THE BIOLOGY OF THE YELLOWTAIL FLOUNDER
(*Limanda ferruginea* - Storer).

by

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THE PROBLEM

The commercial importance of the Yellowtail Flounder (*Limanda ferruginea* Storer) in recent years has greatly increased, partly because of the greater use of otter trawlers in North American waters, and also as a response to the unprecedented demand for fish products during the war. This is particularly true in the case of Canada where, until recently, the traditional method of fishing was line trawling, a method which prevented the capture of yellowtails since its mouth is so small that one is rarely caught on the large hooks used for cod, haddock, and pollock. These factors have led to an extensive exploitation of the yellowtail fisheries, especially in New England waters where, in 1942, more than 65,000,000 pounds of yellowtails were landed. Since then yellowtail landings in New England have steadily decreased, although the fishing intensity has increased, and there are indications that this decrease may be the result of over-fishing. The position of the yellowtail upon the Canadian market, although much less important, is becoming increasingly significant. The annual landings of yellowtails at Canadian ports is shown in Table I.

TABLE I. Annual Landings of Yellowtails at Canadian Ports.

	cwt.	Value		cwt.	Value
1941	10,080	$14,800	1944	7133	$ 14,266
1942	7,882	12,045	1945	19,200 x	36,500 x
1943	8,737	14,557	1946	26,700 x	54,000 x

x Approximate values only.

In 1945 the Fisheries Research Board of Canada initiated an investigation of the important ground fish found in Atlantic fishing areas which are used by Canadian fishermen. As the yellowtail is one of the most abundant flounders on the Nova Scotian banks, the writer, in 1946 commenced a study of this fish. Literature about the yellowtail is meagre and the descriptions and observations provided by such writers as Jordan and Evermann (1896-1900), Williams (1902), Tracy (1910), Dannevig (1919), Bigelow (1925), and Bigelow and Schroeder (1936) constitute most of the recorded information about the yellowtail. Until the present study was started almost nothing was known about the rate of growth of the yellowtail in Canadian waters. Consequently, the objective of this study was to collect as much data as possible about the life history of the fish, and at the same time to determine the discreteness of the populations in different areas. These data supplemented by catch statistics would provide information for the rational utilization of the stock. That the work on this species was undertaken almost as soon as the species assumed economic significance in Canada is of great importance, since many similar investigations in the past have only been induced by alarm at the depletion of a stock.

Since the material in this paper was collected over a short period, May to September 1946, this paper can only be considered as a preliminary report. Although many aspects of the life history of the yellowtail remain unanswered, I believe that sufficient basic information is presented herein to warrant its publication.

DESCRIPTION OF THE FISHING AREAS

According to Hachey (1942) "The submarine physiography of the continental shelf to the south-east of Nova Scotia delineates an area that has been termed the Scotian shelf." The high areas of this shelf form banks which constitute the great fishing areas of the Canadian Atlantic. The positions of the areas considered in this paper are shown in Fig. 1. It will be seen that Middle Ground is the most northerly and the most discrete area whose depths range from 25-40 fathoms on the periphery to less than 20 fathoms in the centre. Middle Ground on the south is separated from Sable Island Bank by a narrow stretch of deeper water whose depths range downwards as far as 90 fathoms. Western Bank is that part of Sable Island Bank which lies west of 61°W longitude and, in general, is a less shallow bank than Middle Ground. The western slope of the banks is not great and until 61°W longitude is approached the depths are greater than 30 fathoms. Extending east towards Sable Island the bank becomes more shallow until there is a considerable area whose depth is less than 20 fathoms. Fishing area XXII Q lies in American waters and its depth varies from 15 fathoms in the inshore waters to depths over 100 fathoms on the outer edge. The part of XXII Q under consideration in this paper has depths of 17 to 25 fathoms.

Hydrographic studies of the continental shelf have been made by Bjerkan (1919) and in several papers by Hachey (1935, 1937, 1938, 1942). Hachey (1942) presents an analysis of data which outlines the more general features of the waters of the Scotian shelf. He states that there are three layers of water whose thicknesses vary with the season: "An upper layer with temperature in summer above and in winter below 5°C., and with salinities always less than 32°/oo; an intermediate layer with temperature generally below 5° and with salinities between 32 and 33.5°/oo; and a bottom layer with temperature above 5° and salinities above 33.5°/oo." Of particular interest in this paper are the seasonal variations in the temperature of the intermediate layer for it is in this layer that the yellowtail spends most of its life. A comparison of water temperatures at different times of the year is shown in Table II. The data has been taken from Hachey's paper (loc. cit.). Stations 129, 130, and 131 are located on Western Bank, Sable Island Bank and Middle Ground respectively.

Table II. Seasonal Variations in Water Temperatures on Nova Scotian Fishing Banks.

Depth	Station 129	Station 130	Station 131
0 m	3.3°C	1.1	1.0
25 m	3.3	1.7	1.0
50 m	3.3	4.1	1.0
75 m	3.3	4.7	-
	April - May 1938		
0	2.8	3.0	2.0
25	2.6	2.8	1.6
50	1.4	2.4	1.6
75	1.4	1.7	-
	August 1938		
0	18.9	19.1	17.7
25	8.8	12.8	12.7
50	2.7	5.9	6.4
75	2.8	2.6	-

It can be seen from the table that in the deeper water the maximum temperature is reached in late summer or autumn and the minimum in the late winter or early spring whereas surface waters show a general increase in temperature from January to the maximum in August. In addition to these data, some water temperatures taken by the writer on Middle Ground during the first week of June indicate the existence of a thermocline between 20 and 30 fathoms with the temperature varying from 5°C at 20 fathoms to 0.2°C at 29 fathoms.

Olsen and Merriman (1946) include temperature readings taken in the vicinity of XXII Q and at a depth of 20-25 fathoms these temperatures vary from 2.4°C in March to 14.3°C in August indicating that the summer maximum is considerably higher than that encountered either on Western Bank or on Middle Ground. This temperature difference is probably due to the effect of the Gulf Stream which passes close to Cape Cod whereas the Labrador Current and a secondary cold current from the Gulf of St. Lawrence affect the hydrographic conditions of the Scotian shelf but their influence is not appreciably effective as far south as Cape Cod.

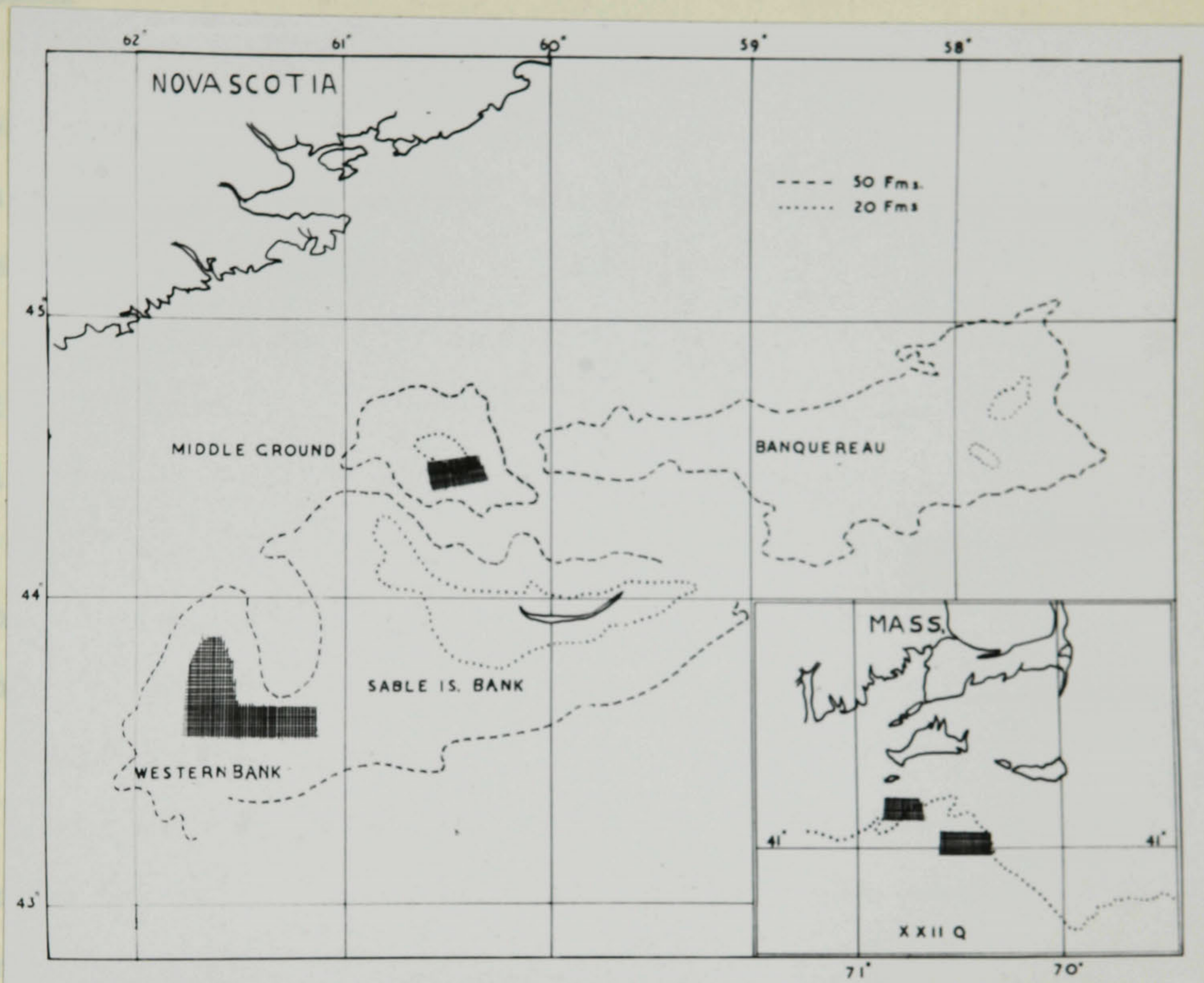


FIG. 1. Map of the Fishing Areas.

(Cross hatched areas show the approximate positions from which the collections were made.)

GENERAL DISCUSSION OF THE FISH.

Description.

It is not within the scope of this paper to deal with the systematic status of the yellowtail whose description is given in detail by Jordan and Evermann (loc. cit.) and Bigelow (loc. cit.). However, a brief discussion of its characteristics should be included.

Limanda ferruginea is a typical flounder of the Family Pleuronectidae and it is represented in European waters by the Common Dab (Limanda limanda). The yellowtail is right-handed; that is, the eyes are on the right side and viscera on the right hand margin as the fish lies on the bottom. Although occasional occurrences of left-handed individuals occur according to Royce (1946) no left-handed individuals have been observed by the writer. It is readily distinguished from other flounders by the small mouth, concave dorsal profile of the head, a lateral line which arches above the pectoral fin, the yellow coloration of the under surface of the caudal peduncle, and the bright rust-coloured spots on the pigmented side. Norman (1934) states that Goode and Bean (1896) have suggested that northern examples may represent a distinct subspecies, (rostrata), distinguished by the lower number of dorsal and anal rays, and by the blunter, more pointed snout.

The yellowtail is one of the thinnest of the flounders and this is of invaluable aid in sex determination as the sexes possess no external morphological differences. If the fish is held between the observer and a source of light, sunlight is sufficient, the lateral margins of the fish are quite translucent and the ovaries, even in an immature female, can be plainly seen extending posteriorly into the body musculature from the peritoneal cavity.

On the other hand, the testes are confined to the peritoneal cavity whose posterior margin is formed by the arch of the post-anal spine and are not apparent without a detailed examination.

Distribution.

Bigelow in 1925 gives the general range of the yellowtail as "North American coastal waters, from the north shore of the Gulf of St. Lawrence, northern Newfoundland (there are specimens from St. Anthony's in the Museum of Comparative Zoology) and the Newfoundland Banks to New Jersey." Hildebrandt and Schroeder (1928) record the occasional occurrence of the yellowtail in Chesapeake Bay but remark that it is of no commercial importance in that area. Subsequently, in 1936 Bigelow and Schroeder record the capture of a specimen, near Hog Island, Virginia, which considerably extends the known range in the south.

Detailed information on the distribution in Canadian waters is still lacking and probably will not be forthcoming until otter trawls are used more extensively. On fishing areas such as Middle Ground, Sable Island Bank and Banquereau which are fished regularly by trawlers the yellowtail is abundant and occasional instances have occurred where more than 50,000 lbs (about 25,000 fish) have been taken in a single trip. Fishing skippers report that it is less common in St. Pierre Bank and uncommon on the Grand Bank of Newfoundland. It is not taken commercially in the Gulf of St. Lawrence and the yellowtail is unknown to Gaspe fishermen. However, in the area of Malpeque Bay, P. E. I., small fish have been taken in seine hauls according to Needler (1946).

The yellowtail does not occur commonly in inshore waters of Nova Scotia although Huntsman (1922) states that in the Bay of Fundy a few large individuals were found in deep water in St. Mary bay and that Perley (1852) recorded it from the upper part of the bay near Parrsboro. On the fishing banks it is most common in depths of 15-30 fathoms and becomes less common in deeper water until it is rarely found in waters over 40 fathoms. Its habits and distribution on the banks appear to be distinct from those of the cod (Gadus callarias) and the haddock (Melanogrammus aeglifinus) since it is rarely caught in large numbers in the same tow as the cod or haddock. The yellowtail is found much more frequently in association with dogfish (Squalus acanthias). This suggests that yellowtails share the preference of dogfish for water warmer than that which provides the optimum temerpature for the cod.

FIG. 2. Limanda ferruginea - Storer.

METHODS AND MATERIALS.

This paper is based on data collected from approximately 3000 fish. The majority of these specimens were examined at sea and the remainder were taken from commercial catches landed at Halifax, Nova Scotia. As has been previously mentioned the three fishing areas under consideration are Middle Ground, Western Bank, and XXII Q. Unfortunately, seasonal variations in the use of the fishing areas made it impossible to collect material continuously from all three banks throughout the summer. Data from Middle Ground were collected in May and June, from XXII Q in July, and from Western Bank in August and September. Consequently, it is possible that some of the differences between populations may be attributed to seasonal fluctuations in the distribution of the yellowtail.

Every effort was made to obtain random samples within the limits of gear selectivity but this problem was complicated by several factors:

1. Only large fish, generally over 40 cm. in length, are landed at Canadian ports.
2. Investigations at sea were conducted on commercial trawlers. This precludes accurate sampling as many small fish are obscured or washed overboard during cleaning operations. However, on one trip to Middle Ground, yellowtails were not retained for landing and it was possible to examine complete hauls. Normally, a trawler's deck is divided into squares or checkers and whenever it was feasible all the yellowtails in one checker were set aside for examination.

3. The spawning season occurs in May and June and it will be shown later that this may have a profound effect upon the distribution of the stock.

The following information was recorded from all or some of the specimens:

1. Sex

The method of sex determination has already been discussed. In the examination of a fish, it was the usual practice to determine the sex after all other measurements had been made. This prevented any personal bias upon the part of the observer when measuring parts in which a sexual difference might exist.

2. Total Length.

Total length was recorded in centimetres on a measuring board with an offset vertical head piece. The measurement was made from the tip of the snout to the end of the caudal fin,

3. Head Length.

Head length was recorded in millimetres from the tip of the upper lip to the posterior edge of the opercular flap.

4. Pectoral Fin Length.

This measurement was from the ventral edge of the base of the right pectoral fin to the tip of the longest fin ray.

5.. <u>Meristic Counts.</u>

Counts of dorsal and anal fin rays were made on approximately 700 fish.

Otoliths were removed from 1600 specimens and scales from over 500 specimens; the scales were taken from the right side of the caudal peduncle. Age determination in fish presents certain problems, and since information about otoliths is much scattered throughout the literature, it has been thought that a detailed account of this topic might be included with advantage in this report.

AGE DETERMINATION

Historical Review.

In the closing years of the 19th century, when European fishery investigations began to assume great importance, it was found that a valid method of age-determination was essential for the correct interpretation of growth in fish. Considerable time was spent by many workers toward this end and Petersen (1894) was one of the first to propose a satisfactory method of age determination. He showed that when a large number of individuals of a species were measured and the material obtained was graphically arranged according to the frequency of different size units, one or more larger groups were always formed around certain sizes. These size-groups were in the case of smaller fish, generally well defined. But, as regards larger fish, the size-groups tended more and more to amalgamate and to become less distinct. Later it was observed that these size-groups corresponded closely to different age-groups of fish. Although this method may be used as corroboration of other methods, it was early abandoned by research workers in the North Sea since it was found that it was vitiated by differences in the distribution of fish of the same age but of different size.

In 1899, Reibisch introduced the examination of otoliths as a means of age determination. This method consits of counting the number of white (opaque) and dark (translucent) rings displayed by the otolith. These rings were stated by Reibisch to be periodically added to the otolith; the white ring in the spring and early summer and the dark in late summer and autumn. He suggested that the phenomenon of alternate white and dark rings is due to, as it certainly is associated with, a difference in the mean temperature of the water; the dark ring being formed under the influence of the higher temperatures. Subsequently, many workers, Wallace (1905), Cunningham (1905), Molander (1925) confirmed the periodicity of the rings but did not all agree with Reibisch's statement about the time of formation of the rings. However, this method of age-determination has been generally accepted by European investigators and much use of it has been made in the complicated problems of the North Sea fisheries. Although the basic premise of the method is correct, care must be taken to determine the times of deposition of the two types of rings in different species and in different areas. Dannevig (1933) investigating the growth of cod in two Norwegian fjords observed that in one fjord the white opaque ring was formed between December and May whereas in the other fjord the ring was deposited between March and July.

