Herring Investigations at Plymouth. III. The Plymouth Winter Fishery during the seasons 1924–25, 1925–26, and 1926–27.

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With 6 Figures in the Text.

CONTENTS.

The Plymouth Winter Fishery.

Although locally caught drift herrings may be landed at Plymouth from the end of September onwards until the beginning of March, the fishery only assumes economic importance during the months of December and January, when a large number of visiting drifters from both Cornwall and East Anglia are making daily fishing trips, using Plymouth as their temporary base. The composition of the fishing fleet in each of the seasons from 1918–19 onwards is shown in the following table kindly supplied by Mr. E. G. Nelder, and published by the courtesy of the Sutton Harbour Improvement Company :—

Boats fishing for Herrings from Plymouth during Winter Herring Seasons.

Season.	East Country steamers.	West Country (Cornish) motor drifters.
1918–19	33	139
1919–20	30	156
1920–21	26	182
1921–22	31	155
1922–23	68	142
1923–24	59	161
1924–25	86	176
1925–26	153	158
1926–27	129	169

The average number of Plymouth boats fishing for herrings is 10. Some years during the above period there were only 3, but in 1925–26, twenty-five.

Port Facilities for the Fishery.

It is to be observed, first, that during the past two seasons the total visiting fleet numbered about 300 vessels, of which nearly one-half were steamers. This considerable increase in the number of vessels participating in the fishery has sorely taxed the available accommodation within Sutton Harbour, and the landing and packing operations have been conducted under most congested conditions. The harbour is a tidal one, so that movements of large fishing vessels within it, as well as arrivals and departures, can only be performed during from four to six hours around the time of high-water. The fish-market itself is small, and comparatively little surrounding ground is available for the packing of fish landed and for the storage of boxes and barrels ; the quayside accommodation adjacent to the market is limited in extent. It is only natural that boats should prefer to land their catches at the market quays, with the result that congestion is particularly manifest in this area. Much valuable work is performed by one or two skilled servants of the Harbour Company in directing the assembly at, and departure of, vessels from these quays ; but despite their efforts much delay in landing catches is caused and there is always a risk of damage to vessels. Obviously, too, no movements of ships can be carried out during unfavourable tidal conditions. Some further improvement may possibly be brought about by continuance of the present efforts to divert part of the landings to other sites within the harbour. The alternative of decentralising the fishery so that some landings could be made at places outside Sutton Harbour would seem to necessitate the withdrawal or modification of the present Parliamentary Act which states that "all fish brought or carried to the harbour of Sutton Pool or to any part of the Borough of Plymouth and whether by sea or land and whether in ships boats carts trucks vans boxes or otherwise for sale shall be sold only by public auction and in the fish market."

A second point to be observed from the above table is that there has been a notable rise in the number of Lowestoft and Yarmouth steamers during recent years. Their presence has led to a great increase in the total quantity of fish landed in the season, as the following official statistics show :—

Season. Dec.–Jan.	Total quantity Herrings landed. cwt.	Landings by steamers only. cwt.	% weight landed by steamers.
1918–19	8,624	7,628	88·4
1919–20	29,425	12,728	43·3
1920–21	40,263	20,973	52·1
1921–22	16,922	10,494	62·0
1922–23	54,839	40,941	74·6
1923–24	98,684	57,519	58·4
1924–25	113,585	83,647	73·7
1925–26	105,643	82,780	78·3
1926–27	63,138	45,932	72·7

The percentages shown on the right of the above table demonstrate the fact that the East Anglian fleet are landing practically three-quarters of the season's catch. Now it has to be remembered, that a large fleet of steamers attracts important outside buyers. The presence of these buyers must tend to keep the purchase price at a steadier higher level. When few buyers are present, particularly if their requirements are limited, the price is apt to fluctuate very considerably from day to day, and always to drop heavily when supplies are good. The steadying influence of a large number of big buyers benefits not only the steamers, but the local motor-drifters as well. Any circumstance, therefore, which tends to discourage the annual visit of the steamers must most seriously affect the annual yield of the winter fishery at Plymouth.

A Comparison between Motor-driven and Steam-driven Fishing Vessels.

The presence of two comparatively large fleets of drifters, the one composed of steamers and the other of motor-propelled craft, renders possible several interesting comparisons of performance. During the nine consecutive seasons from Dec. 1918–Jan. 1919 to Dec. 1926–Jan. 1927, the steamers made 13,625 landings with an average of 26·6 cwt. per landing ; in the same period, motor-vessels (irrespective of size) made 7,781 landings, with an average of 22·1 cwt. per landing. Thus, landing for landing, the steamers do not seem to have exhibited a very marked superiority in density of catch per boat, although by reason of their sea-going advantages they were able to fish over a wider area from as far east as off Berry Head to as far west as Dodman Point. But it is in the actual number of landings made that the steamers reaped the advantage. It is to be remembered that the fishery coincides with the time of most severe weather. In some seasons the whole of the motor fleet may be forced to remain in harbour for days on end, owing to adverse weather conditions, whereas the steamers, or at any rate a number of them, are yet able to work with satisfactory results. A study of the daily landings, also shows that landings by motor craft are rarely, if ever, made on Sundays, Christmas Days, or Boxing Days, although steamers continue to work on these days. The following table gives statistics of daily landings during the five seasons, 1922–23 to 1926–27 (Dec. and Jan. only), when fish was landed by steamers only :—

Season Dec.–Jan.	No. days when fish was landed by steamers only.			No. landings by steamers on these days.	Total weight of fish landed by steamers cwt. on these days.	Total landing by motors throughout *whole season* cwt.
	Sundays, Xmas, & Boxing Day.	Other Days.	Total.			
1922–23	9	13	22	740	22,980	13,898
1923–24	6	9	15	383	11,154	41,165
1924–25	8	14	22	540	20,696	29,938
1925–26	10	20	30	1,510	30,909	22,863
1926–27	6	13	19	523	10,939	17,206

It is seen from the above table that an appreciable amount of fish was landed by the steamers on the days when there were no landings by motor craft, and that in the seasons 1922–23 and 1925–26 this amount exceeded the weight of fish landed throughout the whole of the two months of December and January by the motor-fleet.

General Features of the Fishery.

The fishery itself presents peculiar features. It is always liable to serious interruption by incursions of dogfish (*Squalus acanthias*). These fish may be so numerous on some parts of the ground that shooting drift-nets involves risk of total loss of or severe damage to gear. Some skippers elect to shoot only a very limited number of nets, hauling and reshooting at frequent intervals during the hours of fishing. The catches of dogfish are not always saleable, particularly when they are plentiful, owing to the limited commercial demand for this class of fish. The fishery, again, is characterised by the fact that the herrings appear to be present in shoals of limited size, there being little in the nature of " banks " of herrings. It is generally the case, also, for shoals of mackerel and pilchards to be present in the neighbourhood more particularly to the westward. As a result of these circumstances, individual landings on the same day from boats working in close association may differ to a striking degree, in total quantity, quality, and class of fish. Thus, one boat may land a fine clean catch of excellent full herrings, while a second may have only a few herrings, perhaps spent, together with a quantity of mackerel or pilchards or both. In an individual boat, the nets of the fleet may differ to a similar extent in the class of fish they have captured. Under these conditions it is not surprising that there is a big difference between the boats at the end of the season with regard to their earnings, or that the general average landing is by weight not very high.

French Trawling Activities.

Before leaving the subject of the practical fisheries, some remarks may be made concerning the operations of French steam trawlers off the Devon coasts between Start Point and the Eddystone. It is, perhaps, only natural that the presence of, say, from twenty to thirty powerful steamers within sight of home should arouse grave misgivings in the minds of the local trawlermen lest the grounds should be so depleted of fish as to render their fishing unprofitable. It is true, of course, that the grounds lie in international waters where the French have as much right to fish as our local men. If, therefore, the French by reason of a sound knowledge of the local movements of fish and satisfactory fishery organisation can maintain a commercial steam fishery off our shores, they are entitled to do so. But, at the same time, the present writer is of the opinion that the feelings of our local fishermen are not to be regarded as due merely to a spirit of resentment towards " outside " participation in a local fishery. One has only to observe the thorough manner in which an area is swept by the French trawls to sympathise with the smacksman or motor-trawler whose living is made on that ground, and to believe that the local fishery is seriously affected by the French activities.

