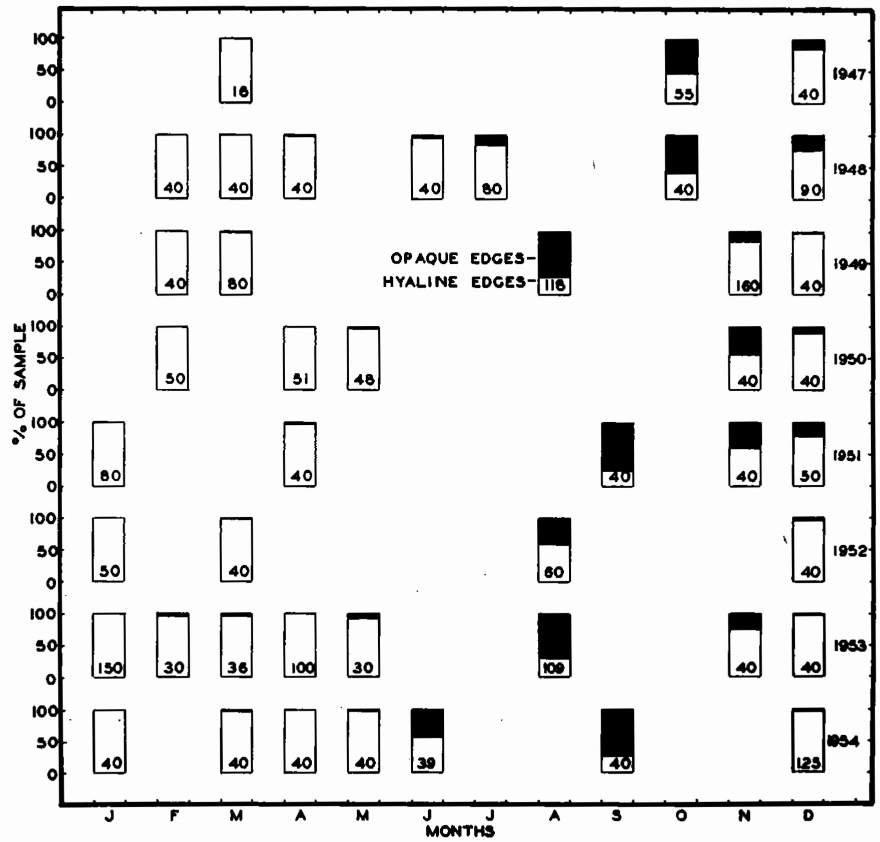

Figure 3. Type of edge deposition found on haddock otoliths from the inshore Lockeport grounds.

presents an interesting comparison of results found in different areas and with different species. He finds it possible to divide the data into groups having hyaline zones or narrow sclerites in the winter and those having the same type of growth predominantly in the summer. However, he points out that in all cases but one the hyaline zones or narrow sclerites dominate the October to December period of the year.

His summaries of zone growth for his collections of haddock from Brandsfjord and Finnmark show that the peak of opaque growth is reached from June to October and June to August, respectively, which is somewhat earlier in the year than indicated in our area. The otoliths he examined from the west coast of southern Norway showed opaque edges from February to July, thus being quite different from his first-mentioned areas and almost the opposite of those from our part of the western Atlantic.

The rhythm of yearly appearance of the two types of zones in scales and otoliths, respectively, has been the subject of comment in many previous papers. Hyaline zones in the otolith and narrow sclerites in scales have usually been associated with slow growth in the fish while opaque zones and broad sclerites have been found to coincide with a period of faster growth. This growth rhythm in the fish has been found to have an annual cycle closely related to the otolith and scale cycles.

Lea (1911) noted that the period of growth stagnation in two- and three-year-old herring occurred in the

December to March time interval, the season in which "winter rings" were formed in the herring scale.

Graham (1929a) working with cod found that the growth stagnation period taken as a whole preceded slightly the period of formation of narrow sclerites. Growth stopped almost completely from October to March, while the majority of scale margins exhibited narrow sclerites from January until July.

In his work on the hake, Hickling (1933) demonstrated that the time of hyaline zone formation on the otolith in the autumn coincided with the period of low growth rate.

Saetarsdal (1953) working on haddock finds that growth and zone formation are closely connected phenomena. He finds hyaline zones in the otoliths and narrow sclerites in the scales during the periods of slow growth, with opaque zones and wide sclerites dominating in periods of fast growth.

In order to investigate the relation of hyaline and opaque zones to slow and fast growth in Lockeport haddock, all the available age and length data accumulated from 1948 to 1954 were used. In the upper part of Figure 4 the mean lengths of groups of four-, five- and six-year-old fish are plotted for each sample taken in the above-mentioned time interval. As the number of fish per age group is quite small in many cases (Table III), the variation in mean lengths of successive samples is misleading in some cases. However, freehand curves have been drawn into the graph adhering most closely to the mean lengths based on the larger number of age determinations. From these curves it can be seen that mean

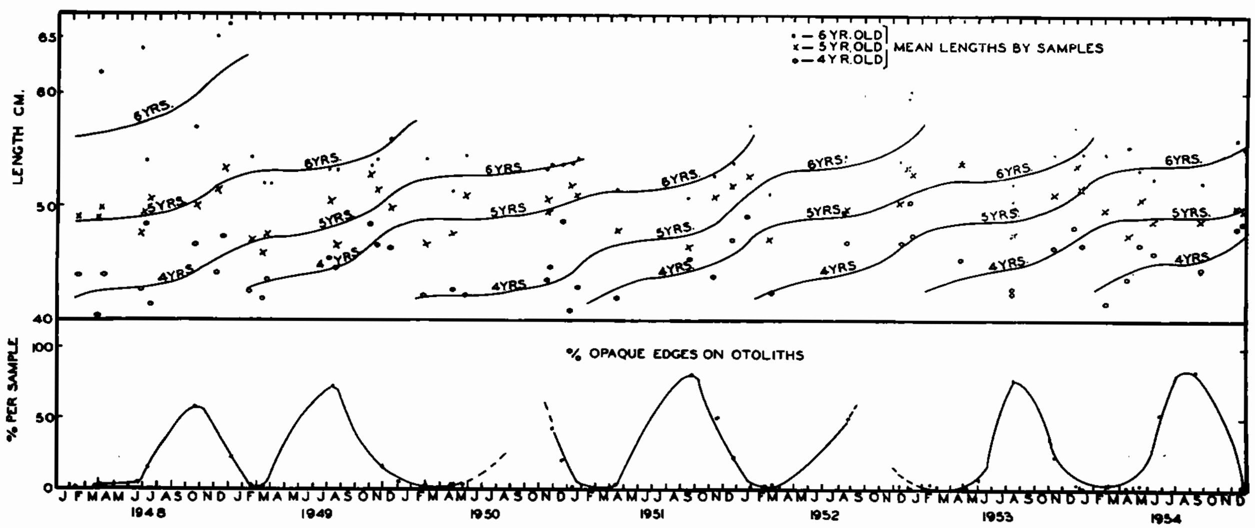

Figure 4. Growth period and otolith zone formation in inshore Lockeport haddock.

lengths increase and thus growth is speeding up starting in the May to July period and lasting in the years sampled until December or January. Needler (1929), working on haddock from the same area taken in 1926 and 1927, found that in the same period over 80% of the year's growth had occurred between August 1 and November 15. He was able to estimate more accurate time limits on growth for that season due to the larger number of individuals in his samples.

In the lower section of Figure 4 the percentage frequency of opaque edges on the otoliths of these samples are plotted against time. Again it is noted that the peak values for opaque zones occur in the August-October period, coinciding with the estimated period of fast growth in the fish. The period of low incidence of opaque edges and high percentage of hyaline margins is seen to occur at the time of the year when the fish is growing slowly. There has been much speculation over possible causes of growth rhythm in marine species of fish. Graham (1929a) indicates that a combination of changing water temperature and an inherent rhythm in the fish are responsible for varying growth rates in his material. Hickling (1933) states that inherent rhythm is the most probable cause of the annual variation in growth rate, condition, season of maturing gonads and zone formation in hake. Saetarsdal (1953) has stated that the effect of the inherent factor may be modified by external factors such as temperature and the abundance of food.

Table III. Length of age groups IV, V and VI taken in samples from 1948-1954.

Date	Age group	No.of fish	Mean length (cm.)	Date	Age group	No.of fish	Mean length (cm.)	Date	Age group	No.of fish	Mean length (cm.)
Feb.18,19/48	IV	5.89	43.9	Oct. 15/48	IV	7.22	46.7	Aug.1/49	IV	7	45.3
	V	32.02	49.1		V	15.58	50.1		V	11.82	50.5
	VI				VI	2	57.0		VI	16.25	53.1
Mar.31/48	IV	14.28	40.3	Dec. 1/48	IV	7	44.3	Aug.15/49	IV	9	44.4
	V	22.76	48.9		V	26	51.5		V	10	46.7
	VI	1.02	62		VI	1	65.0		VI	16	53.1
Apr. 6/48	IV	12.13	43.9	Dec.16/48	IV	11.89	47.4	Nov. 3/49	IV	37.76	48.5
	V	27.21	49.9		V	13.12	53.4		V	50.54	52.9
	VI				VI	1	64.0		VI	14.98	53.6
June 24/48	IV	2	42.5	Feb.15/49	IV	2	42.5	Nov.17/49	IV	13	46.3
	V	16.00	47.5		V	10.16	47.0		V	18	51.6
	VI	1	64.0		VI	20.70	54.4		VI	3	54.0
July 2/48	IV	2	48.5	Mar.18/49	IV	7.42	41.9	Dec.10-11/49	IV	7	46.1
	V	24	49.3		V	11.18	45.9		V	17	49.7
	VI	1	54.0		VI	19.40	52.0		VI	9	55.9
July 13/48	IV	3	41.3	Mar.25/49	IV	10	43.3	Feb.28/50	IV	8.58	42.2
	V	23.65	50.8		V	14.14	47.4		V	21.34	46.7
	VI				VI	12.37	52.0		VI	14	54.1

Table III (cont'd)

Date	Age group	No. of fish	Mean length (cm.)	Date	Age group	No. of fish	Mean length (cm.)	Date	Age group	No. of fish	Mean length (cm.)
Apr. 25/50	IV	2	42.5	Jan.24/51	IV	8.70	42.9	Mar.10-11/52	IV	9.83	42.5
	V	9	47.6		V	9	50.9		V	8.19	47.3
	VI	14	51.2		VI	5	54.2		VI	10	51.1
May 22/50	IV	6	41.7	Apr.18/51	IV	3	42.0	Aug.20-21/52	IV	6	46.7
	V	12	51.3		V	6.84	48.0		V	9	49.8
	VI	11	54.5		VI	11.12	51.5		VI	16	54.6
Nov.15/50	IV	7.36	43.6	Sept.18/51	IV	7.38	45.1	Dec.18/52	IV	9.70	46.8
	V	14.60	50.7		V	7.25	46.5		V	14	50.6
	VI	4.80	53.2		VI	9.80	50.9		VI	3	54.0
Nov.20/50	IV	9.53	44.6	Nov. 10/51	IV	11.44	43.9	Jan.4/53	IV	10.55	50.2
	V	18.10	49.7		V	9.81	50.9		V	8	53.8
	VI	12.36	53.8		VI	7	52.7		VI	3	59.7
Dec.14/50	IV	6	48.5	Dec.20/51	IV	13.04	47.2	Jan.6/53	IV	8.16	47.3
	V	4	48.0		V	8.82	52.0		V	8	53.0
	VI	7	53.7		VI	9	56.4		VI	4	60.2
Jan.11/51	IV	5.06	40.8	Jan.31/52	IV	10.02	49.2	Apr.30/53	IV	5	45.6
	V	6	51.8		V	12	52.7		V	13	53.9
	VI	13	53.9		VI	9	57.4		VI	7	53.9

Table III (cont'd)

Date	Age group	No. of fish	Mean length (cm.)	Date	Age group	No. of fish	Mean length (cm.)	Date	Age group	No. of fish	Mean length (cm.)
Aug.17/53	IV	9.99	42.8	Jan.15/54	IV	4.59	46.7	June 15-18/54	IV	2	46.0
	V	15.42	49.6		V	10	51.5		V	11	48.7
	VI	6	50.5		VI	7	54.8		VI	10	52.5
Aug.17/53	IV	11.37	42.5	Mar. 3/54	IV	6.62	41.7	Sept.28/54	IV	9.70	44.4
	V	16.26	47.5		V	8.88	49.9		V	12.04	48.9
	VI	5	52.0		VI	7.06	54.8		VI	7	52.1
Nov.17/53	IV	8.56	46.4	Apr.21/54	IV	10.41	43.8	Dec.13/54	IV	12	48.1
	V	10.20	51.1		V	7.48	47.5		V	6	49.7
	VI	9	54.7		VI	12.20	55.3		VI	9	56.0
Dec.31/53	IV	9.86	48.3	May 14/54	IV	6	46.7	Dec.28/54	IV	12	48.6
	V	9	53.6		V	8	50.7		V	20	49.9
	VI	8	57.1		VI	12	53.3		VI	17	55.2

Homans and Vladykov (1954) have shown that haddock taken from the Nova Scotian offshore banks display a definite relation between feeding and the sexual cycle. They found that as haddock approach the spawning period they practically cease to take food. This continues until spawning is complete when they commence to feed heavily. As will be shown later, haddock from the Lockeport area have almost the same spawning schedule and there is evidence that their habits as regards feeding during the spawning period are similar to those of the offshore fish.

Figure 5 shows data on feeding and condition of gonads taken from the paper by Homans and Vladykov as well as type and frequency of haddock otolith edge formation at Lockeport. The proportions of empty haddock and the proportions of ripening and spawning fish are expressed as percentages of total samples for each of 12 months. The time interval when almost 100% of Lockeport haddock otoliths display hyaline edge growth can be seen. It has been demonstrated that the hyaline zone in the otolith is laid down during the annual period of slow growth. In Figure 5 it can be seen that this is also the ripening and spawning period and the time of the year during which little feeding is taking place. A reasonable conclusion would seem to be that the onset of the spawning period in haddock brings on a cessation in the feeding with a consequent stagnation of growth and formation of a hyaline zone on the otolith. The evidence indicates that this is a yearly occurrence.