The otolith method has been used with considerable success in work on Pleuronectidae and Gadidae. Other methods of age determination exist, one of the most important involving the use of scales. This method, although extremely useful in age studies of Salmonidae, Coregonidae, Clupeidae, etc., has been rejected by most European workers on flounders whose scales are too small to permit accurate determination of age.

The otoliths are small, bean-shaped, calcareous structures contained in the inner ear. They are easily removed by making a cut with a strong fish ripper behind the preopercular bone at right angles to the longitudinal axis of the fish. Several methods of preservation have been employed by different investigators such as Frost (1945) who used normal saline and lysol, Ketchen (1945) who used 50% solution of glycerin plus a little thymol, and Olsen and Merriman (1946) who kept the otoliths in a dry state at all times. Initially, a method involving the use of sodium triphosphate was employed but this proved unsatisfactory as the opacity of the otoliths appeared to increase with time. Finally Ketchen's method was adopted and this was entirely satisfactory.

Both the right and left otoliths are convex on one side and flat or slightly concave on the other. The convex side is bisected by a sulcus which runs along the long axis of the otoliths. The right otolith is readily distinguishable by the marked excentricity of its core; the excentricity becomes more pronounced with age. The flat surface of the left otolith is generally the easiest to read and, since yellowtail otoliths are quite thin, no grinding was required to reveal the rings.

The otoliths immersed in a drop of glycerin, were examined under a binocular microscope (10.25x) using reflected light against a dark ground. For age determination the left otoliths were read twice without reference to the length or sex of the fish and if there was a discrepancy between the two readings, a third reading was made from both the right and left otoliths and a probable age given to the fish.

The features presented by an otolith for reading can be seen in Photos 1-13. Their interpretation is as follows:

There is a central white opaque core which probably represents the first summer of life. Occasionally within this central core there is a very small dark nucleus whose significance is not readily apparent. It will be shown later that the white rings represent summer growth so it may be that the dark nucleus represents the earliest growth of a spring spawned fish. Following the opaque core is a dark translucent ring whose limits are generally not very distinct. The time of deposition of this dark ring is not certain and, at present, there are indications which suggest that it is deposited in the late spring about May and June. Otoliths from fish of the same year class frequently showed considerable variation in the condition of the outer edge in early June. Some showed a broad white ring on the outer edge while others possessed a suggestion of a dark outer band. At the end of June most otoliths from younger fish showed either a dark edge or a narrow white edge. Bottom temperatures in the North Atlantic during the winter are so low that it seems improbable that any growth occurs during the winter months. Hence, it appears that the dark ring is deposited either in the fall or in the spring and, at present, the evidence supports the spring deposition of the dark ring. Confirmation of this statement can only be obtained by a study of a series of otoliths taken over the entire year. Apart from this uncertainty, it is probable that the white ring and the dark ring are the product of the first year of life. Following this dark ring there is a series of white and dark rings which become increasingly narrow as the fish grows older. The photographs illustrate the fact that the white opaque zone is deposited in the summer and that this deposition apparently commences sooner in the younger age classes. These observations are similar to those made on *Pseudopleuronectes americanus* by Martin and Peterson (1946). Although the peripheral rings in older otoliths are sometimes difficult to read it is likely that the error of estimation does not exceed ± 1 year. Wallace (loc. cit.) in a discussion of age determination in the European plaice is of the opinion that age estimation above 7 years is frequently unsuccessful because the ring produced is too small for differentiation or may be completely absent. However, the accuracy of age determination in very old fish is not too important for the major part of growth has already occurred.

The method of age classification used in this paper is that which has been generally adopted by fisheries biologists. That is, a fish having completed its first year of life and commencing its second year is placed in Age Class I. Similarly a fish in its third year of life is placed in Age Class II. In other words a fish in class II in June of 1946 was spawned in 1944. For the sake of uniformity and comparison, fish taken in May or June were considered to have completed their 1945-46 growth. Before concluding this discussion of otoliths, a very important aid to age determination should be mentioned. The photographs of otoliths show that prominence of the dark rings varies considerably and that this variation has a definite correlation with the age-class of the fish. For instance an otolith in a 5 year old fish has a large, very dark second ring which in 6 year old fish appears as the third dark ring and so on. In cases of doubtful age this criterion of an age class was invaluable.

It has been previously stated that European workers have rejected scales as unsuitable for use in age determination in pleuronectids. However, recent American workers such as Royce (1946) claim that scales are suitable for the determination of age in yellowtails. Consequently, when this study was undertaken it was decided to collect both scales and otoliths from the same individuals in order to assess their relative suitability. The results of this comparison favoured the use of otoliths in the case of fish from Middle Ground and Western Bank. In young fish there was almost complete agreement between the number of zones on the otoliths and the scales, although it appears that the development of the summer zone in scales precedes the deposition of the white zone on the otolith. In older fish the outer zones of the scales become increasingly difficult to distinguish and above five years of age the accuracy of the reading is uncertain. The interpretation of the peripheral rings on otoliths from old fish was sometimes difficult, but even in fish over eight years old it was often possible to obtain clear indications of the exact number of rings. As regards fish from XXII Q growth is much more rapid and this causes the otolith zones to be vague and diffuse in their limits whereas the zones in the scales are much more distinct. In addition the scales from southern fish are much larger than those from northern areas. Since the age of marketable fish from XXII Q is generally about three to five years, the scale method of age determination is more suitable in this area. However, in order to maintain uniformity of method otoliths were used for the age determination of all fish.

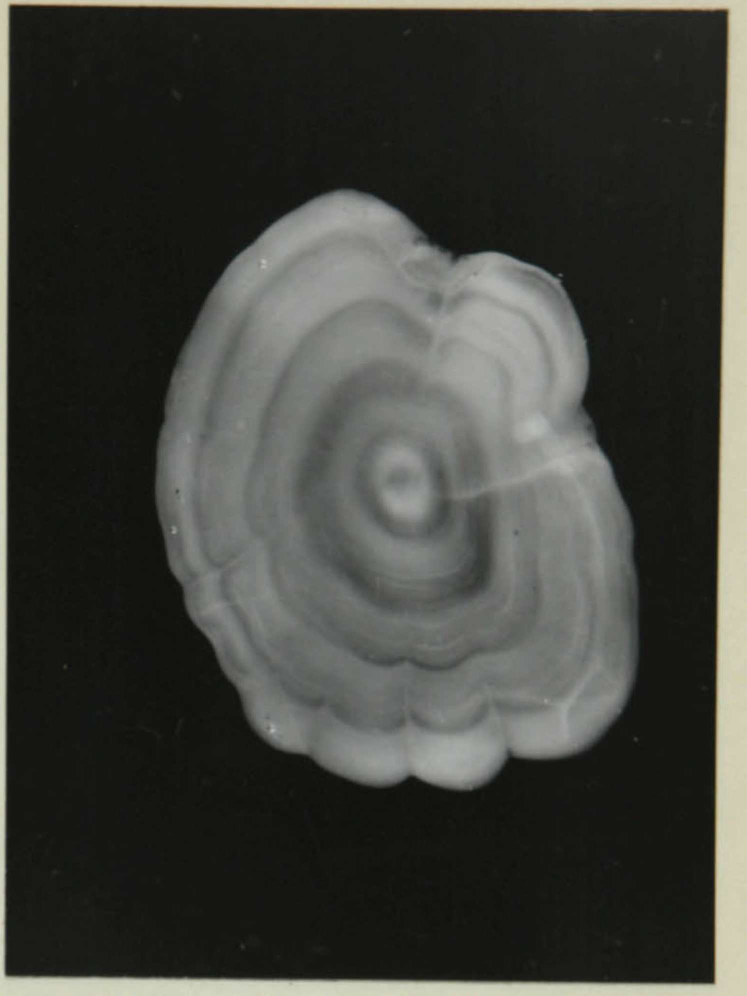
EXPLANATION OF PHOTOS 1-13.

Ph. 1	V,	30 cm.	♀,	4:VI:46,	Middle	Ground
Ph. 2	V	33 "	♀,	1:VII:46	"	"
Ph. 3	VI	31 "	♂	3:VI:46	"	"
Ph. 4	VII	38 "	♂	3:VI:46	"	"
Ph. 5	VIII	40 "	♀	22:V:46	"	"
Ph. 6	IX	42 "	♀	22:V:46	"	"
Ph. 7	X	45 "	♀	25:VIII:46	Western	Bank
Ph. 8	I	9 "	♀	29:VIII:46	"	"
Ph. 9	II	18 "	♂	1:IX:46	"	"
Ph. 10	III	23 "	♀	23:VIII:66	"	"
Ph. 11	IV	27 "	♂	21:VIII:46	"	"
Ph. 12	V	32 "	♂	1:IX:46	"	"
Ph. 13	VI	38 "	♀	29:VIII:46	"	"

The otoliths shown in Phs. 1-6 were taken on Middle Ground in the spring. Phs. 1 and 4 show a dark ring on the periphery, but the outer edge of the otoliths (2, 3, 5, and 6) is not clear, some parts being white and others being dark. It is interesting to follow the course of the 2nd dark ring in age class V (1, 2). It appears as the 3rd dark ring in age class VI (3), the 4th dark ring in age class VII (4), etc.

The otoliths from Western Bank show that a large white increment has been deposited in the young age classes (Phs. 8, 9 and 10) but the older age-classes show a dark outer edge (Phs. 11, 12, 13).

Ph. 1



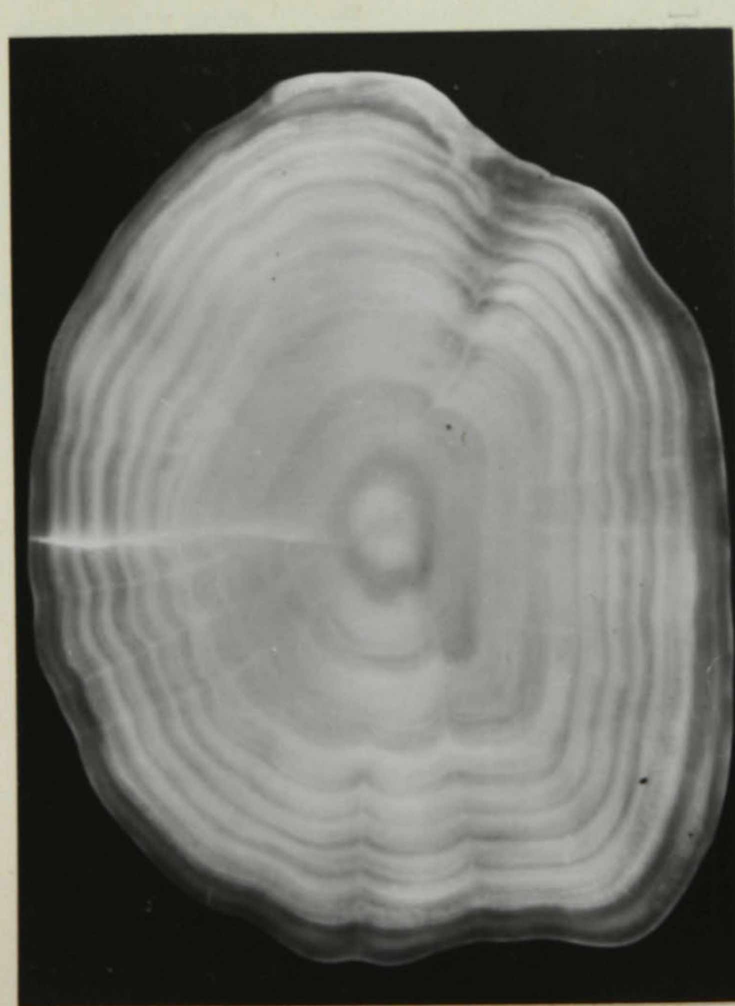
Ph. 2

Ph. 3.

Ph. 3.

Ph. 5.

Ph. 6.



Ph. 7.

Ph. 8.

Ph. 9.

Ph. 10.

Ph. 11.

Ph. 12.

Ph. 13.

BREEDING HABITS AND EARLY DEVELOPMENT

Comparatively little is known about the breeding habits of the yellowtail. Welsh, quoted in Bigelow (loc. cit.), found that spawning commences near Gloucester, Mass., by the middle of March, and although many ripe fish were taken during the last half of April, the majority were still green as late in the season as May 8th in 1913. Bigelow reports that he has taken eggs in tow nets throughout the summer even as late as September 11th and concludes that spawning must last all summer. Royce (loc. cit.), studied the spawning habits of the yellowtail in area XXII Q and observed that spawning had commenced by the middle of April and continued into the first two weeks of July with the peak of spawning occurring in the third week of May. Observations by the present writer on the condition of ovaries in females from the same area indicated that by the middle of July all spawning had ended.

In order to determine the spawning period of fish from Middle Ground all females were classified according to the condition of their ovaries. The following classifications were used:

1. Immature. Ovaries small with the posterior prolongations not greater than 5 or 6 cm. in length.
2. Ripening. Ovaries swollen but ova not fully developed in size and individual eggs not discernible. Females of this type probably will spawn later in the same season.
3. Ripe. Some eggs ready for extrusion.
4. Spawning. Eggs ripe and free in ovarian cavity and easily extruded by slight manual pressure.

5. Spent. Ovaries flaccid and apparently empty of ova.

The result of these observations are presented in Table III.

TABLE III. State of Maturity in Female Yellowtails from Middle Ground area.

DATE	No. of Individuals. Ripening	Ripe and Spawning	Spent	Total
1:V:46	11	0	0	11
3:V:46	14	0	0	14
6:V:46	21	1	0	22
9:V:46	30	0	0	30
13:V:46	22	0	1	23
16:V:46	22	5	5	32
22:V:46	14	11	3	28
5:VI:46	5	28	9	42

Although the number of individuals involved is small, there are sufficient numbers to permit certain conclusions. During the first two weeks of May the fish were still in an unripe condition and it was not until May 16th that any appreciable numbers of ripe or spent fish were observed. By June 5th a marked change had occurred and the great majority of fish were in a ripe or spawning condition. This suggests that in 1946 maximum spawning in this area took place about the second week in June. Unfortunately, it was subsequently impossible to obtain more fish during the spawning period from Middle Ground area and, hence, it was difficult to determine the exact limits of the spawning period. However, it seems probable that spawning occurs over a period commencing the middle of May and persisting, at least, until the end of June.

As regards the Western Bank Area all the mature females examined in August and September were in a spent condition with one exception, a female in spawning condition. In conclusion it is evident that in Canadian waters in 1946 the spawning season was restricted to the months of May, June, and, possibly, the early part of July with the maximum spawning occurring about the middle of June, about one month later than the spawning period in XXII Q as indicated by Royce in 1943.

There was no opportunity during this investigation to collect eggs or to study the developmental processes of the larval stages. According to Bigelow, the egg is buoyant, without an oil globule, spherical, very transparent, and with a narrow perivitelline space. The average diameter of the egg as found by Welsh is 0.9 mm. Initially the larvae are pelagic in their life and it is not until the metamorphosis from a symmetrical condition to the permanent asymmetrical form that they become demersal. Welsh who succeeded in raising the early larvae stages remarked that larvae of 11mm. were still symmetrical, whereas at 14 mm. the asymmetry is apparent and the diagnostic characters of the adult are present. This information was subsequently confirmed by Williams (1902).

AGE AND GROWTH

Methods of Growth Determination.

The most accurate and desirable method of determining the growth of an animal is to measure the individuals of a group of animals of known ages successively as each reaches certain definite ages. However it is generally impracticable to apply this method in the field to a population of wild animals and it is necessary to resort to other methods in order to gain an estimate of the growth of the animal.

In fisheries research there are three methods which are commonly applied in growth determination:

1. Age analyses of the population.
2. Otolith and Scale measurements.
3. Marking and tagging experiments.

Age analyses of the stock possess certain disadvantages of which the most important is caused by the selective action of the fishing gear. Any samples taken from commercially caught fish will possess some degree of error because the fastest growing fish in each age class will be caught first. Consequently, good random sampling is possible only if the mesh size is of dimensions which prevent the escape of the smallest fish in the younger age classes. In addition, in commercial catches the fish are always sorted so that only fish of marketable size are retained. The effect of this is an increase in the average length of those age classes which are within the size limits of a commercial catch and it affects markedly that age class which is at the lower limit of commercial size. In addition, when the fastest growing fish have been removed from the stock, the remainder will show too slow a rate of growth.

In the measuring of otoliths and the calculations of the lengths of different age classes on the basis of the width of the annual zones two difficulties are apparent. Firstly, the fishery always removes the fastest growing fish and since it is probable that they have grown fastest throughout their lives, measurements based on the remaining stock will show too slow a growth. Secondly, the growth of the otolith is not proportional to the growth of the fish, and it will be seen that as the fish increases in length the growth rate of the otolith decreases more rapidly than the growth rate of the fish. In addition the proportion between the length of the fish and that of the otolith varies considerably from individual to individual. This makes a back calculation of the length of age groups not only difficult but liable to error. Jensen (1938) has shown that the assumption of linear proportionality between the lengths of Limanda limanda and the otoliths in the calculations of the length of age classes produced an error of 3 cm. in the case of fish of 25 cm. total length.

