Part III. The Zooplankton-Herring Correlations in the Scottish Fisheries.

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With 7 Figures in the Text.

Contents

Introduction.

This section deals with the Plankton Indicator experiments in the herring fisheries in Scottish waters carried out from 1930 to 1933, together with a note on a few results from Irish waters in the spring of 1931. The Scottish waters are here defined as those lying north of latitude 56° N. This extensive area is divided into two sections, the Eastern Fishery and the Western Fishery, by the meridian of 5° W. longitude. The eastern section, being the more important and having been more thoroughly sampled, will be dealt with first.

The Eastern Fishery.

Area.

The most northerly sample was taken in Lat. 60° 56′ N., and the most easterly in Long. 1° 30′ E.,* so that the area investigated is some 50,000

* Excluding three isolated samples in longitudes 2° 55′ E., 4° 08′ E. and 4° 13′ E.

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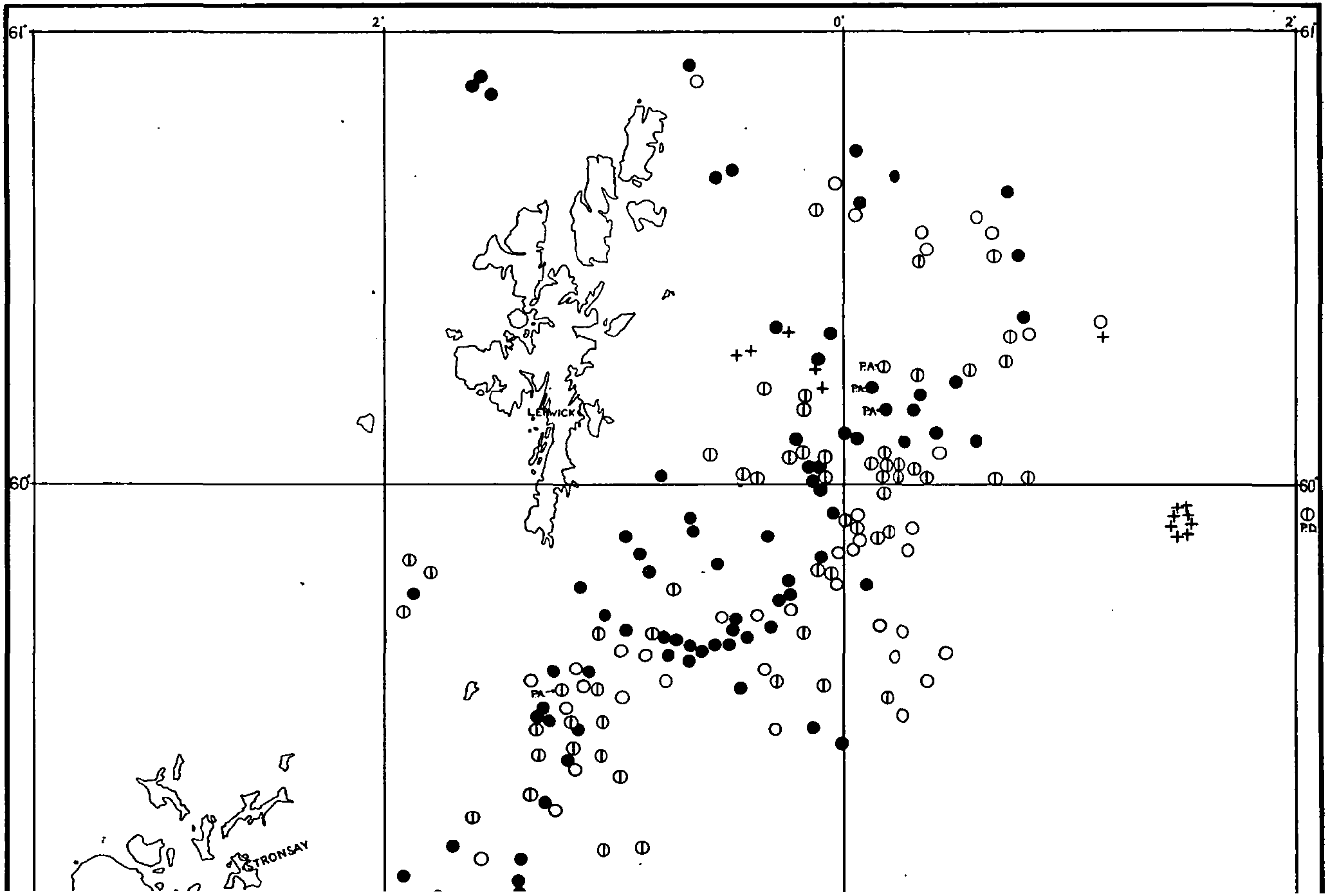
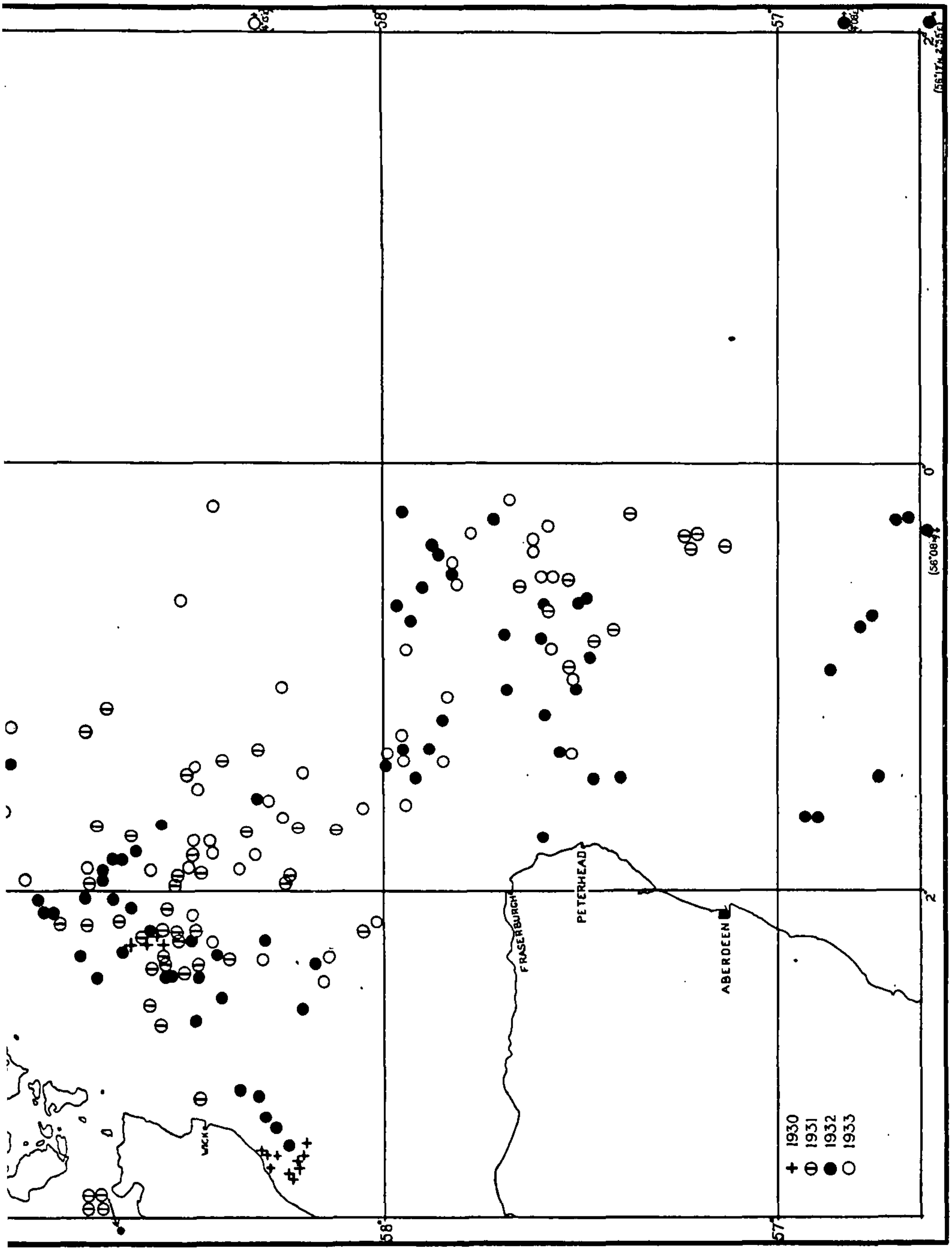


FIG. 1.—Chart showing the distribution of Plankton Indicator samples in the Scottish Eastern Fishery, 1930-1933. (P.D., Position doubtful; P.A., Position approximate. The star indicates that the four samples concerned are situated farther west along the north coast than the chart extends.)



https://doi.org/10.1017/S0025315400011280 Published online by Cambridge University Press

square miles in extent. Ninety per cent of the samples, however, lie within a smaller region of some 18,000 square miles. Even so, in view of the space and time considerations discussed in Part I (p. 161), this is too extensive to be treated as a whole and is divided, by the parallels of latitude of 60° N., 59° N., and 58° N., into four smaller areas (Part I, Fig. 5), which correspond in general to the grounds fished from Lerwick, Stronsay, Wick and Peterhead (and their adjacent ports) respectively. Fig. 1 shows the distribution of the samples taken in the Eastern Fishery.

MATERIAL.