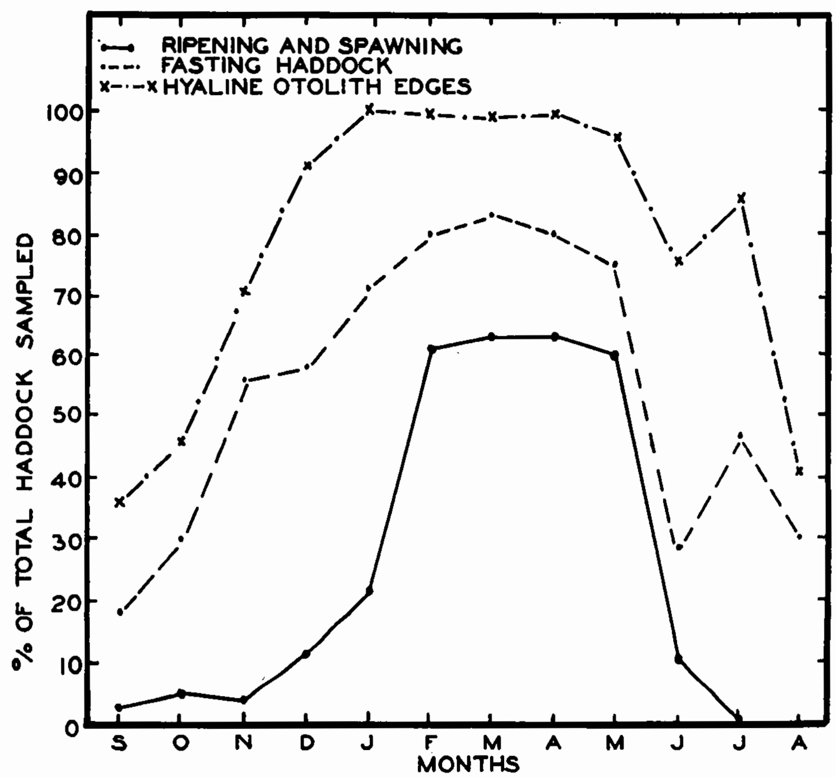

Figure 5. The relationship of feeding, spawning and otolith zone formation in Lockeport haddock.

Relative abundance of year-classes

It has been pointed out by Graham (1929b) that if a stock of fish is observed over a period of years and the persistent abundance or scarcity of strong and weak year-classes can be followed, then this is good evidence that the methods of age determination used is valid. Dannevig (1933), in defending the use of otoliths for aging Greenland cod, points out that the continued good abundance of the 1922 year-class as shown from otolith readings during the years 1926 to 1929 is a justification of the method. Hile (1941) cites the great abundance of the 1923 year-class of rock bass in Nebish Lake, Wisconsin, over a period of three years as a convincing proof that the annulus in the scale was a true year-mark. He goes on to say that since these fish were in age group IX during the last of the three years, the determination of age of the fish by this method is practicable in relatively old fish. Gulland (1955) states that a good idea of the accuracy of age composition comes from a study of the changes of the age composition from year to year. He states that if a strong or poor year-class can be followed through from recruitment until nearly all its members are dead, the age compositions must be substantially correct, and estimates of growth and mortality can be made with confidence, though the difference between year-classes could be under-estimated.

The percentage age composition of haddock caught on the inshore Lockeport grounds and landed at Lockeport, N. S., in the years 1946 to 1954 is shown in Figure 6.

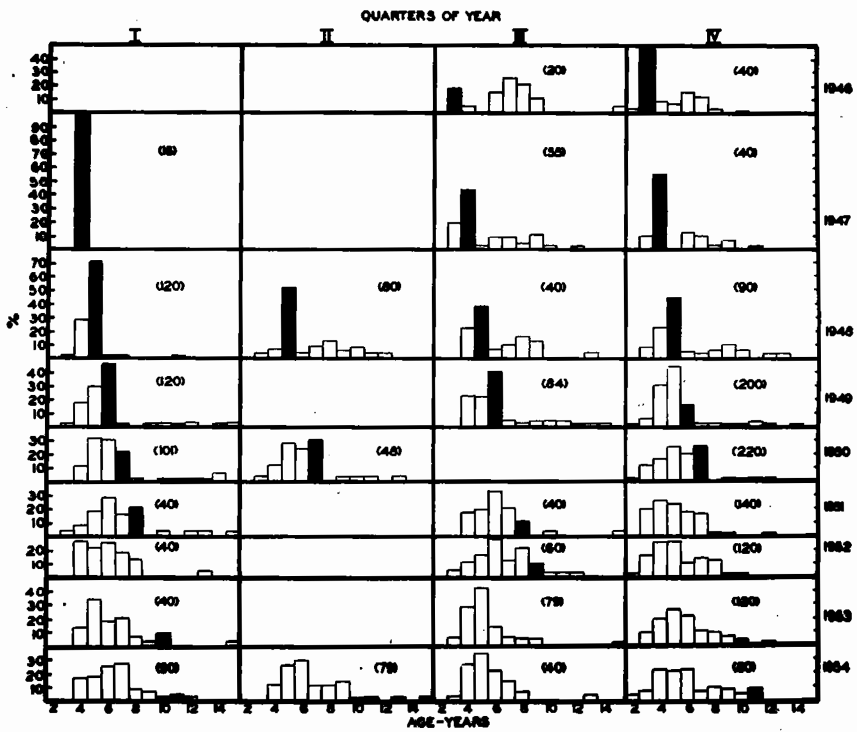

Figure 6. Age composition of the landed line catch of haddock from the inshore Lockeport grounds.

The years have been divided into quarters (February-April, May-July, August-October, November-January). It must be emphasized that the age composition shown is that of the landed catch, fish of about 40 centimetres length and over. As such, many fish from the younger age groups present in the area are missing. Martin (1953) states that haddock first appear in the landings when they are two years old but are not fully recruited before they are five years of age. The figure shows that very few three-year-old fish are landed in the first two quarters of the year, but they are found in increasing quantities in the third and fourth quarters as they grow to acceptable commercial size. As the size ranges of the four year olds overlap considerably with the ranges of the three year olds, it is obvious that many of the former must also be discarded. The same is true of the five year olds although to a much smaller degree.

The validity of the otolith method of age determination for these haddock is demonstrated by the continued dominance, over a period of three years, of the abundant 1943 year-class. It can be seen in Figure 6 that this year-class first entered the fishery in large numbers as three year olds in the fourth quarter of 1946. These fish then continued to dominate landings for each quarter until the third quarter of 1949. In contrast to the large year-class of 1943, the 1942 year-class is notable for its lack of numbers. This relation can be followed throughout most of the quarterly landings summarized in the figure. Thus the continued abundance of the 1943 year-class and scarcity of the 1942 year-class in the age composition of the landings are good evidence that the majority of readings are correct. This factor also indicates that reliable readings can be obtained at least to eight years of age and in many cases to 10 and 11 years.

It is interesting to note that since the 1943 year-class has passed through the fishery, there has been no single year-class that has been strongly dominant over a number of years in the landings. Four-, five-, six-, and seven-year-old fish have made up the bulk of the landings for each quarter with a number of year-classes contributing.

Length distribution of 1946-1949 samples and the 1943 year-class

Graham (1929b) points out that if zone formation can be correlated with the Petersen method of assigning ages to groups in a length-frequency graph, the method of aging must produce a majority of correct determinations. He goes on to say that the test is only applicable to the first three or four age groups. Menon (1950) says that in applying this test only the modes of the early years will be distinct and well defined. He states that as the rate of growth decreases with age, the differences in the lengths of older age groups become very small and the Petersen curve tends to flatten for these later age groups. One of the conditions that the test must be based on is that the samples must contain all the year groups in a proportion at least fairly comparable with their size in the population.

Statements placing value on the examination of length distributions for aging confirmation only in the very early years of the fish's life are based on the assumption that the sizes of broods in the population are not very different. However, it is obvious that if one year-class of very large numbers appeared in a population preceded and followed by one or two very poor year-classes, the peak produced in length distributions of samples of the population would be traceable throughout its life. This is an ideal condition which is seldom met.

In the length distribution of catches landed at Lockeport, a noticeable peak enters the samples in the third quarter of 1946. Figure 7 shows a summary of the length distributions of samples taken from that time until the third quarter of 1949. It is possible to follow this peak in the samples as it moves up the length scale throughout this period. Independent age readings for the samples show that the 1943 year-class makes up this length group as shown in Figure 7. In 1946 the length group was made up of three-year-old fish; in 1947 they were four year olds; in 1948, five year olds; and in 1949, six year olds. Thus, the evidence shows that this particular group of fish have added one year-mark per year on their otoliths during this period. There is no reason to believe that this annual marking did not occur both before and after this interval.

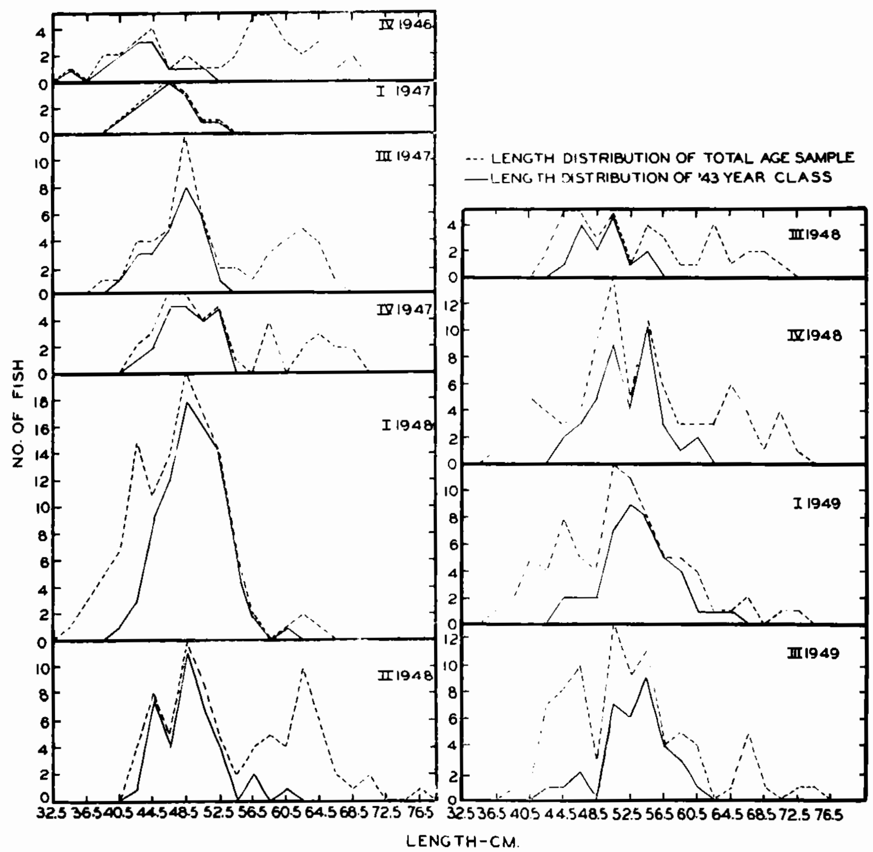

Figure 7. Length distributions of the landed haddock catch (1946-1949).

The reason that this length group is discernible from the rest of the distribution can be seen by referring back to Figure 6. The exceptionally good 1943 year-class entered the catch, preceded by an exceptionally poor 1942 year-class and followed by a mediocre 1944 year-class. The 1942 and 1944 year-classes were therefore weakly represented in the length distribution on either side of the 1943 year-class individuals, thereby making the peak more noticeable.

COMPARISON OF SCALE AND OTOLITH READINGS FROM HADDOCK TAKEN IN SUBAREAS 4 AND 5 OF THE ICNAF CONVENTION AREA

Material used and general results

Although no examinations of scales and otoliths have been made for the inshore Lockeport haddock, a series of comparisons have recently been made on fish taken adjacent to the area. All the otolith examinations were carried out by the author with the exception of the initial examination of the first three samples. However, the author subsequently re-examined these. The scale examinations for samples 1 to 6 and samples 7 to 10, respectively, were performed by John R. Clark and Albert C. Jensen of the Fish and Wildlife Service, Woods Hole, Mass. The conclusions from the examinations can be considered to apply to most of the haddock populations in the Nova Scotian areas.

Ten samples of scales and otoliths from the same fish were examined. Of these samples, five were from subarea 5 fishing grounds and five from subarea 4. A list of the fishing areas and sample numbers can be seen in Table VII. The size of the samples varied from 39 to 102 fish. Scales were examined at Woods Hole and otoliths at St. Andrews.

The method of examination of scales used by the United States' biologists was as follows: Scale impressions were made on cellulose strips and the impressions were projected on white paper, usually at a magnification of 40x. Sometimes scales from young fish with well-defined annuli were projected at 25x magnification. Annuli were counted on at least three scales from each fish.

Otoliths were examined in the manner explained in an earlier section.

In Table VII it can be seen that disagreement per sample between scale and otolith readings after the first examination ranged from 22% to 54%. Sample 1 is recorded as having only 10% but this was found upon a second reading when a misinterpretation of a weak hyaline zone in some of the otoliths was cleared up. The average amount of disagreement for all samples combined was 40%. In 84% of the cases of disagreement, ages arrived at by the two methods varied by one year.

Specific difficulties in otolith and scale reading

In order to point out some of the difficulties involved in using otoliths and arriving at the correct age of a haddock during certain times of the year, Figure 2 is referred to again. In the diagram there are two split hyaline rings and what appears to be the beginning of a third split ring. When an otolith of this type is sampled from subarea 4 in the September to January period of the year, the reader is faced with the problem of two choices for an age. If the hyaline edge ring is assumed to be the third ring, but split and incomplete (3 N.H.), it will be classed as a two year old (see Table II). If the otolith is assumed to have three complete winter rings plus some summer opaque growth, it will be classed as a three year old (3+). In a case of this type where the first two rings are split, it is quite likely that the third one will be also. Therefore, the age would be recorded as 3 N.H. However, this interpretation is always open to errors in judgement. The danger becomes less as the otolith reader becomes more familiar with the eccentricities of the otoliths of populations with which he is dealing.

Table IV shows results obtained at this time of the year when the otolith reader is not familiar with the otoliths of the population being studied. Scale ages are on the horizontal axis and otolith ages on the vertical. The boxes running diagonally enclose the number of readings that agreed in the samples. Above the diagonal is the number of cases in which scale readings were higher than otolith readings for the same fish. Below the diagonal is the number of cases in which otolith readings were higher than scale readings. Otolith reader "A" misinterpreted a zone in the otoliths quite consistently when it was weak, thus causing the otoliths to give higher readings than the scales in the majority of cases of disagreement. The mistake can be blamed directly on the formation of zones found in this season of the year. When the author re-examined sample 1 in which much of the above-mentioned type of disagreement was found, he reduced the error between scale and otolith readings from 37% to 10%. This was due to his comparative familiarity with the otoliths of the population.

Table IV. Summary of individual age readings from samples 1 and 4.

<u>Sept.-Dec. (199 fish)</u>

Age -- Otoliths \ Age -- Scales	2	3	4	5	6	7	8	9	10	11	12
2	48	3									
3	30	10	1	1							
4	1	4	16	1							
5		4	7	42	3						
6		1		3			1				
7					4	5	2				
8				1			1				
9						3	3				
10							1				
11							2				
12								1			

In contrast to the above situation, Table V shows results obtained from comparisons made on fish caught in the April-June period of the year. The type of edge growth found on the otolith in this season is not as important to age group assignation (Table II). It can be seen that disagreement is spread fairly randomly above and below the diagonal line. There seems to have been no tendency in these samples to get consistently higher or lower readings by either method.

Table V. Summary of individual age readings from samples 2, 3, 8 and 9.