Marking and tagging experiments are subject to the same disadvantages. If the marking experiments have been made on young fish then the fastest growing individuals will be the first victims of the fishery and recaptures will indicate too high an increase in growth and, finally, subsequent recaptures will indicate too slow a growth. In the present investigation it was not practicable to carry out marking and tagging experiments and, consequently, growth determinations have been based largely upon the first method described above.

Rate of Growth in Length.

The mean lengths for the different ages classes are contained in Table IV. These data are a product of the combination of all samples made throughout the investigation.

TABLE IV - Mean length of age classes of male and female yellowtails from Middle Ground, Western Bank, and XXII Q. All samples combined.

AGE CLASS		MIDDLE GROUND ♂ N	♂ $\bar{X}$ cm.	♀ $\bar{X}$ cm.	♀ N	WESTERN BANK ♂ N	♂ $\bar{X}$ cm.	♀ $\bar{X}$ cm	♀ N	XXII Q ♂ N	♂ $\bar{X}$ cm	♀ $\bar{X}$ cm	♀ N
I	1945	-	-	-	-	-	-	9.2	1	-	-	-	-
II	1944	-	-	-	-	15	16.8	16.7	22	23	29.1	30.2	23
III	1943	1	22.0	21.0	3	56	21.5	21.3	65	14	34.0	35.0	20
IV	1942	11	22.3	23.7	7	23	26.6	26.0	14	23	34.4	37.3	18
V	1941	21	29.3	31.3	26	44	31.6	31.6	37	12	35.3	38.8	40
VI	1940	39	34.6	35.0	36	32	36.4	36.5	43	-	-	38.7	11
VII	1939	49	37.4	39.4	52	29	39.9	43.8	52	-	-	42.0	5
VIII	1938	68	40.1	42.8	44	28	41.3	46.0	60	-	-	-	-
IX	1937	36	42.3	45.3	50	16	42.0	46.2	51	-	-	-	-
X	1936	8	43.8	46.8	20	3	42.7	48.4	25	-	-	-	-
XI	1935	-	-	48.4	5	-	-	47.3	3	-	-	-	-

Early in this study it became apparent that a differential growth rate existed between the sexes and, as a result, the sexes were treated as distinct stocks. The growth curves for male and female yellowtails from Western Bank are presented graphically in Fig. 3. These growth curves are similar in form to growth curves obtained for many other species of fish by other workers such as Tester (1932), Hile (1936), Ketchen (1945). Growth in length is rapid in early life and gradually becomes slower in older fish.

Although in early years the male yellowtails are slightly larger than the females from Western Bank the rate of growth between the second and the seventh year is essentially the same. During the seventh year of life the growth rate of the sexes diverges, that of males decreasing sharply and remaining low throughout the remainder of life whereas that of the female continues at the same rate until the eighth year when it also decreases with old age. The growth curves for Middle Ground fish indicate the same thing, namely, a diminution in growth in males occurring between age classes VI and VII and a decrease in growth in females about one year later. Although the curves for XXII Q show a similar form the change in growth is not so obvious, but it seems to decrease by the end of the second year of life. Summarizing, we can state that the initial rate of growth for both sexes is very similar and that the rate of growth in males decreases earlier than that of the females. What is the cause of this difference in growth?

Assuming that environmental factors are the same for both sexes then the change in growth rate must be due to some physiological change associated with the difference in sex. Wallace (1904-5) in his work on the European Plaice and Hickling (1933), who studied the growth of the Hake, have both suggested that this difference is due to differences in the size at which sexual maturity is reached and that the maintenance of the changed growth rate is due to demands made upon the sexes for reproduction. It will be shown later that males from Middle Ground and Western Bank mature at a length of about 35 cm.. at the age of six years; males from XXII Q mature at a length of about 30 cm. at the age of two or three years. The females from the Canadian areas mature at a length of about 40 cm. and an age of seven or eight years whereas females from XXII Q mature at a length of about 30 cm. at an age of two or three years. Since the males in all areas mature at the same or at a younger age than the females, the energy requirements of the male are devoted at a younger age to the development of the testes with a consequent decrease in rate of growth which precedes that of the females.

In addition to the difference in rate of growth, the females evidently live to a greater size and an older age than the males. This can be explained on the basis of the relative reproductive activity of the two sexes. Hickling (loc. cit.) quoted by Ketchen (loc. cit.) found that, after a male hake has spawned onee, the energy demands are increased to such an extent that for every increase of 10 cm. in length the sperm production is doubled. It is not improbable that a similar condition obtains in the yellowtail. Orton (1929) also quoted by Ketchen suggests that this remarkable increase in the reproductive activity of male fish with increase in age illustrates how reproduction may eventually overbalance the normal metabolism and result in death. Consequently, and this applies to females also, the increased energy requirements will reduce the body growth each year. Wallace in his study of the plaice concluded that the female expends more energy in the initial spawning than in any of subsequent years. This, if it is correct, would mean that the female could devote more energy than the male to body growth for two or three years after the onset of sexual maturity and thus reach a greater size and an older age.

Comparisons of the growth rates for males and for females of the three areas are contained in Figs. 4 and 5. In an analysis of these graphs it should be recalled that the data from Middle Ground were collected at the beginning of the growing season in May and June and these values will be more accurate than the values for XXII Q and Western Bank. The mean lengths for the age classes from the latter two areas are, in reality, the mean lengths at the end of the last growing season, June 1945 to June 1946, plus whatever increment of growth has been added during the summer of 1946. Although the growth rates will not be changed by this the mean length for any age class of XXII Q or Western Bank fish will be higher than it should. If this fact is considered, it will be seen that the growth rate and the mean length of any age class of fish from Middle Ground or Western Bank is very similar, except in the older age classes where the growth rate of Western Bank fish is less than that of Middle Ground fish. This is possibly due to the fact that older fish do not add their seasonal growth until much later in the season and so the growth increment for 1946 may not be present on Western Bank fish of age classes VIII, IX, and X, and, consequently, the growth rate of old Western Bank fish is apparently less than that of Middle Ground fish. The rate of growth of yellowtails from XXII Q is much different from that of the northern fish. After the second year of growth, the rate is less but the rate of growth in first two years must be much more rapid as it can be seen that the mean length of females in class II from XXII Q in July is 30.2 cm. while the females in class II in Western Bank have a mean length of only 16.7 cm. A similar large difference exists between the males of the two areas.

Before leaving this discussion of rate of growth, some possible irregularities in the mean length values should be pointed out. The value of 43.8 cm. for Class VII females from Western Bank appears to be excessively high. Since females of this age are just on the margins of the lower limit of commercial size it is possible that too many seven year old fish from commercial catches have been included in the data. It is obvious also that the values of the oldest and youngest age classes will be open to inaccuracies; the former have values too low and the latter, values too high.

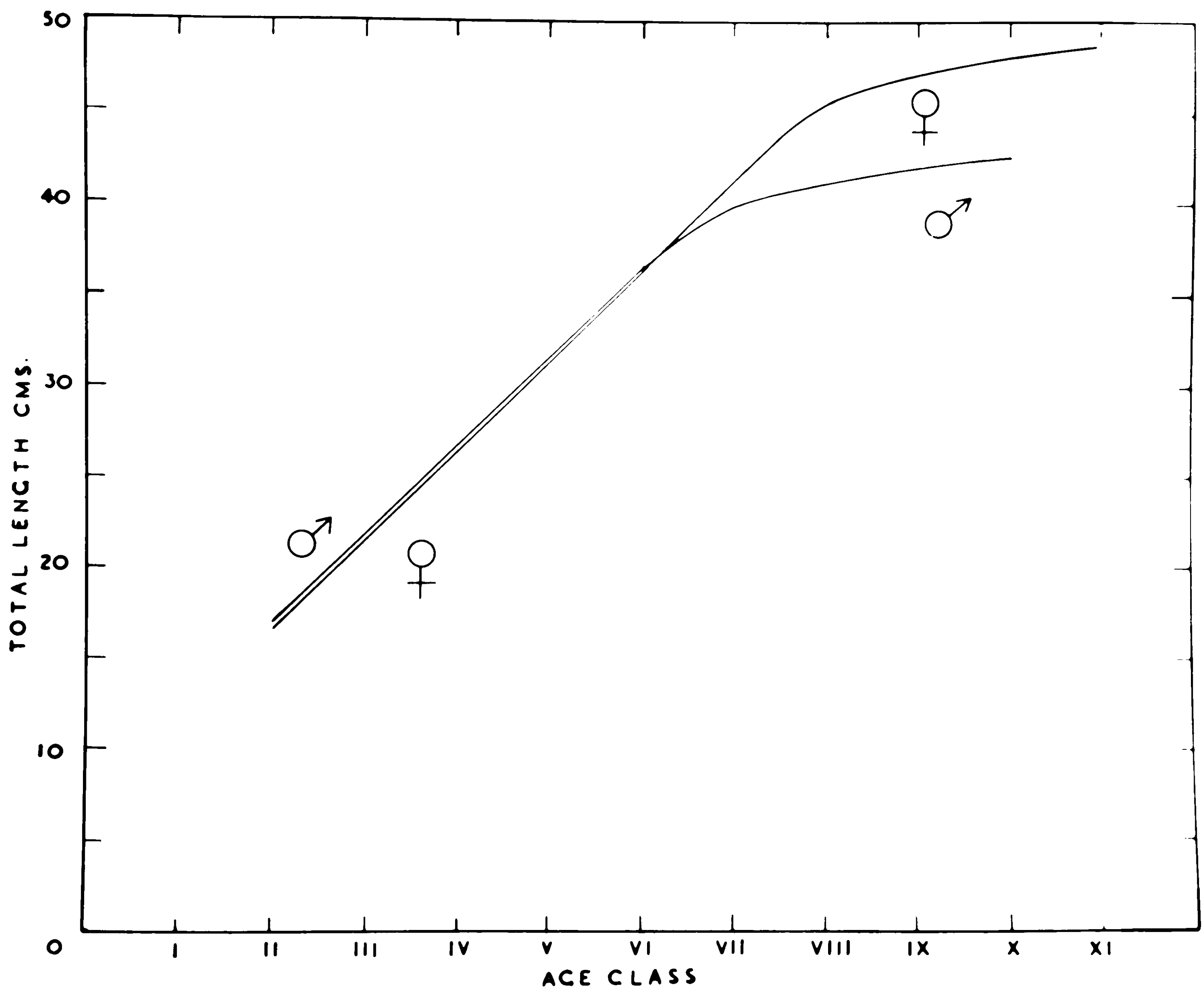


FIG. 3. WESTERN BANK. Age/Length Relationship of Male and Female Yellowtails.

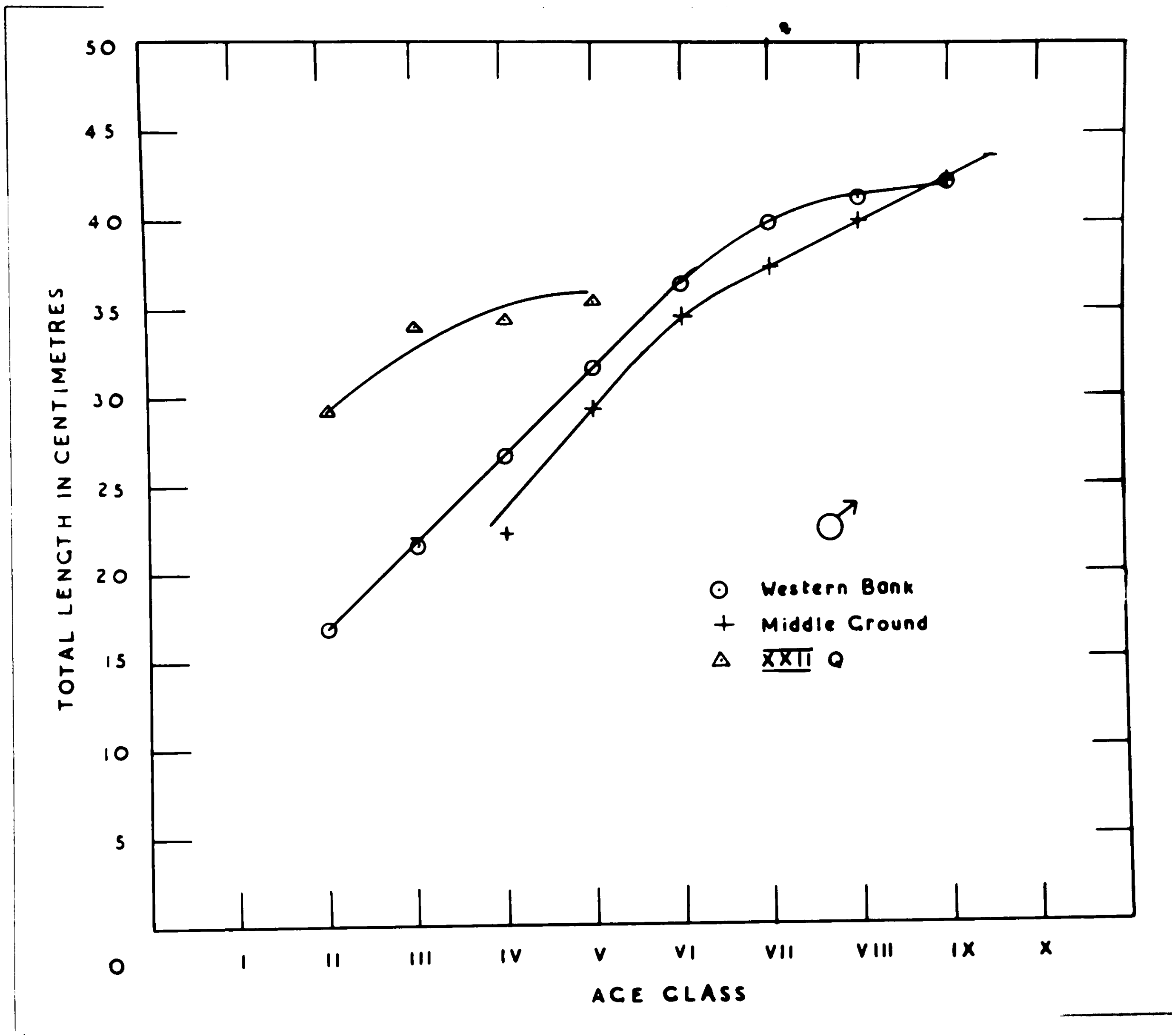


FIG. 4. MALES. Growth Curves of Yellowtails from Middle Ground, Western Bank, and XXII Q.

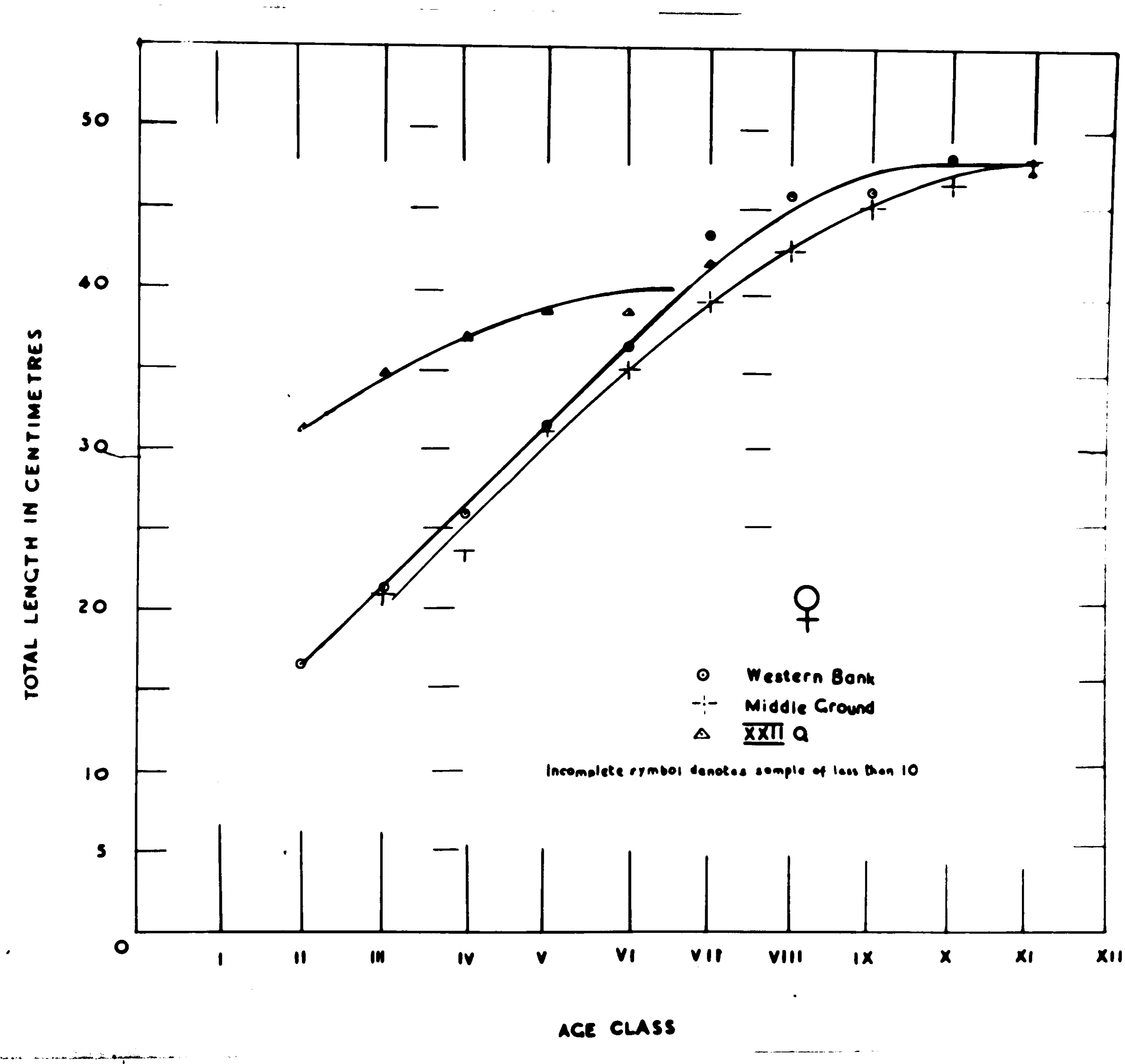


FIG. 5. FEMALES. Growth Curves of Yellowtails from Middle Ground, Western Bank, and XXII Q.