In all, 377 plankton samples were obtained with records of 410 catches of herring, distributed through four summer seasons as follows :—

1930	28	samples	with	46	catches	of herring.
1931	112	,,	,,	117	,,	,,
1932	150	,,	,,	157	,,	,,
1933	87	,,	,,	90	,,	,,

In 1930 all the samples returned were taken by patrol ships,* and were so distributed that several somewhat restricted regions were sampled on occasions separated by considerable intervals of time. In 1931, 1932, and 1933, however, drifters engaged in the fishery took the majority of the samples,† so that the distribution, both in space and time, is much more even. While the 1930 material is insufficient in itself to provide reliable results, we may use it to support those obtained from the more extensive material of the other three years.

ABUNDANCE AND DISTRIBUTION OF CALANUS.

The importance of the copepod *Calanus finmarchicus*‡ in the ecology of the herring is well known (Hardy 1924, Jespersen 1928, Savage 1931), and, since the main correlations are with this species, its abundance and distribution are discussed first.

Table I shows the average numbers of Calanus per sample for half-month periods, the index figures showing the numbers of samples averaged. The two more southerly areas are combined as there are relatively few samples

* Cruisers of the Scottish Fishery Board and gunboats of the Fishery Protection and Minesweeping Flotilla. These have sometimes towed the instrument between the nets of two or more drifters fishing close together (within a distance of a mile) and noted all the catches. This accounts for the number of catches being greater than the number of samples.

† The methods of using the Indicator from patrol ships and drifters are described in Part I, page 153.

‡ Where the term Calanus is used in this paper the species *Calanus finmarchicus* (Günn.) is referred to.

from S. of 57° N. lat., and the Shields figures* are entered for comparison. Omitting the restricted material for 1930 the outstanding features may be summarised as follows :—

(1) There appears to be a progressive increase in the abundance of Calanus over the three years, the average numbers being 125 for 1931, 241 for 1932 and 894 for 1933 (these figures being based on 112, 150 and 87 samples respectively). Restricting the material to that obtained between mid-June and the end of July, a period well sampled in all the

TABLE I.

AVERAGE CALANUS PER SAMPLE PER HALF-MONTH.

Year.	Area.	May 16–31	June 1–15	June 16–30	July 1–15	July 16–31	August 1–15	August 16–31
1930	N. of 60° N.		175^{5}	—	—	0^{1}		
,,	59°–60° N.			897^{8}				
,,	S. of 59° N.					8^{4}	16^{10}	
1931	N. of 60° N.			326^{15}	49^{8}	93^{5}		
,,	59° to 60° N.		11^{2}	110^{9}	82^{10}	161^{11}		
,,	S. of 59° N.			35^{8}	5^{11}	63^{17}	272^{11}	
,,	Shields		41^{6}	99^{24}	64^{21}	76^{37}	93^{17}	68^{29}
1932	N. of 60° N.			188^{10}	7^{13}	127^{8}		
,,	59° to 60° N.			102^{18}	57^{9}	145^{21}	1420^{1}	
,,	S. of 59° N.	512^{3}	1375^{1}	—	279^{16}	620^{14}	306^{28}	265^{6}
,,	Shields	474^{43}	864^{50}	912^{45}	189^{32}	—	175^{11}	99^{21}
1933	N. of 60° N.			458^{7}	817^{3}			
,,	59° to 60°		2947^{9}	1330^{17}	688^{5}			
,,	S. of 59° N.		283^{3}	448^{11}	389^{15}	682^{11}	93^{5}	
,,	Shields		200^{40}	389^{38}	1022^{25}	648^{25}	70^{39}	

years, the figures are a little lower but show the same upward trend as follows :—111 for 1931, 197 for 1932 and 724 for 1933 (based on 97, 109 and 69 samples respectively). These figures confirm the conclusion of Ogilvie (1934) who, comparing 1933 with 1931, says Calanus "was considerably more abundant in 1933." It is worthy of note here that the influx of Atlantic water into the North Sea was greater than usual in 1932 and 1933, particularly in the latter year.†

* For further information relating to the abundance of Calanus in the Shields Fishery, see Part II.

† Strong Atlantic inflow resulted in temperatures $1\frac{1}{2}$° to 2° C. greater than normal in 1932, 2° to 3° C. in 1933, and salinities described as "higher than usual" in the summer of 1932, and "unusually high" in surface layers in the extreme north, and in sub-surface layers farther south, in June and July of 1933. Further evidence is the recovery of drift bottles liberated in Scottish waters from the coasts of Lincolnshire, Norfolk and Suffolk, a somewhat unusual occurrence. Also significant numbers of such drift bottles were recovered from the Danish coast south of 56° 30′ N. Lat. (Ann. Rep. Fish. Bd. Scot. 1933 and 1934.) See also Part II (p. 224).

(2) In each of the three years there is a general tendency for the Calanus numbers to be low in the first half of July.* Gibbons (1933) finds for earlier years that June and September are the periods of greatest abundance in the area South of 58° 45′ N., but that North of this July is the month of maximum numbers. Differences in the vertical distribution of Calanus in the northern and southern parts of the area in the summer months may explain the difference between our results in the area N. of 59° N. and those of Gibbons, since our sampling is confined to a depth of 7–10 metres (the region of the herring nets) while Gibbons' material is largely from vertical hauls. However, it should be noted that Lucas shows, for the Shields area (Part II, p. 219), how in general the variations in the Calanus numbers taken by the Indicator (at 7–10 metres) correspond with the fluctuations in the numbers found by Savage in the herring stomachs during the same period. The figures showing the abundance of Calanus for the area South of 59° N., while not extensive enought to permit a detailed comparison, indicate a general agreement with Gibbons' results.

CALANUS-HERRING CORRELATIONS.

Since there are such wide differences in the ranges of Calanus numbers in different areas and at different seasons it is not possible to adopt a fixed scale with which to correlate the herring catches. The method adopted is discussed in detail by Prof. Hardy in Part I (pp. 161–164), and briefly is as follows :—The samples in each area are grouped into short-time periods, and for each area-period the samples, with their corresponding catches, are arranged in ascending order of Calanus numbers : the series thus formed is divided into two parts, one containing the lower half, and the other the higher half, of the Calanus numbers. The catches corresponding to the samples in each half can then be compared. Examples of two such correlations are given on pages 162 and 163 of Part I.

In the Scottish Fisheries the half-month† was adopted as the shortest time-period which gave a reasonable number of " units " (i.e. Calanus sample and corresponding herring catch) in the correlation, and we have fixed 10 as the number of units required to form a " valid " or " primary " table from which deductions may be made. Tables for those area-periods which have only 6 to 9 units have been drawn up, but will be termed " secondary," and will only be used to indicate the probable trend of the

* The writer, working in a drifter to the eastward of the Shetlands during the middle of July, 1932, found very few Calanus in the samples obtained (rarely more than *ca.* 25) although a fairly wide area was covered, and samples taken frequently when steaming in addition to those taken just before shooting.

† Occasionally, at the beginning or end of a period, an odd day, not otherwise included, has been added to increase the number of units in a correlation, e.g. 16 July to 1 August, 1932.

correlations. These are listed separately from the primary tables. Periods having less than 6 units available have been discarded.

There are twenty primary area-periods during the four years 1930 to 1933 and eleven secondary area-periods ; Tables II and III below show their distribution and indicate the sign of the correlation in each, i.e. whether it is positive in that more herring were taken in the richer Calanus water, or negative in that fewer herring were taken in such water.

TABLE II.

Primary Correlation Tables.

Area.	1930.		1931.		1932.		1933.	
N. of 60° N.			16–30 June	+	16–30 June	+		
					1–15 July	+		
59° to 60° N.	16–30 June	+	1–15 July	+	16–30 June	+	16–30 June	–
			16–31 July	+	16 July–1 Aug.	+		
58° to 59° N.	1–15 Aug.	–	16–30 June	+	1–15 Aug.	–	1–15 July	+
			1–15 July	+			16–31 July	+
			16–31 July	+				
56° to 58° N.			31 July–15 Aug.	+	1–15 July	–	16–30 June	–
					1–15 Aug.	+		

TABLE III.

Secondary Correlation Tables.

Area.	1930.		1931.		1932.		1933.	
N. of 60° N.	1–15 June	+	1–15 July	+	16–31 July	+	15–30 June	–
59° to 60° N.			16–30 June	+	1–15 July	–	1–15 June	+
							1–15 July	+
58° to 59° N.	16–31 July	+			16–31 July	+		
56° to 58° N.					16–31 July	–		

Table II above shows fifteen positive and five negative correlations, and in Table III the eleven secondary area-periods suggest eight positive and three negative correlations. We see that on the whole the tendency of the correlations is positive. The secondary tables support in detail, as well as in general, the main results. Summaries of the results of these correlations of primary and secondary periods are shown in Tables IV and V respectively.

It is interesting to note how closely the results for the Shields Fishery (Part II, p. 209) agree with those for the Scottish Fishery. For the Shields Fishery the "all boat" results give fifteen positive and five negative correlations, and the "individual boat" results twenty-three positive and eight negative correlations. That is, in each series, two Scottish and two Shields, we find a three-to-one ratio of positive to negative correlations.

COMMERCIAL SIGNIFICANCE OF THE CALANUS-HERRING CORRELATIONS.

A brief statement of the results of the correlation tables, as such, has been given above, and the next step is to show how these results are of value to the herring fishery if the Indicator is used as a means of locating the water rich in Calanus. The commercial application of the Indicator is discussed in Part I (p. 165). The results of the correlations, expressed as being positive or negative, are not sufficient to enable an evaluation of the method to be attempted, so that a " term " must be found which is common to all the correlations and independent of variations in range of Calanus figures and catches. The method of obtaining such a " term," in the form of the gain or loss which would have resulted from avoiding the waters poorer in Calanus, expressed as a percentage of the total actual catch, is demonstrated, with examples, in Part I (p. 162), and Table IV gives these figures (in col. 13) for all the primary correlations, Table V giving the secondary results. The reasons for adopting this method of evaluating the correlations rather than one of a number of other methods are fully discussed in Parts I (p. 161) and II (p. 180).