Apr.-June (279 fish)

Age -- Scales

Age -- Otoliths	2	3	4	5	6	7	8	9	10	11	12
2											
3		4	2	1							
4		3	58	14	1	1					
5			10	76	11			1			
6				7	17	6	1				
7					12	16	10		1		
8						6	10	1			
9						2		2			
10							2		1		
11							1		1		
12											1

In Table VI the results of individual comparisons for all samples have been summarized. The initial readings have been used for all samples except the first where the re-examinations made by the author have replaced the originals. It can be seen that in cases where the scale or otolith age is eight or lower, that is to the upper left of the dotted line, the disagreements are spread randomly in either direction with one exception. The non-conformity is the large number of disagreements where the fish were aged five years old according to the otoliths and four years old according to the scales.

Table VI. Summary of individual age readings for all samples.

Age -- Otoliths \ Age -- Scales	1	2	3	4	5	6	7	8	9	10	11	12	13
1													
2		75	7										
3		4	15	8	2	1							
4			16	85	22	1	1						
5			6	47	201	19	3	1	1				
6			1		18	28	8	6					
7					1	34	46	24		1			
8					2	4	19	19	2		1		
9						1	7	9	4				
10							1	3		1			
11								3		1	1		
12									1		1	1	
13										1			

The explanation of the discrepancy lies in sample 10 where 19 out of 26 disagreements were in this category. This was later explained for the majority of cases on the basis of a misinterpretation of zones in the scales.

In cases of disagreement where either the scale or otolith age is above eight years, to the lower right of the dotted line, the scale readings were predominantly lower than the otolith readings. The scale readers state that above eight years of age annuli are difficult to distinguish in the edges of haddock scales. In usual practice, they seldom attempt to read ages over nine years.

Difficulty in reading scales from old fish has previously been found by investigators working on gadoids. Dannevig (1933) in discussing the relative merits of the scale and otolith aging methods for cod says "For adult fish the two methods give divergent results, as we evidently lose sight of zones when using the scale-method." Concerning the same species, Rollefsen (1933) writes "The skrei otoliths show in very many cases more zones than the scales and a careful comparison of the corresponding rings in the two classes of objects made it clear that the scale rings corresponding to the outermost otolith zones were difficult to identify on the scales." Saetarsdal (1953) working on haddock, sums up his impressions of the relative merits of haddock and cod scales and otoliths for age determination by stating "One is tempted to conclude that in the case of the haddock and cod the otolith is a more sensitive instrument than the scale, and records smaller differences in the condition of the fish than does the scale."

In regard to the above, it is interesting to note that in our comparisons, percentage disagreement per sample was found to increase with increasing average age of the sample. In Table VII the samples are arranged from top to bottom in order of decreasing mean otolith age.

Table VII. Percentage disagreement and mean age in samples.

No. of sample	Area	No. of fish	Mean age of sample in years from scales	Mean age of sample in years from otoliths	Percentage disagreement of age readings
9	LaHave	39	6.56	6.72	46
6	Western	60	6.57	6.60	52
8	Sable Island	41	6.02	5.98	49
7	Western	59	5.59	5.97	44
5	Georges	102	5.65	5.66	54
4	Georges	99	5.16	5.56	40
3	Georges	99	5.32	5.26	34
10	Banquereau	65	4.78	5.17	40
2	Georges	100	4.96	4.86	22
1	Georges	100	2.36	2.35	10

It can be noticed that the mean scale and otolith ages for each sample are nearly equal. Comparing the group of mean scale or otolith ages of the upper five samples listed (numbers 9, 6, 8, 7, 5) to the ages of the lower five samples, it can be seen that the average ages for the bottom five are all lower than those for the top five. Referring to the percentage disagreement column, it is noticed that disagreement for the former group ranges up from 10% to 40%, while the range of the latter is from 44% up to 54%. There seems to be a definite trend toward increasing disagreement between readings for individual fish with increasing mean age of the sample.

The use of samples from several populations to illustrate the above-mentioned point might be criticized on the basis of differing factors related to the various areas sampled. However, taking the samples from Georges Bank only, the same results are found. Average otolith ages range from 2.35 years up to 5.66 years and the corresponding disagreement in methods ranges from 10% up to 54%.

Effect of differing scale and otolith readings on age composition and growth rate

In order to compare the effects that disagreements due to age reading methods may have on information derived from the determinations, some age and growth data have been summarized for the samples. The summarized age composition for the samples examined is shown in Figure 8. Samples from subarea 5 consisting of a total of 500 determinations are shown on the left of the figure while the 264 fish sampled from subarea 4 are combined on the right hand side.

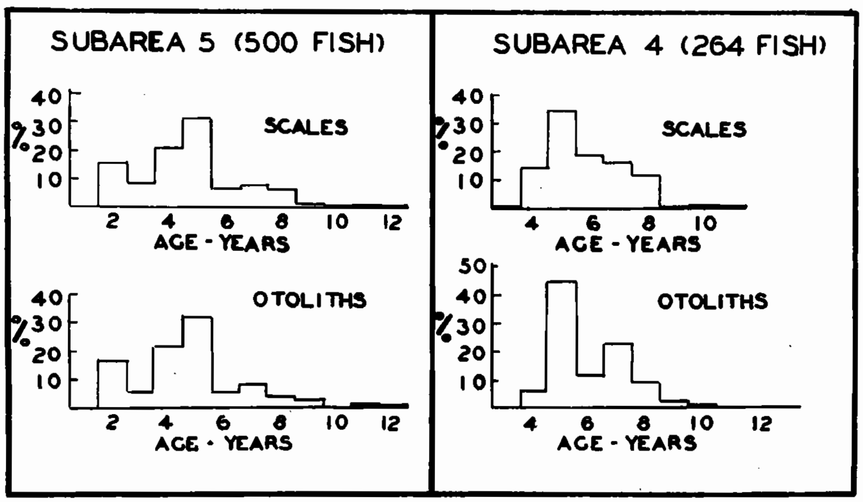

Figure 8. Average age composition, subarea 5, from samples 1 to 5, subarea 4 from samples 6 to 10.

Comparing the scale and otolith age compositions summarized for subarea 5, it can be seen that most of the fish sampled were in the two- to five-year-old range. The age compositions agree very well in spite of the disagreement found in individual cases. In the subarea 4 graphs there is quite a bit more variation in the relative strength of age groups as found by the two methods. In this area only about half the fish sampled were found to be in the five years and younger group.

Since prior to this experimental comparison of methods the scale readers had had no experience with subarea 4 material and likewise the otolith readers with subarea 5 material, it is of interest to compare trends in disagreements for each area as a whole. In Table VIII the results of all individual comparisons for subarea 5 are summarized. Although the otolith readers were inexperienced in examining otoliths from this stock, it appears that below about eight years of age there was no consistent trend towards higher or lower readings than those found in the scales. Above this age the otoliths did give higher readings. The difficulty in reading old scales has been dealt with previously.

Table VIII. Results of scale-otolith comparisons for subarea 5.

Age -- Otoliths \ Age -- Scales	2	3	4	5	6	7	8	9	10	11	12	13
2	75	7										
3	4	15	8	2	1							
4		14	76	17	1	1						
5		5	19	123	10	1		1				
6		1		9	9	5	5					
7				1	14	21	10					
8				2	1	8	9	1		1		
9					1	4	7	3				
10							2					
11							2		1	1		
12								1			1	
13												

In Table IX the results of comparisons for subarea 4 are summarized. Here the fish are older and the scale readers had no previous experience in examining material from this area. It can be seen that in the majority of cases of disagreement, the scale ages were lower than the otolith ages. The evidence would seem to indicate that scale readers tend to miss counting certain annuli in scales from this area. This factor would account for discrepancies in subarea 4 age compositions as seen in Figure 8. Other data collected from subarea 4 during the same period strongly indicated that the order of strength of age groups in landings of the fishery at this time was five year olds, seven year olds and six year olds in that order. Apparently some of the seven year olds were aged six by the scale readers.

Table IX. Results of scale-otolith comparisons for subarea 4.

Age -- Scales

Age -- Otoliths	2	3	4	5	6	7	8	9	10	11	12	13
2												
3												
4		2	9	5								
5		1	28	78	9	2	1					
6				9	19	3	1					
7					20	25	14		1			
8					3	11	10	1				
9						3	2	1				
10						1	1		1			
11							1					
12										1		
13									1			

Gulland (1955) has recently calculated the effect of mistakes in age determination on age compositions and on survival rates calculated from age compositions. He concludes that survival rates are not too much affected provided the error does not change abruptly from one age to another.

In order to see the effect that disagreement in aging would have on growth data, age-length data have been plotted in Figure 9. Graphs are presented for each of the 10 samples examined. It is seen that where points represent observations from 10 or more fish, the average lengths for that age derived from each method lie close together. In 17 out of 19 cases where this occurs, the scale mean length is slightly higher than that found by means of otolith readings. This displacement is to be expected since mean scale ages for each sample averaged slightly lower than mean otolith ages for the same group in most cases (Table VII). Gulland (1955) has mentioned this occurrence and states that if error is reasonably consistent, the whole growth curve is moved bodily and the shape is preserved with little distortion. He indicates that error will probably be a fraction of a year and his statement seems to be experimentally verified in this comparison.

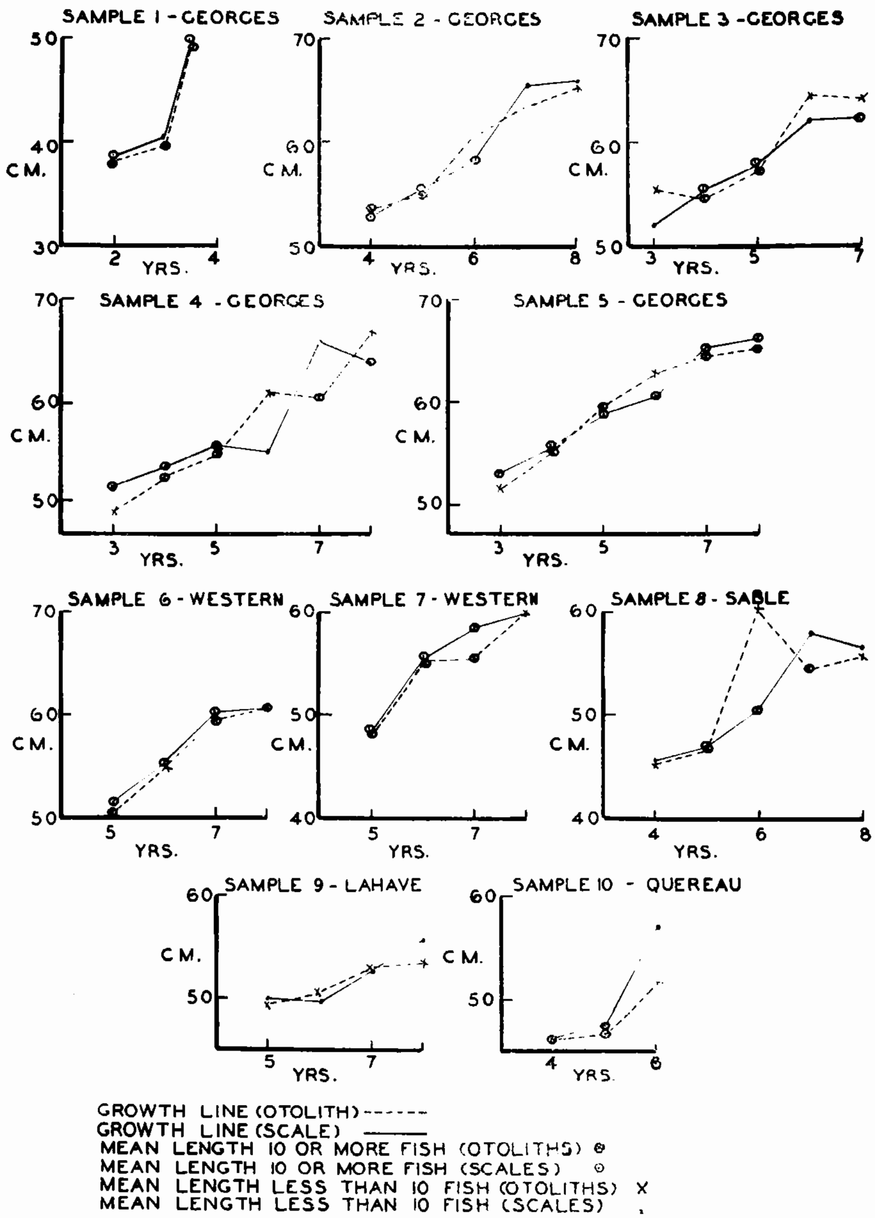

Figure 9. Age-length comparisons from scale-otolith data.

GROWTH IN LENGTH OF HADDOCK

Previous investigations in the Nova Scotian region

The earliest published growth curve for Nova Scotian haddock was calculated from measurements made on the scales of 75 fish by Duff (1916). The fish were taken in 1914 from Bay of Fundy, Passamaquoddy Bay and St. Mary's Bay. Huntsman and Needler (1927) studied haddock from Passamaquoddy Bay and published a figure showing growth curves for haddock taken in the years 1922 to 1926. Their average length at ages two to five was much higher than that found by Miss Duff and they blame this on a possible failure on her part to recognize the occasional doubling of the annual check mark in the haddock scale during one year.

Needler (1929) published the earliest growth curve for Lockeport haddock composed of age-length data from about 1,000 fish taken between June 14 and August 14 in 1926. Ages were read from scales and mean lengths for age groups were determined empirically. In 1930 the same author published growth lines for haddock from a number of localities in the Nova Scotian and New England regions. Empirical data were presented in the form of smoothed curves for each of the localities. Needler points out that by making use of the average lengths of different age groups in one year's sample, the growth rate is based on data for several broods. He indicates that this is likely to add to the apparent irregularity of the rate of growth. When plotting length against age, the points would not lie on a smooth curve even if sampling and age determinations were correct. Needler states that by drawing a smooth curve through the points, average growth can be approximated.

Vladykov (1934) presents growth lines for fish from the vicinity of Halifax, N. S., taken in 1932. The ages of fish available in this area were from one to four years as determined from scale readings. A growth rate of Nova Scotian haddock is to be seen in a paper by Thompson (1939). It has been inferred that the fish represented were taken from Banquereau although Thompson does not state the location of the sampling area precisely. In 1951 Schuck and Arnold published age-length data resulting from examination of samples from Browns and Georges Banks taken on the 1949 and 1950 summer cruises of the "Albatross III". They found that haddock on Georges Bank grow at a faster rate than those on Browns Bank.

Data from Lockeport sampling

The continued sampling of otoliths and lengths of haddock from the inshore Lockeport grounds has presented an excellent opportunity for deriving their average growth during the years 1946 to 1954. The problem is somewhat complicated by selection in the size of fish sampled. The cull for size acceptable for commercial purposes has resulted in the discarding by fishermen of fish under about

40 centimetres in length. Thus in the sampling of landings the small fish are not available. It has been shown that the smallest hook size in use by fishermen in the area takes few haddock that are not of acceptable size (McCracken, 1956), thus effectively eliminating small haddock from the catch. This selection appears to reduce markedly the number of shorter fish in age groups up to about four years of age, resulting in too great a mean length for the younger fish.