LENGTH FREQUENCY STUDIES

Size-Distribution.

The factors governing the collection of good length distribution information have already been discussed. However, on one occasion on Middle Ground, it was possible to collect length data from complete hauls and this information is presented in the form of length frequency curves in Fig. 6. In addition the data have been summarized in Table V.

TABLE V. Summary of Length Frequencies of Middle Ground Yellowtails caught May 31st - June 5th, 1946.

Length	♂ N = 326		♀ N = 537	
in centimetres	f	%N	f	%N
Above 39 cm.	245	75.1	458	85.3
Below 39 cm. Above 30 cm.	70	21.5	69	12.8
Below 30 cm.	11	3.4	10	1.9
Range	22 - 48 cm.		25 - 56 cm.	
Mean	40.1 cm.		44.3 "	
S. D.	±4.25 cm.		±5.14 "	
Mode	43 cm.		47 "	

The curves are remarkably similar in their shape differing chiefly in the greater size achieved by the females. In addition the curves are skewed to the right showing a great concentration of individuals in the larger size groups. In this respect the curve for females bears a striking resemblance to that of the size distribution of female plaice in the Barentz Sea as shown by Atkinson (1907-10). It is evident in Atkinson's study that the stock of plaice consisted largely of very old fish and it is possible that the Middle Ground fishery is still so insignificant that the accumulated stock of old fish has not yet been depleted. At first it appeared that some selective action of the gear was causing the almost complete absence of small fish less than 30 cm. in length but later trips to Western Bank showed that similar gear was capable of catching large numbers of small fish. It must be remembered that these data were collected during the spawning season for Middle Ground yellowtails and it appears likely that the scarcity of small fish is due to seasonal variation in the distribution induced by the spawning season. This conclusion was partially verified by observations made in XXII Q. On this occasion a fine mesh net was used inside the cod end of the trawl; the haul contained 138 yellowtails, all longer than 24 cm. It would seem that the distribution of yellowtails varies with the size or age class and the distribution may be particularly affected by the spawning period when mature fish start to congregate on the spawning grounds. As a result of this uneven distribution the problem of obtaining samples which accurately represent the population is further complicated.

Since satisfactory size distribution data for the whole range of the population was unobtainable, fish from the three areas may only be compared on the basis of the size distribution of the commercial catches. In making this comparison it must be remembered that the approximate lower limit of size in Canadian commercial catches is 39-40 cm. whereas that of commercial catches from American waters is about 28 cm. Length-frequency curves for the two sexes from the three areas are shown in Fig. 7 and 8. It has already been stated that females from Middle Ground area grow to a greater length than the males and the same situation exists in fish from Western Bank and XXII Q. The females from Middle Ground are larger than those from Western Bank which in turn are larger than individuals from XXII Q. The females from Middle Ground have their highest frequency at 46.5 cm., those from Western Bank at 43 cm. and those from XXII Q at 38 cm. The maximum lengths of females from Middle Ground, Western Bank, and XXII Q are 56, 59 and 42 cm. respectively. Similarly, the males from Middle Ground have their peak at 43 cm., those from Western Bank at 41 cm., and those from XXII Q at 35 cm. The maximum lengths of the males from Middle Ground, Western Bank, and XXII Q are 49, 46, and 35 cm. respectively.

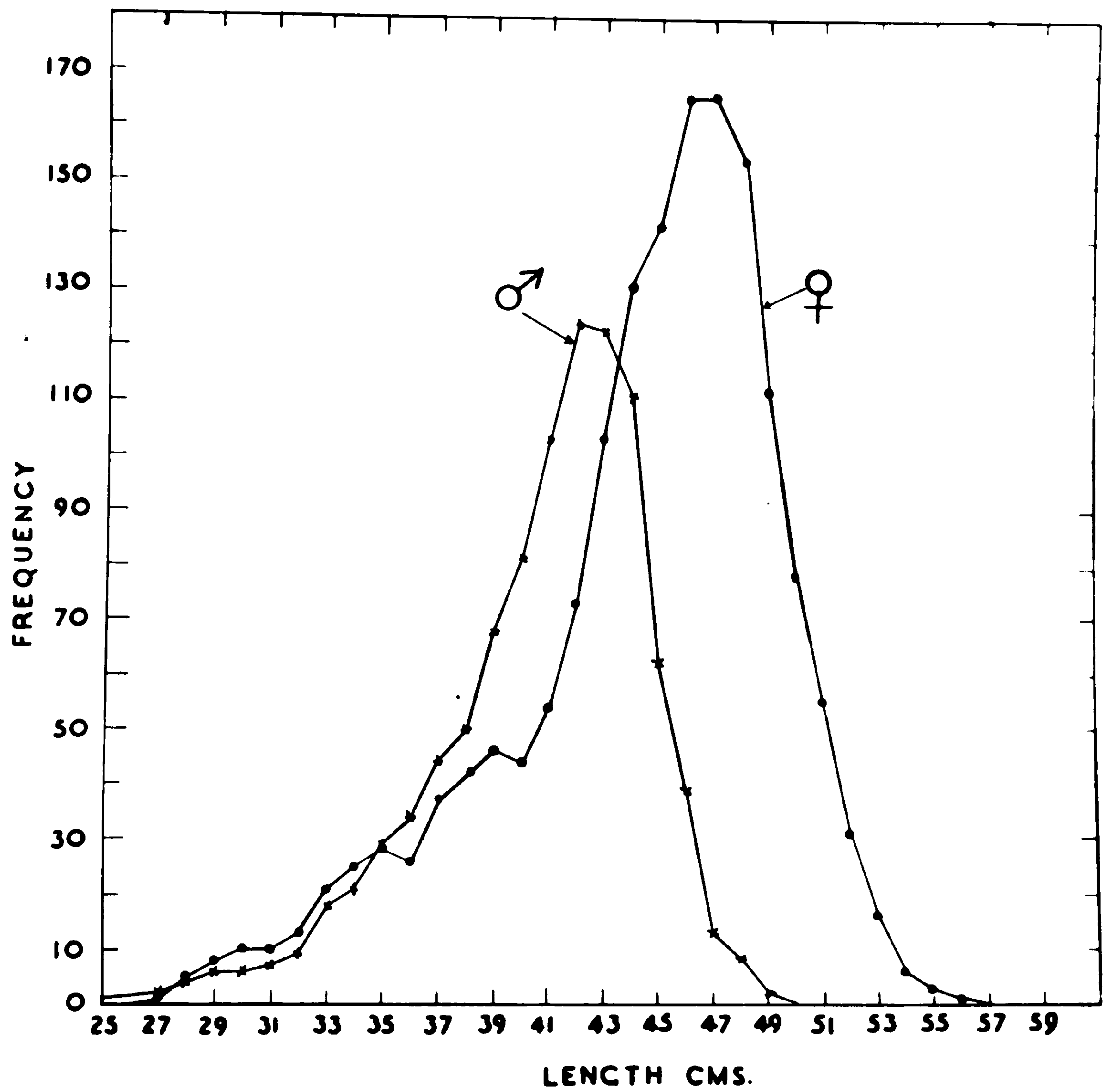


FIG. 6. MIDDLE GROUND. Length Distribution Curves of Male and Female Yellowtails. (Data smoothed by 3'S).

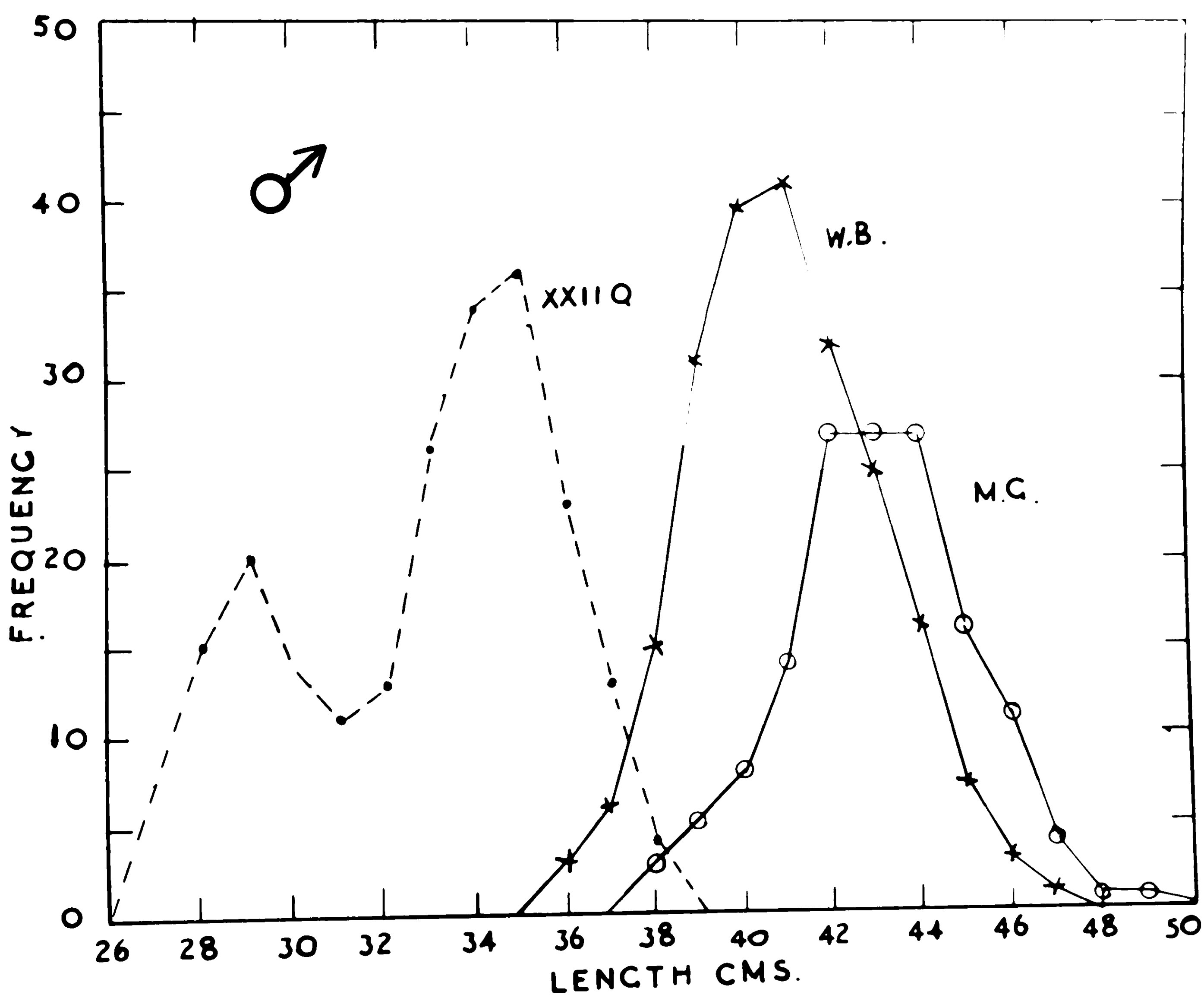


FIG. 7. MALES. Length Distribution Curves of Yellowtails from Middle Ground, Western Bank, and XXII Q. (Data smoothed by 3'S).

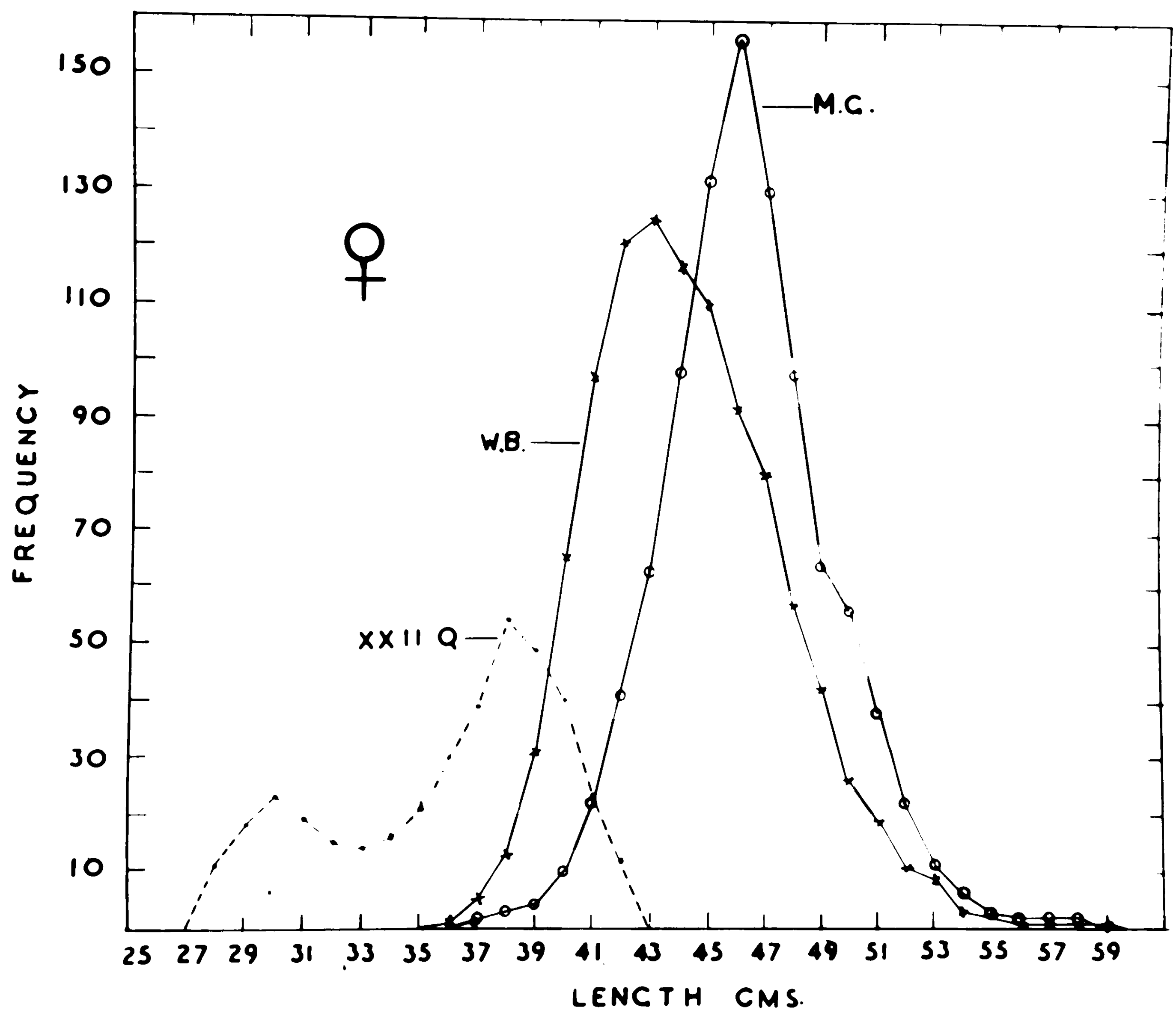


FIG. 8. FEMALES. Length Distribution Curves of Yellowtails from Middle Ground, Western Bank, and XXII Q. (Data smoothed by 3'S)

AGE COMPOSITION

Age Composition of Landed Catches.

The age composition of the landed catches is shown in Table VI.

TABLE VI. Age Composition of Landed Catches.

Age Class	Middle Ground 117 ♂ %	Middle Ground 144 ♀ %	Western Bank 69 ♂ %	Western Bank 190 ♀ %	XXII Q 69 ♂ %	XXII Q 131 ♀ %
I	-	-	-	-	-	-
II	-	-	-	-	33.3	21.4
III	-	-	-	-	18.8	16.0
IV	-	-	-	-	30.4	16.0
V	-	-	2.9	-	17.4	33.6
VI	8.5	5.6	13.0	5.3	-	8.4
VII	13.7	20.1	23.2	23.2	-	4.6
VIII	40.2	22.9	34.8	30.5	-	-
IX	30.8	34.0	21.7	26.8	-	-
X	6.8	13.9	4.3	12.6	-	-
XI	-	3.5	-	1.5	-	-

The oldest fish are found in the Middle Ground area where the dominant age class in the females is age class IX while the dominant age class in the males is age class VIII. Both males and females from Western Bank are most frequently found in age class VIII but there is a higher percentage of famàles in classes IX and X.