The correlation tables for 1930, for two primary and two secondary area-periods, differ from those for the other years in that each is based on material collected by a patrol ship on a single day within a very restricted area.* In one table, for 7th August, where a markedly negative correlation is found, sixteen of the nineteen samples had Calanus numbers ranging from 0 to 20 and the highest did not exceed 100. These 1930 results are not, therefore, included with those of the other three years except where stated.

For the years 1931 to 1933 there are eighteen primary area-period correlation tables. Five of these tables show a gain or loss not greater than 10%, which might commercially be regarded as unimportant† and so will be termed " neutral." Of the remaining thirteen, eleven show gains ranging from 12·3% to 85·2% and two show losses of 11·1% and 30·4%. The eighteen tables show an average gain of 24·5%.

Nine secondary area-period tables during 1931–33 indicate results as follows :—four are neutral, four indicate gains ranging from 28·5% to 100%,‡ and one indicates a loss of 100%.§ These secondary tables when combined indicate an average gain of 16·4%.

* The most extensive group only covered an area about 8 × 5 miles.

† These results average a gain of 0·5%.

‡ All catches in poorer Calanus water blank, total catch in richer Calanus water 7·5 crans.

§ All catches blank, except one of 5·75 crans in poorer Calanus water.

TABLE IV.

SUMMARY OF DATA RELATING TO THE CALANUS-HERRING CORRELATIONS IN THE SCOTTISH FISHERIES 1930 to 1933, FOR PRIMARY PERIODS ONLY.

Year.	Period.	Area.	No. of Samples.	Calanus Range.	Calanus Av.	Catch (in crans). Range.	Catch (in crans). Av.	Total catch in water of Lower Calanus Numbers.	Total catch in water of Higher Calanus Numbers.	Average catch in water of Lower Calanus Numbers.	Average catch in water of Higher Calanus Numbers.	Percentage Gain or Loss on total catch.
1930	16–30 June	59° to 60° N.	10	510–1360	922	23·00–55·75	43·00	188·75	241·00	37·8	48·2	+12·2
	1–15 Aug.	58° to 59° N.	19	0–100	21	0·00–30·00	5·40	96·50	6·50	10·2	0·7	—87·4
1931	16–30 June	N. of 60° N.	15	0–1560	326	0·00–50·00	12·60	82·75	106·00	11·0	14·1	+12·3
	,,	58° to 59° N.	13	4–74	40	0·00–5·50	1·00	3·75	9·00	0·6	1·4	+41·2
	1–15 July	59° to 60° N.	10	0–416	82	0·00–6·00	2·00	9·00	10·50	1·8	2·1	+ 7·7
	,,	58° to 59° N.	11	0–40	5	0·00–38·00	7·70	20·75	64·25	3·8	11·7	+51·2
	16–31 July	59° to 60° N.	11	1–800	161	0·00–27·00	8·20	17·50	72·50	3·2	13·2	+61·0
	,,	58° to 59° N.	15	0–200	64	0·00–5·50	1·20	4·30	14·10	0·6	1·9	+53·1
	31 July–15 Aug.	56° to 58° N.	11	14–656	261	0·00–3·50	1·20	1·00	12·50	0·2	2·3	+85·2
1932	16–30 June	N. of 60° N.	10	0–515	188	4·00–35·00	15·00	72·50	77·50	14·5	15·5	+ 3·3
	,,	59° to 60° N.	19	0–395	97	0·00–90·00	22·80	183·125	250·725	19·3	26·4	+15·6
	1–15 July	N. of 60° N.	13	0–50	5	0·00–40·00	10·10	62·92	68·59	9·7	10·6	+ 4·3
	,,	56° to 58° N.	12	0–865	222	1·00–14·00	8·30	54·50	45·50	9·1	7·6	— 9·0
	16 July–1 Aug.	59° to 60° N.	22	1–1420	194	0·00–72·00	22·80	157·00	345·25	14·3	31·4	+37·5
	1–15 Aug.	58° to 59° N.	22	0–820	184	0·00–30·00	5·10	73·50	39·25	6·7	3·6	—30·4
	,,	56° to 58° N.	10	5–1080	510	0·00–17·00	5·30	21·50	31·25	4·3	6·25	+18·5
1933	16–30 June	59° to 60° N.	19	88–4200	1306	0·00–52·00	14·40	142·40	131·90	15·0	13·9	— 4·0
	,,	56° to 58° N.	10	10–2000	393	1·00–30·00	12·15	67·50	54·00	13·5	10·8	—11·1
	1–15 July	58° to 59° N.	11	0–1580	423	0·00–71·00	13·30	58·00	88·25	10·6	16·1	+20·7
	16–31 July	58° to 59° N.	11	0–1415	682	0·00–30·00	3·90	3·50	39·50	0·6	7·2	+83·7

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TABLE V.

SUMMARY OF DATA RELATING TO THE CALANUS-HERRING CORRELATIONS IN THE SCOTTISH FISHERIES 1930 TO 1933, FOR SECONDARY PERIODS ONLY.

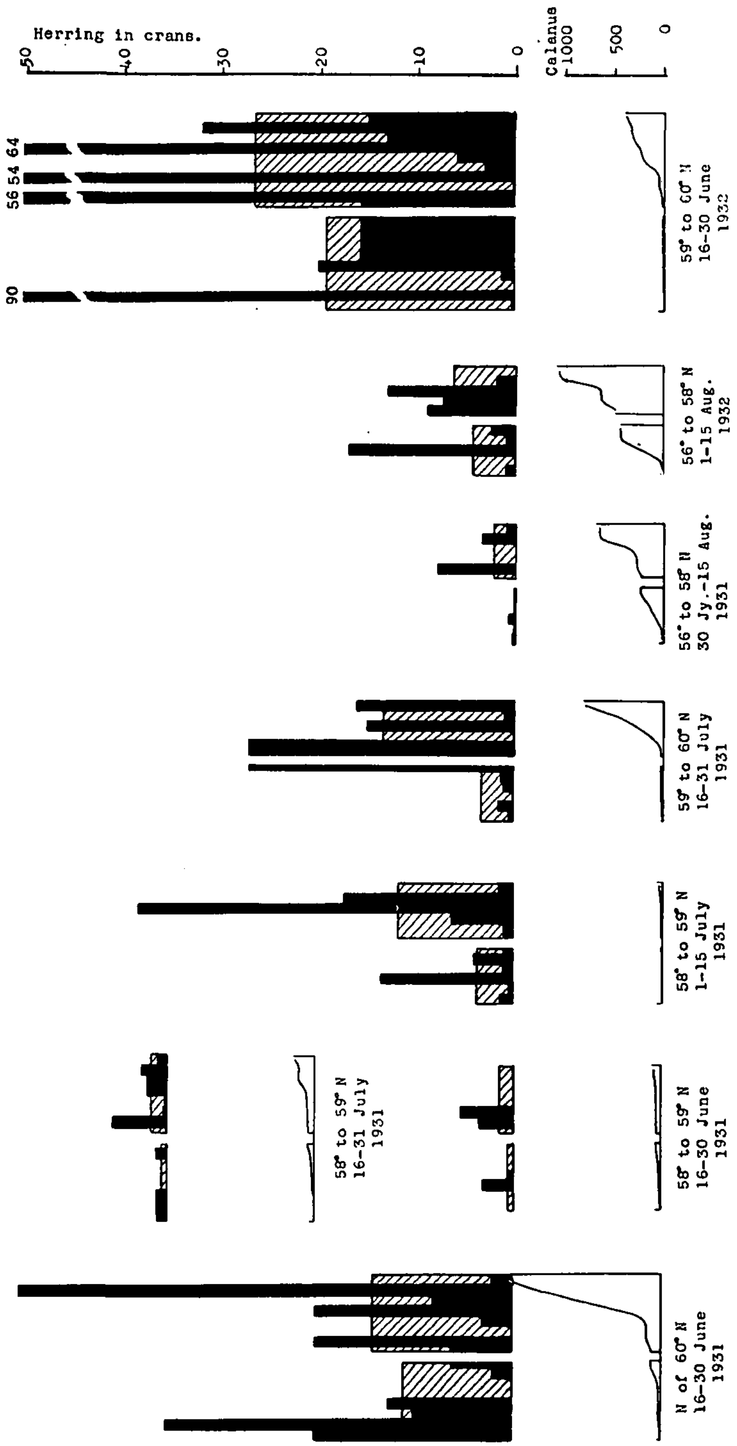
Year.	Period.	Area.	No. of Samples.	Calanus Range.	Calanus Av.	Catch (in crans). Range.	Catch (in crans). Av.	Total catch in water of Lower Calanus Numbers.	Total catch in water of Higher Calanus Numbers.	Average catch in water of Lower Calanus Numbers.	Average catch in water of Higher Calanus Numbers.	Percentage Gain or Loss on total catch.
1930	1–15 June	N. of 60° N.	7	64–300	191	6·50–69·00	29·10	80·70	123·30	23·1	35·2	+20·9
	16–31 July	58° to 59° N.	9	0–16	8	1·00–3·00	1·75	6·40	9·40	1·4	2·1	+19·0
1931	16–30 June	59° to 60° N.	9	1–450	110	3·00–40·00	20·60	92·00	93·50	20·4	20·8	+ 0·8
	1–15 July	N. of 60° N.	8	3–160	49	0·00–100·00	15·30	13·75	109·00	3·4	27·3	+77·6
1932	1–15 July	59° to 60° N.	9	1–244	57	0·50–25·00	6·90	32·00	30·25	7·1	6·7	− 2·8
	16–31 July	N. of 60° N.	8	0–540	127	1·00–61·25	12·20	27·30	70·20	6·8	17·5	+43·9
	,,	58° to 59° N.	8	132–1075	331	1·00–35·25	18·20	71·75	74·00	17·9	18·5	+ 1·5
	,,	56° to 58° N.	6	60–3155	1005	1·00–25·00	10·70	32·75	31·50	10·9	10·5	− 1·9
1933	1–15 June	59° to 60° N.	9	22–8000	2947	0·00–53·00	18·50	59·50	107·00	13·2	23·8	+28·5
	15–30 June	N. of 60° N.	7	32–1400	458	0·00–5·75	0·80	5·75	0·00	1·6	0·0	−100·0
	1–15 July	59° to 60° N.	6	80–1640	587	0·00–5·00	1·25	0·00	7·50	0·0	2·5	+100·0