The question considered in relation to the drift-fishery for herrings is also of importance. Le Gall (**3**) states that the French trawlers working in the " Baie de Plymouth " take some herrings at all times of the year. From July to September to the south and south-west of the Eddystone, and in September in the region of the Start, good catches are made. In the months of January, February, and March, " spent " herrings are caught within the same area. Le Gall inclines to the view that these are the same herring which come to spawn off the south coasts of Devon and Cornwall, and which form the stock for the winter drift-fishery at Plymouth. Now in the first weeks of November, 1927, some thirty to forty French trawlers were intensively engaged by day on grounds where a few hours later the Plymouth drifters were shooting their nets for herring. It is neither illogical nor unreasonable to suspect that the trawling had a material effect on the prospects for the subsequent drifting.

From the above it would seem that in purely local considerations the possible effects of French trawling activities must not be overlooked.

The Characters of the Fishes landed.

From what has been said concerning the fishery, it will be appreciated that a small sample taken at random from a commercial catch conveys only a very rough estimate of the herring population present at the time of sampling. A second sample taken from another boat might easily differ appreciably from the first. A series of such samples, however, taken at intervals during a season, does provide a much better picture than just one or two isolated samples, no matter how big the latter may be.

Condition of Gonads (Roes and Milts).

In using the data on the state of the gonads of fishes in the series of samples as a guide to the progress of spawning, a good deal of irregularity would be expected ; but in spite of this they do provide a clear idea of the general situation. Table I (at the end of this paper) and Fig. 1 show for each sample taken during the season 1924–25 the proportions of females in the following classes :—

1. Full fish.—Ovaries filling the body cavity, but eggs opaque and not mature.
2. Fish ready to spawn or spawning.—Ova quite transparent and ready to be shed from the ovaries.
3. Spent fish or recovering spents.

It is seen from Fig. 1 that during November and the early part of December the catches largely consisted of unripe fishes (Class I, above). In the latter part of December and throughout January ripe fishes predominated, while from the end of January until the end of the season, spent fishes were most in evidence. The data also show that while some spent fishes were caught early in December, some 12% of a sample taken on March 2nd, 1925, were still unripe. In the following season, an earlier start with sampling was possible, and fishes ready to spawn were taken towards the end of September. It is interesting to record that this early run of ripe fishes was detected in samples taken from catches by stop-nets within Plymouth Sound, during September and October, 1925, and again in October, 1926. The same early spawners were also present among catches of seine-caught sprats from the River Tamar. During these same months, however, fishes caught outside Plymouth Breakwater in the open sea were all in an unripe condition.

The duration of the spawning time in the Plymouth area is of

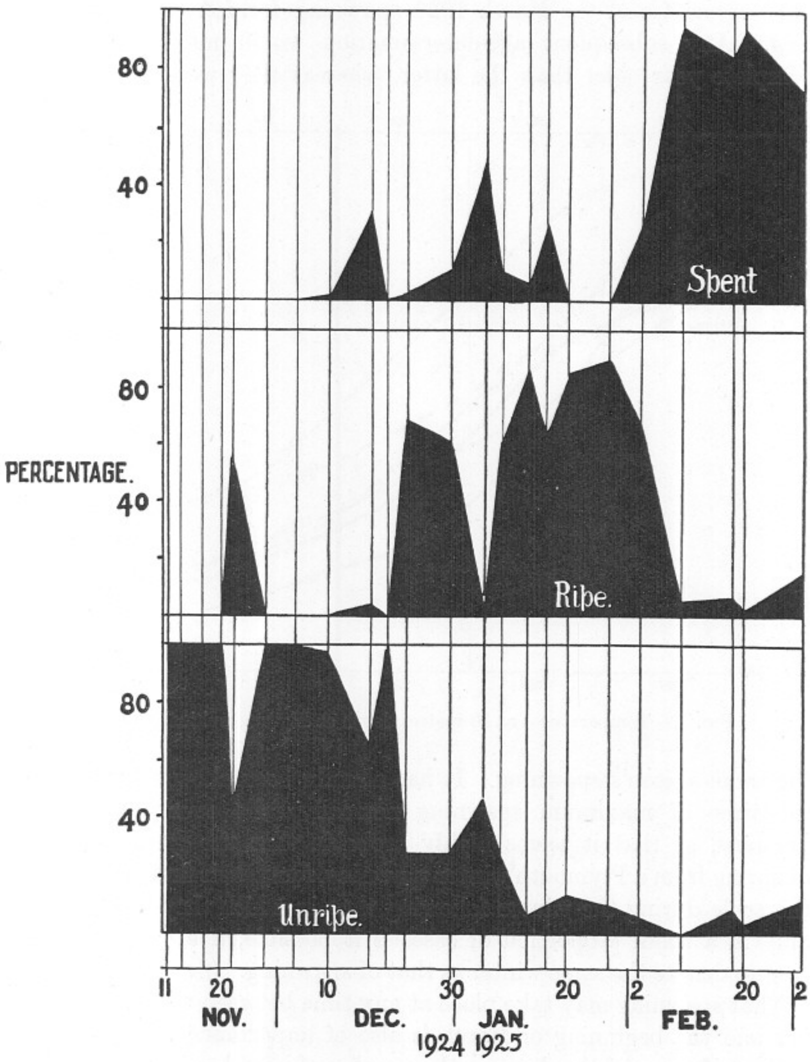

Fig. 1.—Condition of Ovaries (roes) in herrings landed at Plymouth during season 1924–25. Percentage of each class marked off along vertical lines erected at dates when the samples were taken.

importance when considering the question of the significance of the first winter-ring on the scales of adult fishes. The offspring from the fish which spawned in September, 1925, obviously had over five calendar months in which to grow before the offspring spawned in March, 1926, had appeared. It has yet to be determined whether the September spawned fish acquired scales by the end of the year 1925; but if they did, then in the winter of 1926–27 they formed their *second* winter-ring, while their associates of the March 1926 spawning formed their *first* winter-ring. Any subsequent age-determination would make the former a complete year older than the latter, whereas they were the product of

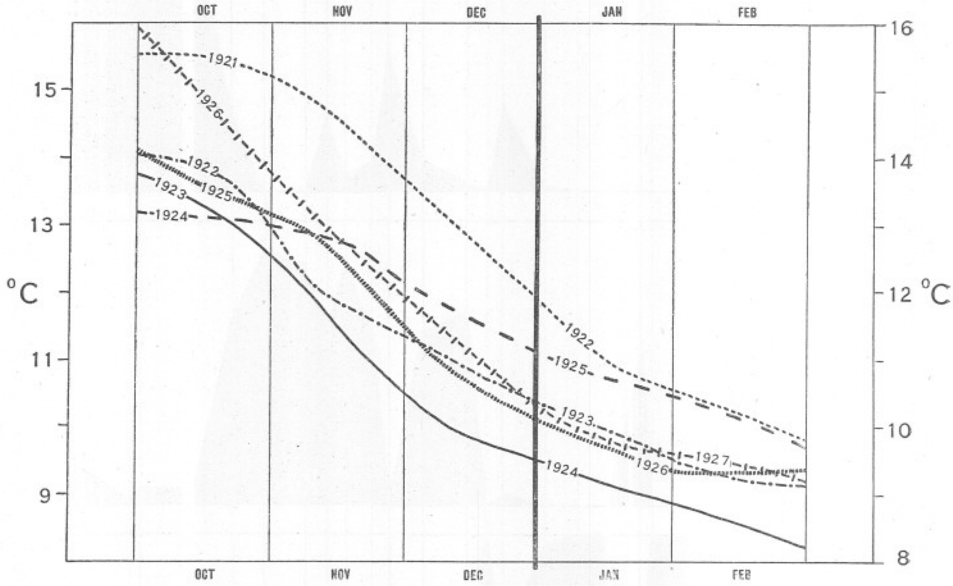

Fig. 2.—Temperatures at 10 metres depth at Hydrographical Station E_1.

the same season's spawning. It has already been shown, however, that the time of maximum spawning normally falls over December and January, so that it seems highly probable that the great bulk of the offspring from a Plymouth winter spawning, form their first winter-ring on the scale during the winter following that in which they were spawned; only in a small proportion of cases is it possible, if at all, for the first ring to denote the same winter as that of spawning. (See Part IV, p. 313.)