This information indicates that the females from both areas grow to an older age than the males. A similar condition exists in XXII Q where the dominant male age-classes are II and IV but the most abundant female age-class is class V. It will be seen that there are far more old fish in the northern populations, these occurring in considerable numbers up to nine and ten years old, whereas in the population from XXII Q, which is more heavily fished, there are very few over five years of age. Russell (1942) commenting upon a similar situation in two haddock populations stated: "This contrast in age-composition between a lightly fished population and one that is heavily fished is just what one would expect if fishing is the main cause of the reduction of average age of the heavily fished stock."

Age-class III is not well represented in the samples from XXII Q and it will be seen in Figs. 7 and 8 that there is a pronounced depression at 31-33 cm. in the length frequency curves. Since the mean lengths for class III males and females are 34.0 cm. and 35.0 cm. respectively it appears that this depression is caused by the scarcity of class III fish in the population. This conclusion supports the validity of the otolith method as a means of age determination.

Among the younger age-classes of yellowtails from Western Bank, age-class III (year-class of 1943) is most strongly represented while age-class IV individuals are least commonly found. In spite of their small size, about 17 cm., age-class II is represented as frequently as class IV fish and, with due allowance for the selective action of the gear, class II may well be a rich year class. It will be recalled that the 1943 year class from XXII Q was poorly represented. This suggests not only that the conditions favouring the production of the rich 1943 year-class on Western Bank were inoperative on XXII Q in 1943 but that the populations of Western Bank and XXII Q are distinct and separate in their distribution.

The relative abundance of the first six year-classes of Western Bank yellowtails is shown in Table VII. The sampling for these age-classes was done under good conditions and should be a reliable representation of the population in this area.

TABLE VII. Relative Abundance of Year-classes (1940-1945) on Western Bank. Sexes combined.

YEAR-CLASS	AGE-CLASS	N	%
1945	I	1	0.3
1944	II	37	10.5
1943	III	121	34.4
1942	IV	37	10.5
1941	V	81	23.0
1940	VI	75	21.3

Age and Size at Maturity.

The age and size of fish at maturity is one of the most important considerations in the rational development of a fishery since the lower limit of size in commercial catches should be controlled by the size of the fish at maturity. If the demands upon the stock are too great then the average length of the commercial catches decreases until it approaches the size of maturing fish. When this occurs the number of spawning fish is greatly reduced and the fishery is in imminent danger of rapid depletion. Only yellowtails from the Middle Ground area were examined during the spawning season when it is relatively simple to decide between the immature and mature condition. When the samples from XXII Q and Western Bank were collected the spawning season had been completed and it was frequently difficult to decide whether a female was mature or immature. However, the similarities between the rates of growth of fish from Middle Ground and Western Bank are such that it may be safely assumed that the size of maturation on Western Bank is essentially the same as that of Middle Ground yellowtails. The determination of maturity is much harder in males than in females as it is not always possible to tell by casual observation whether or not the testis is mature. In many males of 30-35 cm. from Middle Ground the testes were well developed and exuded a white semen-like substance when squeezed. Although the testes were not as large as those of old males it seems likely that these young male fish were in an "adolescent" condition and it is quite possible that males of this size may take part in spawning.

The relative percentages of immature and mature females on Middle Ground are shown in Table VIII.

TABLE VIII. Relative Percentages of Mature and Immature Females. Middle Ground.

Length	34	35	36	37	38	39	40	41	42	43	44	45
% Immature	100	100	83	83	91	69	50	20	14	5	3	0
% Mature	0	0	17	17	9	31	50	80	86	95	97	100
N	9	7	12	12	11	13	10	10	7	19	34	33

At 40 cm. in length 50% of females are still immature but at 45 cm. all females are mature. Therefore the size at which maturity is first reached ranges from 36 to 45 cm. and the age range for these size lengths is about six to eight years. Since the maximum age of female yellowtails is only eleven years the productive life of a female will rarely exceed four or five years.

No exact determination of the size at maturity of fish from area XXII Q was made. However, no females over 32 cm. in length were judged to be immature so it is probable that XXII Q females mature in their third or fourth summer while they are in age classes II and III. On the other hand all the males examined appeared to be mature or maturing. This suggests that males also mature in their third or fourth summer.

TABLE IX. Otolith radius in millimetres for each year class at end of each complete year of growth. MALES.

WESTERN BANK

YEAR CLASS		1	2	3	4	5	6	7	8	9	10
1944	II	0.61	1.52								
1943	III	0.51	1.29	1.89							
1942	IV	0.62	1.20	1.77	2.19						
1941	V	0.55	1.20	1.69	2.19	2.52					
1940	VI	0.57	1.23	1.87	2.22	2.65	2.87				
1939	VII	0.57	1.16	1.78	2.25	2.52	2.79	2.97			
1938	VIII	0.54	1.15	1.73	2.16	2.52	2.74	2.93	3.11		
1937	IX	0.56	1.20	1.73	2.14	2.44	2.65	2.85	3.06	3.21	
MEAN		0.55	1.24	1.79	2.22	2.53	2.78	2.94	3.10	3.21	
Mean Annual Increment		0.55	0.69	0.55	0.43	0.31	0.25	0.16	0.16	0.11	

TABLE IX (Continued).

MIDDLE GROUND

YEAR CLASS	1	2	3	4	5	6	7	8	9	10
1943 III	0.78	1.46	1.94							
1942 IV	0.64	1.16	1.65	2.09						
1941 V	0.54	1.21	1.62	2.11	2.46					
1940 VI	0.57	1.13	1.64	2.06	2.46	2.72				
1939 VII	0.53	1.04	1.49	1.96	2.26	2.61	2.90			
1938 VIII	0.55	1.07	1.47	1.84	2.19	2.46	2.71	2.94		
1937 IX	0.57	1.12	1.59	1.99	2.28	2.56	2.80	2.98	3.14	
1936 X	0.42	1.00	1.55	1.91	2.19	2.45	2.65	2.89	3.06	3.20
MEAN	0.55	1.09	1.55	1.97	2.30	2.57	2.79	2.95	3.12	3.20
Mean Annual Increment	0.55	0.54	0.46	0.42	0.33	0.27	0.22	0.16	0.17	0.08

TABLE IX. (Continued)

XXII Q

YEAR CLASS	1	2	3	4	5	6	7	8	9	10
1944 II	0.68	2.21								
1943 III	0.67	2.11	2.75							
1942 IV	0.61	2.17	2.70	3.03						
1941 V	0.57	2.05	2.70	2.98	3.22					
MEAN	0.63	2.13	2.71	3.01	3.22					
Mean Annual Increment	0.63	1.50	0.58	0.30	0.21					

TABLE X. Otolith radius in millimetres for each year class at end of each complete year of growth. FEMALES.

WESTERN BANK

YEAR CLASS	1	2	3	4	5	6	7	8	9	10	11
1945 I	0.58										
1944 II	0.67	1.42									
1943 III	0.50	1.20	1.83								
1942 IV	0.59	1.12	1.69	2.12							
1941 V	0.54	1.25	1.73	2.25	2.56						
1940 VI	0.61	1.29	1.89	2.25	2.63	2.88					
1939 VII	0.55	1.22	1.85	2.32	2.66	2.99	3.23				
1938 VIII	0.58	1.25	1.84	2.30	2.63	2.88	3.11	3.35			
1937 IX	0.54	1.21	1.81	2.23	2.55	2.85	3.10	3.30	3.49		
1936 X	0.60	1.28	1.92	2.38	2.69	2.92	3.14	3.32	3.48	3.61	
1935 XI	0.61	1.26	1.91	2.36	2.55	2.75	2.94	3.13	3.27	3.40	3.52
MEAN	0.56	1.24	1.83	2.27	2.61	2.90	3.14	3.33	3.46	3.58	3.52
Mean Annual Increment	0.56	0.68	0.59	0.44	0.34	0.29	0.24	0.19	0.16	0.12	- 0.06

TABLE X (Continued)

MIDDLE GROUND

YEAR CLASS	1	2	3	4	5	6	7	8	9	10	11
1943 III	0.71	1.42	2.02								
1944 IV	0.71	1.21	1.71	2.21							
1941 V	0.56	1.23	1.73	2.19	2.57						
1940 VI	0.58	1.09	1.68	2.01	2.38	2.75					
1939 VII	0.48	0.94	1.43	1.91	2.25	2.63	2.97				
1938 VIII	0.52	1.01	1.42	1.84	2.26	2.57	2.85	3.12			
1937 IX	0.55	1.15	1.65	2.08	2.38	2.72	2.95	3.10	3.35		
1936 X	0.55	1.11	1.72	2.16	2.48	2.73	3.00	3.19	3.36	3.56	
1935 XI	0.49	0.97	1.58	2.11	2.33	2.62	2.86	3.09	3.21	3.35	3.48
MEAN	0.54	1.08	1.65	2.02	2.35	2.67	2.93	3.15	3.35	3.51	3.48
Mean Annual Increment	0.54	0.54	0.57	0.37	0.33	0.32	0.26	0.22	0.20	0.16	-0.03

TABLE X (Continued).

			XXII Q				
YEAR CLASS	1	2	3	4	5	6	7
1944 II	0.67	2.23					
1943 III	0.70	2.06	2.85				
1942 IV	0.69	2.03	2.81	3.21			
1941 V	0.60	2.06	2.88	3.14	3.42		
1940 VI	0.58	2.13	2.77	3.15	3.36	3.55	
1939 VII	0.64	2.15	2.89	3.22	3.44	3.61	3.77
MEAN	0.64	2.10	2.81	3.16	3.41	3.57	3.77
Mean Annual Increment	0.64	1.46	0.71	0.35	0.25	0.16	0.20

GROWTH OF OTOLITHS AND ANNUAL INCREMENTS OF GROWTH.

If we assume that the width of the zones of the otolith is an index of the yearly increments of growth in the fish, then the annual increments of the otoliths and the fluctuations in the size of these increments should reflect important changes in the conditions of the stock and should give a picture of the past growth of any individual or of any year-class.

When the concave surface of the left otolith was examined, with the straight edge of the otolith facing away from the observer, it was noticed that the left radius, measured along the long axis, was consistently greater than the right radius. Most of this difference in length appeared to be due largely to a projection which always occurs on the left side of the otolith. As this projection varies considerably in size it was considered that the right radius varied less in length and, thus, would present a more accurate picture of growth of the otolith. The measurements consisted of the right radius and the radius of each annual ring.

If two annual increments of length in an otolith are found to be the same it does not follow that the annual increments of growth in the otolith are the same. Let us consider three concentric circles whose radii are r, 2r, and 3r respectively. Then the areas of those circles will be πr^2, $4\pi r^2$, and $9\pi r^2$ and the differences between the areas are in the proportion of 1:3:5. Although the annual zones of the otoliths do not form perfect concentric circles the same reasoning should apply in the case of otolith growth. Therefore, if in two successive years the increments are the same, it follows that more growth occurred during the second year. Moreover, if the otoliths provide a reliable index of fish growth then we can say that when the annual increments of the otolith in terms of the radius are the same then the growth of the fish will be greater in the later year observed.

The numerical information on otolith growth has been tabulated in Tables IX, X, XI, XII. Tables IX, X, show the otolith radius for each age class at the end of each complete year of growth. From these tables the annual increment of radius for each age class has been calculated and is expressed as t_1 t_2, etc. in Tables XI, XII.

A comparison of the mean annual increments of the males and females reveals that there is no significant difference between the sexes in the growth of the otolith for the first two years but by the third year t_3 is greater in the females than in the males and this condition persists in most cases throughout the remainder of the yearly increments. It follows then that the differential rate of growth between the two sexes is manifested in otolith growth at an earlier age than it is in the growth in length of the fish. In the latter case it is not apparent until the fish are about six or seven years old.

The pattern of otolith growth from the three areas bears a marked resemblance to the growth curves for length of the fish. For the first three years the otoliths from XXII Q grow much more rapidly than the otoliths from the northern areas, the greatest growth occurring in the second year. After the third year the annual increments decrease in size until they are consistently less than the increments of either Western Bank or Middle Ground fish. The first year growth of Middle and Western Bank otoliths is approximately the same but t_2, t_3, and t_4 are greater on Western Bank than on Middle Ground. Thereafter the annual increments of Middle Ground otoliths are greater than those of Western Bank. Thus we see that as far as otolith growth is concerned XXII Q and Middle Ground possess the two extremes of values and Western Bank values are in an intermediate position although the latter have a much closer resemblance to the Middle Ground values. The otolith growth values from the three areas have the same sequence as the values of growth in the length of the fish. In general, the growth of the otolith and, presumably, the fish has three stages:

1. An early period of slow growth covering the first year of life.
2. A period of rapid growth lasting from two to three years. In XXII Q the maximum growth is in the second year, in Middle Ground it is in the third year, and in Western Bank the maximum growth occurs in the second and third years.
3. A period of growth whose annual increments steadily decrease in succeeding years.

Ottestad (1938) states that growth follows a sigmoid course. The growth increments are small at first but rise to a maximum, and then fall to zero. It is obvious that the three phases of growth described above are part of this sigmoid course. Presumably, if it were not for the death of the individual, the growth increments throughout life would eventually possess a value of zero.

No fish in age-class 0 and only one in age class I were collected during the investigation. Since it is desirable to know something of the rate of growth in the first two years some method must be used which will permit extrapolation in order to obtain values for 0 and I. The most obvious method is by a comparison of otolith and fish growth and the establishment of some relationship between the two. In Fig. 9 the length growth curve for females from Western Bank is plotted along with two curves expressing the relationship between otolith radius and age. Curve 3 is the otolith/age relationship existing in August while curve 2 is the mean otolith radius (v. Table X) plotted against age. It will be seen that the curves 2 and 3 are much different from curve 1 in so far as the growth of the otolith decreases more rapidly than the growth of the fish. Secondly, the most obvious difference between curves 2 and 3 is the otolith growth which has occurred between spring and August. This growth is greatest in the youngest age classes, smallest in age classes VI, VII and VIII and absent in age classes IX and X. It may be inferred from this that not only is the growth of younger fish much greater, but that growth in the young age classes occurs earlier in the growing season than the growth in old fish. In addition the values for otolith radius of any young age class are almost equal to the value of the next older age class in the spring. For example the mean otolith radius for class II individuals in August is 1.75 mm. as compared with a spring value of 1.83 mm. for three year old fish. So we can say that the annual growth of otoliths in young fish is almost complete by the end of August, whereas annual growth in the oldest fish has not yet begun.
A hypothetical length/age curve for the spring should bear the same relation-

ship to curve 1 as curve 2 bears to curve 3, providing that otolith growth occurs at the same time as fish growth. Assuming the validity of this statement we can derive values of 3.7 cm. for class I and 11.4 cm. for class II. The one fish in Class I which was taken was 9.2 cm. long in the late summer of its second year. This value combined with the hypothetical value indicates that the value of Class II females at the beginning of their third year is approximately 10 to 11 cm. Bigelow and Schroeder (1936) state that the yellowtail reaches a length of approximately 5 inches at 1 year of age in the Gulf of Maine, but they do not give any exact locality.

Although there is no linear relationship between otolith radius and fish length when the data are plotted arithmetically, there is linear proportionality between the logarithm of otolith radius and the logarithm of total length. Such a relationship is demonstrated graphically in Figs. 10 and 11 and the data are tabulated in Table XIII. If the same linear relationship is present during the first two years, then extrapolation produces values of 3.0 cm. at the end of year 1, and 9.9 cm. at the end of year 2 for females of Western Bank. These values are sufficiently in agreement with the hypothetical values already obtained to suggest that the length of class I is 3-4 cm. and the length of class II is 10-11 cm.

TABLE XI. The Annual Increment (t) of Otolith Growth measured as the Radius in millimetres. MALES.

WESTERN BANK

YEAR CLASS	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9
1944 II	0.61	0.91							
1943 III	0.51	0.78	0.60						
1942 IV	0.62	0.58	0.57	0.42					
1941 V	0.55	0.65	0.49	0.50	0.33				
1940 VI	0.57	0.66	0.64	0.35	0.43	0.22			
1939 VII	0.57	0.59	0.62	0.47	0.27	0.27	0.18		
1938 VIII	0.54	0.61	0.58	0.43	0.36	0.22	0.19	0.18	
1937 IX	0.56	0.64	0.53	0.41	0.30	0.21	0.20	0.21	0.15

TABLE XI. (Continued).

MIDDLE GROUND

YEAR CLASS	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}
1943 III	0.78	0.68	0.48							
1942 IV	0.64	0.52	0.49	0.44						
1941 V	0.54	0.67	0.39	0.49	0.35					
1940 VI	0.57	0.56	0.51	0.42	0.40	0.26				
1939 VII	0.53	0.51	0.45	0.47	0.30	0.35	0.29			
1938 VIII	0.55	0.52	0.40	0.37	0.35	0.27	0.25	0.23		
1937 IX	0.57	0.55	0.47	0.40	0.29	0.28	0.24	0.28	0.16	
1936 X	0.42	0.58	0.55	0.36	0.28	0.26	0.20	0.24	0.17	0.14

TABLE XI. (Continued)

XXII Q

YEAR CLASS	t_1	t_2	t_3	t_4	t_5
1944 II	0.68	1.53			
1943 III	0.67	1.44	0.64		
1942 IV	0.61	1.56	0.53	0.33	
1941 V	0.57	1.48	0.65	0.28	0.24

TABLE XII. The Annual Increment of Otolith Growth measured as the Radius in Millimetres. FEMALES.