The details of these gains and losses are shown in tabular form, primary results being shown in heavy type, as follows :—

Gains		Neutral.		Losses.	
85·2%	100·0%	**7·7%**	1·5%	**– 11·1%**	– 100·0%
83·7%	77·6%	**4·3%**	0·8%	**– 30·4%**	
61·0%	43·9%	**3·3%**	– 1·9%		
53·1%	28·5%	**– 4·0%**	– 2·8%		
51·2%		**– 9·0%**			
41·2%					
37·5%					
20·7%					
18·5%					
15·6%					
12·3%					

It is important that the values for the individual periods should not be stressed, as the results for any individual period may be affected by the fortuitous nature of the fishing. The value of these results lies in their consideration as a whole, and Prof. R. A. Fisher suggested that the significance of the different series of tables should be demonstrated by the estimation of their Standard Errors. Thus the primary correlations for the years 1931–33 give an average gain of 24·5±7·7% ('t' 3·182), while if the year 1930 is included the result becomes 18·3±8·9% ('t' 2·056). The secondary correlations, as should perhaps be expected, do not approach this level of reliability, 1931–33 giving an average gain of 16·4±19·1% ('t' 0·859) and 1930–33 17·0±15·5% ('t' 1·097). Fig. 2 shows graphically the details of the catches in the poorer and richer Calanus waters for each of the periods of gain, and Fig. 3 for each of the periods of loss. The neutral periods are not figured. The average catches in poorer and richer Calanus waters are also shown, superimposed on the individual catches. These figures show quite clearly that the position in the Calanus range of one high catch in a period may weight the result, in that it may dominate the other figures wherever it falls. The higher catches do not all occur in the richer Calanus waters, an appreciable number falling in the poorer waters, but it is found that more high catches occur in the richer Calanus waters than in the poorer. Conversely more blank catches occur in the poorer Calanus waters than in the richer. Catches of intermediate value are more equally distributed. The following table shows the numbers of occurrences of catches of different magnitudes in the poorer and richer Calanus waters.

Herring catches, Range.	Numbers of Occurrences in Poorer Calanus waters.	Richer Calanus waters.
0·0 crans	33	27
0·1–5·0 ,,	52	49
5·1–10·0 ,,	27	25
10·1–20·0 ,,	22	18
20·1–30·0 ,,	9	9
Over 30·0 ,,	7	22



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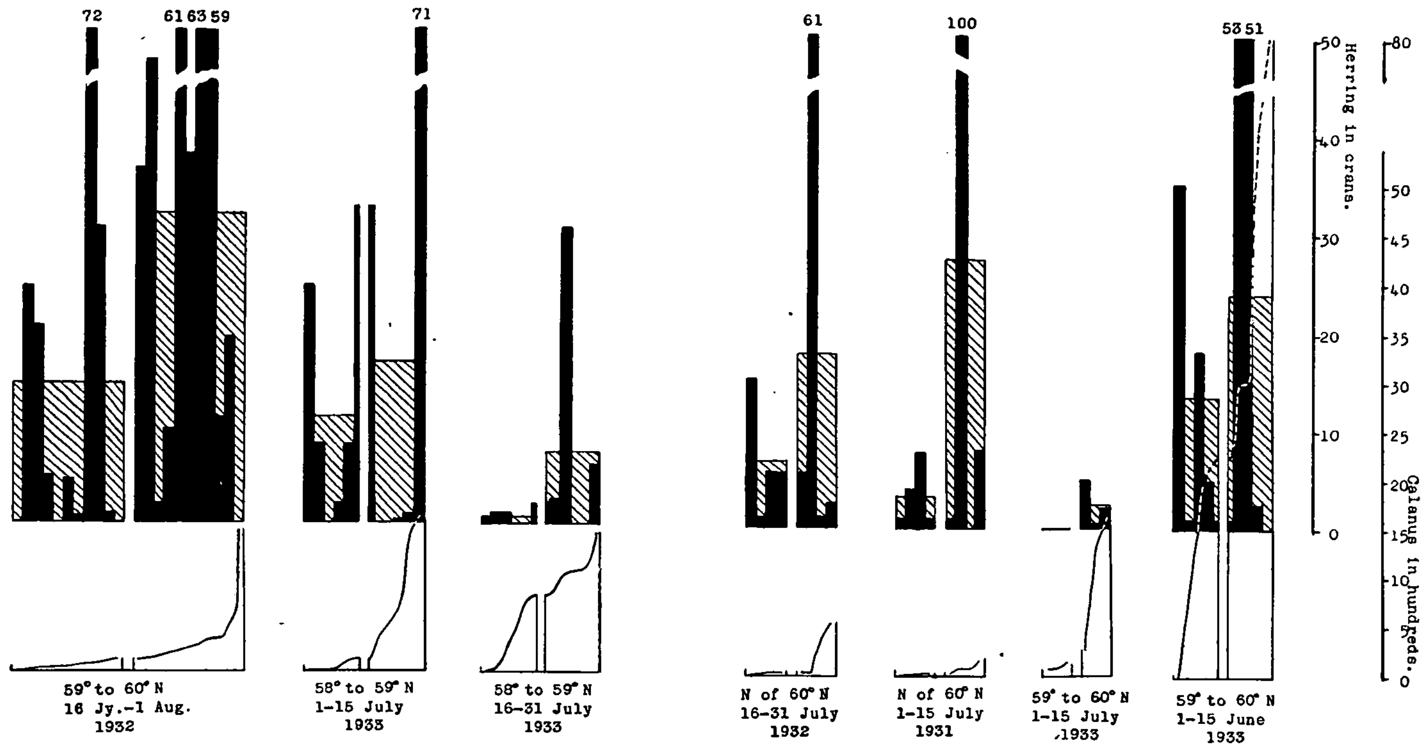

FIG. 2.—Histograms showing (in black) the individual catches of herring in each area-period which showed a theoretical *gain* of over 10% (see text). There are fifteen such area-periods, eleven of which are primary (with 10 or more catches) and are shown first, and four secondary (6–9 catches) shown last. In each period the catches are arranged from left to right in the order of ascending values of Calanus in the associated plankton samples: each series is divided into halves, the left half representing the catches in the poorer and the right half those in the richer Calanus water. The average catches of herring in each half are shown as shaded histograms. Below each histogram is a graph showing the associated Calanus values. The diagrams are in fact graphical representations of the area-period tables drawn up for correlation purposes.

Fig. 4 shows the percentage of catches below given values which occur in the poorer and richer Calanus waters, the years 1931, 1932 and 1933 are shown separately, and the combined result is also given. It is seen that in the poorer Calanus waters the percentage of catches below any given level is greater than that in the richer Calanus waters, and that in the combined curve for 1931–33 the difference tends to increase when the higher catch levels are reached.

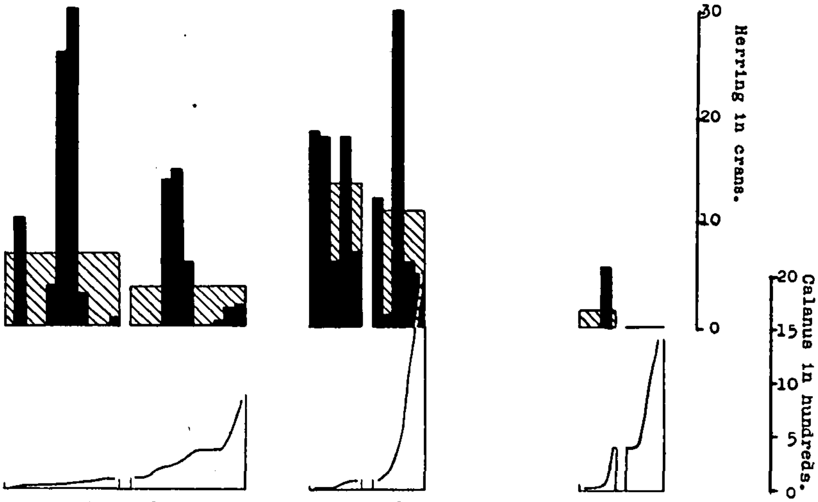

Fig. 3.—Diagrams of the same kind as those in Fig. 2, but for those area-periods showing a theoretical *loss* of over 10% (see text). Two of these are primary area-periods (10 or more catches) and one is a secondary area-period (7 catches).