That spawning may take place at any time between the end of September and the beginning of March is also of importance when considering the significance of the data on the number of vertebræ. If the "racial" theory be true, it is possible that the earlier spawning fishes are of different racial origin from those which spawn later. On the other hand, if the number of vertebræ is materially influenced by environmental conditions prevailing at the critical period, the fishes spawning, say, in October, would give rise to larvæ having on average a different number of vertebræ from those spawned by the December or January spawners. The temperature conditions prevailing during spawning cannot be stated with exactitude, but Fig. 2, depicting the temperature at a depth of 10 metres at hydrographical station E1 (situated some 10 miles S.W. of the Eddystone), kindly supplied by my colleague, Mr. H. W. Harvey, may be used as a close approximation. Probably on the coastal region where spawning takes place, the total range is somewhat greater, and the temperatures slightly lower. It will be seen that maximum spawning coincides with a temperature of, say, from 9° C. to 11° C. It is also apparent that the total possible range of spawning from October to March covers an appreciable range of temperature even when allowance is made for probable annual fluctuation in spawning time.

Average Length.

The data on length, taken in the three successive seasons, 1924–25, 1925–26, and 1926–27, serve to indicate the length groups upon which the fishery is chiefly centred. In Table II on page 301 the values of the median (Q_2), quartiles (Q_1 and Q_3) and the upper and lower limits of size of fishes of samples taken from commercial landings during the three seasons, are given. These same values are recorded graphically in Fig. 3. The range in size of the middle 50% (Q_3–Q_1) of each sample may be used as a convenient index of the sizes occurring most frequently. It is seen that the value of the lower quartile (Q_1) dropped below 25 cm. on two occasions only (both during the season 1926–27), while on all but three occasions (one in each of the three seasons) the value of the upper quartile (Q_3) was under 29·0 cm. Thus, it may be taken that the fishery is centred chiefly upon fishes of the 25, 26, 27, and 28 cm. groups (i.e. roughly 10 in. to 11 in.).

Comparing season with season, however, it is seen that there was an appreciable and general depression of length during the season 1926–27. It will be shown later that this was due to an influx of younger fishes. It should be noted for future reference that samples of the " Smalls " trawled fishes during the autumn of 1925, and also those of the " drift " fishes caught at Padstow in November and December of 1925 showed a similar increase in the percentage of fishes of shorter length.

The data for the Plymouth samples of 1924–25 were analysed according to the locality in which the fishes were captured to determine whether or no the statistics would confirm the view of local fishers that the " Bay " herring caught inshore to the eastward of the port are a smaller " class "

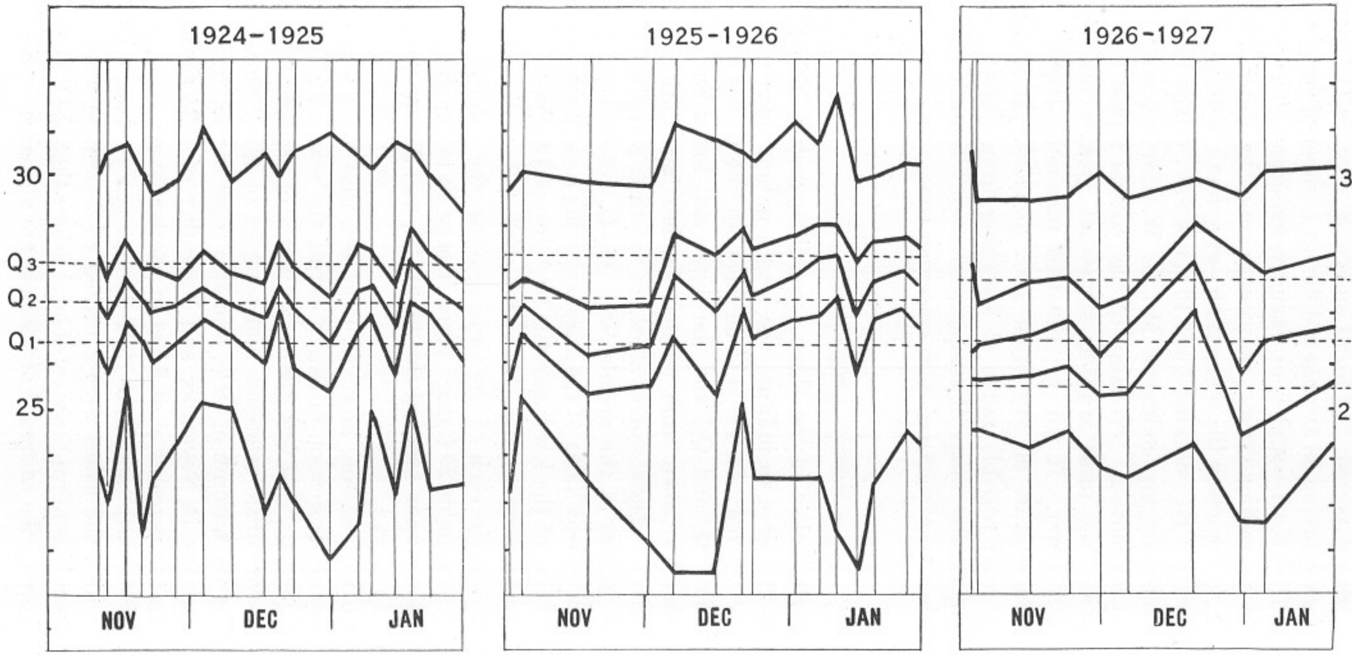

FIG. 3.—Length of fishes landed at Plymouth.

Vertical lines indicate the dates when samples were taken. For each sample the following values are shown :—

Upper limit of length.
Upper Quartile (Q_3).
Median (Q_2).
Lower Quartile (Q_1).
Lower limit of length.

of herring than those taken to the westward. Accordingly, samples were grouped into three classes dependent on whether they were taken from (*a*) eastward, (*b*) off harbour, or (*c*) to the westward. The divisions were admittedly rough, but only a rough comparison could be made under the circumstances. The rearranged data on length are shown in Fig. 4 in convenient form to demonstrate differences between the values of Q_1, Q_2, and Q_3 in the three areas. It is interesting to observe that these values show a general tendency to be lowest to the eastward, intermediate off the harbour, and greatest to the westward. It would not be advisable to stress this indication, but that it may have some significance will become apparent at a later date when the samples landed at the neighbouring port of Brixham are under review.

Age Composition of Shoals.

As stated on page 243 of Part I of this series, the first winter-ring on the scales of the Plymouth fishes was assumed to have been laid down during the winter following that in which the fish was born. It has also been shown on page 284 of the present paper that the spawning period overlaps two calendar years. If, therefore, we follow the principle of referring fishes to "year-groups" named after the calendar year in which the first summer zone was formed on the scale, it means that we shall have to include fishes born in two calendar years within one and the same year-group. For instance, the year-group 1920 would include fishes derived both from the spawning of November and December, 1919, and from that of January and February, 1920. Although this may not be the most convenient method of recording age, it has been followed in the present work because it permits of more ready comparison of results with those of other workers in other areas.

The age-composition of the samples taken in the three seasons 1924–27 is given in the form of percentages in Table III on page 303 and graphically in Fig. 5 in terms of the actual age at the time of sampling. It is seen that fishes of the 1920 year-class formed a dominant element of the samples in all three seasons. During the season 1924–25, as 5-zoned 5-ringed fishes they comprised more than half of many samples. In the following season, as 6-zoned 6-ringed fishes they still greatly outnumbered those of any other year-group. In the third season (1926–27), when 7-zoned 7-ringed, although not so heavily represented as previously, they yet formed an important constituent.