WESTERN BANK

YEAR CLASS	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
1945 I	0.58										
1944 II	0.67	0.75									
1943 III	0.50	0.70	0.63								
1942 IV	0.59	0.53	0.57	0.43							
1941 V	0.54	0.71	0.48	0.52	0.31						
1940 VI	0.61	0.68	0.60	0.36	0.38	0.25					
1939 VII	0.55	0.67	0.63	0.47	0.34	0.33	0.24				
1938 VIII	0.58	0.67	0.59	0.46	0.33	0.25	0.23	0.24			
1937 IX	0.54	0.67	0.60	0.42	0.32	0.30	0.25	0.20	0.19		
1936 X	0.60	0.68	0.64	0.46	0.31	0.27	0.22	0.18	0.16	0.13	
1935 XI	0.61	0.65	0.65	0.45	0.19	0.20	0.19	0.19	0.14	0.13	0.12

TABLE XII. (Continued)

MIDDLE GROUND

YEAR CLASS	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}
1943 III	0.71	0.71	0.60								
1942 IV	0.71	0.50	0.50	0.50							
1941 V	0.56	0.67	0.50	0.46	0.38						
1940 VI	0.58	0.51	0.59	0.43	0.37	0.37					
1939 VII	0.48	0.46	0.49	0.48	0.34	0.38	0.34				
1938 VIII	0.52	0.49	0.41	0.42	0.42	0.31	0.28	0.27			
1937 IX	0.55	0.60	0.50	0.43	0.30	0.34	0.23	0.21	0.19		
1936 X	0.55	0.56	0.61	0.44	0.32	0.25	0.27	0.19	0.17	0.20	
1935 XI	0.49	0.48	0.61	0.53	0.22	0.29	0.24	0.23	0.12	0.14	0.12

TABLE XII. (Continued)

XXII Q

YEAR CLASS	t_1	t_2	t_3	t_4	t_5	t_6	t_7
1944 II	0.67	1.56					
1943 III	0.70	1.36	0.79				
1942 IV	0.69	1.34	0.78	0.40			
1941 V	0.60	1.45	0.82	0.26	0.28		
1940 VI	0.58	1.55	0.64	0.38	0.21	0.19	
1939 VII	0.64	1.51	0.74	0.33	0.22	0.17	0.16

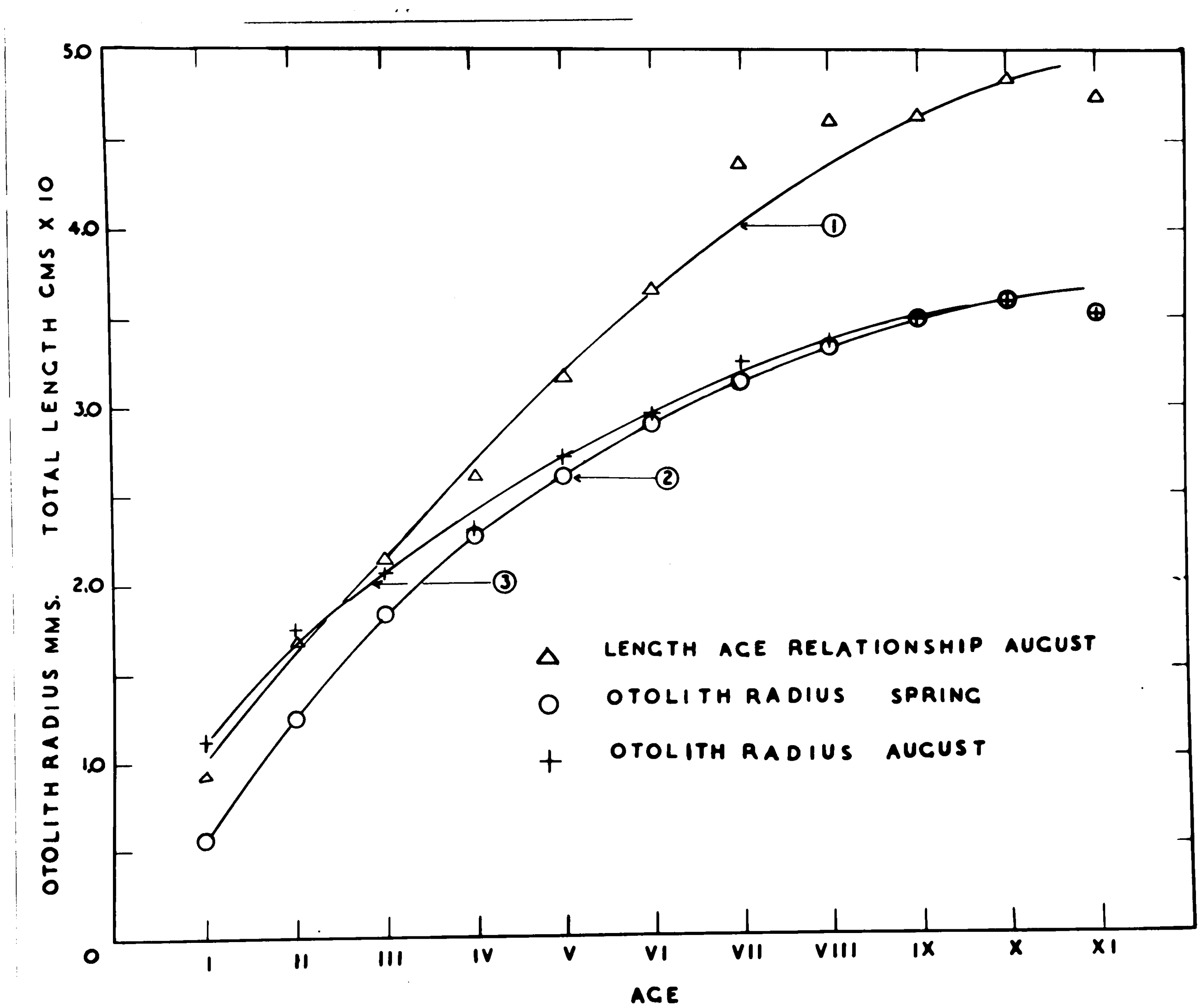


FIG. 9. WESTERN BANK. Total Length and Otolith Radius Growth Curves of Female Yellowtails.

FLUCTUATIONS IN THE YEAR CLASSES.

The relative abundance of age classes III and IV on Western Bank has already been mentioned. This variation in the size of broods is characteristic of all great fisheries and Hjort (1914) maintained that the fluctuation of year classes was perhaps the predominating factor determining fluctuations in the fisheries and he advanced the following theory:

"The rich year-classes appear to make their influence felt when still quite young; in other words, the numerical value of a year-class is apparently determined at a very early stage, and continues in approximately the same relation to that of other year-classes throughout the life of the individuals."

Hjort (1926) also noted that the quantity of eggs spawned is not a factor, in itself, sufficient to determine the numerical strength of a year class and in this statement he is supported by the observations of Thompson (1924) on the fluctuations of the year classes of the haddock. He drew attention to the fact that the spawning shoals which produced the successful brood of haddock in 1923 were smaller than in the two previous unsuccessful years. Hjort came to the conclusion that the numerical value of a new year class was dependent upon the contemporary hatching of the eggs and the development of the food required by the larvae and that this in turn is probably correlated with water temperatures.

Many investigators such as Poulsen (1938) in his studies on the Baltic plaice and Raitt(1939) in studies on the North Sea Haddock have concluded that there is close agreement between the growth rate and the numerical strength of the year class. It is thought likely that the larger the year-class the greater is the competition for food and, hence, the slower the growth rate. Such a correlation was observed in the growth of the otoliths in year classes 1943 (III) and 1942 (IV) from Western Bank. For the 1943 class the value of t_1 is 0.50 and 0.51 for males and females respectively. This value is the lowest t_1 value present while the 1943 class is the most strongly represented in the population. On the other hand, the t_1 values for the 1942 class are among the highest t_1 values present, in fact, the t_1 value for the males is the highest of any male year class. The 1942 class is poorly represented in the stock. It is difficult to avoid the conclusion that there is an inverse relationship between the size of the brood and the rate of growth. Moreover the conditions which permitted these variations are reflected in the yearly increments of other year classes. For example, the low t_1 value of 1943 females is present as a low t_2 value in the 1942 class, and continues low as the t_3, t_4 values in the 1941 and 1940 classes. Similarly the high t_1 value for 1942 males is shown as a high value in the t_2, t_3, t_4 and t_5 values for the four preceding year -classes. This indicates not only that the conditions controlling these variations are manifested in several year classes but that the fish in these year classes must remain together in the same area or in the same environment throughout the early years of their life. Further study of Tables XI and XII reveals that the year classes with the highest t_1 value on both Middle Ground and Western Bank are the 1944 and 1942 year classes while the lowest value of t_1 is found in the 1943 year class. However, in XXII ♀ the 1944 class has one of the lowest t_1 values. This suggests that the environmental factors affecting the Middle Ground and Western Bank stocks were considerably different in 1944, 1943, and 1942 from the factors influencing the growth of XXII Q fish in those years, and this is evidence of the discreteness of the southern and northern populations. The t values for any of the very old age classes have not such significance because they probably represent slow growing fish.

ENVIRONMENTAL FACTORS INFLUENCING GROWTH.

The causes of differences in the rate of growth in marine fishes and the effect of these differences in terms of the ultimate age and size of the fish are not completely understood. Small environmental differences which must exist probably exert a great influence upon the development of fish. Therefore, it remains for us to explain the difference in the growth rates of yellowtails from the three areas. Vladykov (1934) pointed out that as far as the influence of the physical environment is concerned there are only three important factors which can be readily separated, namely:-

1. Temperature.
2. Space.
3. Salinity.

The effect of temperature upon the rate of growth of any organism is well known. As the temperature of the environment is increased so is the rate of growth increased. Within narrow limits this relationship may approximately follow Van't Hoff's Law which states that for every 10°C rise in temperature the rate of chemical (metabolic) processes is doubled. Knowing that the bottom temperatures in area XXII Q are considerably higher than the bottom temperatures in the northern areas it is possible to resolve part of the differences in growth between the two areas into terms of the temperature differences. Since the onset of maturity is probably a matter of physiological age rather than chronological age it is easy to see why yellowtails from XXII Q mature much more rapidly than fish from either Western Bank or Middle Ground. Recalling the discussion of the effects of maturation upon the rate of growth we can explain why the rate of growth of XXII Q fish should be less than that of fish from the northern areas after the reproductive age has been reached. In other words, it appears that when the rate of growth in the first few years is very rapid then the subsequent decrease in the growth rate will be relatively greater than in areas where the initial rate has been less. This will explain, in part, why fish from XXII Q do not reach the old ages and large sizes characteristic of Canadian yellowtails. We have also seen that Middle Ground yellowtails are older and larger than Western Bank yellowtails and a study of their early growth rates revealed that Western Bank yellowtails grow faster in the first three or four years but eventually their growth rate becomes less than that of Middle Ground yellowtails. Summing up, we can say that there is a distinct growth cline from north to south between the three areas. The Middle Ground yellowtails show the slowest initial growth rate, and ultimately, the fastest growth rate which results in the occurrence of the largest and oldest yellowtails on Middle Ground. On the other hand yellowtails from XXII Q show a very fast growth rate which persists for three or four years but the ultimate growth rate is the slowest found in the three areas. The growth rate of Western Bank yellowtails represents an intermediate condition which, however, resembles that of Middle Ground much more closely than the conditions existing in area XXII Q.

The conception of space as an environmental factor is not one of geographical space alone but it also involves a consideration of population densities. Obviously an animal living in a population of low density has more space in which to exist and feed than an animal living in an area of equal size which possesses a high density of population. The effect of population density on the rate of growth of marine fishes has been of profound significance in the work of many fisheries investigators. European investigators studying the relationship between density of populations and the rate of growth in fishes, particularly the plaice, observed two important facts:

1. Fish transplanted from an area of high population density to a sparsely populated area showed an increase in the rate of growth.
2. An increase in the rate of growth accompanied a decrease in the density of the stock in the same area.

Petersen (1909) was one of the first workers to conduct transplantation experiments on a large scale. This work which was begun late in the nineteenth century proved so successful that it has been continued as part of the Danish fisheries program. The increase in growth in the new area was striking; in many cases the growth in the first year in the new area was more than twice as much as would have occurred if the plaice had remained in the old area. Many similar transplantations of plaice showed that the phenomenon of increased growth was not confined to Limfjord, the area utilized by Petersen. Borley (1912) and Garstang (1922) both found that when young plaice, taken from English and Dutch coastal waters, were transplanted to Dogger Bank a great increase in growth occurred within a year. In some instances, the growth increment between April and November was as much as 13 cm.

Heincke and Buckmann (1926), quoted by Thursby-Pelham (1926) studied the plaice fisheries off the German coast before and after World War I. Before the war when the area was overfished the growth of the plaice was rapid. During the war the intensity of fishing decreased and a large stock of plaice was accumulated. Following the war when fishing was resumed it was found that large fish were very common but the growth rate had decreased. Increased fishing soon reduced the accumulated stock of plaice and the rate of growth increased. Buckmann (1932), quoted by Hile (loc. cit.), "expressed the relationship between growth in weight and the density of population as being inversely proportional. He expressed this relationship by the equation,

$$w^1 = w\frac{n}{n^1},$$

where w is the weight increase per individual in a population of n individuals and w^1 is the increase in weight that would occur if the number of individuals were changed from n to n^1. Buckmann recognized the law to be inexact and mentioned certain disturbing influences. He pointed out that it is incorrect to assume that all the food consumed is applied to increase in size. A certain definite amount is utilized to maintain individual metabolism. The percentage of the food that is so used varies according to the total amount of food available to each individual." The amount of food available to the individual depends not only upon interspecific competion but also upon intraspecific competition. Recently, Raitt (1939), has shown that, in North Sea haddock, there is a close agreement between the variations in growth rate and the degree of brood density.

The question which now arises is what effect the relative population densities have upon the growth rates of yellowtails from Middle Ground, Western Bank, and XXII Q. Catch statistics indicate that the fishing intensity is much greater in XXII Q and that it is causing a depletion of the stock. The composition of the yellowtail stocks from the northern areas suggest that they consist of an accumulation of older fish. Therefore, it seems safe to assume that part of the differences in growth rates may be attributed to differences in the fishing intensity and, thus, to differences in the population densities.

The effect of salinity upon growth is not adequately understood. Schmidt (1918) in his studies of Zoarces viviparus concluded that differences in salinities had little or no effect upon the racial characteristics of two races. Molander (1938) considered that local differences which he observed in the rate of growth of the flounder in the Baltic Sea were closely connected with the continuous decrease in salinity from west to east. Molander (1931), also showed that in Stig Fjord, Sweden, the plaice had a slow rate of growth in spite of a very rich bottom fauna and he ascribed it to the comparatively low salinity of 21-24°/oo. However, Jensen (1938b) points out that North Sea plaice may thrive well at salinities as low as about 15°/oo, and it must be assumed that other factors contributed to the slow growth rate recorded by Molander.

RELATIVE GROWTH STUDIES.

Introduction.

An organ which is growing at a different rate from the body displays heterogonic growth. The term heterogony was first introduced by Pezard (1918) according to Huxley (1932). If the organ is growing at the same rate as the body it displays isogonic growth. Huxley (1924) was the first to demonstrate a quantitative relation between the magnitudes of two variables and he expressed this relationship in the form of the equation:

$$Y = bX^k$$

where X and Y are the two variables

b is a fractional coefficient

k is the coefficient of differential growth ratio.

The value of k has an important meaning and Huxley (loc. cit.) states:

"It implies that, for the range over which the formula holds the ratio of the relative growth-rate of the organ to the relative growth-rate of the body remains constant, the ratio itself being denoted by the value of K."

The linear expression of this equation may be shown if the values of two variables are plotted on double logarithmic paper and, in this case, K represents the slope of the line. The interpretation of the values of K is as follows:

1. When K has a value of 1 the structure is growing at the same rate as the body. This condition is called isogony.
2. When K has a value less than 1 the structure is growing at a slower rate than the body. This condition is called negative heterogony.
3. When K has a value greater than 1 the structure is growing at a faster rate than the body and this condition is called positive heterogony.

Mottley (1936), commenting upon the dimensions of the body parts in relation to size, states:

"The actual dimensions of the various characters, in relation to size, provide a static view of the form. Thus fish of a certain size range may be characterised by an index based on some datum of comparison such as the standard length. But Huxley (1932) says 'to neglect the fundamental fact of change of proportions with absolute size, and proceed as if certain arithmetic (percentage) proportions were immutable "characters" of the species, may lead to serious error.' The logarithmic presentation of the mean values obviates this difficulty and provides a dynamic expression of the change of characters with size."

Results.

Since the length distributions for adjoining age classes overlap considerably it was decided to plot the mean values of the body part of each age class against the mean length of each age class. Thus variation caused by any age class will be apparent at first sight. The mean values of the body parts are presented in Table XIV (otolith radius), Table XV (head length), and Table XVI (right pectoral fin length). The relationships between body part and total length are shown in Figs. 10, 11, 12, and 13 and the values of the coefficient of differential growth ratio are given in Table XIII.

TABLE XIII. Values of Coefficient of Differential Growth Ratio (K) for Body Parts of Yellowtail.