There is a noticeable difference in the distribution of catches of various magnitudes in the Shields Fishery (Part II, p. 211) and the Scottish Fishery. Whereas in the latter for the years 1931–33 20·0% of the total catches are blank and 15·7% are over 20 crans, in the Shields Fishery for the years 1932–33 only 9·4% are blank and only 5·3% exceed 20 crans.* That is, more high catches were secured in the Scottish Fishery, but there was a greater chance of getting a blank haul; in the Shields Fishery

* Percentage occurrences of blank catches and catches over 20 crans are as follows for individual years. The 1931 Shields figures are not used here (see Part II, p. 210).

	Scotland.				Shields.		
	No. of samples.	% blank.	% over 20 crans.		No. of samples.	% blank.	% over 20 crans.
1931	103	28·2	10·7				
1932	139	16·5	20·1	1932	214	9·8	1·0
1933	73	27·4	19·2	1933	190	8·9	10·0

blank hauls were relatively less frequent, but on only a few occasions was a really high catch obtained.

The results outlined above indicate the nature of the benefit which could be derived by the fishermen from consistent use of the Plankton Indicator on the basis of the Calanus-Herring Correlations. Over a long period more higher catches, and fewer blank catches, will be the result

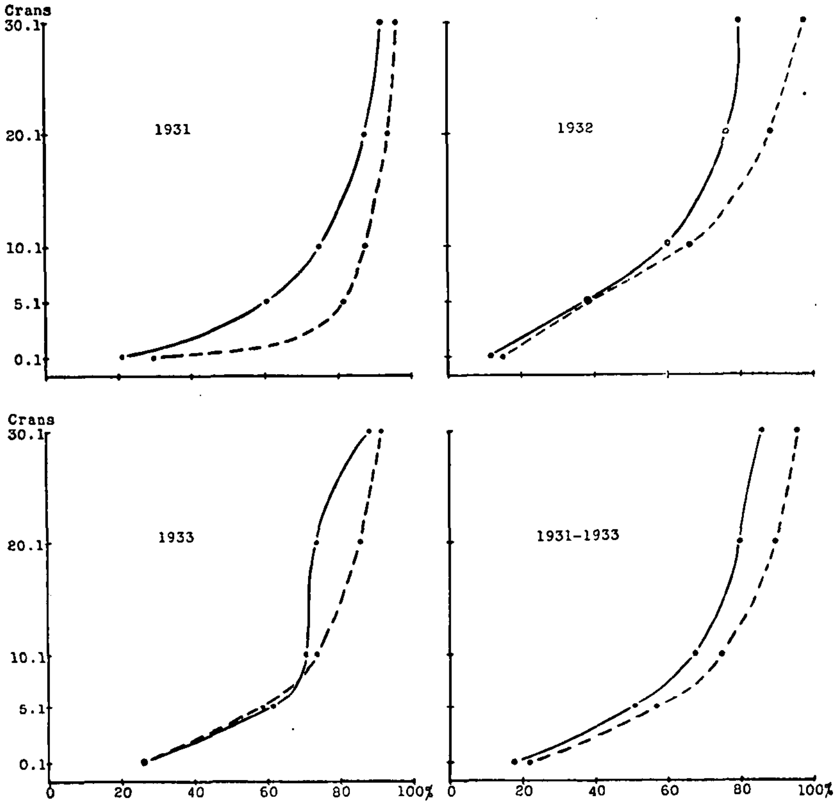

FIG. 4.—The broken-line curves show for the catches taken in the poorer Calanus water the percentage falling below given values (vertical scale), and the continuous-line curves show the corresponding percentages for the catches taken in the richer Calanus water. They show that the larger catches are taken more frequently in the richer Calanus water.

of fishing always in waters giving the larger numbers of Calanus, although it would be necessary to use discretion in determining how much extra time may reasonably be spent in looking for such waters.

Owing to the fortuitous nature of the fishing it would be necessary to continue these investigations over a long period of years, and to have many more samples in each year, before we could discuss with certainty the seasonal variations in the degree of correlation between Calanus and

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herring, and thus the variations in the efficiency of the Indicator as a commercial instrument. Our results do, however, indicate that an increasing gain may be expected from mid-June to the end of July, and this increase is evident in the individual years as well as in the combined result (Fig. 5).

TABLE VI.

Percentage Gains and Losses in Areas and Periods.

Year.	Area.	June 1–15	June 16–30	July 1–15	July 16–31	August 1–15
1930	N. of 60° N.	+20·9^{7}				
1931			**+12·3**^{15}	+77·6^{8}		
1932			**+3·3**^{10}	**+4·3**^{13}	+43·9^{8}	
1933			−100·0^{7}			
1930	59° to 60° N.		**+12·2**^{10}			
1931			+0·8^{9}	+7·7^{10}	**+61·0**^{11}	
1932			**+15·6**^{19}	−2·8^{9}	**+37·5**^{22}	
1933		+28·5^{9}	**−4·0**^{19}	+100·0^{6}		
1930	58° to 59° N.				+19·0^{9}	**−87·4**^{19}
1931			**+41·2**^{13}	**+51·2**^{11}	**+53·1**^{15}	
1932					+1·5^{8}	**−30·4**^{22}
1933				**+20·7**^{11}	**+83·7**^{11}	
1931	56° to 58° N.					**+85·2**^{11}
1932				**−9·0**^{12}	−1·9^{6}	**+18·5**^{10}
1933			**−11·1**^{10}			

Table VI shows the figures for all the results, primary (in heavy type) and secondary, and the average overall gains, for primary periods only, in the different areas are as follows :—

Area	N. of 60° N.	+ 6·6%	based on 3 tables.
	59° to 60° N.	+23·6%	,, 5 ,,
	58° to 59° N.	+36·6%	,, 6 ,,
	56° to 58° N.	+20·9%	,, 4 ,,

and in each year there is a resultant net gain for all area-periods.

1931.	1932.	1933.	1931–33.
+44·5%	+5·7%	+22·3%	+24·5%

If the two primary area-periods for 1930 are included the average for 1930–33 is +18·3%, but on page 250 it is shown that there are good grounds for omitting these results from the general conclusions.

Table VI also shows that the general increase in gain from 16–30 June to 16–31 July, indicated by the average curve in Fig. 5, occurs, almost without exception, in each year in each area where sufficient figures are available. Even where the 16–30 June figure is a loss, it is seen

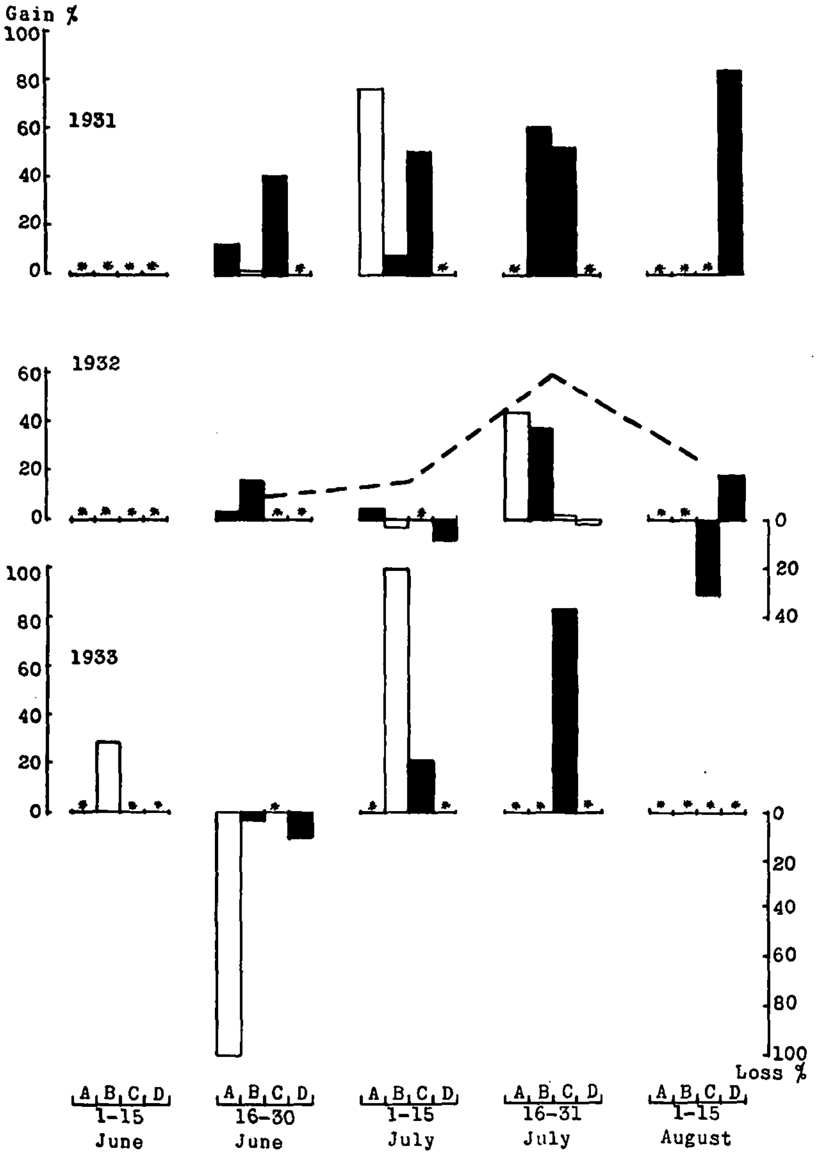

FIG. 5.—Histograms showing the variations in the Calanus-herring correlations, expressed as theoretical percentage gains or losses (see text), for the area-periods in the Scottish Eastern Fishery for the years 1931, 1932 and 1933. The areas N. of 60° N., 59° to 60° N., 58° to 59° N. and 56° to 58° N. are indicated by the letters A, B, C and D respectively. The primary area-periods are shown as black histograms and the secondary area-periods as open histograms. Asterisks indicate that too few samples were obtained to make even a secondary period. The broken-line curve, superimposed on the 1932 base, indicates the trend of the seasonal variation in the primary correlations, obtained by averaging all the primary results available in each period.

that the loss diminishes or turns to a gain in the subsequent periods (excluding 1–15 August). Two secondary results in 1–15 June indicate gains higher than the average for the second half of the month, but this cannot be confirmed on the limited material available.