In contrast with the importance of the 1920 year-class, the relative insignificance of the proportion contributed by the 1921 year-class is to be noted. In the seasons 1924–25 and 1925–26 it was completely overshadowed by the 1920 class, while during the season 1926–27 it was

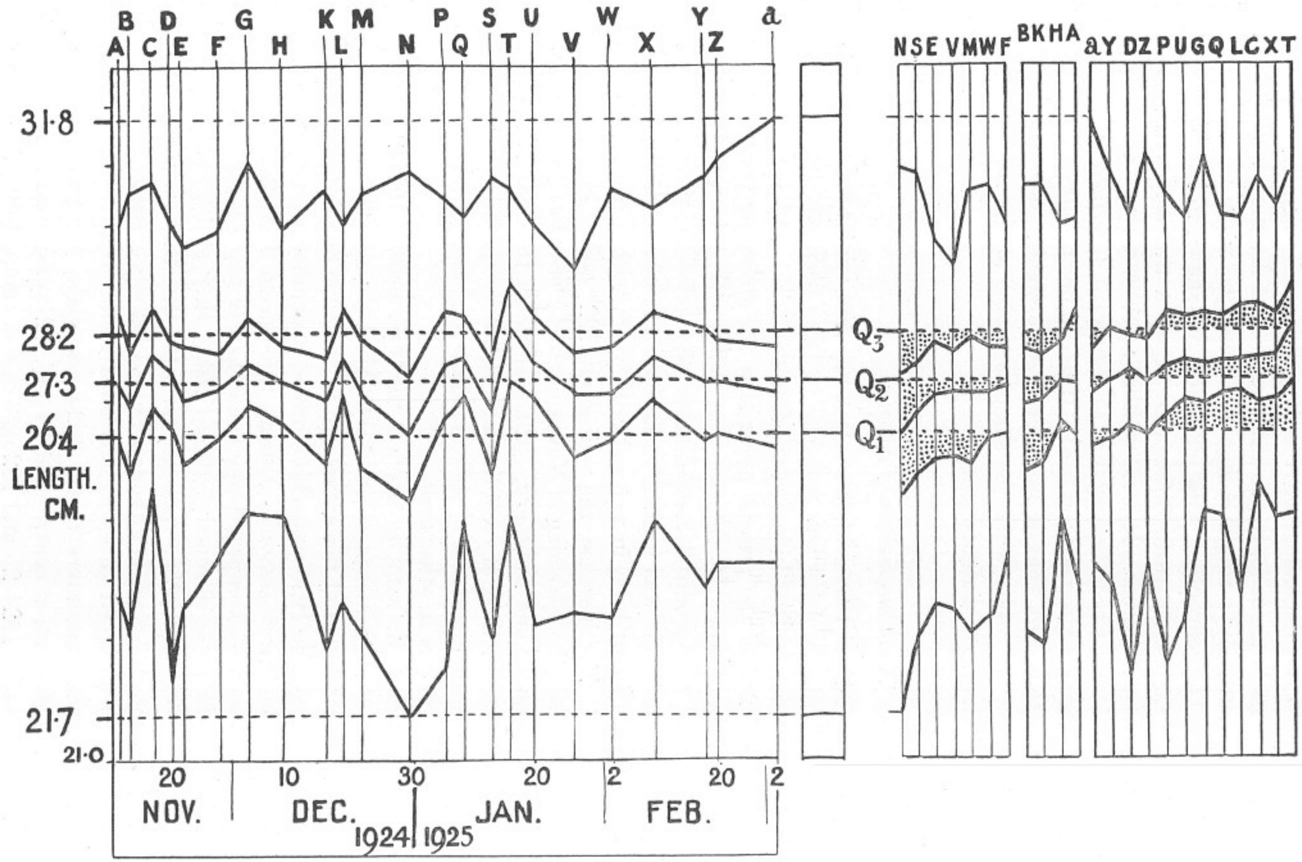

FIG. 4.—Length of fishes landed at Plymouth during season 1924–25.

On left, data shown as in Fig. 3. On right, samples arranged according to locality :—

Samples N, S, E, V, M, W, F	East Bay.
Samples B, K, H, A	Off Harbour.
Samples a, Y, D, Z, P, U, G, Q, L, C, X, T .	Westward samples.

The order of the samples in the three areas is according to the magnitude of (Q_2).
The dotted areas indicate the deviations from the mean values.

even less in evidence than the two immediately younger classes of 1922 and 1923.

It is seen from the 1926–27 results that the 1920 class showed definite signs of a decline in intensity, and that the 1921 class gave no signs that it would ever become important, while of the younger classes, that of 1923 was the most promising. It would, therefore, seem reasonable to expect that in the coming season of 1927–28, the samples will show a fair proportion of the 1923 class as 5-zoned 5-ringed fishes. Whether or not the 1923 class will prove to be the dominant element depends, of course, on the extent to which still younger fishes arrive.

Dominance of the 1920 *Year-class.*

The fact that the 1920 year-class constituted a large proportion of the samples at Plymouth in at least three consecutive seasons is worthy of especial comment. Storrow (**4**, p. 10) shows that in samples examined by him during January, February, and March, 1924, from about the Shetlands, the North of Scotland, Eyemouth, and the north-west of Ireland, there was a strikingly high percentage of fishes with four winter-rings (i.e. the 1920 year-class). Two of his samples from Wick were composed almost entirely of this one year-class; in the one sample of 211 fishes there were 208 with four winter-rings, and in the other of 214 fish, 203 showed four winter-rings. In the following year (1925) the same year-class was again of first importance in the samples from Wick and yielded a large percentage in the samples from off Flugga, Eyemouth, and the north-west of Ireland (Storrow, **5**, p. 9). In 1926, Storrow (**6**, pp. 11 and 14) reported that in the north of Scotland and north-west of Ireland, the 1920 year-class was still abundant.

Watkin (**7**), also supplies data which shows the dominance of the 1920 class in samples taken off the Welsh and Cornish coasts during the winters of 1923–24 and 1924–25.

The above results are sufficient to show that the richness of the 1920 year-class was a widely-spread phenomenon. Its observance at Plymouth must therefore not be stressed as evidence of the return year after year of the same body of fish. The likelihood of this latter fact can only be estimated after the examination of the growth and morphological characters of the fishes of the same year-class which came each year.

Variation in Length among Fishes of same Sample.

Differences in length between fishes of the same sample may be due to the fact that the fishes are not all of the same age, for obviously we should not expect the younger fishes normally to be so large as their older associates, although there is evidence that the larger members of