BODY PART	MIDDLE GROUND ♂	MIDDLE GROUND ♀	WESTERN BANK ♂	WESTERN BANK ♀	XXII ♂	XXII ♀
OTOLITH	.63	.69	.58	.64	?	i) .86 ii) 1.20
HEAD	.97	.98	.97	.98	1.09	1.30
RIGHT PECTORAL FIN	1.07	i) 1.09 ii) .85	1.07	i) 1.09 ii) .85	?	1.19

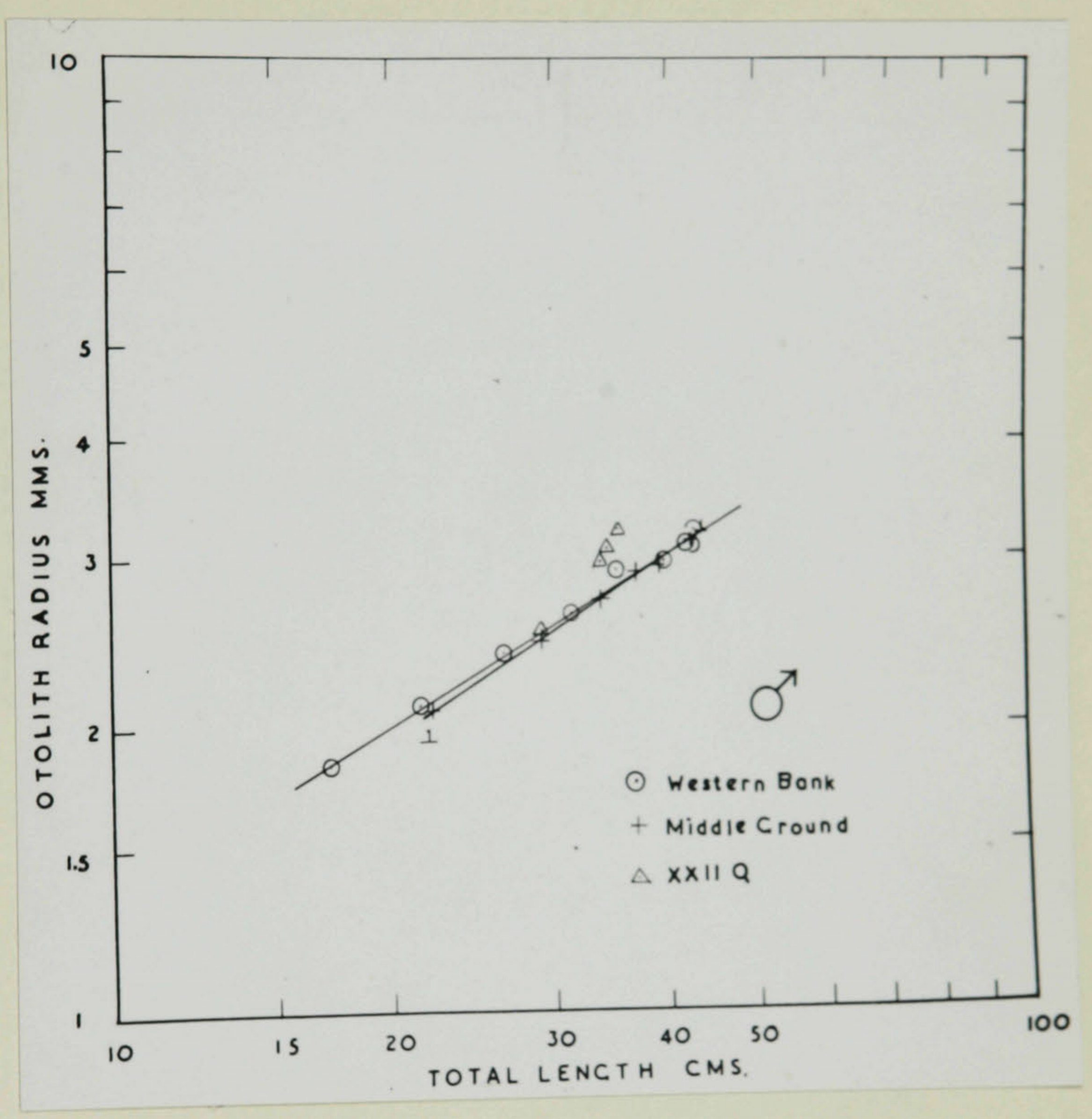


FIG. 10. MALES. Relative Growth of Otoliths of Yellowtails from Middle Ground, Western Bank, and XXII Q.

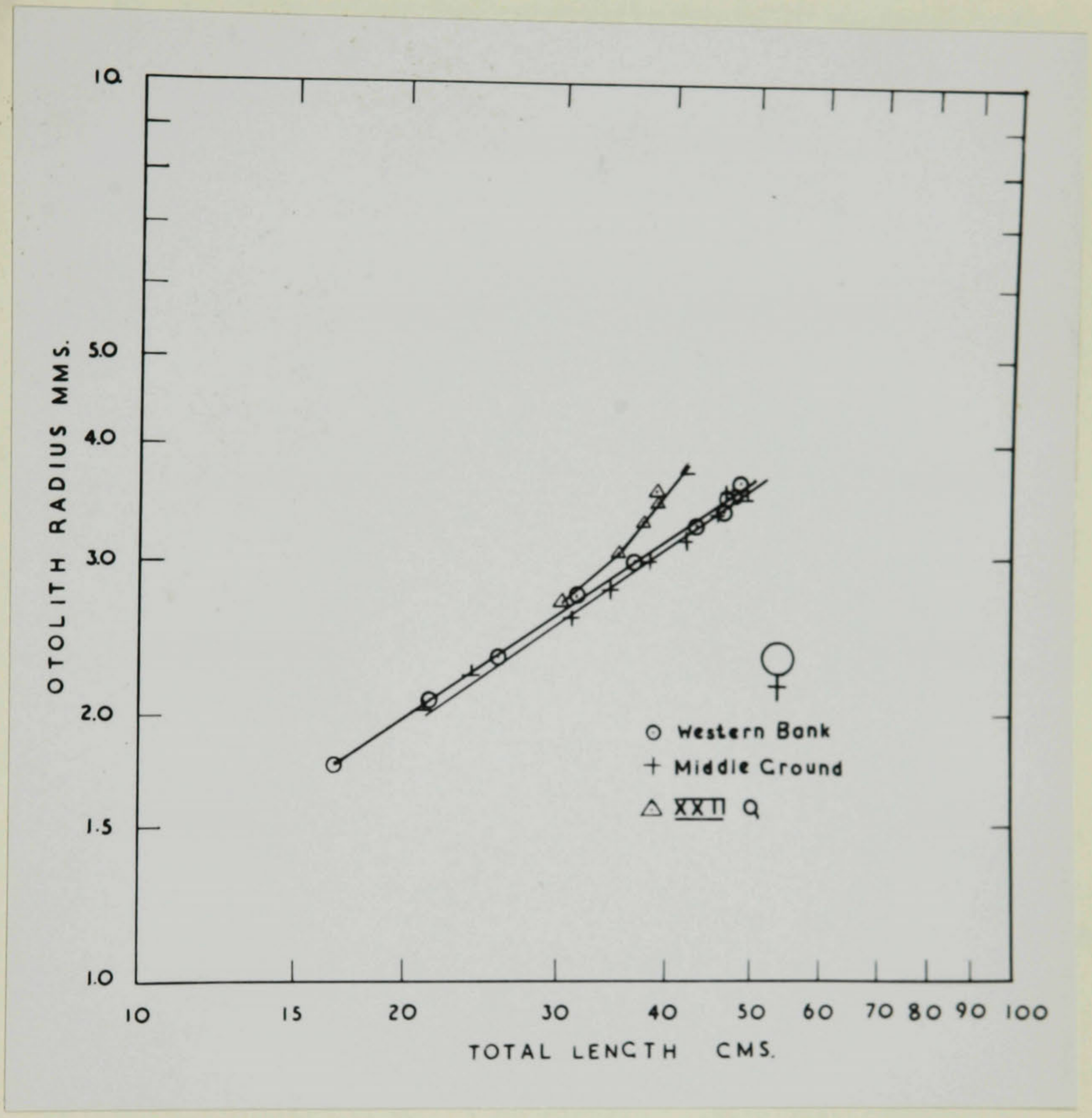


FIG. 11. FEMALES. Relative Growth of Otoliths of Yellowtails from Middle Ground, Western Bank, and XXII Q.

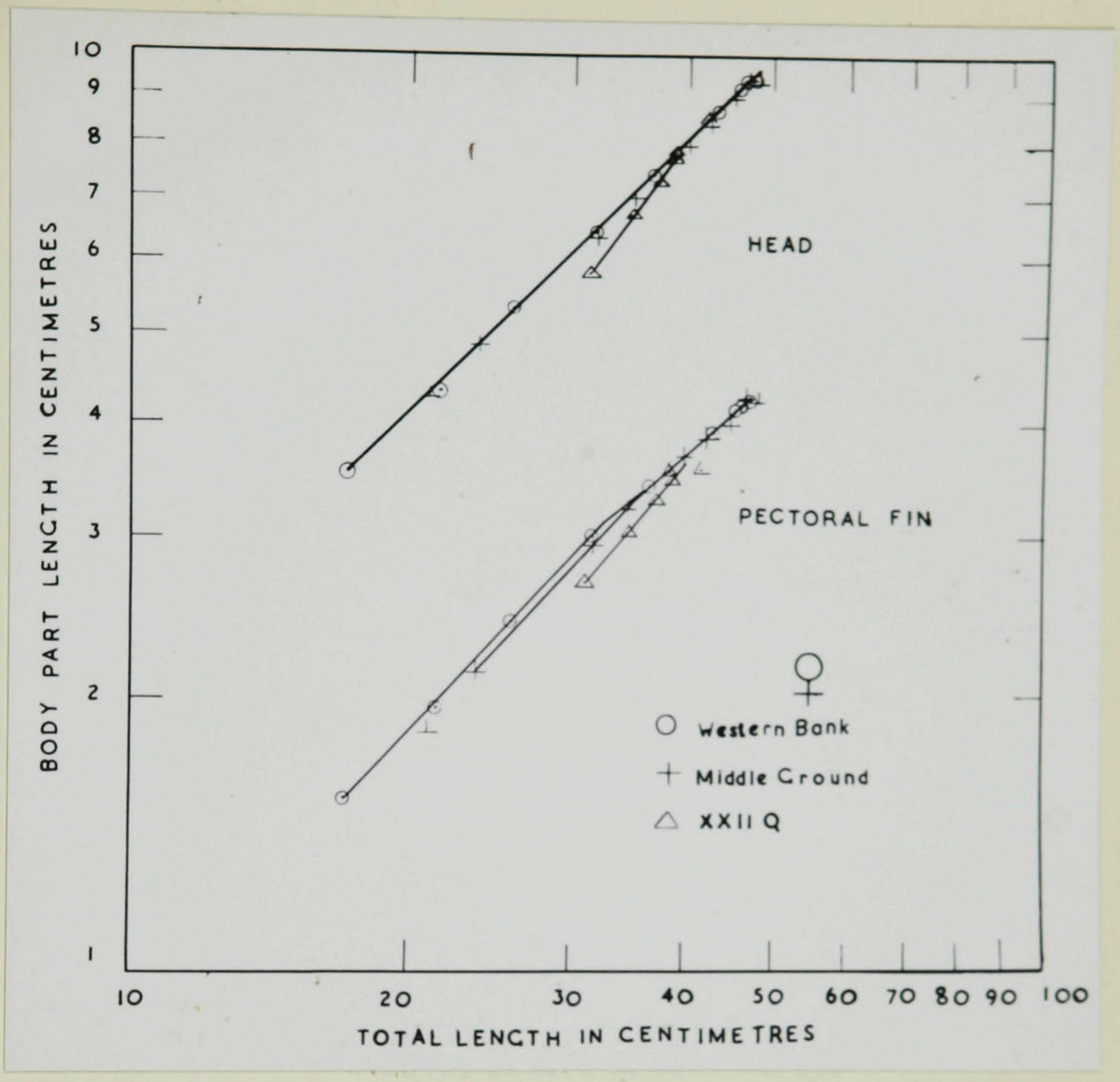


FIG. 12.FEMALES. Relative Growth of Body Parts of Yellowtails from Middle Ground, Western Bank, and XXII Q.

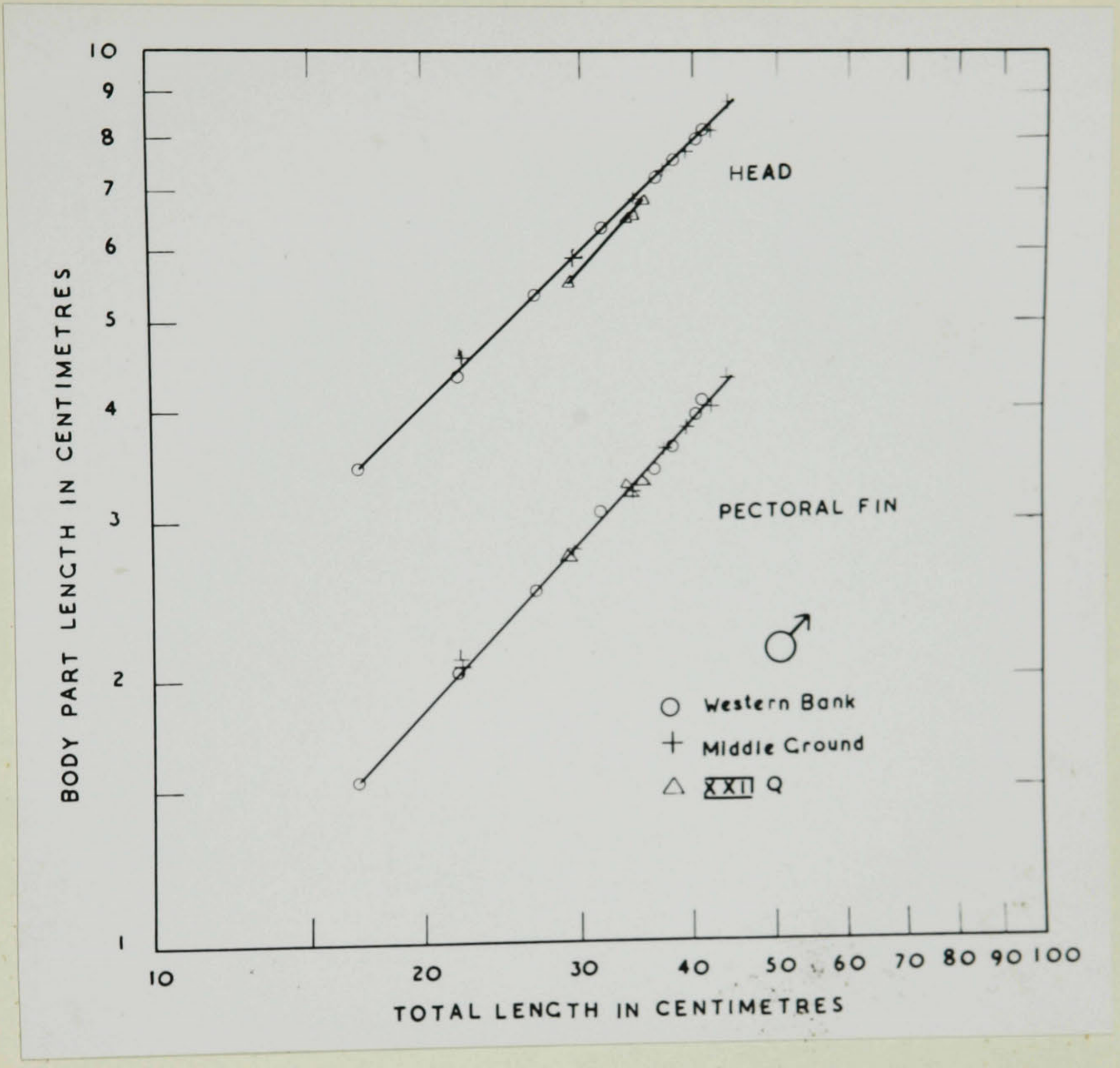


FIG. 13. MALES. Relative Growth of Body Parts of Yellowtails from Middle Ground, Western Bank, and XXII Q.

(a). Otolith Growth.

The values of K for Middle Ground and Western Bank fish show that the growth of the otolith in length is negatively heterogonic in both sexes, the values for Middle Ground being slightly higher than the values for Western Bank. In other words the otolith is growing in length at a rate slower than that of the body. The growth of the otolith in XXII Q females can be divided into two parts; in the first part the growth is negatively heterogonic with a K value of 0.86 but in the third year the relative growth rate of the otolith increases and positive heterogony results. This division of the growth into two phases depends entirely upon the accuracy of the values for age class II females. Because the class II fish measured will be the largest in the class the value of the otolith/length relationship may not be truly representative of the age class as a whole. More data on the length of otoliths in age class I and II would determine the validity of this growth change. If such a change does exist its cause may be associated with the onset of maturity which coincides with the change in growth form. The data for XXII Q males were too limited to derive a good K value but it appears that the growth is positively heterogonic after the second year. In any case the values of K for XXII Q yellowtails are considerably higher than those obtained for Middle Ground and Western Bank fish.

(b). Head Growth.

Growth in length of the head of male and female yellowtails from Middle Ground and Western Bank is essentially isogonic, the K values being 0.98 for the females and 0.97 for the males. This means that the head is growing at the same rate as the body. On the other hand, head growth in yellowtails from XXII Q is positively heterogonic, the value of K for the females is 1.36 and for the males is 1.09.