The course of the Summer Fishery is described by Wood (1930) who states that it " begins in May or early in June and is continued generally till about the middle of September, i.e. from the time that the reproductive organs of the Autumn spawners begin to develop until spawning is completed and the bulk of the spent fish has left the fishing grounds." The seasons over which this work extends have, however, been shorter; full-scale operations have rarely commenced till the second, or even the third, week in June,* so that our material, which is scanty in May and early June, does in fact cover the beginning of the fishery in the years concerned. The end of the fishery is less satisfactorily sampled, as although in the Northern waters (Shetlands and Orkneys) large-scale operations have ceased about the end of July, further south they have continued till the end of August or first week in September, and after mid-August we have little material as the drifters taking samples have rarely finished the season in these waters.

The main period of high productivity (mid-June to mid-July) is, however, fairly well represented, and fair numbers of samples are available for the second half of July. In August material is less plentiful, only four correlation tables, one of which is for 1930, being possible, giving rather erratic results. It is possible that this wide variation in the August results is associated with the fact that, at this time, the shoals fished are composed mainly of spawners and spents, when catches are much more variable than at any other time. According to Wood (ibid. p. 9) a suitable condition of tide and weather, i.e. a considerable amount of sea disturbance, is by far the most important factor in determining the chances of a good catch of ripe herring; heavy catches of spents are not infrequent, but are rarely maintained for long on account of the rapid dispersal of the shoals after spawning. In each of the three years, 1931–33, periods of calm weather occurred in the Scottish Eastern Fishery in August. Spents formed an appreciable proportion of the landings after about the first week of August, and when the calm weather occurred the average catch level dropped to a low value. Any incidence of rough weather gave an increase in average catch.† Under these conditions it is not to be expected that the Indicator results will be absolutely reliable.

Although the number of drifters taking samples is relatively small, the curves expressing the weekly average landings of these boats, while not

* Due to agreements within the trade fixing dates for the commencement of curing.

† Weekly reports on the Herring Fisheries in *The Fishing News* and *The Fish Trades Gazette* are the sources of this information.

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absolutely coincident with the curves showing the weekly average landings at the ports (Fig. 6), do indicate fairly exactly the changes in productivity through the season and are thus sufficiently representative of the work of the fleet to render the results obtained in this work applicable to the fishery as a whole. We are indebted to the Fishery Board for Scotland for permission to use their figures and for putting at our disposal the data necessary for determining the weekly average landings at the ports.

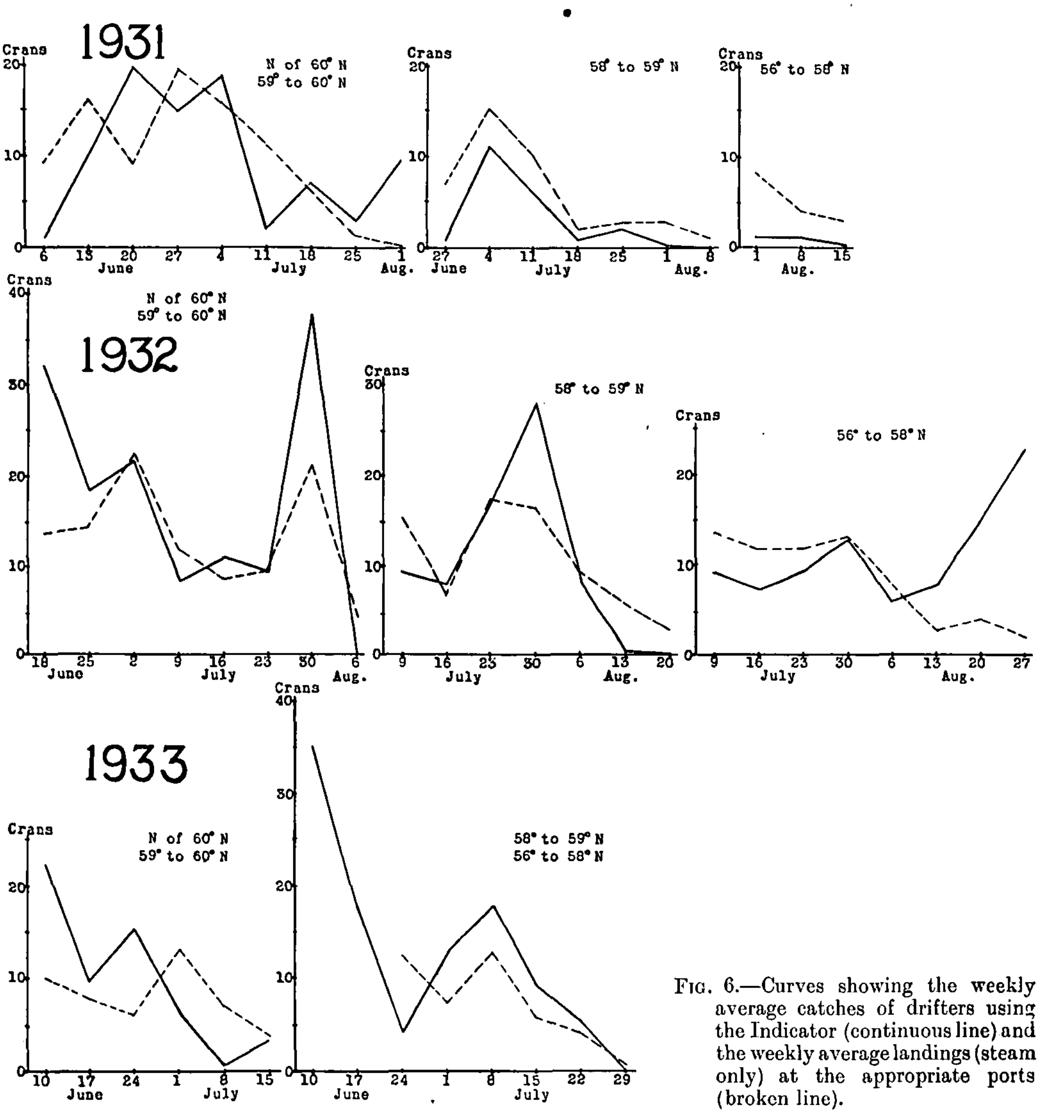

FIG. 6.—Curves showing the weekly average catches of drifters using the Indicator (continuous line) and the weekly average landings (steam only) at the appropriate ports (broken line).

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An interesting example of the way in which these results can be applied to the fishery and evaluated may conveniently be quoted here. On the 23rd June, 1932, in the area 59° to 60° N. sufficient units are available to enable a correlation table to be compiled for this one day in the period 16–30 June. The material is all from an area to the south-east of Lerwick, triangular in shape with the apex pointing north-west and about twenty miles from apex to base. The higher Calanus numbers were more to the south-east than the lower (Fig. 7 shows the distribution of Calanus and catches) so that boats steaming only 20 to 25 miles off did not reach the area of richer Calanus, while those going 30 miles or more did get into good Calanus waters.

TABLE VII.

Calanus-Herring Correlation Table.

Area, 59° to 60° N. 23rd June, 1932.

	Lower Calanus numbers.		Higher Calanus numbers.	
	Calanus.	Herring in crans.	Calanus.	Herring in crans.
	1	0·0	395	15·0
	10	0·0	305	13·0
	10	0·0	260	64·0
	10	2·2	60	54·0
	10	50·0	21	56·0
Total	41	52·25	1041	202·0
Average	8⁵	10·45⁵	208⁵	40·4⁵

Grand total catch : 254·25 crans for 10 landings.

If all the catches had been made in waters of the richer Calanus values the expected (theoretical) total catch would have been 404·0 crans; i.e. a theoretical gain of 149·75 crans over the actual total catch obtained when fishing at random. This may be expressed as a (theoretical) gain of 58·9%.

The boats going farthest, i.e. getting into good Calanus waters, would have gained 30 crans apiece or *ca.* 300% over the boats which did not steam so far, and 15 crans or 58·9% over the average for all the boats fishing on that ground. The average landing at the port the next morning (24th June) was 18 crans* and prices were 15s. 3d. per cran for curing

* *Fishing News*, 2nd July, 1932.

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(Russian contract) and 25s. per cran for freshing, so that boats which got into the richer Calanus waters would have made 22 crans over the average and have been anything from £16 15s. 6d. to £27 10s. up on the night's fishing.

This example is quoted to show that these results can be evaluated and applied to the fishery, and, although it is realised that during periods of glut the use of the instrument to find the best fishing ground may be of less value, yet even here it may help to reduce the cost of catching the same amount of fish that would be obtained by fishing without its aid.