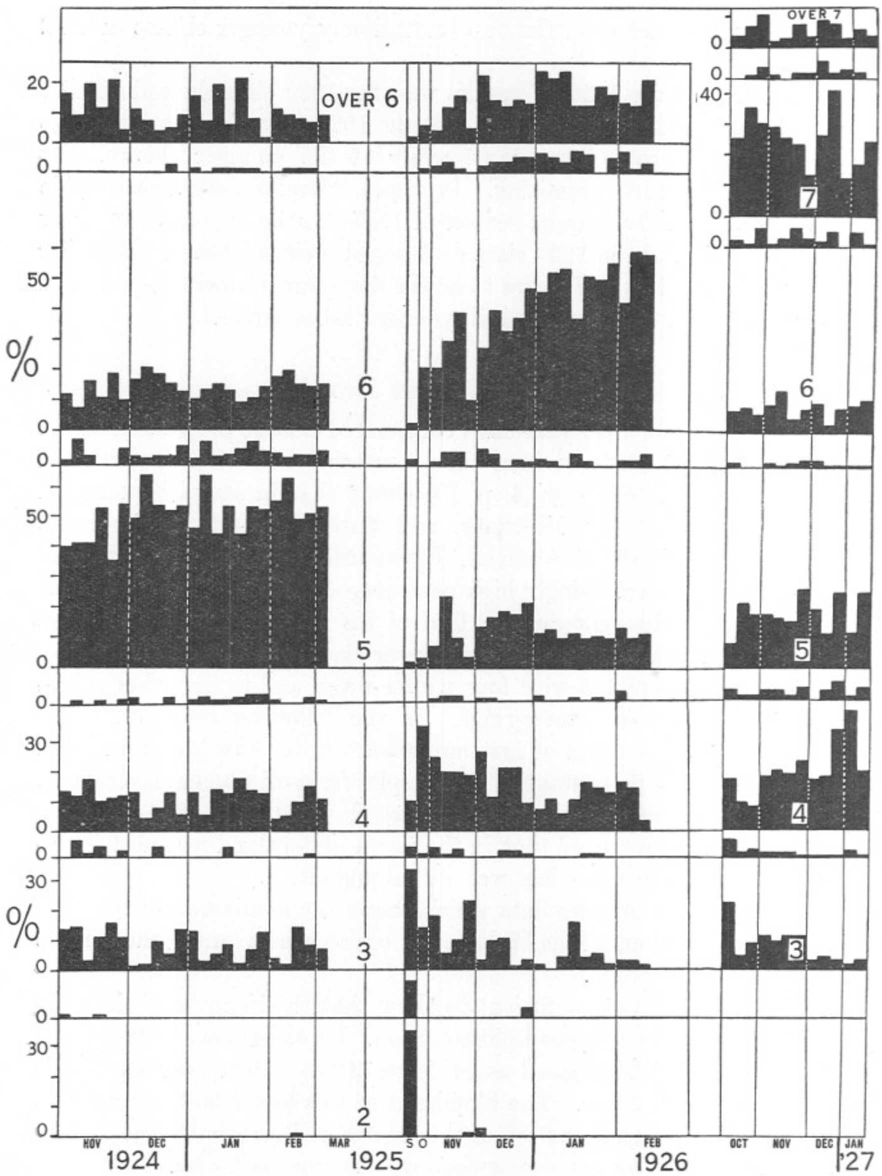

FIG. 5.—Age composition of samples of Plymouth fishes.

Sample percentages are shown as small vertical blocks. The age classes are as follows :—

2	. . . . . .	2-zoned 2-ringed.
3	. . . . . .	3-zoned 3-ringed.
4	. . . . . .	4-zoned 4-ringed.
5	. . . . . .	5-zoned 5-ringed.
6	. . . . . .	6-zoned 6-ringed.
7	. . . . . .	7-zoned 7-ringed.

The " interval " classes are obviously 2 or 3, 3 or 4, 4 or 5, etc.

a younger year-class do swim with the smaller members of an older class. But it is found that the individuals of the same year-class themselves vary in length over a considerable range, and such differences must be attributed to one or both of the following causes :—

1. Some of the individuals were spawned earlier in the season than others.
2. Some of the individuals had experienced better conditions for growth than others during the whole or part of their life.

The study of the growth in length of the Plymouth fish from measurements of their scales has shown that fishes of the same year-class vary to a most perplexing degree in the lengths l_1, l_2 . . . etc., attained at the end of the 1st, 2nd . . . etc., year of life. Whereas, ordinarily, the annual increments of length become successively smaller as the fish gets older, it is frequently seen that some fishes have grown more in a late year than during a preceding one. We have, therefore, to determine how this complex state of affairs has been brought about by the operation of causes (1) and (2) above.

Length for Age.

In the following table the average length and individual variation of fishes of different ages are given :—

Age.	Season.	No. fishes in each of 11 Length groups (cm.). 21	22	23	24	25	26	27	28	29	30	31	Total No.	Average length. cm.	Year-class.
	1924–25	–	3	19	39	68	36	15	3	1	–	–	184	25·5	1922
3-zoned 3-ringed	1925–26	2	10	9	32	44	13	3	–	–	–	–	113	24·9	1923
	1926–27	–	–	4	11	33	27	12	–	–	–	–	87	25·9	1924
	1924–25	–	–	6	13	34	67	72	53	10	2	–	257	27·0	1921
4-zoned 4-ringed	1925–26	–	4	11	33	59	94	87	22	–	–	–	310	26·4	1922
	1926–27	–	2	13	59	88	46	19	14	2	–	–	243	25·7	1923
	1924–25	–	–	–	11	96	304	481	251	33	4	1	1181	27·4	1920
5-zoned 5-ringed	1925–26	–	–	–	10	35	58	79	37	12	2	–	233	27·1	1921
	1926–27	–	–	3	21	54	65	48	25	2	–	–	218	26·5	1922
	1924–25	–	–	1	2	12	59	140	65	26	–	–	305	27·6	1919
6-zoned 6-ringed	1925–26	–	–	–	6	37	106	250	304	97	6	–	806	27·9	1920
	1926–27	–	–	–	4	10	21	34	18	9	2	–	98	27·4	1921
7-zoned 7-ringed	1926–27	–	–	–	–	8	32	90	116	62	3	–	311	28·1	1920

The data as they stand suffice to illustrate the three following points :—

(*a*) Fishes of the same age vary considerably in length.
(*b*) The younger fishes are on average smaller than their older associates.
(*c*) The average length for fishes of the same age is not constant from season to season.

The data may be rearranged to show the successive average lengths for fishes of the same year-class, thus :—

Year-class.	Average Length in cm. during following seasons. 1924–25.	1925–26.	1926–27.
1919 . .	27·6	—	—
1920 . .	27·4	27·9	28·1
1921 . .	27·0	27·1	27·4
1922 . .	25·5	25·4	26·5
1923 . .	—	24·9	25·7
1924 . .	—	—	25·9

It is seen that each year-class, on average, tends to increase in length, but that the absolute increases exhibited cannot be accepted as reliable estimates of the actual increments of growth added.

Length at Formation of First Winter-ring.

As already stated, there is a lack of uniformity in the length l_1, at which the first winter-ring is formed on the scale. The following table shows the value of l_1 for each of a total of 1122 fishes of the 5-zoned 5-ringed class (1920 year-class) taken during the season 1924–25 :—

L_1. Central Values of 13 Classes (cm.).

6·5	7·5	8·5	9·5	10·5	11·5	12·5	13·5	14·5	15·5	16·5	17·5	18·5	Total.
1	14	39	56	100	170	210	174	159	129	57	11	2	1122

Average Value of L_1 = 12·86 cm.
Standard Deviation σ = 2·13 cm.

It is seen from the total range of variation (6·5 cm. to 18·5 cm.) and from the standard deviation (σ=2·13 cm.) that the value of l_1 varies very considerably from fish to fish. The magnitude of the mean l_1 (=12·86 cm.) merely indicates that fishes with l_1 between, say, 11·5 cm. and 14·5 cm. are the most common. These results, in conjunction with those of Hjort (**1**), Storrow (**4**, **5**, **6**), Watkin (**7**), Hodgson (**2**), and Le Gall (**3**), clearly show that wide individual variation in the value of l_1 is a general feature among fishes of the English Channel and to the south-west. Moreover, they show that values of l_1 of 12 cm. and over are most common. It is, therefore, of the greatest importance to determine the relative ages of the fishes at the time when the first winter-ring was formed. This question is considered in Part IV (p. 313).

Growth subsequent to Formation of First Winter-ring.

As was shown in Part I (p. 252), the increment of length added during any one season of growth is dependent upon the length of the fish at the commencement of that season. Thus, having shown above that there is a great amount of variation in the length l_1, it is essential that we should make due allowance for this fact when considering any subsequent growth. The following table shows the calculated values of l_1, l_2, l_3, and l_4 from scale measurements for a total of 244 fishes of the 4-zoned 4-ringed class taken during the season 1924–25 at Plymouth :—

Central Values of 23-length Classes. (cm.).

	8·5	9·5	10·5	11·5	12·5	13·5	14·5	15·5	16·5	17·5	18·5	19·5
l_1	2	7	19	25	26	37	46	48	26	8	–	–
l_2	–	–	–	–	–	–	–	–	2	8	19	39
l_3	–	–	–	–	–	–	–	–	–	–	–	–
l_4	–	–	–	–	–	–	–	–	–	–	–	–

	20·5	21·5	22·5	23·5	24·5	25·5	26·5	27·5	28·5	29·5	30·5	Mean (cm.)	σ (cm.)
l_1	–	–	–	–	–	–	–	–	–	–	–	13·88	2·04
l_2	52	45	51	21	6	1	–	–	–	–	–	21·03	1·68
l_3	1	6	37	48	47	41	46	17	1	–	–	24·68	1·61
l_4	–	–	–	6	13	33	61	69	52	9	1	27·02	1·33

The successive values of the coefficient of correlation (r) between the values l_1 and l_2, l_2 and l_3, and l_3 and l_4 ; and the regression equations linking these values are :—

l_1 and l_2....r=·82 ; l_2=·675 l_1+11·68 .... i.
l_2 and l_3....r=·91 ; l_3=·871 l_2+ 6·36 .... ii.
l_3 and l_4....r=·88 ; l_4=·727 l_3+ 9·07 ....iii.