Hook selection is somewhat compensated for in the hook and line fishery by the sudden subjection of the population to fishing mortality when the individuals grow to 40 centimetres in length or thereabouts. The effect here is to reduce the abundance of the longer fish in the age group while the short ones remain unaffected until they grow to the size liable to capture on the hooks used in the fishery. Therefore, it appears that when age five is reached, the lengths in the group will be nearly normally distributed and will give a mean less biassed than those from younger age groups. As the length distributions move out of the ranges affected by commercial cull, they may be slightly skewed towards shorter lengths due to effects of fishing mortality mentioned above. However, this cannot be demonstrated with confidence in the data used in this investigation.

Age length data from inshore Lockeport have been summarized in four parts corresponding to the time of year when the sampling took place. The four quarters are

February to April, May to July, August to October and November to January. Age and corresponding length frequencies for these periods can be seen in Tables X, XI, XII and XIII, respectively. The dates of samples taken and the numbers in them are listed in Table I. It will be noticed that sampling intensity has not been equally spread over the four quarters or over the years 1946 to 1954.

Frequencies for length classes of age groups are expressed in decimals due to the use of the sample weighting factors in the distributions. This has been necessary in order to get an unbiassed sample of lengths for each age. If actual sample numbers were used and the scrod haddock had been too lightly sampled, as explained in the section on sampling, the effect would be to make the mean length in question too high. In the series of samples used, most of the weighting factors have been so close to 1.00 that the difference would, in reality, be hardly perceptible.

Table X. Age and length frequencies of haddock samples taken in the February to April period from the inshore Lockeport grounds.

Length	Age in years												
cm.	3	4	5	6	7	8	9	10	11	12	13	14	15
76													
75								,91					
74													1.00
73												1.00	.98
72										.91		1.00	
71													1.02
70										.98		1.00	
69													
68					.91			1.11	.91	1.02		1.93	
67						1.02	.98	1.00		.98	.96		
66			1.00		1.00	1.82	1.91						
65					1.00	1.02		1.00	1.04			1.00	
64				.98	2.00				1.00				
63					3.93	.91	.91	1.02	.91		1.02		
62				2.80	2.91	2.93							
61			.91	4.04	2.89	4.89		.98	.98	1.00	1.00		

(cont'd)

Table X (cont'd)

Length cm.	Age in years 3	4	5	6	7	8	9	10	11	12	13	14	15
60			1.13	5.75	2.91	.96							
59				2.82	7.02	1.98		1.93	.91				.94
58			4.00	3.99	4.82	1.87	.91						
57			.93	7.65	3.89	.96							
56			2.94	9.76	3.98	1.93							
55			3.86	5.96	3.90	1.02							
54		1.13	9.15	11.64	3.73		.91						
53		.91	6.31	13.03	2.93								
52		.94	16.13	14.51	3.04	1.02	.91						
51		1.04	11.39	9.00	2.02								
50		4.02	17.80	7.64									
49		4.01	10.72	6.35	1.11								
48		5.76	22.76	6.21									
47		4.81	21.99	6.35									
46		8.08	12.33	3.15									
45		3.15	19.01	5.64									
44		12.23	9.07	1.06									
43	.92	15.20	8.48	1.04									
42		12.30	3.82	.92									
41	1.06	11.56	2.96										

(cont'd)

Table X (cont'd)

Length cm.	Age in years 3	4	5	6	7	8	9	10	11	12	13	14	15
40		12.36	2.03										
39	1.99	5.15	1.04										
38		3.93	1.00										
37		1.85											
36		5.64											
35		1.02											
n		115.09	190.76	130.29	53.99	22.33	6.53	7.95	5.75	4.89	2.98	5.93	3.94
$\bar{x}$		43.09	48.59	52.86	57.88	60.32	60.99	64.61	63.35	67.51	63.62	69.35	69.40
$S_{\bar{x}}$		.36	.32	.40	.57	.80	2.36	1.87	1.29	1.88	1.76	1.22	3.45

Table XI. Age and length frequencies of haddock samples taken in the May to July period from the inshore Lockeport grounds.

Length cm.	Age in years 3	4	5	6	7	8	9	10	11	12	13	14	15
77									.88				
76													
75													
74					1.34			1.00					
73									1.00				
72													
71									1.00				
70							1.00	1.00	1.00				
69													
68						1.00							
67													
66				1.00		.88	1.34	.88					
65						1.00	1.00			.88	1.00		
64				1.88				1.00			1.34		
63			1.00		3.76	.88	2.34	1.34	.88	2.34			
62				1.34		1.76	1.88				1.00		
61			1.00	1.00	4.34		4.00	1.88					

(cont'd)

Table XI (cont'd)

Length cm.	Age in years 3	4	5	6	7	8	9	10	11	12	13	14	15
60			1.00		2.00			2.22					
59			1.00	1.00		2.64							
58				1.00	4.00	4.00	2.00						
57			4.56	2.00	4.76	1.00	1.00						
56			2.00	4.00	5.00	1.00	1.00	1.00					
55			3.34	2.00	.88								
54		1.00	1.00	3.00	3.00								
53			6.10	6.00		2.00	1.00						
52			5.24	4.00	1.00	1.00							
51	.88	1.00	14.78	3.00									
50		1.00	8.32										
49		1.00	7.64	2.00	.88								
48		2.04	9.92	1.00									
47			9.32	2.00									
46		1.00	2.36	1.00									
45		1.00	7.68										
44		1.04	6.68										
43		3.34	3.00										

(cont'd)

Table XI (cont'd)

Length cm.	Age in years 3	4	5	6	7	8	9	10	11	12	13	14	15
42	2.00	3.66	.66										
41													
40		2.70	1.00										
39		1.00											
38													
37													
36		1.00											
35													
n		20.78	96.70	37.22	30.96	17.16	16.56	10.32	4.76	3.22	3.34		
$\bar{x}$		44.25	49.75	54.34	58.45	59.11	61.20	63.41	70.84	63.55	63.70		
$S_{\bar{x}}$		.98	.63	.88	.85	1.35	1.44	2.11	2.28	.60	.78		

Table XII. Age and length frequencies of haddock samples taken in the August to October period from the inshore Lockeport grounds.

Length cm.	Age in years 3	4	5	6	7	8	9	10	11	12	13	14	15
84													1.03
74									1.00				.98
73													
72									.94				
71													
70						1.14			1.00				
69								2.00				1.00	.93
68					1.14	1.00	1.14						
67					1.14	2.92	2.03		.94	1.00	1.14		
66					2.16	1.03						1.00	
65				2.16	1.16		3.16						
64					1.03	2.00	1.14		.94	1.16			
63				2.14	1.16	2.06	3.32						
62				1.00		6.28	3.17	1.16					
61				1.00	2.03	5.33	2.10						
60				5.22	2.14	1.96	1.92	1.92					

(cont'd)

Table XII (cont'd)

Length cm.	Age in years 3	4	5	6	7	8	9	10	11	12	13	14	15
59				3.98	4.93	3.16	.93						
58		1.14		4.10	3.81	.98	2.10				.94		
57			1.00	3.28	1.92	2.03	1.00						
56	1.16	1.03	.98	7.86	2.01	2.00	2.06						
55	1.16	1.14	1.93	8.74	3.12								
54		1.92	5.30	6.66	3.96	.93							
53	1.16	3.14	3.69	7.68	2.96								
52			5.06	4.82	2.00	.98							
51		4.19	9.98	13.84									
50		2.32	12.47	3.94									
49	2.32	4.19	7.55	7.80									
48	3.32	8.03	8.68	1.85	2.00								
47		8.92	14.35	2.02	1.00								
46		7.97	5.71	.98									
45	.71	6.46	8.77	.92									
44	.88	8.14	6.38	.98									
43		8.41	3.36										
42	1.73	7.29	1.11	1.21									
41	2.81	6.93											

(cont'd)

Table XII (cont'd)

Length cm.	Age in years 3	4	5	6	7	8	9	10	11	12	13	14	15
40	.88	5.43											
39	1.59	3.18											
38		1.11											
37													
36	3.63	1.23											
35													
n		92.17	96.32	92.18	39.67	33.80	24.07	5.08	4.82	2.16	2.08	2.00	2.94
$\bar{x}$		45.47	48.65	53.79	57.63	61.34	61.90	64.00	69.46	65.39	62.93	67.50	75.92
$S_{\bar{x}}$		.46	.33	.48	.83	.69	.71	2.03	1.81	1.39	4.31	1.50	4.50

Table XIII. Age and length frequencies of haddock samples taken in the November to January period from the inshore Lockeport grounds.

Length cm.	Age in years 3	4	5	6	7	8	9	10	11	12	13	14	15
76										1.03			
75			1.07										
74									1.00				
73							1.97			1.00			
72		1.07											
71				1.02					1.00	1.00			
70						1.13	1.00	1.00	2.07	1.04			
69							3.00		1.00				
68		1.07		1.07	1.00	2.36	3.98	1.03			1.00		
67				.68	1.11	1.00	1.02	1.00	.95		1.00		
66		1.07		2.00	2.05	1.09	2.02		3.00	1.00			
65				1.00	6.49	2.13	1.00	3.13	1.00	1.00			
64			1.07	5.95	7.90	3.09		2.00	1.00				
63			1.00	6.03	3.00	2.11	2.03	3.88	1.05				
62				4.21	1.98	6.00	4.00	1.13	2.00				
61		1.07	2.99	6.85	5.09	5.99	2.13		1.07				

(cont'd)

Table XIII (cont'd)

Length	Age in years												
cm.	3	4	5	6	7	8	9	10	11	12	13	14	15
60			4.23	5.68	6.63	4.22	1.00	1.00	.95				
59		3.05	6.60	11.99	15.98	5.24	3.00						
58	2.00	1.07	6.28	13.78	13.30	3.26							
57			11.55	10.97	8.16		3.04						
56		2.01	11.32	9.85	14.81	1.11	1.13	2.00	1.07				
55		2.70	21.37	9.09	8.98		2.02						
54		4.26	30.87	14.00	7.62	1.11							
53	1.09	12.16	21.31	16.40	4.12								
52	1.00	13.72	28.97	16.90	7.02	3.08							
51	1.05	20.40	23.50	9.25	5.03	1.00			1.07				
50	2.52	15.33	24.66	8.90	1.05				1.07				
49	2.70	13.32	25.13	4.11	1.99								
48	6.17	20.88	19.93	2.12									
47	9.80	19.30	17.82	4.04									
46	7.09	26.34	14.06	.86	.95								
45	8.94	20.02	7.74	1.88									
44	11.30	14.60	3.90	1.02									
43	10.65	21.29	7.55										
42	7.81	6.10	2.12										

(cont'd)

Table XIII (cont'd)

Length	Age in years												
cm.	3	4	5	6	7	8	9	10	11	12	13	14	15
41	7.81	6.10	1.02										
40	13.87	5.32	1.02										
39	8.58	5.20											
38	3.40	5.81											
37	5.76	2.83											
36	7.26	1.12											
35	1.52												
n	122.79	251.72	297.08	169.65	124.26	43.92	32.34	16.17	19.30	6.07	2.00		
$\bar{x}$	43.0	47.2	51.5	55.6	57.7	60.8	63.3	63.4	63.7	70.2	67.5		
$S_{\bar{x}}$	.40	.10	.26	1.18	.39	.66	.85	.94	1.43	1.67	.71		

Total samples have been considered to be sufficiently large and free from bias to give accurate average lengths for ages five to nine in all quarters. The standard error of the mean length has been calculated for these ages and is shown in the tables.

In order to depict graphically the form that these empirical annual increments take, growth curves from these data have been plotted in Figure 10. It can be seen that the increase in length per year of age progresses in a regular manner between ages for which there is a total of more than 10 observations. For age groups with a scarcity of observations there is much variation in mean length. The regular increase in increment per year in well sampled ages is further evidence that the method of age determination is valid, as observed by Hile (1941).

To pursue this point to a finer degree, average length at age "x" has been plotted as determined for each of the four quarters for ages five to nine in Figure 11. Again, the general pattern of increasing length with increasing age can be seen. Explanation for discrepancies in the five-, six- and seven-year-old ranges can be observed by referring back to Tables I, XI and XII. The May to July points (ages 5.25, 6.25, 7.25) which were calculated from sampling in years 1948 and 1954 showed sizes that were evidently greater than normal. The August to October points are a better reflection of average growth for the ages in question, being calculated from samples for all years from 1946 to 1954 except 1950. The latter averages were found to be slightly less than the second quarter

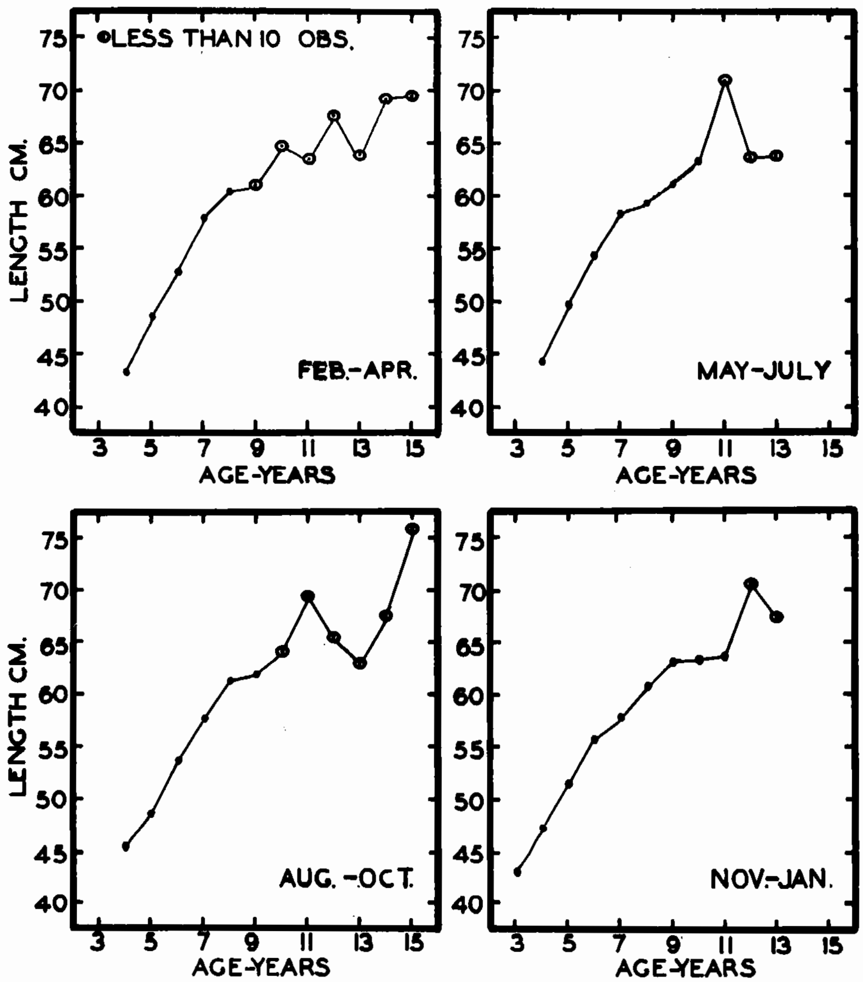

Figure 10. Growth in length of inshore Lockeport haddock as indicated from age-length data.