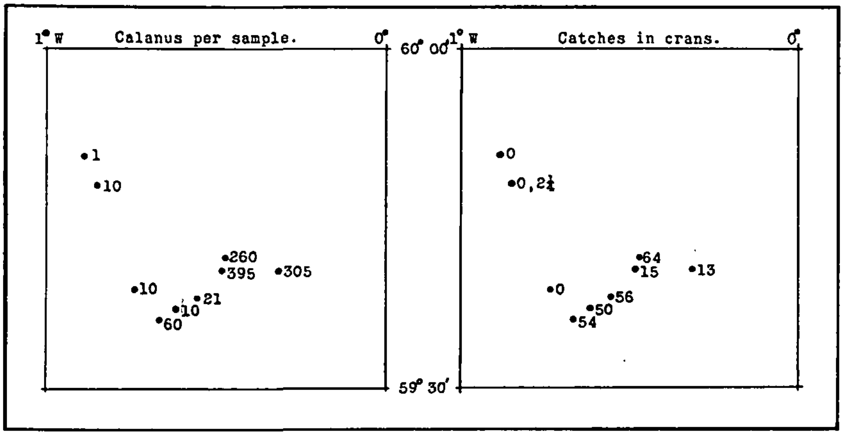

FIG. 7.—Showing the distribution of Calanus from Indicator samples (left-hand chart) and the associated herring catches (right-hand chart) for the 23rd June, 1932.

The reservation (discussed on p. 260) regarding the latter part of the fishery (August) will need to be borne in mind when applying these results commercially.

ABUNDANCE AND DISTRIBUTION OF LIMACINA.

The negative correlation of herring catches with numbers of Limacina* is discussed in Part I (p. 160) and an account of the distribution of this form in the Scottish waters precedes here the detailed discussion of these correlations and their significance.

In the limited material from 1930 Limacina is recorded in only two of the four series of samples (59°–60° N., 17th June, average 15; and S. of 59° N., 7th August, average 1). Table VIII shows the average numbers of Limacina per sample for half-monthly periods for the years 1931 to 1933; the two more southerly areas have been combined as was done for Calanus,

* The term Limacina used throughout this paper refers in general to *Limacina retroversa* (Flemming). See also Part II, page 179, footnote †.

and the Shields figures* are entered for comparison. The index figures show the number of samples averaged.

TABLE VIII.

Average Limacina per Sample per Half-month.

Year.	Area.	May 16–31.	June 1–15.	June 16–30.	July 1–15.	July 16–31.	August 1–15.	August 16–31.
1931	N. of 60° N.			14^{15}	2^{8}	5^{5}		
	59° to 60° N.		4^{2}	1^{9}	39^{10}	61^{11}		
	S. of 59° N.			6^{8}	12^{11}	130^{17}	174^{11}	
	Shields				18^{21}	138^{37}	269^{17}	811^{29}
1932	N. of 60° N.			35^{10}	15^{13}	88^{8}		
	59° to 60° N.			48^{18}	81^{9}	145^{21}	72^{1}	
	S. of 59° N.	5^{3}	0^{1}	—	105^{16}	71^{14}	89^{28}	1525^{6}
	Shields	3^{43}	16^{50}	64^{45}	88^{32}	—	365^{11}	72^{17}
1933	N. of 60° N.			70^{7}	17^{3}			
	59° to 60° N.		24^{9}	98^{17}	147^{5}			
	S. of 59° N.		132^{3}	574^{11}	86^{15}	117^{11}	418^{2}	228^{3}
	Shields	5^{11}	39^{40}	28^{38}	25^{25}	91^{25}	96^{28}	810^{11}

The outstanding features may be summarised as follows :—

(1) There is a general increase in abundance from north to south in all three years, which is evident also in nearly all the individual periods. The figures for the three years are as follows :—

Area.	1931.	1932.	1933.	1931–33.
N. of 60° N.	9^{28}	40^{31}	54^{10}	29^{69}
59° to 60° N.	34^{32}	96^{49}	84^{31}	75^{112}
S. of 59° N.	91^{47}	211^{68}	240^{45}	184^{160}

(2) There is a general increase in abundance through the three years, the average numbers per sample being as follows :—

	1931.	1932.	1933.
All samples	82^{112}	135^{150}	160^{87}
Samples mid-June to end July only	73^{97}	79^{109}	171^{69}

It appears that, while over the whole period the increase from 1931 to 1932 was greater than that from 1932 to 1933, over the well-sampled period mid-June to end of July the reverse is the case, the figures for 1931 and 1932 not differing to any marked extent. It is seen from the figures in (1) above that this increase in abundance occurs both N. of 60° N. and S. of 59° N., but that in the area 59° to 60° N. there is a small drop in numbers after 1932.

(3) The increase in abundance of Limacina is therefore similar to that

* See Part II for details of the abundance of Limacina in the Shields Fishery.

of Calanus, but it is, generally speaking, less abundant than Calanus in this area over the years concerned. At the end of the season, however, as will be seen from a comparison of the tables of average figures for Calanus and Limacina, there is some evidence which suggests that the Calanus figures, which are tending to decrease to some extent, may become lower than the Limacina averages, which are tending to increase. This statement must, however, be regarded as a suggestion which cannot be confirmed on the restricted material available at this part of the season.

(4) An abnormal influx of Atlantic water into the North Sea appears to affect the Limacina population of the latter. Ogilvie (1934) says that " while there is a certain amount of carry-over of this species from one year to another the stock is annually augmented by an influx from the North which takes place from June or July onwards." In 1930 although Limacina was abundant on the West Coast, numbers were very low on the East Coast; and in 1931, with a considerable abundance on the West side, the East Coast figures were still rather low, while with a greater influx of Atlantic water in 1932 and 1933 the numbers on the East Coast increased to an appreciable extent.*

LIMACINA-HERRING CORRELATIONS.

When the material for the years 1930 and 1931 was all worked up, the correlation table for Limacina and herring, compiled from all the figures then available, showed a marked negative result (Part I, p. 160); and

TABLE IX.

Limacina-Herring Correlation Tables.

Indices denote number of catches averaged (crans).

Limacina.	1930.	1931.	1932.	1933.	1931–33.	1930–33.
0–99	$16 \cdot 4^{46}$	$7 \cdot 1^{106}$	$14 \cdot 6^{109}$	$10 \cdot 1^{51}$	$10 \cdot 7^{266}$	$11 \cdot 6^{312}$
100–249	—	$0 \cdot 3^{6}$	$7 \cdot 9^{32}$	$11 \cdot 9^{25}$	$8 \cdot 8^{63}$	$8 \cdot 8^{63}$
250–499	—	—	$9 \cdot 0^{12}$	$10 \cdot 2^{9}$	$9 \cdot 5^{21}$	$9 \cdot 5^{21}$
500–999	—	$1 \cdot 0^{3}$	$35 \cdot 0^{2}$	$17 \cdot 0^{2}$	$15 \cdot 3^{7}$	$15 \cdot 3^{7}$
1000 and over	—	$0 \cdot 1^{2}$	$0 \cdot 0^{3}$	$7 \cdot 7^{3}$	$3 \cdot 3^{7}$	$3 \cdot 3^{7}$
or 100 and over	—	$0 \cdot 5^{11}$	$9 \cdot 0^{48}$	$11 \cdot 4^{39}$	$9 \cdot 0^{98}$	$9 \cdot 0^{98}$
% samples 100 and over	0·0%	9·4%	30·6%	43·3%		

it was thought that this correlation might be more useful even than the Calanus one, in that it would be easier to steam out of dense concentrations of Limacina than to find the largest numbers of Calanus. When, however,

* There were only eight samples from the West Coast in 1932 and none in 1933, so that no information is available as to the state of the Limacina stock on the West side in these two years.

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the material from the later years was also available, and subdivision in space and time was found necessary for reasons already discussed, it was seen that the results were less consistent, some being positive, and the later years less satisfactory than the earlier.

Table IX above shows the results for the years 1930 to 1933, and the combined result with and without the 1930 figures. In addition the figures for average catch in water with Limacina 100 and over are given, and the number of such catches is expressed as a percentage of the total. In 1930, with no catches in water where the Limacina figure per sample is 100 and over, there is no correlation; in 1931 only 9·4% of the catches are in water of Limacina 100 and over, the correlation being negative for above and below this level. In 1932 the percentage of catches in water of Limacina 100 and over has increased to 30·6%, the correlation here also being negative. In 1933 43·3% of the catches are from water of Limacina 100 and over, and the correlation here for above and below 100 is slightly positive, but is neutral if the figure taken as a division is raised to 250 (Limacina 0–249—Catch $10{\cdot}7^{76}$, Limacina 250 and over—Catch $10{\cdot}6^{14}$). The figures for average catches associated with Limacina 500 and over are based on too few catches to be significant.

Table X shows the correlations obtained for the individual periods in the various areas, although these are not as numerous as the Calanus results.

TABLE X.

Limacina-Herring Correlations for Area-Periods.

Indices denote number of catches averaged (crans).

Year.	Area.	Period.	Average catch with Limacina 0–99.	Average catch with Limacina 100 and over.	Sign of Correlation.
1931	58° to 59° N.	16–31 July	$1{\cdot}3^{11}$	$1{\cdot}1^{4}$	−
1932	59° to 60° N.	16–30 June	$25{\cdot}2^{15}$	$13{\cdot}9^{4}$	−
	,, ,,	1–15 July	$5{\cdot}2^{7}$	$13{\cdot}0^{2}$	+
	,, ,,	16 July–1 August	$28{\cdot}3^{11}$	$17{\cdot}3^{11}$	−
	58° to 59° N.	16–31 July	$18{\cdot}6^{6}$	$17{\cdot}0^{2}$	−
	,, ,,	1–15 August	$7{\cdot}2^{14}$	$1{\cdot}5^{8}$	−
	56° to 58° N.	1–15 July	$7{\cdot}5^{6}$	$9{\cdot}1^{6}$	+
	,, ,,	16–31 July	$14{\cdot}4^{4}$	$3{\cdot}4^{2}$	−
	,, ,,	1–15 August	$6{\cdot}1^{6}$	$4{\cdot}0^{4}$	−
1933	N. of 60° N.	15–30 June	$1{\cdot}2^{5}$	$0{\cdot}0^{2}$	−
	59° to 60° N.	16–30 June	$10{\cdot}5^{12}$	$21{\cdot}1^{7}$	+
	58° to 59° N.	1–15 July	$9{\cdot}4^{8}$	$23{\cdot}8^{3}$	+
	,, ,,	16–31 July	$1{\cdot}2^{6}$	$7{\cdot}2^{5}$	+
	56° to 58° N.	16–30 June	$8{\cdot}5^{3}$	$13{\cdot}7^{7}$	+

This information has little real significance, there being eight area-periods showing negative correlations and six showing positive results. It should, however, be noted that four of the positive results occur in 1933. Further

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work may establish a reliable correlation between Limacina and herring. Our information suggests that it might be profitable to avoid really dense concentrations of this organism, but no commercial significance can reasonably be attached to the results so far obtained.