From equations i to iii it is possible to determine how much a fish of given length will grow during the next season. The following results as calculated from the equations are shown in conjunction with the actual observations :—

Values of l_1 (cm.).

	8·5	9·5	10·5	11·5	12·5	13·5	14·5	15·5	16·5	17·5
Values of l_2—										
Observed	(18·5)	17·93	18·87	19·58	20·15	20·82	21·22	22·29	22·69	(24·0)
l_2= ·675 l_1+11·68	17·42	18·09	18·77	19·44	20·12	20·79	21·46	22·14	22·81	23·49
Growth (l_2–l_1)—										
Observed	(10·0)	8·43	8·37	8·08	7·65	7·32	6·72	6·79	6·19	(6·50)
Calculated	8·92	8·59	8·27	7·94	7·62	7·29	6·96	6·64	6·31	5·99

Values of l_2 (cm.).

	16·5	17·5	18·5	19·5	20·5	21·5	22·5	23·5	24·5	25·5
Values of l_3—										
Observed	21·0	21·87	22·76	23·50	24·02	25·06	26·11	26·79	(27·33)	28·5
l_3= ·871 l_2+6·36	20·73	21·60	22·47	23·34	24·22	25·09	25·96	26·83	27·70	28·57
Growth (l_3–l_2)—										
Observed	4·5	4·37	4·26	4·00	3·52	3·56	3·61	3·29	(2·83)	3·00
Calculated	4·23	4·10	3·97	3·84	3·72	3·59	3·46	3·33	3·20	3·07

Values of l_3 (cm.).

	20·5	21·5	22·5	23·5	24·5	25·5	26·5	27·5	28·5
Values of l_4—									
Observed	(23·50)	(24·17)	25·53	26·39	26·97	27·55	28·22	28·97	(30·5)
$l_4 = \cdot727\ l_3 + 9{\cdot}07$	23·97	24·70	25·43	26·15	26·88	27·61	28·34	29·06	29·79
Growth $(l_4 - l_3)$—									
Observed	(3·00)	(2·67)	3·03	2·89	2·47	2·05	1·72	1·47	(2·0)
Calculated	3·47	3·20	2·93	2·65	2·38	2·11	1·84	1·56	1·29

It is seen from the above, first, that the equations are a reasonable practical "fit" to the data; and, second, that during any one growth-period, the smaller fish adds the larger increment.

Now if we accept equations i to iii and the values of the means as roughly representative of the 4-zoned 4-ringed fishes which visited Plymouth during the season 1924–25, and compare them with the corresponding data for similar-aged fish taken off the Sussex coast (*vide* Part I, p. 248), we find that there is an appreciable difference. In the following table the mean values for l_1, l_2, l_3, and l_4 in the two cases, and the regression equations are shown together, and in Fig. 6 the differences for individual values of l_1, l_2, and l_3 are demonstrated graphically :—

	Plymouth Sample.	Sussex Sample.
Mean l_1 (cm.)	13·88	10·73
Mean l_2 (cm.)	21·03	18·04
Mean l_3 (cm.)	24·68	21·89
Mean l_4 (cm.)	27·02	23·65
Regression Equations	$l_2 = \cdot675\ l_1 + 11{\cdot}68$	$l_2 = \cdot59\ l_1 + 11{\cdot}70$
	$l_3 = \cdot871\ l_2 + 6{\cdot}36$	$l_3 = \cdot504\ l_2 + 12{\cdot}80$
	$l_4 = \cdot727\ l_3 + 9{\cdot}07$	$l_4 = \cdot774\ l_3 + 6{\cdot}71$

It is clear that the Plymouth fish had made a superior growth throughout. This suggests that the Plymouth fish had frequented grounds more favourable for growth than had the Sussex ones, and in seeking to discover grounds where such superior conditions prevail, we naturally look to the more open waters to the south-west. As an immediate working hypothesis, therefore, let us accept the Plymouth regression equations as representative of a life spent in the more open westerly waters, and the Sussex regression equations as representative of a life spent in the enclosed waters of the English Channel. Under this hypothesis we should say that the 4-zoned 4-ringed Plymouth fish had spent all their life in westerly conditions, while those from the Sussex coast had always remained under Channel conditions. So far as is known at present, however, there is no reason to insist that a fish after spawning necessarily returns to the same feeding area from which it came. That is to say, we need not insist that a fish coming from the open west to spawn at Plymouth shall return to the westward again—it may possibly elect to spend the next feeding season within the confines of the enclosed Channel. Here it will be subject to Channel conditions of growth, and on its next return to Plymouth to spawn, if such return happens to take place, it will be of an inferior length to that shown by a western migrant. If this same process was repeated year by year, it is easily seen that the

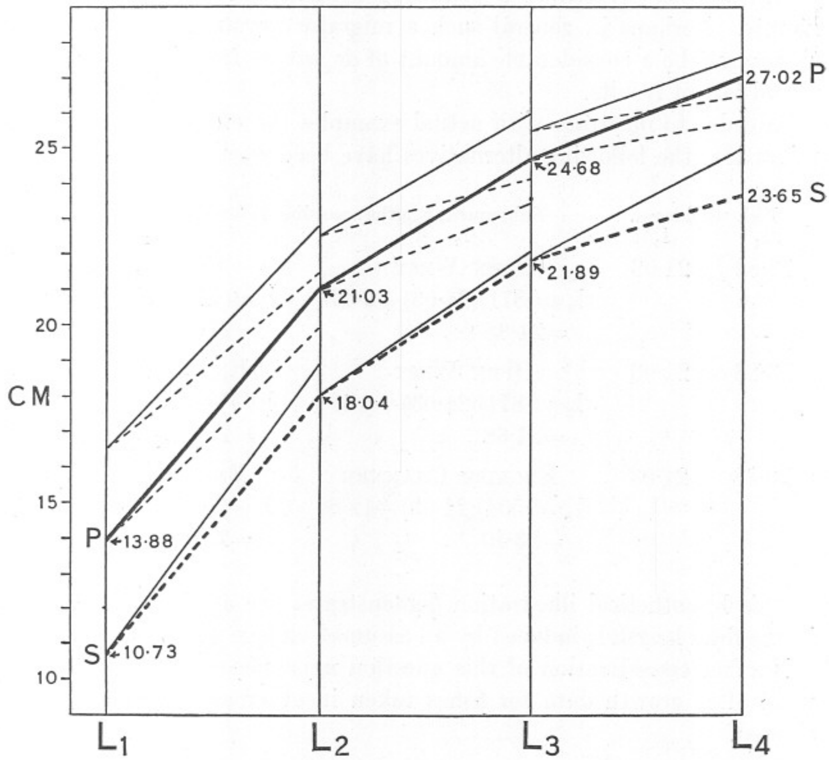

FIG. 6.—Comparison between growth of 4-zoned 4-ringed fishes from Plymouth (1924–25) and from the Sussex Coast.

Continuous line PP . . Mean values for Plymouth fish.
Continuous dotted line SS . ,, ,, ,, Sussex fish.

The Plymouth and Sussex values for given values of l_1, l_2, and l_3 are calculated from the regression equations given in the text on opposite page.

growth characters of the spawning stock at Plymouth would yearly become more and more complicated.

But it may also be said that we have, as yet, no proof that a fish invariably returns to the same ground to spawn. Thus, a fish coming from the westward to spawn at Plymouth might then proceed to the eastward for a season's feeding there and then move off to spawn, not at Plymouth, but on a spawning ground, say, at the east end of the Channel off the

French coast. This process in operation would also tend to produce a complex spawning population.