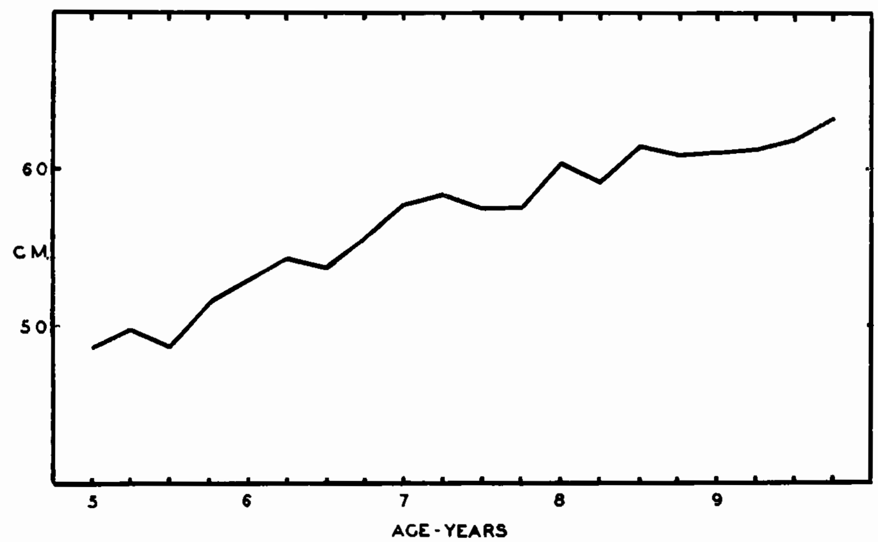

Figure 11. Increase in mean length with age of haddock as seen from empirical data collected at Lockeport.

means for these ages. However, despite the slight discrepancies, average length can be seen to increase with average age.

Equation of growth in length for Lockeport haddock

In order to reduce the above data to a form which might be interpreted as the equation typical of growth in length of haddock from the inshore Lockeport region, a combination of methods was applied. The average lengths for ages five to nine for each quarter of the year were selected as being fairly reliable on the basis of regular distribution of lengths in age-length summaries, (Tables X, XI, XII, XIII). These lengths were then combined to give one average length at each age as can be seen in Table XIV. The ages at which the grand average lengths would be reached are theoretically 5.5 years, 6.5 years, etc.

Table XIV. Average length in centimetres of inshore Lockeport haddock (1946-1954).

Quarter	Age				
of year	5	6	7	8	9
Feb.-Apr.	48.6	52.9	57.9	60.3	61.0
May-July	49.8	54.3	58.4	59.1	61.2
Aug.-Oct.	48.7	53.8	57.6	61.3	61.9
Nov.-Jan.	51.5	55.6	57.7	60.3	63.3
Average (all quarters)	49.7	54.2	57.9	60.4	61.9

Walford (1946) has demonstrated a method for graphically describing growth of animals by a straight line. The equation derived expresses growth only past the inflection point common in the sigmoid growth curves of most fish. This factor does not affect the data used in this investigation as sampling has not been efficient for those fish under five years of age, which are assumed to be well past the inflection point on the age-length curve. Using arithmetic graph paper, Walford found that when length at ages 2, 3, 4, 5 .... n on the x axis was plotted against length at ages 3, 4, 5, 6 ...... n+1 on the y axis, the points fell along a straight line for the growth data which he examined. The equation of this line can be expressed in the form:

$$l_{t+1} = kl_t + b \qquad (1)$$

for which constants k and b are to be found by fitting a line to the data by least squares. Ford (1933) had previously shown this straight-line equation relationship between chronologically equal successive increments for herring. He has also shown how equations derived from data for different stocks can be used to compare relations between growth rates in different areas.

Both Ford and Walford have also demonstrated that l_∞ or the theoretical limiting mean length for an age group of the population in question can be found. This is accomplished in one of two ways. One method is to draw the line fitted to the datum points on the graph and read off the value where the line intercepts the 45° line, i.e., where $l_{t+1} = l_t$. Alternatively, and probably more accurately, the value for l_∞ can be calculated from equation (1) above, as:

$$l_\infty = \frac{b}{1 - k} \qquad (2)$$

If the line calculated by substitution in equation (1) were applicable to the whole of the fish's life, then lengths at various ages could be found from equation (1) by letting length at age zero equal 0, then when:

$$t = 0$$

$$l_1 = b$$

Then this value is substituted again in equation (1) for l_t to get l_{t+1} and so on. However, since it is probable that the growth relation changes in the early stages of the development of the fish, the most accurate method for getting theoretical length-at-age points is to pick from the age-length data available the most reliable empirical point. Substituting this value in equation (1) will give a good theoretical relationship for ages above and including the lowest length-at-age used in calculating values for equation (1).

Ricker (1956) has demonstrated a simplified method of fitting the upper part of a sigmoid curve to growth data for fish in the range of ages above the inflection point. He has combined a number of relationships used by Brody (1927, 1945), Bertalanffy (1938), Walford (1945) and Beverton (1954). These equations apply particularly well to the data on growth available from Lockeport sampling.

They were fitted to the average points for ages five to nine (Table XIV). As a first step, the straight-line equation (1) was fitted to these points by least squares, giving the relation (in cm.):

$$l_{t+1} = 18.557 + .7208\ l_t$$

the "Walford transformation". This line is plotted in Figure 12 together with the points to which it was fitted. The line intersects the diagonal at $l_\infty = 66.4$ centimetres and this is the point where l_t equals l_{t+1} or the theoretical limiting length. The point may also be calculated by letting $l_{t+1} = l_t = l_\infty$ in equation (1). Then:

$$l_\infty = \frac{b}{1-k} \qquad (3)$$

Substitution of values found for Lockeport haddock gives

$$l_\infty = 66.4 \text{ cm.}$$

Ricker (1956) points out that this value can usually be found with sufficient accuracy by reading it from the graph (Fig. 12).

The slope k of the growth line is found to be .7208 from the equation.

In order to fit the upper half of a sigmoid curve to the empirical points, Ricker uses a transformation of an equation from Brody (1927, 1945) for the part having the decreasing slope. This equation is given by Brody as:

$$l_t = B\text{-}Ce^{-Kt} \qquad (4)$$

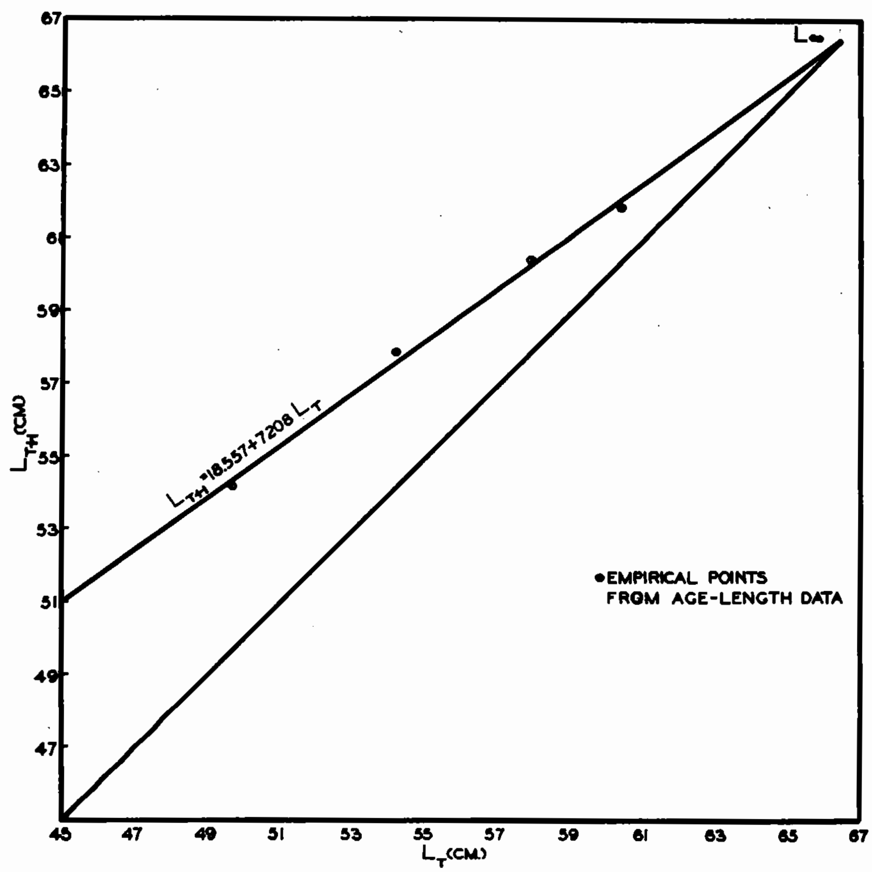

Figure 12. Walford graph of increase in length of inshore Lockeport haddock as determined from otolith ages. Length at age t is plotted against length at age t+1 for ages 5 to 9.

Ricker notes that in the equation, B and C are constants having the dimensions of length while K is a constant determining the rate of change in length increment. By means of an algebraic transformation the relationship is changed to the form used by von Bertalanffy (1938). Ricker explains the transformation in two stages. He first puts equation (4) in another form:

$$l_t - (B-C) = C(1 - e^{-Kt}) \qquad (5)$$

In this form, putting $t = 0$, it can be seen that $l_t = (B-C)$. It is pointed out that the constant quantity (B-C) is an adjustment which shifts the time axis of the graph so that the adjusted length is zero when age is zero. By adjusting the age using some constant, t_o, giving a new time scale with the origin at $t-t_o$ and shifting the length axis, the same effect can be achieved. This form is used by von Bertalanffy (1938); replacing B by l_∞, equation (5) becomes:

$$l_t = l_\infty (1-e^{-K(t-t_o)}) \qquad (6)$$

Ricker explains that the transformation has involved replacing the constant C by the new constant t_o, the relation between them being:

$$t_o = \frac{\log_e (C/B)}{K} \qquad (7)$$

Thus, in equation (6), instead of using the age as measured from the time of hatching, it has been measured from the time t_o, at which the fish would have been zero length if it had always grown in the manner described by the equation.

In order to be able to complete the fitting of equation (6) to the empirical points, the time-axis intercept of the curve, t_o, must be located with reference to calendar age, t. Ricker suggests following Beverton (1954, p. 157), transposing and taking logarithms in (6) giving:

$$\log_e (l_\infty - l_t) = \log_e l_\infty + Kt_o - K_t \quad (8)$$

Values of $\log_e (l_\infty - l_t)$ are computed for the best empirical points. A straight line is fitted to them and extrapolated back to calendar age zero. The value found at age zero is then equated to $\log_e l_\infty + Kt_o$ in equation (8). K is calculated from the value found in the Walford equation ($K = -\log_e k$), as is $\log_e l_\infty$. Substitutions are made and the value for t_o is found. The series of $t-t_o$ "ages" can then be computed.

Applying the method to Lockeport haddock, the values for l_∞ and k have already been found for the Walford transformation. From k the value for K is computed:

$$K = -\log_e k = .326$$

In Table XV the values of $l_\infty - l_t$ and $\log_e(l_\infty - lt)$ can be found in columns 3 and 4, respectively. The values for $\log_e(l_\infty - lt)$ are plotted against actual age from column 1, Table XV, in Figure 13. Only the good empirical points (ages V to IX) are used and the line fitted to them is extrapolated back to age zero where a value for $\log_e(l_\infty - lt)$ of 6.80 is read off. $\text{Log}_e l_\infty$ is found to be 6.498. Substituting in equation (8) t_o can be computed:

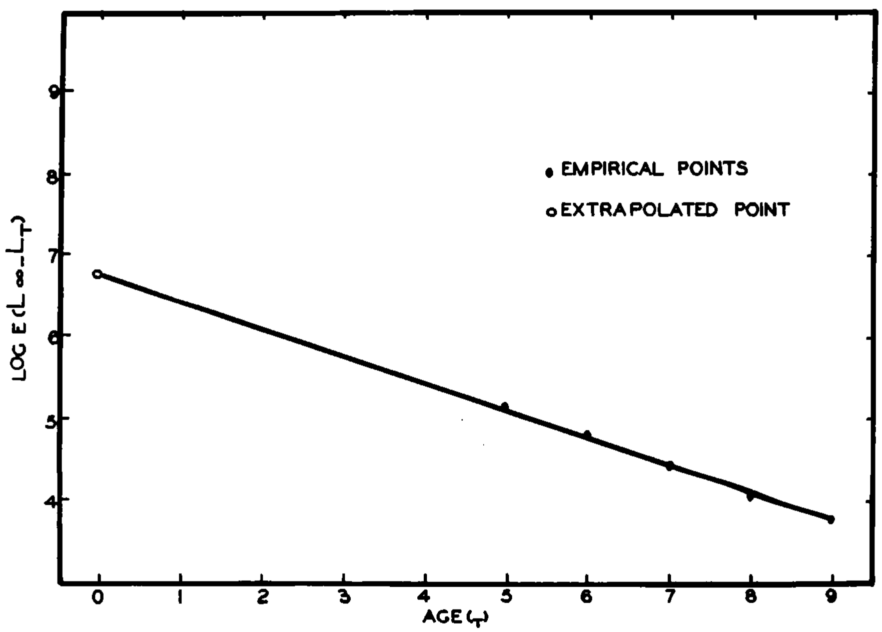

Figure 13. The determination of t_0 in Bertalanffy's equation by extrapolation (see text).

$$\log_e l_\infty + Kt_o = 6.80$$

$$6.498 + .326\ t_o = 6.8$$

$$t_o = .93$$

The series of $t-t_o$ "adjusted ages" are then calculated and can be found in column 5 of Table XV. Substituting the values given above in equation (6) the relationship (in cm.) for Lockeport haddock becomes:

$$l_t = 66.4\ (1-e^{-0.326(t-0.93)})$$

Both the Walford and von Bertalanffy forms of the growth equation apply only to haddock of age V or over.

Table XV. Growth in length of Lockeport haddock and data for fitting the Walford-Bertalanffy relationship. Bracketed figures are extrapolated.

Age n	Length cm.	$l_\infty - l_t$ cm.	$\log_e(l_\infty - l_t)$	Adjusted "age" $t-t_o$
0	(-21.2)		(6.80)	-.93
I	(3.25)			.07
II	(20.9)			1.07
III	(33.6)			2.07
IV	(42.8)			3.07
V	49.7	16.7	5.118	4.07
VI	54.2	12.2	4.804	5.07
VII	57.9	8.5	4.443	6.07
VIII	60.4	6.0	4.094	7.07
IX	61.9	4.5	3.807	8.07
X	(63.2)			9.07
XI	(64.1)			10.07

(cont'd)

Table XV (cont'd)

Age n	Length cm.	$l_\infty - l_t$ cm.	$\log_e(l_\infty - l_t)$	Adjusted "age" $t-t_o$
XII	(64.8)			11.07
XIII	(65.3)			12.07
XIV	(65.6)			13.07
XV	(65.8)			14.07

Growth in length from tagging data

Recaptures of haddock tagged off Lockeport in 1953 (McCracken, 1956) afforded an opportunity of measuring growth by comparing length at tagging to length at recapture. Since it was desirable to compare this line to the one calculated from age readings, fish were selected that had been in the water approximately one year from the time of tagging. Previous investigators (Manzer and Taylor, 1947; Lindner, 1953) have used this type of data to plot a "Walford" line. With the use of the same one year interval for both tagging and age-length data, it can be seen that the resulting lines would be directly comparable and in an ideal situation should coincide.