(c) Pectoral Fin.Growth

Growth of the right pectoral fin in male yellowtails from Middle Ground and Western Bank is positively heterogonic. In the females there is a change in the form of growth which occurs about the sixth year. Before this time the growth is positively heterogonic and the value of K is 1.09 which is almost the same as the K value for males. After the sixth year the relative growth rate of the pectoral fin changes to a negatively heterogonic condition and, thereafter, the pectoral fin of the female has a lower relative growth rate than the males. Since this change occurs at a time when the females are approaching maturity it seems probable that the decrease in the growth rate of the pectoral fin is a response to the increased energy requirements of reproduction. However, this does not explain why a similar change in the growth form of the males does not occur. Positive heterogony also marks the growth of the pectoral fin in females from XXII Q but the value of K is 1.19 which is somewhat higher than the K values for the Canadian areas.

Conclusion.

The relative growth rates of the body parts studied are considerably higher in XXII Q than in Middle Ground or Western Bank fish. This may be due to the much higher rate of growth shown by XXII Q yellowtails. In addition these data confirm earlier observations that the population of yellowtails in XXII Q is considerably different from the northern stocks.

TABLE XIV. Mean Values of Otolith Radius (cm.) and Total Length for each Age Class.

FEMALES

AGE CLASS	MIDDLE GROUND			WESTERN BANK					
	Otolith Radius mm.	Total Length	N	Otolith Radius mm.	Total Length	N	Otolith Radius mm.	Total Length	N
I	.-	-	-	1.12	9.2	1	-	-	-
II	-	-	-	1.75	16.6	16	2.66	30.2	23
III	2.02	21.0	3	2.07	21.3	50	3.02	35.0	20
IV	2.21	23.7	7	2.31	25.6	12	3.27	37.3	18
V	2.57	31.0	23	2.72	31.4	29	3.44	38.8	40
VI	2.75	34.2	29	2.96	36.6	28	3.55	38.7	11
VII	2.97	38.0	38	3.25	43.0	29	3.77	42.0	5
VIII	3.12	41.8	30	3.36	46.3	41	-	-	-
IX	3.35	45.5	34	3.49	46.6	37	-	-	-
X	3.56	46.5	16	3.63	48.3	19	-	-	-
XI	3.48	49.0	4	3.52	47.3	3	-	-	-

MALES

AGE CLASS	Otolith Radius mm.	Total Length	N	Otolith Radius mm.	Total Length	N	Otolith Radius mm.	Total Length	N
II	-	-	-	1.83	17.2	15	2.53	29.1	23
III	1.94	22.0	1	2.12	21.5	47	2.97	33.9	13
IV	2.09	22.2	10	2.39	26.5	19	3.08	34.3	21
V	2.46	29.1	16	2.63	31.4	36	3.22	35.3	12
VI	2.72	33.8	30	2.92	35.3	19	-	-	-
VII	2.90	37.0	40	2.99	39.9	19	-	-	-
VIII	2.94	39.2	49	3.11	42.0	16	-	-	-
IX	3.14	42.5	26	3.21	42.9	8	-	-	-
X	3.20	43.4	7	3.10	42.7	3	-	-	-

TABLE XV. Mean Values of Head Length (cm) and Total Length for each Age Class.

FEMALES

AGE CLASS	MIDDLE GROUND Head Length	MIDDLE GROUND Total Length	N	WESTERN BANK Head Length	WESTERN BANK Total Length	N	XXII Q Head Length	XXII Q Total Length	N
II	-	-		3.53	17.1	15	5.81	31.2	28
III	4.27	21.0	3	4.32	21.5	45	6.72	34.7	21
IV	4.87	23.7	7	5.36	25.9	12	7.30	37.1	21
V	6.37	31.8	22	6.48	31.7	31	7.74	38.8	42
VI	7.06	34.9	34	7.43	36.4	39.	7.87	38.7	11
VII	8.10	39.9	40	8.72	43.0	39	8.56	41.8	6
VIII	8.40	42.1	30	9.24	45.4	31	-	-	-
IX	9.01	44.9	33	9.41	46.1	23	-	-	-
X	9.47	46.7	15	9.44	47.1	15	-	-	-
XI	9.35	47.5	2	-	-	-	-	-	-

MALES

AGE CLASS	MIDDLE GROUND Head Length	MIDDLE GROUND Total Length	N	WESTERN BANK Head Length	WESTERN BANK Total Length	N	XXII Q Head Length	XXII Q Total Length	N
II	-	-	-	3.45	16.9	13	5.51	29.1	23
III	4.60	22.0	1	4.37	21.9	38	6.51	34.0	11
IV	4.57	22.2	10	5.38	26.8	17	6.55	34.4	23
V	5.90	29.6	18	6.37	31.7	39	6.82	35.3	12
VI	6.84	34.4	32	7.23	36.5	31	-	-	-
VII	7.37	37.2	40	7.57	38.2	19	-	-	-
VIII	7.72	39.5	47	7.99	40.5	22	-	-	-
IX	8.18	42.0	23	8.19	41.2	11	-	-	-
X	8.75	44.0	2	-	-	-	-	-	-

TABLE XVI. Mean values of Right Pectoral Fin (cm.) and Total Length for each Age Class.

FEMALES

AGE CLASS	MIDDLE GROUND Pectoral Fin	Total Length	N	WESTERN BANK Pectoral Fin	Total Length	N	Pectoral Fin	Total Length	N
II	-	-	-	1.55	17.1	15	2.67	31.2	28
III	1.83	21.0	3	1.95	21.5	45	3.03	34.7	21
IV	2.14	23.7	7	2.43	25.9	12	3.30	37.1	21
V	2.96	31.8	22	3.01	31.7	31	3.45	38.8	42
VI	3.23	34.9	34	3.41	36.4	39	3.55	38.7	10
VII	3.70	39.9	40	3.91	43.0	39	3.58	41.8	6
VIII	3.86	42.1	30	4.15	45.4	31	-	-	-
IX	4.00	44.9	33	4.20	46.1	28	-	-	-
X	4.26	46.7	15	4.24	47.1	15	-	-	-
XI	4.25	47.5	2	-	-	-	-	-	-

MALES

AGE CLASS	MIDDLE GROUND Pectoral Fin	Total Length	N	WESTERN BANK Pectoral Fin	Total Length	N	Pectoral Fin	Total Length	N
II	-	-	-	1.53	16.9	13	2.74	29.1	23
III	2.10	22.0	1	2.03	21.9	38	3.29	34.0	14
IV	2.06	22.2	10	2.61	26.8	17	3.21	34.4	23
V	2.79	29.6	18	3.82	31.7	39	3.42	35.3	12
VI	3.23	34.4	32	3.43	36.5	31	-	-	-
VII	3.62	37.2	40	3.64	38.2	19	-	-	-
VIII	3.81	39.5	47	3.95	40.5	22	-	-	-
IX	4.03	42.0	23	4.10	41.2	11	-	-	-
X	4.35	44.0	2	-	-	-	-	-	-

ANALYSIS OF MERISTIC COUNTS.

One of the main purposes of this investigation was to determine whether or not the yellowtail stocks in the three areas were distinct and separate from one another. It has long been known that numerical differences in the meristic characters of fish are often an index of population differences. Rounsefell and Dahlgren (1935), discussing the races of herring, Clupea pallasii, stated:

"It is well known that different populations may exhibit different structural peculiarities owing to differences in environment or to differences in heredity arising during long periods of isolation. The study of the individuality of the population has been based largely on these structural differences. Whether the differences in the characters chosen are due to heredity or to environment has not been considered as being of great importance, as long as the characters are fairly stable within each population so that significant differences indicate very slight intermingling, if any, between the adjacent stocks of herring."

Probably the meristic characters which are most suitable for examination in the field are the dorsal and anal fin rays. Consequently, dorsal and anal fin ray counts were made on yellowtails from Middle Ground, Western Bank, and XXII Q. It was noted that no significant differences in the number of fin rays existed between the sexes, so the combined counts for both sexes have been used.

The distribution of anal fin ray numbers is contained in Table XVII and the dorsal fin ray numbers are shown in Table XVIII.

TABLE XVII. Distribution of Anal Fin Ray Numbers in the Yellowtail. (Sexes and age classes combined).

NUMBER FIN RAYS	MIDDLE GROUND f	WESTERN BANK f	XXII Q f
55	-	-	3
56	-	-	7
57	3	1	7
58	2	8	26
59	18	21	47
60	35	29	34
61	54	26	37
62	52	48	26
63	30	31	9
64	11	21	8
65	10	1	4
66	5	-	1
67	2	2	-
68	1	-	-
TOTAL	223	188	209
MEAN	61.63	61.48	60.05

TABLE XVIII. Distribution of Dorsal Fin Rays in the Yellowtail. (Sexes and age classes combined).

NUMBER FIN RAYS	Middle ground f	Western Bank f	XXII Q f
73	-	-	1
74	-	-	6
75	-	-	5
76	1	1	20
77	5	9	18
78	9	16	18
79	24	20	32
80	34	19	22
81	34	44	30
82	35	22	26
83	35	28	16
84	28	22	7
85	14	23	5
86	12	9	0
87	10	6	1
88	2	1	-
89	1	-	-
90	1	-	-
91	1	-	-
TOTAL	246	220	207
MEAN	82.11	81.80	79.61

The distributions and means of the fin ray numbers have been analysed and compared statistically by the method of variance as described by Snedecor (1937). The tests have been made to test the validity of the hypothesis that the samples are part of one population.

TABLE XIX. Analysis of Anal Fin Ray Numbers.

(i) Middle Ground and Western Bank

Variance	Degrees of Freedom	Sum of Squares	Mean Squares	F
Between Samples	1	2.28	2.28	0.68
Within Samples	409	1369.02	3.35	

The F value of 0.68 is much greater than the 5°/o level of probability. The hypothesis is sustained and we can conclude that the samples are drawn from yellowtail populations with the same anal fin ray characteristics.

(ii) Middle Ground and XXII Q.

Variance	Degrees of Freedom	Sum of Squares	Mean Squares	F
Between Samples	1	197.70	197.70	51.6
Within Samples	430	1648.54	3.83	

(iii) Western Bank and XXII Q

Variance	Degrees of Freedom	Sum of Squares	Mean Squares	F
Between Samples	1	201.28	201.28	53.2
Within Samples	395	1493.34	3.78	

In (ii) and (iii) the F values of 51.6 and 53.2 are much less than the 1°/o level of probability and we can conclude that the samples differ significantly.

TABLE XX. Analysis of Dorsal Fin Ray Numbers.

(i) Middle Ground and Western Bank.

Variance	Degrees of Freedom	Sum of Squares	Mean Squares	F
Between Samples	1	10.86	10.86	1.61
Within Samples	464	3130.45	6.75	

The F value of 1.61 is much greater than the 5°/o level of probability and we can conclude that the samples were drawn from yellowtail populations with the same dorsal fin ray characteristics.

(ii) Middle Ground and XXII Q.

Variance	Degrees of Freedom	Sum of Squares	Mean Squares	F
Between Samples	1	698.12	698.12	97.6
Within Samples	451	3178.38	7.05	

(iii) Western Bank and XXII Q

Variance	Degrees of Freedom	Sum of Squares	Mean Squares	
Between Samples	1	509.82	509.82	72.9
Within Samples	425	2970.33	6.99	

In (ii) and (iii) the F values of 97.6 and 72.9 are so much less than the 1% level of significance that the hypothesis must be rejected.

On the basis of the analyses of anal and dorsal fin rays the conclusion can be made that the yellowtail population of XXII Q is distinct from either the population of Middle Ground or Western Bank.

It will be noticed that the mean fin ray numbers of yellowtails from the northern areas are considerably greater than the mean values for XXII Q yellowtails. This decrease in fin ray numbers from north to south is found commonly in fish according to Huxley (1942), and Mayr (1942). Huxley states that the number of fin rays and vertebrae in many fish varies inversely with the temperature.

There are many exceptions to this rule. Jensen (1939) found in the plaice and in the dab that the number of anal fin rays seems to be positively correlated with the temperature of the water during the time at which the larvae are quite small. More recently, Taning (1944) has demonstrated in the sea trout that the number of rays in the dorsal and pectoral fins increase with rising temperature. In addition Taning confirmed Schmidt's (1921) findings that the highest number of vertebrae occur in fish raised at high and low temperatures, and that the lowest values are obtained at intermediate temperatures.

Gabriel (1944), in his interesting paper on vertebral variation in *Fundulus heteroclitus* concluded,"... that, other things being equal vertebral numbers are subject to genetic control; and that the rate of development of the embryo affects the number of vertebrae it is to have, so that environmental agents, particularly temperature, which affect the developmental rate may modify the vertebral number." In general, he found that an inverse relationship existed between temperature and the number of vertebrae. Gabriel postulated the following mechanism for the modification of vertebral numbers by developmental rate:

"If the temperature relations of growth and differentiation differ so that, under inhibiting conditions, differentiation is retarded but growth is unimpeded, the embryonic length will be greater and more material will be available at the time that the somites are differentiated, and a greater number of somites will be produced." This hypothesis is in accord with observations by Hubbs (1926) and Gray(1928) on growth in fish.

Although much of the preceding discussion has dealt with vertebrae formation, it is very probable that the same principles apply to the formation of fin rays. The evidence in this paper does not justify any categorical conclusions with regard to the causes of variation in the fin ray numbers of the yellowtail. However, in view of our knowledge of the temperature conditions existing in the different areas it seems safe to assume that at least part of the higher fin ray numbers in the northern yellowtails is due to the colder water temperatures.

SUMMARY AND CONCLUSIONS.

1. The purpose of this study of the yellowtail was two fold. Firstly, knowledge of the general biology of the yellowtail was desired and, secondly, samples were collected from three distinct fishing areas in order to determine the amount of variation between stocks from different areas.

2. Data were collected from more than 3000 yellowtails. These data included measurements of the total length, head length, and pectoral fin length, and counts of anal and dorsal fin rays. In addition more than 1600 sets of otoliths were collected.

3. The otolith method of age determination, first introduced by Reibisch (loc. cit.), was employed throughout the investigation. The relative merits of otoliths and scales in age determination have been briefly compared.

4. The formation of the otolith was discussed and it was decided that the white, opaque rings are deposited in the summer months, June to September, under conditions of high water temperatures. The exact time of deposition of the dark, translucent ring is still in doubt. Some evidence is presented to support the belief that the dark ring is formed in the late spring and early summer.

5. The spawning period of yellowtails from Middle Ground and Western Bank is restricted to the months of May and June with maximum spawning occurring early in June. This is, at least, two or three weeks later than the spawning period in XXII Q.

6. A differential growth rate exists between the two sexes. This has been related to differences in the age of the sexes at maturity and to subsequent energy requirements for reproduction.

7. The three populations show consistent differences in the rate of growth in length. Their order with respect to initial growth rate in length, from maximum to minimum, is: XXII Q, Western Bank, and Middle Ground. The differences between the populations of XXII Q and Western Bank are much greater than differences between the Western Bank and Middle Ground stocks.

8. The maximum size and age of females is greater than in males. The size and ages of commercial catches is the greatest in Middle Ground fish and the least in yellowtails from XXII Q. The ultimate age and size of the yellowtail stocks appears to be inversely related to the initial rate of growth.

9. The age and size of the yellowtail at maturity has been determined. When the growth rate is rapid the yellowtail matures at a much younger age

and a smaller size. Males mature at a younger age than the females.

10. Fluctuations in the year classes have been noted. Because of the dissimilarities occurring between the northern and southern areas, it must be concluded that the relative abundance of a particular year class depends on the local conditions. This suggests that the populations of the Nova Scotian banks are distinct from that of XXII Q. In addition it has been observed that there appears to be an inverse relationship between the numerical strength of the brood and its rate of growth.

11. The environmental factors influencing the rate of growth have been discussed. The conclusion has been made that low temperatures and an older, denser population restrict the growth rate of the yellowtail stocks of Middle Ground and Western Bank.

12. Relative growth studies of the head, pectoral fin, and otolith revealed striking differences between the yellowtails from XXII Q and the yellowtails from the other areas.

13. The mean values of fin ray counts follow a north-south cline with the maximum numbers in the north. A very significant difference exists between the mean values of fin rays in XXII Q fish and either of northern stocks of yellowtails. There is no significant difference between the Middle Ground and Western Bank populations.

14. Sufficient differences exist between the yellowtail populations of Middle Ground and Western Bank and the population of XXII Q to justify the conclusion that the XXII Q population is distinct and separate from the northern populations. The majority of the evidence suggests that the Western Bank yellowtails are intermediate in their characteristics although

they resemble the Middle Ground population very closely. More detailed work will be necessary to define the exact relationship of the Western Bank and Middle Ground populations.

The slow rate of growth of the northern yellowtails and its effect upon the composition of the stock has considerable economic importance. The lower limit of size in Canadian commercial catches already includes many immature fish. If the fishing becomes more intense in response to the demands of the market then, almost certainly, the marketable size will become less and eventually, as the larger fish become depleted, the catches will consist of smaller immature fish. If the slow rate of growth is largely caused by unfavourable temperature conditions the development of the Canadian yellowtail fishery will be limited. However, if the density of the population and the presence of large numbers of large, old fish is the cause of the slow growth rate, an increase in fishing intensity would lessen the density of the population. This might produce better environmental conditions for young fish and this, in turn, would result in an increased rate of growth bearing with it changes in the age and size at maturity.

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