The above may be criticised by some as highly speculative, but it must be remembered that the spawning stock under investigation at Plymouth seems so mixed that it is almost impossible to believe that it may be explained in terms of some simple uniform unaltered annual movement from one feeding area to a spawning ground and a return to former haunts. Perhaps in general such a migratory system does apply, but there must be a considerable amount of departure from it to account for the observed results.

In order to illustrate with actual examples the effects of a change of migration, the following alternatives have been worked out :—

Fish considered.		Subsequent lengths according to feeding-area visited.	
l_1	l_2	l_3	l_4
13·88	21·03	OPEN WEST $l_3=(\cdot 871)(21\cdot 03)+6\cdot 36$ $=24\cdot 68$	OPEN WEST $l_4=(\cdot 727)(24\cdot 68)+9\cdot 07$ $=27\cdot 02$
13·88	21·03	OPEN WEST $l_3=(\cdot 871)(21\cdot 03)+6\cdot 36$ $=24\cdot 68$	ENGLISH CHANNEL $l_4(\cdot 774)(24\cdot 68)+6\cdot 71$ $=25\cdot 82$
13·88	21·03	ENGLISH CHANNEL $l_3=(\cdot 504)(21\cdot 03)+12\cdot 80$ $=23\cdot 40$	ENGLISH CHANNEL $l_4=(\cdot 774)(23\cdot 40)+6\cdot 71$ $=24\cdot 82$

This hypothetical illustration demonstrates the appreciable difference in the final length l_4 induced by an assumed change in migration.

Further consideration of this question must necessarily be postponed until after growth data for fishes taken in other areas have been considered.

The Average Number of Vertebræ.

Details of the sample averages obtained for the Plymouth fishes have already been given in Part II of this series (see Table I on p. 277). Little may be added at this stage to what was given in Part II, save to emphasize the need for study of the effect on the average number of vertebræ of the possible change of spawning and feeding grounds by a fish from one year to the next. A change of feeding ground may result in significant differences in average number of vertebræ among samples taken in the feeding area, while a change in spawning ground may similarly result in significant differences in average number of vertebræ among samples taken on that spawning ground.

Movements of Shoals.

From what has been said in the preceding paragraphs it will be evident that the writer favours the hypothesis that the shoals which visit Plymouth for the winter spawning arrive both from the English Channel and from the more open waters off the south-west coast. The fishes coming from the west show a better increment of growth for the previous summer than those arriving from the east. After spawning, neither easterly nor westerly migrants necessarily return to the feeding grounds from whence they came. The general situation on the spawning grounds may be further complicated by reason of the presence of fish which in other years had spawned elsewhere. But as the distance over which a herring migrates during any one season is not likely to be excessively large, fishes will tend to remain roughly centralised about the spawning area in which they themselves were spawned.

The above must, however, be regarded purely as a working hypothesis until the data for samples in other areas have been discussed. With regard to the Plymouth samples already obtained it would provide a feasible explanation of the mixed populations experienced, and it would account for the fact that French trawlers can capture herrings during the summer months in the English Channel. It would also account for the similarity in growth between fishes caught off the south-west coast of Cornwall and those at Plymouth, as recorded by Watkin (**7**).

ACKNOWLEDGMENTS.

I thank Mr. T. Edser, of the Statistical Department, Ministry of Agriculture and Fisheries, for his kindness in giving me free access to statistical returns relating to the western fisheries, and Mr. A. J. Smith, of the Laboratory staff at Plymouth, for keeping a most helpful diary of the daily landings of herrings at the fish markets. I would also like to express my gratitude to those members of the local and visiting fleets who have so kindly volunteered information concerning their catches and the fishery in general.

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TABLE I.

Condition of Ovary (Season 1924–25 at Plymouth).

Sample.	Date.	Total No. fishes examined.	Percentage No. of Specimens with Ovaries in following condition. Unripe.	Mature.	Spent.
	1924				
A	Nov. 11	51	100	–	–
B	Nov. 13	55	100	–	–
C	Nov. 17	70	100	–	–
D	Nov. 20	65	100	–	–
E	Nov. 22	39	44	56	–
F	Nov. 28	57	100	–	–
G	Dec. 3	58	100	–	–
H	Dec. 9	53	98	–	2
K	Dec. 16	55	65	4	31
L	Dec. 19	51	100	–	–
M	Dec. 22	71	28	69	3
N	Dec. 30	65	28	60	12
	1925				
P	Jan. 5	64	47	3	50
Q	Jan. 8	54	28	61	11
R	Jan. 8	50	30	48	22
S	Jan. 13	68	7	87	6
T	Jan. 16	49	10	63	27
U	Jan. 20	65	14	86	–
V	Jan. 27	40	10	90	–
W	Feb. 2	68	6	66	28
X	Feb. 9	84	–	5	95
Y	Feb. 18	57	9	7	84
Z	Feb. 20	65	3	3	94
a	Mar. 2	66	12	15	73

TABLE II.

Sample.	Date.	Total No. of Fishes.	Length Distribution (cm.). Lower Limit.	Lower Quartile Q_1.	Median Q_2.	Upper Quartile Q_3.	Upper Limit.
	1924						
A	Nov. 11	100	23·7	26·3	27·3	28·5	30·0
B	Nov. 13	100	23·0	25·7	26·9	27·8	30·5
C	Nov. 17	119	25·5	26·9	27·8	28·6	30·7
D	Nov. 20	116	22·3	26·5	27·4	28·0	30·0
E	Nov. 22	112	23·5	25·9	27·0	27·9	29·6
F	Nov. 28	117	24·4	26·4	27·2	27·8	29·9
G	Dec. 3	124	25·1	26·9	27·6	28·4	31·0
H	Dec. 9	115	25·0	26·6	27·3	27·9	29·9
K	Dec. 16	134	22·8	25·9	27·0	27·7	30·5
L	Dec. 19	106	23·6	27·1	27·7	28·6	30·0
M	Dec. 22	173	23·0	25·8	27·1	28·0	30·5
N	Dec. 30	136	21·7	25·3	26·4	27·4	30·9
	1925						
P	Jan. 5	121	22·5	26·7	27·6	28·5	30·4
Q	Jan. 8	123	25·0	27·1	27·7	28·4	30·1
R	Jan. 8	115	24·5	27·0	27·75	28·7	30·5
S	Jan. 13	126	23·0	25·7	26·8	27·6	30·8
T	Jan. 16	118	25·0	27·3	28·2	29·0	30·6
U	Jan. 20	126	23·2	27·0	27·6	28·4	30·0
V	Jan. 27	97	23·4	26·0	27·1	27·8	29·2
W	Feb. 2	124	23·3	26·3	27·1	27·9	30·6
X	Feb. 9	140	24·9	27·0	27·7	28·5	30·2
Y	Feb. 18	119	23·8	26·3	27·3	28·2	30·8
Z	Feb. 20	123	24·2	26·4	27·3	28·0	31·1
a	Mar. 2	119	24·2	26·2	27·1	27·9	31·8
	1925						
b	Sept. 2	53	21·4	22·6	23·5	25·1	26·7
e	Oct. 25	121	23·4	25·1	26·0	27·1	29·2
f	Nov. 1	110	23·2	25·6	26·7	27·6	29·6
g	Nov. 4	121	25·2	26·6	27·3	27·8	30·1
h	Nov. 18	110	23·4	25·3	26·1	27·2	29·9
k	Dec. 1	119	22·1	25·5	26·3	27·2	29·8
l	Dec. 6	120	21·5	26·6	27·9	28·8	31·1
m	Dec. 15	116	21·5	25·3	27·1	28·3	30·8
n	Dec. 21	115	25·1	27·2	28·0	28·9	30·5
o	Dec. 23	119	23·5	26·5	27·4	28·4	30·3