However, many sources of variation in growth enter into the picture. In the first place, the tagging line is usually a representation of only one year's growth of a number of different year-classes. This cannot be directly compared to an average picture from age-length data for a number of years, due to yearly fluctuations in conditions concerned with growth, such as temperature and available food. It is possible to eliminate this source of variation by extracting age-length data for the tagging year only if sufficient data are available.

Both Walford (1946) and Lindner (1953) state that in the case of fitting the "Walford" transformation to points for single specimens, a great many individuals must be used in order to get an average picture. Ricker (1956) further points out that data should extend into the region of decreasing increments in order to read off mean lengths for older ages. In this regard, the writer's opinion is that there should not only be plenty of data and a good range of sizes in them, but also a fairly even distribution of ages. The reason is that, given two fish of the same length, one six years of age and the other 12 years of age, it is expected that in the next year of growth the younger fish will usually show a greater increase in length than the older. Thus, if the line is fitted to growth of long, young fish, it will not necessarily be applicable to the growth of old fish of the same length. In order to be representative of the whole of the life of the fish, the "Walford" line for tagged fish recaptures should be fitted to equal quantities of data for each age.

In any case, the assumption must be made that the tagging operation and the tag itself do not materially interfere with the growth of the fish. These effects will probably vary with type of tag and care in handling the fish during the tagging operation. McCracken (1956) has pointed out that in the case of the tagging of haddock referred to here, the utmost precautions were taken to ensure that only the fish in good condition were returned to the water. However, the tags, which were fastened to stainless steel wire inserted through the back of the fish or clamped onto the lower fleshy part of the tail, may have had some effect in slowing up growth.

The tagging of haddock at Lockeport was carried out at an unfortunate time for easy estimation of growth. The period of operations was from May 27 to October 20, 1953, and it can be seen by reference to Figure 4 that this season includes the period of opaque otolith edges and fast growth. The ideal situation for estimation of growth from tagging is to tag in the season of growth stagnation and use recaptures from this period in the following year. In this way it is fairly certain that a year's increment is being measured.

In spite of the fore-mentioned limitations on tagging growth data, a total of 23 recaptures were found to be suitable for estimation of growth. Data on length and time of tagging and recapture together with age at recapture are to be found in Table XVI. It can be seen in column 4 of this table that more than 85% of the fish recaptured were of ages five to eight, inclusive, at the time of recovery. Thus, we have a measure of growth of these haddock from their fourth to fifth year, fifth to sixth year, etc., up to the eighth year. when inspecting individual cases. The tagging growth equation shown below is thought to be most applicable to these ages. In order to have a comparison to growth from age and length data, age-length means were calculated from samples taken in 1953 and 1954 at Lockeport. Those used are shown in Table XVII. Length at time t was taken to be lengths of age-groups in 1953, and corresponding lengths at t+1 were taken to be the length of the same year-classes in 1954 when they were one year older, or in the next highest age group. The ages shown are comparable to those found for recovered tagged fish.

Table XVI. Growth and age of haddock tagged at Lockeport, N. S., 1953, and recaptured in 1954.

l_t Length at tagging in cm.	Month of tagging (1953)	Month of recapture (1954)	l_{t+1} Length at recapture in cm.	Age in years at recapture
51	May	March	53	6
47	May	April	48	9
52	May	April	54	5
49	May	May	50	6
48	May	May	49	7
53	May	May	54	6
56	May	July	58	..
51	May	July	54	6
47	June	May	50	..
53	July	May	56	7
47	July	June	49	5

(cont'd)

Table XVI (cont'd)

l_t Length at tagging in cm.	Month of tagging (1953)	Month of recapture (1954)	l_{t+1} Length at recapture in cm.	Age in years at recapture
58	July	June	60	11
46	July	June	51	6
47	July	June	51	5
64	July	August	64	11
65	July	August	66	..
53	July	August	55	8
48	July	August	50	6
49	July	September	52	6
49	July	September	54	5
47	August	May	50	6
51	August	June	56	6
45	August	August	50	6

Table XVII. Ages and mean lengths of haddock sampled at Lockeport in 1953 and 1954.

		Age 4	5	6	7	8
1953	Mean length cm. (l_t)	46.5	51.9	55.5	58.6	....
1953	No. in sample	21	30	25	12	....
1954	Mean length cm. (l_{t+1})	....	49.5	56.0	58.7	59.7
1954	No. in sample	....	26	27	7	10

Straight lines were fitted by the least squares method to l_t, l_{t+1} points for both tagging and age reading. The equation for the tagging line was as follows (in cm.):

$$l_{t+1} = 9.8 + .86\ l_t$$

The relation for the age-length line was found to be (in cm.):

$$l_{t+1} = 10.3 + .86\ l_t$$

The two lines together with the points to which they are fitted are to be seen in Figure 14. It can be seen from the figure and the equations that both lines have the same slope and are separated by a .5 centimetre gap, the age line

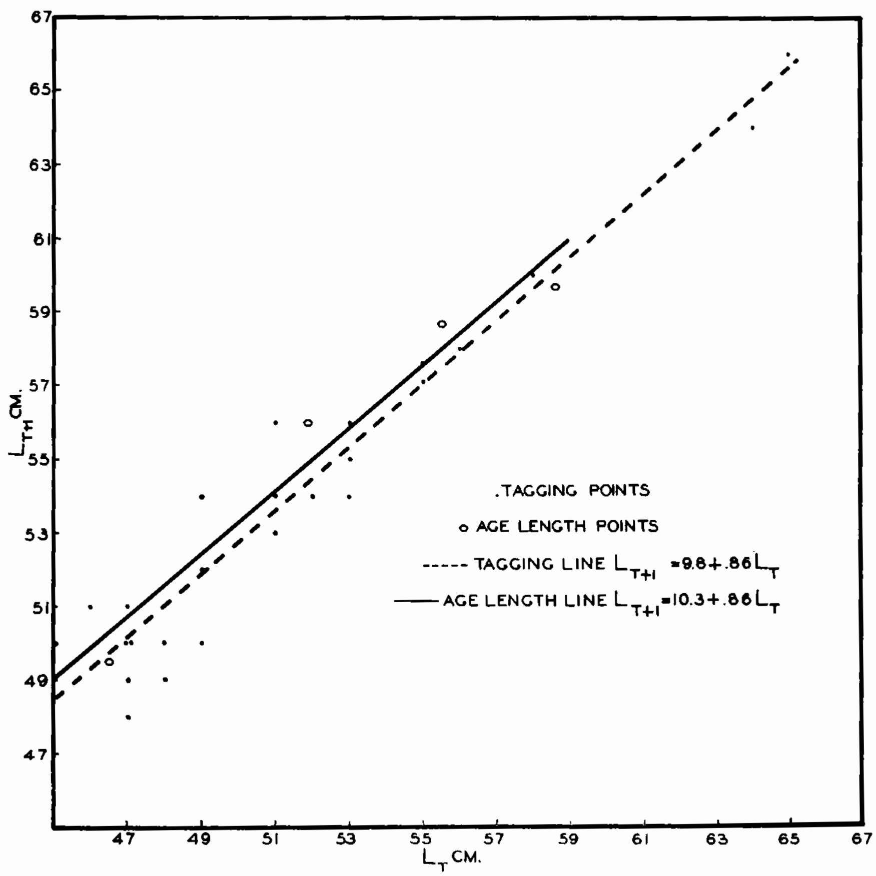

Figure 14. Walford graphs for growth in length of Lockeport haddock from tagging and age-length data.

being slightly higher. It appears that expected yearly increase in length for a length range of about 45 to 60 centimetres is almost the same whether calculated from measurements of growing fish or deduced from otolith readings and measurements. Ricker (1956) says that agreement of these two lines justifies moderate confidence in both as a representation of growth.

Another important point is that this agreement further justifies the use of otoliths as an age-determination tool for these haddock. It can be seen that growth as calculated from otolith readings is essentially the same as that found by observations on the living haddock. The slightly slower growth observed for tagged fish may well be due to some interruption in the growth pattern due to the tagging operation.

It will be noticed that the fitting of the tagging line and the 1953-54 line has resulted in a much smaller value for b than that found for the average growth of these haddock in an earlier section. An extra point for older, slower-growing fish has been used for fitting the average line and it has displaced the right hand end of the line downward. The pivoting point on the line is close to the right hand end of it, thus displacing the Y-axis intercept a considerable distance upwards. This gives it a much higher value than that found for the tagging and age-length lines representing younger haddock.

Comparisons of haddock growth

Needler (1929) has published a growth curve for Lockeport haddock as determined from scale samples and lengths taken in 1926. This line is reproduced in Figure 15 together with the theoretical average line for fish from this area for the period 1946 to 1954. The two lines may be said to be comparable as to time of year in that Needler's data were collected from June 15 to August 15, while data used in the present study were averaged for the whole year, thus approximating the summer season.

Observing Figure 15, it can be seen that there is about 5 centimetres difference in length at age five. The gap increases fairly regularly to about 7.5 centimetres at age 13. Growth of haddock seems to have become considerably slower in the approximate 25-year period separating the two representations. There are, however, other factors which may have contributed to the apparent decrease.

In the first place, the relative merits of scales and otoliths for haddock age determination have been discussed in a previous section. It has been shown that the reader is more apt to lose sight of annuli in older specimens when working with scales. This would have the effect of placing more long fish in younger age groups when using the scale method. Thus, a growth line for scales would tend to be shifted above a line from like specimens for otoliths. The scale line in Figure 15 may be affected in this way, especially since the spread between the scale and otolith lines can be seen to increase with age.

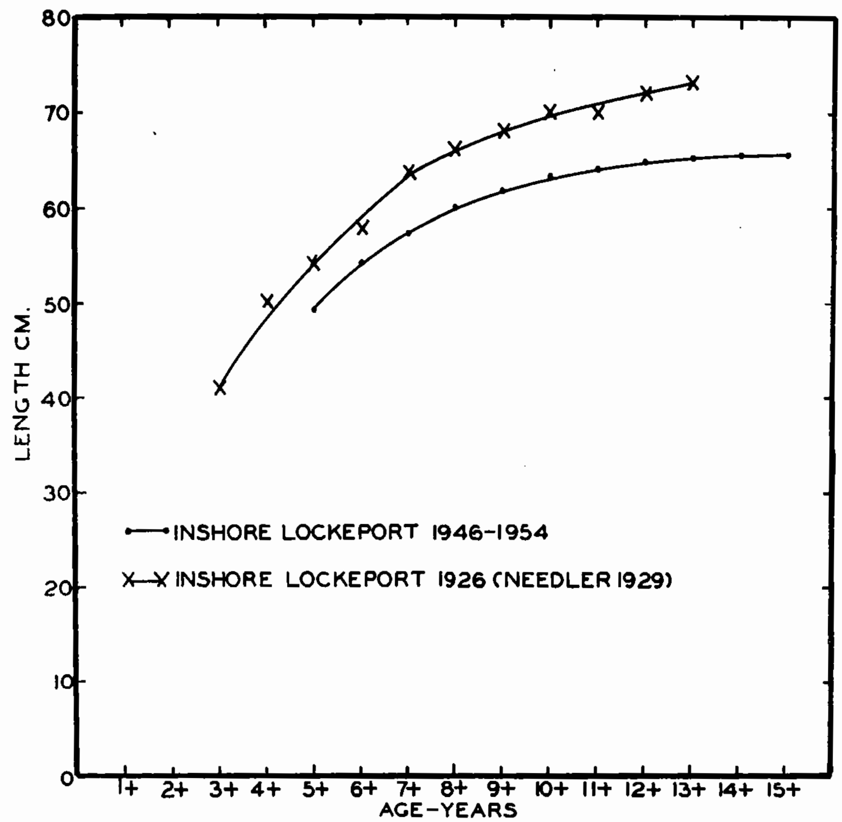

Figure 15. Growth curves for inshore Lockeport haddock.

Secondly, fishing practice and intensity will have some effect on an empirically calculated growth curve. The rate at which the long fish of an age group are captured as they enter the size range vulnerable to fishing could result in the raising or lowering of the mean size at any one time. If many haddock are being taken in the years when an age group is entering the fishery, the age group will appear to have a shorter mean length when it is fully recruited than if fewer of the longer members had been captured. Canadian statistics for haddock landings (Anon. 1955, Fig. 2) indicate comparatively low haddock landings for the five years preceding 1926, which may have meant a fairly good survival of long fish in age groups being recruited in those years. The statistics also show an average increase in landings for the 1946-1953 period over that mentioned above of about 50% by weight. This may have resulted in an increased mortality in the fore-mentioned long fish. Thus, fluctuations in the fishery may have been partially responsible for differing growth curves found for the area.

Consideration must also be given to the fact that the 1926 growth curve represents only one year's sampling of haddock, while the present relation has been calculated from data for a number of years. Needler (1930) has pointed out that when making use of average lengths for different age groups in one year's sampling, the growth rate is based on data for several broods. Ricker (1954) lists authors who have stated that abundant year-classes have often been found to consist of smaller than average individuals. There seems to be a certain amount of variation among the growth patterns of almost all broods of fish present in most fisheries. The state of conditions influencing growth can also vary tremendously from year to year thus altering the growth picture for any one year from the average for the area for an interval of, for example, a decade.

In order to provide some idea of the growth pattern of Lockeport haddock as compared to that found in other areas of the northwest Atlantic, curves were drawn in Figure 16. The Newfoundland curve is from Thompson (1939) and the Georges Bank relation from Graham (1952). Thompson states that his published mean sizes for age groups are attained early in the current year of growth. This may make them slightly low for direct comparison with the Lockeport data. The only other published data for haddock in Newfoundland waters come from Annual Reports of the Fisheries Research Board (Anon. 1952, 1953) where modal lengths of haddock of the 1949 and 1946 year-classes are mentioned. The 1949 brood is given as three and four year olds and the 1946 year-class as five year olds. The three and five year olds were presumably sampled during summer cruises of the Newfoundland research vessel, while the peak size of the four year olds is stated to be for the April-June period in 1953. In Figure 16 these points can be seen to be about 2.5 centimetres above Thompson's curve.

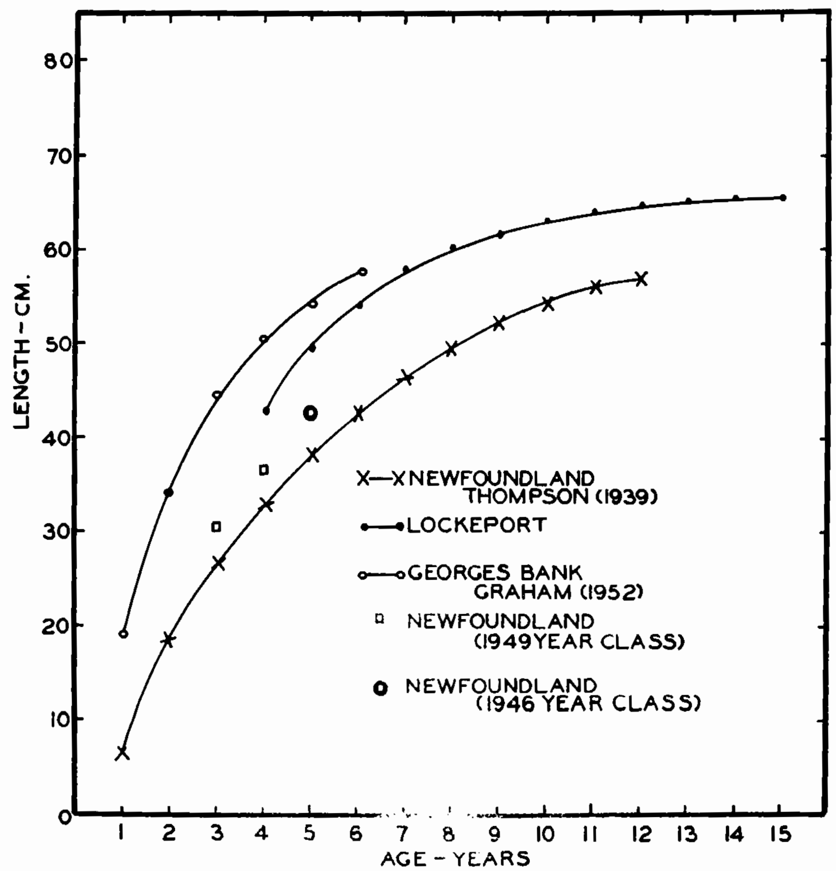

Figure 16. Growth curves for haddock from northwest Atlantic fishing grounds.

The time of year for Graham's (1952) curve for Georges Bank is not stated. Comparison of age-length data for Georges Bank from Schuck and Arnold (1951) for June shows that the two lines would almost coincide. The Georges Bank curve can therefore be taken to represent conditions at approximately the same time of year as that for Lockeport.

Observing the three lines, it can be seen that there are differences in growth in the three areas. The lines may be taken as being representative of haddock growth in the three major ranges of the fish in North American waters. The areas have been separated by Needler (1930) into New England, Nova Scotian and Newfoundland regions on the basis of the Fundian and Laurentian Channels dividing them. Growth seems to increase in a northeast to southwest direction, being least on the Newfoundland Banks and greatest on Georges Bank.

It is not intended to examine in great detail the reasons for differing haddock growth in these three areas as values for most of the environmental and hereditary factors involved are not available. Vladykov (1934) has indicated that among the measurable environmental variables determining the characters of fishes are temperature, salinity and available space. The relation of salinity is doubtful and density-dependent factors require a fairly precise measure of such things as depth and movement of favourable water conditions, light, number of animals present, etc. In the area dealt with here, the best records available for comparison are those that have been kept for temperature.

It may be noted that there are differing opinions as to the effect of temperature on growth in the literature. For example, Dehnel (1955, 1956) has shown that intertidal gastropod larvae from cold northern areas grow more rapidly at all experimental temperatures than those from warmer, southern parts. He suggests a compensatory mechanism in those from cold water. Taking all factors into consideration, he finds little difference in intrinsic growth rate between populations of Mytilus from Californian and Alaskan waters. Thorson (1950) dealing with invertebrates finds that in relatively cold water growth is slower, although metabolism may be as high as that found in warmer areas. However, for species retaining larval stages, he states that northern as well as tropical larvae seem, on the average, to spend a similar time in the plankton.

Dannevig (1933) in reviewing Fulton's (1906) experiments on whiting and cod kept in tanks notes that these species grew faster at higher temperatures. However, he notes that extraordinary increases in sizes did occur with very little change in temperature, indicating that other factors must have interfered. For his own experiments with cod, Dannevig states that in general the fish have exhibited the least growth in seasons of maximum and minimum temperature with the best length increment in seasons of moderate temperature. Brown (1946) has shown experimentally an even more complicated temperature-growth relationship for trout kept under controlled conditions. He found that the specific growth rates of trout living at different constant temperatures and of those living in water of changing temperature were high between 7° C. and 9°C. and between 16°C. and 19° C. and were low above, between and below these temperatures. He explains this by describing a differential effect of temperature on the amount of food eaten and the activity of the fish, the former being maximal between 10° C. and 19°C. and the latter between 10° C. and 12° C.

It is of interest to note the difference in temperature conditions found in general in the three fore-mentioned haddock regions in the northwest Atlantic. Thompson (1939) states that there is an increase in average water temperature in an east to west direction off the east North American coast from Newfoundland to New England. Hachey, Hermann and Bailey (1954) have shown in their Figure 13 that this was still the case in 1950. Georges Bank data for 1914 from Bigelow (1928) show temperatures much warmer than those found on the inshore Nova Scotian grounds and doubtless similar conditions still exist. The trend then seems to be towards higher temperatures as observed when moving southwest from Newfoundland Banks to Georges Bank. Figure 16 shows that haddock growth tends to become greater when observed in the same sequence. It seems likely that there is some positive relation between higher temperature and possibly other of the environmental conditions affecting the haddock that results in better growth of the fish in its more westerly range in the northwest Atlantic.

LENGTH-WEIGHT RELATIONSHIP FOR INSHORE LOCKEPORT HADDOCK

The sampling program for haddock at Lockeport in recent years has included length-weight measurements. Lengths are recorded in centimetres and weights in pounds and ounces for the individual fish. For the purpose of ease in calculation, ounces have been converted to decimal fractions of pounds in this study. As the fish are gutted before measurement, the variation in weight of the sexual organs due to condition and variation due to amount of food in the stomach is eliminated. However, differences in weight of even a gutted fish at any chosen length are noticeable at different times of the year, especially for mature fish.

Homans and Vladykov (1954) divided feeding habits of Nova Scotian haddock into two main phases on the basis of data taken from September, 1934, to August, 1935. These were a summer and fall feeding season (June to October) characterized by a relatively high percentage of feeding haddock followed by a winter and spring season (November to May) during which a large proportion of the haddock examined did not take food. They also show that during the months February to May of the winter and spring period, only a very small percentage of the haddock continued to feed.

These feeding habits can be related to gutted weight and condition of the reproductive organs of the fish at any particular size. For this purpose, samples have been condensed to form averages for three periods of the year. The choice of the months used in each period is based partially on conclusions formed by Homans and Vladykov (1954) and partially on the data available from Lockeport. Referring to Table XVIII, it can be seen that the majority of fish are heaviest for any given length in the October to January period, of medium weight in the June to September period and lightest in the February to May period. Observing the relation between weight and feeding activity, it can be seen that the relative weight is greatest following the heavy feeding period and just before the spawning season. During the approximate spawning season (February to May) the fish are doing very little feeding and are found to be of the least weight. In the June to September season, spawning is practically finished and the fish are feeding heavily. In this period they regain weight lost due to reproductive activities and cessation of feeding.

In order to obtain a representative relation comparing lengths and weights for Lockeport haddock, average weights for each of the three periods mentioned above were combined to give a grand average for each length (Table XVIII).

Table XVIII. Data used in calculating the length-weight relation for Lockeport haddock.

Length (cm.)	Weight in lbs. (eviscerated) Feb.-May	June-Sept.	Oct.-Jan.	Average for year	Values calculated from equation	No. of fish examined
36	0.92	0.88	0.95	0.92	0.94	11
37	1.00	0.96	1.00	0.99	1.02	7
38	1.11	1.05	1.08	1.08	1.10	18
39	1.21	1.15	1.18	1.18	1.19	24
40	1.28	1.29	1.35	1.31	1.28	18
41	1.37	1.32	1.38	1.36	1.38	38
42	1.48	1.45	1.52	1.48	1.48	53
43	1.63	1.59	1.62	1.61	1.59	52
44	1.69	1.68	1.78	1.72	1.70	63
45	1.79	1.82	1.90	1.84	1.82	63
46	1.92	1.94	2.02	1.96	1.95	83
47	2.08	2.14	2.16	2.13	2.07	79
48	2.26	2.25	2.38	2.30	2.21	65
49	2.27	2.31	2.48	2.35	2.35	80
50	2.47	2.52	2.62	2.54	2.50	78
51	2.59	2.70	2.80	2.70	2.65	82
52	2.65	2.78	2.95	2.79	2.80	89
53	2.89	3.03	3.18	3.03	2.97	72
54	3.12	3.13	3.32	3.19	3.14	55
55	3.20	3.21	3.50	3.30	3.30	45
56	3.51	3.45	3.52	3.49	3.50	44

(cont'd)

Table XVIII (cont'd)

Length (cm.)	Weight in lbs. (eviscerated) Feb.-May	June-Sept.	Oct.-Jan.	Average for year	Values calculated from equation	No. of fish examined
57	3.33	3.42	3.85	3.53	3.69	42
58	3.50	3.71	4.09	3.77	3.88	35
59	3.82	4.12	4.27	4.07	4.09	36
60	4.00	4.59	4.55	4.38	4.30	16
61	4.51	4.38	4.77	4.55	4.52	23
62	4.46	4.47	5.06	4.66	4.74	26
63	4.50	4.88	5.38	4.92	4.97	18
64	4.50	5.14	5.92	5.19	5.21	18
65	5.11	5.25	5.69	5.35	5.46	11
66	5.00	5.56	6.69	5.75	5.71	13
67	5.44	6.03	6.32	5.93	5.97	11
					Total	1368

Hile (1936) points out that the length-weight relationship in fishes can be satisfactorily described by use of an expression of the form:

$$W = CL^n$$

where W = weight

L = length

n = some power of L

and C = a constant.

In this equation the values of both C and n are determined empirically. Ricker (1956) notes that to obtain a true value for n, either the individual fish or means of L and W for narrow length ranges must be used rather than means for broad length ranges such as age groups. This is because the average weight of fish that all have a length of exactly L tends to be less than the average weight of a series of fish of varying lengths whose average length is L.

The expression above was fitted to the average for the year for Lockeport haddock giving the relation:

$$W = .00002127L^{2.98369}$$

where W = weight in pounds

and L = length in centimetres

Theoretical weights calculated from this equation are tabulated in Table XVIII and are found to correspond closely to the empirical values. This is further demonstrated in Figure 17, where the theoretical curve is plotted together with the points from which it was calculated. The value for n shown above is very close to 3.0, indicating that the relation for haddock approaches the cube law. This type of growth was termed "isometric" by Huxley and Teissier (1936), an adjective describing growth as resulting from unchanging body form and specific gravity.

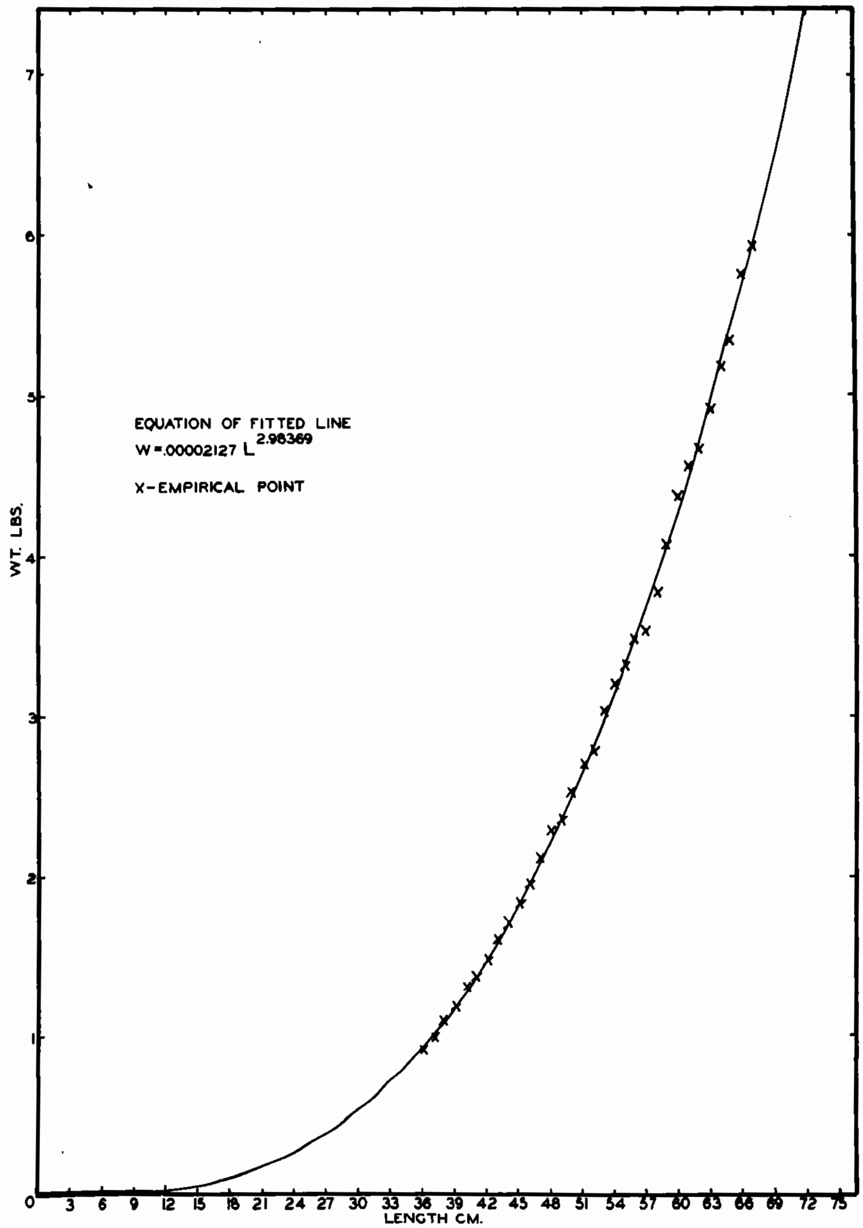

Figure 17. The length-weight relationship for inshore Lockeport haddock.

MATURITY AND SPAWNING OF INSHORE LOCKEPORT HADDOCK

Collection and classification of data

In 1953 a groundfish bait experiment on the Lockeport grounds provided an opportunity for examination of the sexual products of haddock caught by hook and line. Fish captured were measured and a gross examination of their gonads was made. Otoliths were taken from slightly more than 20% of the fish examined. Dates and numbers of fish examined were as follows:

January 23 (283 fish)
February 24 (171 fish)
March 23 (176 fish)
April 16 (48 fish)
May 1 (48 fish)

The gonads of both males and females were placed, according to condition, into one of five classifications. These were immature, maturing, ripe, running and spent. The criteria used for this classification are shown in Table XIX. They are taken in part from Table I of the paper on the sexual cycle of haddock by Homans and Vladykov (1954). It should be noted that Stage 2 haddock as described by these authors is recorded in this study as the early indication of the maturing stage defined in Table XIX.