TABLE II—*continued.*

Sample.	Date.	Total No. of Fishes.	Length Distribution (cm.). Lower Limit.	Lower Quartile Q_1.	Median Q_2.	Upper Quartile Q_3.	Upper Limit.
	1926						
p	Jan. 1	120	23·5	26·9	27·8	28·7	31·2
q	Jan. 6	117	23·5	27·0	28·2	29·0	30·7
r	Jan. 10	119	22·2	27·4	28·3	28·9	31·8
s	Jan. 14	120	21·5	25·7	27·0	28·1	29·9
t	Jan. 18	117	23·4	26·9	27·8	28·6	30·0
u	Jan. 25	116	24·5	27·2	28·0	28·7	30·3
v	Jan. 28	116	24·1	26·75	27·7	28·5	30·3
w	Feb. 2	112	23·3	27·2	27·9	28·6	30·5
x	Feb. 4	120	23·5	26·8	27·7	28·5	29·9
y	Feb. 10	119	24·5	27·1	27·8	28·7	30·0
	1926						
AA	Oct. 18	111	24·5	26·5	27·7	28·95	30·5
BB	Oct. 21	115	23·7	27·1	27·8	28·6	30·9
CC	Oct. 25	115	23·3	26·5	27·7	28·6	30·2
DD	Nov. 3	119	24·5	25·6	26·2	28·1	30·5
EE	Nov. 4	117	24·5	25·6	26·4	27·2	29·5
FF	Nov. 15	110	24·1	25·7	26·6	27·75	29·5
GG	Nov. 23	110	24·5	25·9	26·9	27·8	29·6
HH	Nov. 30	120	23·7	25·3	26·1	27·2	30·1
JJ	Dec. 6	115	23·5	25·3	26·6	27·4	29·5
LL	Dec. 20	110	24·3	27·1	28·2	29·0	29·9
MM	Dec. 20	120	23·0	24·4	25·4	26·9	29·8
NN	Dec. 30	203	22·5	24·4	25·7	27·3	29·5
	1927						
OO	Jan. 4	117	22·5	24·7	26·4	27·9	30·1
PP	Jan. 19	120	24·3	25·6	26·6	28·3	30·2

TABLE III.

Percentage Age Composition.

Sample.	Date.	2	2–3	3	3–4	4	4–5	5	5–6	6	6–old.	Older than 6.	Total No. of Fish in Sample.
	1924												
A	Nov. 11	–	1·0	13·5	–	13·5	–	41·7	1·0	12·6	–	16·7	96
B	Nov. 13	–	–	14·4	5·2	12·4	1·0	42·3	8·2	7·2	–	9·3	97
C	Nov. 17	–	–	2·6	·9	17·1	–	41·8	2·6	15·4	–	19·6	117
D	Nov. 20	–	·9	10·6	2·7	9·8	·9	53·9	–	10·6	–	10·6	113
E	Nov. 22	–	–	15·7	–	11·1	–	35·2	–	17·6	–	20·4	108
F	Nov. 28	–	–	10·7	1·9	11·7	1·9	55·4	4·9	9·7	–	3·9	103
G	Dec. 3	–	–	1·0	–	13·7	2·1	52·6	3·2	15·8	–	11·6	95
H	Dec. 9	–	–	2·0	–	4·1	–	65·3	2·0	19·4	–	7·2	98
K	Dec. 16	–	–	9·4	3·1	8·3	–	55·3	3·1	17·7	–	3·1	96
L	Dec. 19	–	–	5·2	–	13·5	2·1	54·2	3·3	14·6	2·1	5·2	96
M	Dec. 22	–	–	13·5	–	5·8	–	53·8	5·8	11·5	–	9·6	104
N	Dec. 30	–	–	–	–	No Data.		–	–	–	–	–	–
	1925												
P	Jan. 5	–	–	13·1	–	13·1	1·0	46·5	2·0	9·1	1·0	14·2	99
Q	Jan. 8	–	–	3·0	–	6·0	2·0	64·0	7·0	12·0	–	6·0	100
R	Jan. 8	–	–	4·7	–	14·0	1·2	44·2	2·3	14·0	1·2	18·6	86
S	Jan. 13	–	–	8·1	3·0	13·1	1·0	53·6	3·0	12·1	1·0	5·1	99
T	Jan. 16	–	–	2·0	–	17·0	2·0	44·0	5·0	8·0	1·0	21·0	100
U	Jan. 20	–	–	6·0	–	14·0	3·0	53·0	7·0	9·0	1·0	7·0	100
V	Jan. 27	–	–	12·4	–	13·4	3·1	52·6	4·1	13·4	–	1·0	97
W	Feb. 2	–	–	4·3	–	4·3	1·0	58·5	3·2	17·0	–	11·7	94
X	Feb. 9	–	–	2·0	–	5·0	–	63·0	2·0	18·0	1·0	9·0	100
Y	Feb. 18	1	–	14·1	–	10·1	–	49·6	3·0	14·1	1·0	7·1	99
Z	Feb. 20	–	–	8·0	1·0	15·0	2·0	51·0	3·0	13·0	1·0	6·0	100
a	Mar. 2	–	–	7·1	–	11·1	1·0	53·6	4·0	14·1	–	9·1	99
	1925												
b	Sept. 2	36	12	32	–	10	–	2	2	2	–	2	50
e	Oct. 25	–	–	14	2	35	–	3	–	21	1	6	100
f	Nov. 1	–	–	18	4	22	1	7	1	21	2	4	100
g	Nov. 4	–	–	5	1	19	2	24	4	30	3	12	100
h	Nov. 18	1	–	10	3	19	2	10	4	39	1	16	100
j	Nov. 20	3	3	23	–	18	–	4	–	10	–	5	100
k	Dec. 1	–	–	3	–	27	1	13	5	27	2	21	100
l	Dec. 6	–	–	9	–	12	1	16	3	40	3	14	100
m	Dec. 15	–	–	10	2	22	–	18	–	34	3	11	100

TABLE III—*continued.*

Sample.	Date.	2	2–3	3	3–4	4	4–5	5	5–6	6	6–old.	Older than 6.	Total No. of Fish in Sample.
n	Dec. 21	–	–	1	2	22	–	17	2	38	4	14	100
o	Dec. 23	–	–	3	1	10	–	21	1	48	4	12	100
	1926												
p	Jan. 1	–	–	2	–	8	2	11	2	47	5	23	100
q	Jan. 6	–	–	–	–	11	–	12	1	53	4	18	100
r	Jan. 10	–	–	4	–	6	–	9	–	54	3	23	100
s	Jan. 14	–	–	16	1	11	1	11	3	38	7	11	100
t	Jan. 18	–	–	4	1	17	–	9	1	51	6	11	100
u	Jan. 25	–	–	5	1	15	1	10	–	50	–	18	100
v	Jan. 28	–	–	2	–	13	–	9	–	55	4	15	100
w	Feb. 2	–	–	3	–	17	3	12	1	42	7	13	100
x	Feb. 4	–	–	3	–	15	–	9	1	59	1	12	100
y	Feb. 10	–	–	1	–	4	–	11	3	58	3	20	100

	1926	2	2–3	3	3–4	4	4–5	5	5–6	6	6–7	7	7–old.	Older than 7.	Total No. of Fish in Sample.
AA	Oct. 18	–	–	22	5	17	3	8	2	7	2	26	–	4	100
BB	Oct. 21	–	–	4	1	9	1	22	–	8	1	36	1	7	100
CC	Oct. 25	–	–	8	2	8	1	18	–	6	6	31	4	11	100
DD	Nov. 3	–	–	11	1	18	3	18	2	9	1	30	1	2	100
FF	Nov. 15	–	–	9	1	20	3	17	1	14	3	26	–	3	100
GG	Nov. 23	–	–	11	1	19	1	16	2	5	6	24	2	8	100
HH	Nov. 30	–	–	11	–	23	4	26	3	8	3	14	2	4	100
JJ	Dec. 6	–	–	3	–	17	–	20	3	10	2	27	6	9	100
LL	Dec. 20	–	–	4	–	18	3	11	1	3	5	42	2	8	100
MM	Dec. 20	–	–	3	–	34	6	25	1	8	–	13	3	3	100
	1927														
OO	Jan. 4	–	–	2	2	40	1	12	1	9	5	17	2	6	100
PP	Jan. 19	–	–	3	–	20	4	25	1	11	1	25	–	4	100