The spawning period

Needler (1930) states that haddock in North American waters were thought to spawn in depths usually 40 fathoms or over although time and place were variable. Bigelow and

Schroeder (1953) give the dates of spawning in the Gulf of Maine as late February to May. This has also been found by Walford (1938) who made an extensive study of spawning haddock on Georges Bank. McKenzie (1940) in a study of the trap fishery at Jordan Harbour, N. S., found that spent haddock began to arrive in the traps in the last half of May, and continued to be caught until July. Thus, spawning began somewhere near this area prior to the month of May. Homans and Vladykov (1954), in their study of haddock from the Western Banks of Nova Scotia, found that fish were recovering from July to January, ripening from December to February and spawning in March and April.

The spawning period for Lockeport haddock is depicted in Figure 18. The fish have been divided according to sex and assigned to one of the five fore-mentioned categories. It can be seen that in the January and February period the fish are apparently approaching the spawning stage but none have yet completed the act. In March a few ripe and spent females were found, indicating that spawning had begun in that month. In April over half of both the males and females were either in a running condition or spent, while in May most of both sexes were spent. The sampling indicates that the bulk of the spawning took place in the latter part of March, April and the first part of May.

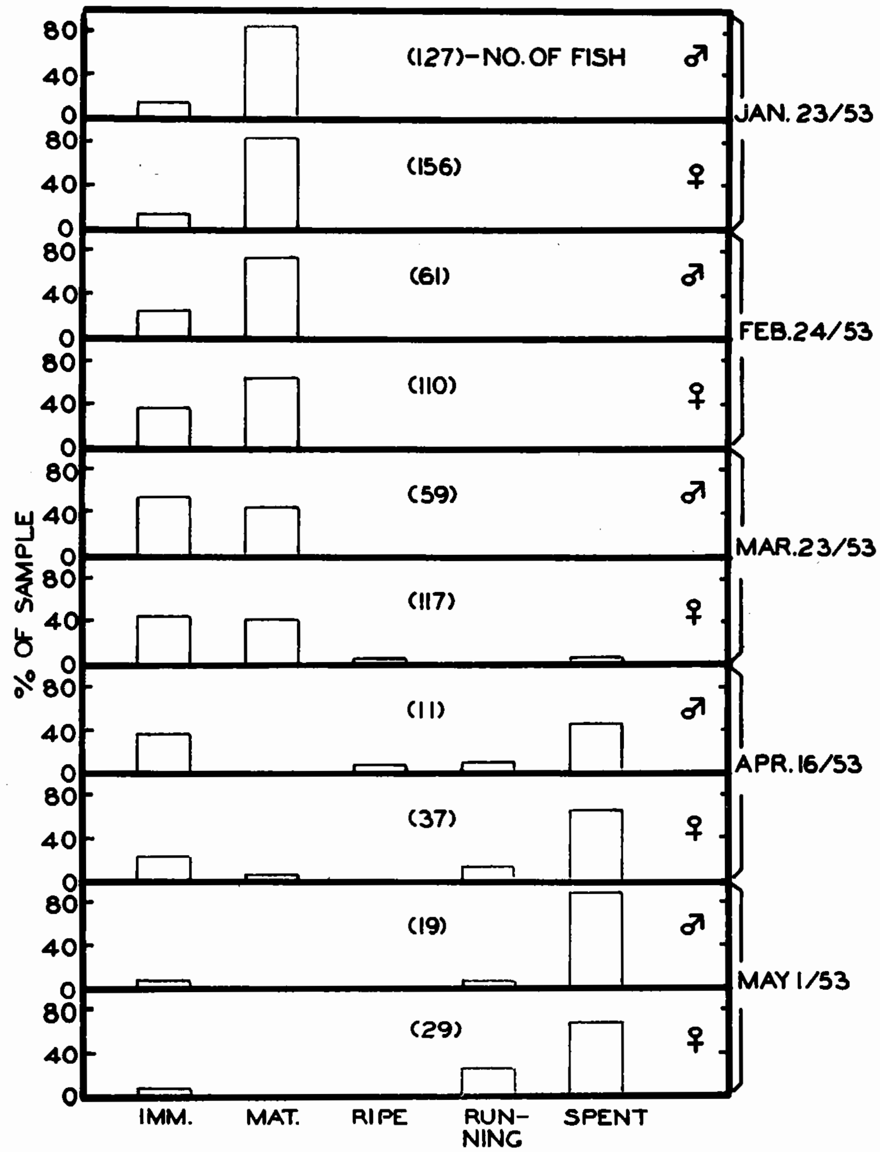

Figure 18. The haddock spawning period in inshore Lockeport waters.

Table XIX. Definitions of sexual stages found in inshore Lockeport haddock during the spring of 1953.

Stage	Female	Male
Immature	Ovaries small and firm. Contents reddish yellow and bright looking. Membrane thin and somewhat transparent.	Small testes appear as a clear, crimped and slender string; colourless to gray.
Maturing	Ovaries larger and becoming reddish with numerous blood vessels. Minute opaque eggs are visible to the naked eye, giving the ovaries a granular appearance.	The testes are larger and somewhat distended. They are pinkish to white in colour and wavy with fine but conspicuous blood vessels.
Ripe	Ovaries well developed, reddish golden in colour and opaque with blood vessels becoming inconspicuous. Contents consist of some translucent eggs, and eggs which are yellow and opaque. Few eggs running.	The testes are distinctly wavy, white and quite distended with large lobes. A few drops of milt may be obtained by pressing.

(cont'd)

Table XIX (cont'd)

Stage	Female	Male
Running	Ovaries very much developed. Eggs transparent or light amber colour and running freely.	The testes are very white and fully distended. Milt runs freely at the slightest pressure.
Spent	Ovaries soft, flabby and bloody. Practically no eggs remain. Membrane thick and tough.	The testes are shrunken. Very large vas deferens. Later become wrinkled and string-like.

This seems to be in accordance with the previously mentioned findings in surrounding areas.

It is of interest to note that only a small percentage of ripe and running fish were taken. Two factors are the cause of this. These two stages probably occupy only a very short period in the spawning cycle as compared to the other three. Thus, there is less chance of catching the haddock in this condition. Also, Homans and Vladykov (1954) show that a large proportion of these fish cease to feed as the spawning time approaches, thus making them unavailable to the hook and line fishery.

Age at maturity

It is of interest in conservation studies to know the size and age at which fish reach maturity in order to have an estimate of the mortality of potential spawners in relation to fishing gear. Figure 19 shows the percentage of mature fish by ages from the catch of males and females. The mature portion includes fish in all conditions of maturity. For male fish, it can be seen that the majority are immature at three years of age and mature at five years. They are about 50% mature when four years old. The majority of females seem to mature between the fourth and fifth years, being about 75% immature when four years old and more than 90% mature at the age of five. All the members of both sexes were mature at the age of seven and above. The indication is that the male haddock usually begins to mature at an earlier age than the female.

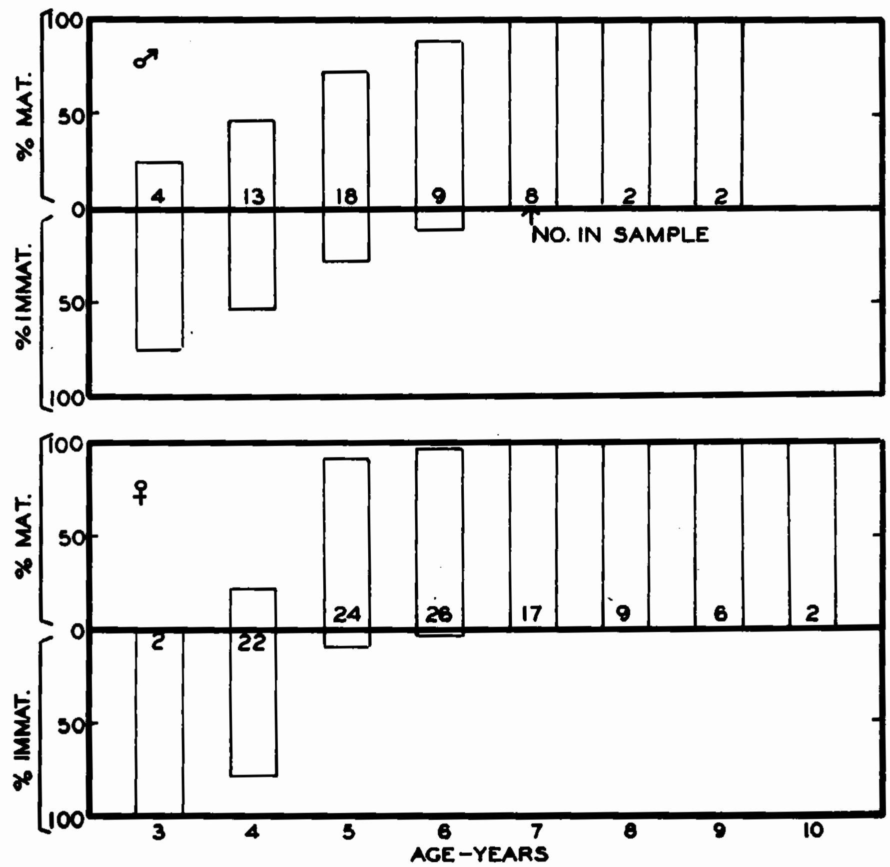

Figure 19. Age at maturity of haddock catch from the inshore Lockeport grounds in the spring of 1953.

Size at maturity

Length at maturity is plotted for these fish in Figure 20 in the form of smoothed curves. Comparing the curves, it can be seen that the male fish mature at shorter lengths than the females. This is to be expected after noting results from age data, provided that there is no difference in growth rate between males and females. In this study sufficient data were not available from sexed fish to compare growth of males and females but Duff (1916) found no marked difference for haddock from the Bay of Fundy area. It may be noted that the amount of data used for lengths of 33 to 39 centimetres in this study is fairly small due to hook selection eliminating most of the small fish from the catch.

Raitt (1932) found that in the North Sea haddock population, the same results were evident. Males matured at smaller sizes and younger ages than the females. His fish were more precocious than those of the Lockeport area with the majority of the male two year olds and the female three year olds being mature. This may be an indication of compensation for greater fishing intensity in this area. However, Molander (1955) notes that for the plaice and flounder in the Baltic, size but not age at maturity has changed with increased fishing intensity. The size at first spawning has become greater due to an increased growth rate. It may be that the thinning out of a stock to an optimum production level has this effect, while overfishing produces a reduction in both size and age at first spawning.

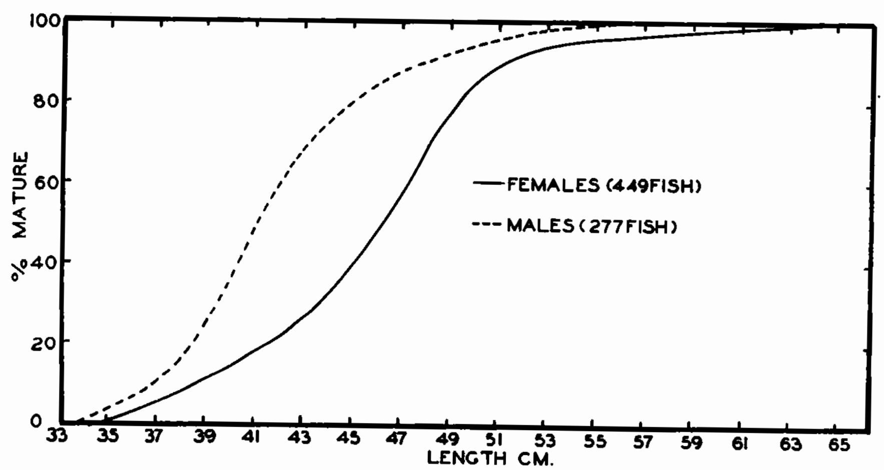

Figure 20. Length at maturity of haddock caught in the spring of 1953 on the inshore Lockeport grounds (data smoothed by 5's).

SUMMARY AND CONCLUSIONS

1. This study of inshore Lockeport haddock was carried out for two reasons: to establish a valid method of determining the ages of these fish and to estimate certain parameters of this particular population for comparison with those of other areas.

2. Length, weight, sex and stage of maturity data, as well as otoliths and scales for age determinations, have been collected for haddock in the years 1946 to 1954. The accumulated material has been analysed.

3. The validity of the otolith method of age determination is confirmed in three ways:

(a) In the first place the annual formation of one hyaline and one opaque zone on the periphery of the otolith is demonstrated. The peak abundance of hyaline zone formation at the edge is usually from November to July while opaque rings are found here from August until October. Hyaline zone formation is correlated with cessation of feeding, stagnation of growth and the spawning period.

(b) The second piece of evidence is the consistency of the relative strength of year-classes found by the otolith reading method. The richness and poorness of the 1943 and 1942 year-classes are contrasted through the sampling. It is indicated that reliable age readings can be obtained from otoliths at least to eight years of age and in many cases to 10 or 11 years.

(c) The peak in the length distributions caused by the strong 1943 year-class during the years 1946 to 1949 is examined. The samples of fish composing this peak were found to add one annulus per year to their otoliths, thus providing further evidence of the validity of the method.

4. A comparison of the scale and otolith methods of age determination for haddock led to the following conclusions:

(a) Disagreements between scale and otolith readings are randomly spread up to about eight years of age.

(b) Otolith readings are generally higher than scale readings over eight years of age.

(c) Disagreement of scale-otolith readings increases with average age of the sample.

(d) Scale annuli are usually difficult to identify above eight years of age.

(e) Random disagreement of scale and otolith readings for a sample effects little difference in growth and mortality rates calculated from each method.

(f) For populations of older haddock such as are found in subarea 4 of the I.C.N.A.F. Convention area, otoliths are believed to be the best tool for age determination.

5. Equations of growth in length are presented for Lockeport haddock. The regular increment per age found in the empirical data is further justification of the otolith age-reading method.

6. Growth from tagging experiments is found to agree with growth as calculated from age determinations. Since the tagging line is calculated from observations on the living fish, the agreement of the two lines also supports the validity of the otolith age-reading method. Limitations of confidence in growth lines from tagging data are discussed.
7. The apparent change in growth of haddock at Lockeport as shown from 1926 data and 1946-1954 data is noted. Several possible explanations are advanced for the anomaly.
8. Growth of Lockeport haddock is compared to increments found for this species on Georges Bank and the Newfoundland Banks. In general, growth is seen to increase in a north-east to southwest direction, being least on the Newfoundland Banks and greatest on Georges Bank. The increase in growth in this direction is considered in relation to a similar trend toward increasing temperatures in these areas. Environmental conditions related to these temperatures may approach the optimum for these fish in the more westerly parts of the area considered.
9. A general length-weight equation is derived for Lockeport haddock. The relation is noted to be of the type resulting from unchanging body form and specific gravity during growth. These fish are found to be lightest in the February to May period, of medium weight from June to September, and heaviest from October to January. Changes in weight are related to reproductive activity and cessation of feeding.

10. Lockeport haddock spawned in the latter part of March, April and the first part of May in 1953. The males reach maturity at between three and five years of age while the females seem to mature later, between their fourth and fifth years. Male haddock mature at shorter lengths than do the females.

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