There is little evidence of correlations between the catches of herring and other zooplankton forms (see Part I, p. 159), but more extensive examination might have afforded some information of this kind.

GENERAL NOTES ON THE PLANKTON.

Zooplankton.

The abridged method of analysis adopted to economise in time affected all the material after 1931 (see Part I, p. 159), so that full information over the four years is available for a limited number of organisms only. Of these Calanus and Limacina have already been discussed in detail, leaving only the figures for Total Copepoda to be dealt with here. The figures for Total Copepoda, excluding Calanus, are shown in Table XI.

TABLE XI.

Total Copepoda (excluding Calanus): Average Numbers per Sample per Half Month.

Indices denote numbers of samples averaged.

Year.	Area.	May 16–31.	June 1–15.	June 16–30.	July 1–15.	July 16–31.	Aug. 1–15.	Aug. 16–31.
1930	N. of 60° N.		30^{5}	—	—	112^{1}		
	59° to 60° N.			43^{8}				
	S. of 59° N.					331^{4}	680^{10}	
1931	N. of 60° N.			97^{15}	24^{8}	111^{5}		
	59° to 60° N.		31^{2}	76^{9}	98^{10}	240^{11}		
	S. of 59° N.			352^{8}	360^{11}	844^{17}	1111^{11}	
1932	N. of 60° N.			621^{10}	139^{12}	455^{8}		
	59° to 60° N.			259^{18}	294^{9}	1378^{21}	2320^{1}	
	S. of 59° N.	654^{3}	1230^{1}	—	1652^{16}	1955^{14}	1410^{28}	1832^{6}
1933	N. of 60° N.			209^{7}	342^{3}			
	59° to 60° N.		2745^{9}	1122^{17}	1088^{5}			
	S. of 59° N.		785^{3}	997^{11}	504^{15}	548^{11}	317^{5}	

	Area.	1930.	1931.	1932.	1933.
Average per area in years and totals.	N. of 60° N.	43^{6}	79^{28}	384^{30}	249^{10}
	59° to 60° N.	43^{8}	136^{32}	787^{49}	1588^{31}
	S. of 59° N.	580^{14}	709^{47}	1580^{68}	625^{46}
	Whole area	312^{28}	373^{107}	1072^{147}	925^{87}

The information afforded by this table may be stated as follows :—

(1) There is an increase in abundance of Copepoda (excluding Calanus) from 1930 to 1932, and a slight drop in numbers in 1933. This is shown in

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the area N. of 60° N., the drop in 1933 being small, while in the area S. of 59° N. the drop in numbers in 1933 is considerable. In the area 59° to 60° N., however, the increase is continuous from 1930 to 1933.

TABLE XII.

Zooplankton : Average Numbers per Sample per Half Month.

Indices denote number of samples averaged.

Form.	Year.	Part of area.	June 1–15.	June 16–31.	July 1–15.	July 16–31.	Aug. 1–15.	Area Av.	Year Av.
Paracalanus parvus	1930	N.	0^{5}	9^{8}	—	68^{1}		10^{14}	21^{28}
and *Pseudocalanus*		S.				74^{4}	14^{10}	31^{14}	
elongatus	1931	N.	10^{2}	37^{24}	6^{18}	15^{16}		21^{60}	41^{107}
		S.		4^{8}	28^{11}	89^{17}	113^{11}	66^{47}	
Centropages typicus	1930	N.	0^{5}	0^{8}	—	0^{1}		0^{14}	141^{28}
and *hamatus*		S.				87^{4}	360^{10}	282^{14}	
	1931	N.	1^{2}	3^{24}	15^{18}	11^{16}		9^{60}	46^{107}
		S.		18^{8}	54^{11}	110^{17}	158^{11}	93^{47}	
Temora longicornis	1930	N.	2^{5}	28^{8}	—	0^{1}		17^{14}	39^{28}
		S.				42^{4}	70^{10}	62^{14}	
	1931	N.	0^{2}	11^{24}	27^{18}	154^{16}		53^{60}	251^{107}
		S.		316^{8}	260^{11}	576^{17}	775^{11}	504^{47}	
Acartia longiremis	1930	N.	0^{5}	3^{8}	—	0^{1}		2^{14}	76^{28}
and *clausi*		S.				6^{4}	208^{10}	150^{14}	
	1931	N.	15^{2}	17^{24}	3^{18}	7^{16}		10^{60}	17^{107}
		S.		15^{8}	7^{11}	37^{17}	33^{11}	25^{47}	
Oithona	1930	N.	0^{5}	3^{8}	—	12^{1}		3^{14}	2^{28}
		S.				0^{4}	2^{10}	1^{14}	
	1931	N.	1^{2}	11^{24}	6^{18}	5^{16}		8^{60}	7^{107}
		S.		0^{8}	3^{11}	12^{17}	3^{11}	6^{47}	
Evadne	1930	N.	80^{5}	150^{8}	—	4^{1}		115^{14}	60^{28}
		S.				22^{4}	0^{10}	6^{14}	
	1931	N.	3^{2}	0^{24}	1^{18}	1^{16}		1^{60}	10^{107}
		S.		17^{8}	45^{11}	17^{17}	6^{11}	21^{47}	
Podon	1930	N.	0^{5}	0^{8}	—	24^{1}		2^{14}	4^{28}
		S.				13^{4}	4^{10}	6^{14}	
	1931	N.	8^{2}	1^{24}	1^{18}	5^{16}		2^{60}	20^{107}
		S.		2^{8}	30^{11}	59^{17}	64^{11}	44^{47}	
Lamellibranch	1931	N.	19^{2}	10^{24}	11^{18}	5^{16}		9^{60}	7^{107}
larvæ*		S.		2^{8}	9^{11}	2^{17}	3^{11}	4^{47}	
Cyphonautes	1931	N.	41^{2}	2^{24}	72^{18}	3^{16}		25^{60}	40^{107}
larvæ*		S.		37^{8}	111^{11}	31^{17}	68^{11}	60^{47}	

This increase in abundance with the passage of time is evident in most of the areas in each year, there being a general tendency to increase in abundance up to the second half of July or first half of August. The 1933 figures

* Not observed in 1930. N.=Northern, S.=Southern, parts of area, 59° N. Lat. being taken as a division.

do not show this tendency so well, but they are not so extensive, there being little information after the middle of July.

(2) There is an increase in abundance from North to South in practically all the individual periods and in the total figures up to 1932, while in 1933 the greatest abundance is in the area 59° to 60° N.

Figures for individual species of Copepods are available for 1930 and 1931 only, and those present in significant numbers are as follows :— *Paracalanus parvus* and *Pseudocalanus elongatus*, which are grouped together, *Temora longicornis*, *Centropages typicus* and *hamatus*, *Acartia longiremis* and *clausi*, and Oithona. Table XII above sets out the figures for these copepods, and other forms, for the Northern and Southern portions of the Eastern Fishery (59° N. Lat. being taken as a division).

It will be seen that, with regard to the Copepods, there is evidence of the same increase with the passage of time in the individual forms as is shown by the figures for Total Copepoda. It is noticeable also that the abundance in the southern part of the area is on the whole greater than that in the northern part. Of the other zooplankton forms, omitted from Table XII, Sagitta and the larger crustacea (e.g. Amphipods, Euphausians, and Decapod larvæ*) are scarce or absent in the Indicator samples, the numbers per sample per half-month rarely exceeding 3. The Cladocera, however, are more abundant, Evadne earlier than Podon, the latter more abundant in the southern part of the area. Lamellibranch larvæ, more abundant in the northern part, and decreasing in numbers with the passage of time ; and Cyphonautes larvæ, with greater numbers in the southern part of the area and fairly high figures for 1–15 July, are found in 1931 only, no records of these forms occurring in 1930.

Phytoplankton.

The abridged method of analysis adopted for all the samples after 1931 did not affect diatoms and dinoflagellates, and the details of the Phytoplankton-Herring correlations obtained will be found in Part IV where also their commercial significance is discussed.

Diatoms are found, at times in large numbers, in all the areas of the Scottish Eastern Fishery. In 1930, however, there are only two records of diatoms (Rh.+† for two samples on the 24th July in the area 58° to 59° N.) ; while over the four years in the area N. of 60° N. there is only one record (Rh.+ for 20th June, 1931). For the other areas, over the years 1931–33, there are more occurrences of diatoms and these are set out in Table XIII.

* These forms may have been considerably more abundant than our figures suggest as it is possible that they are not caught in representative numbers by the Indicator. See Part I, page 153, for fuller discussion on this point.

† See footnote to Table XIII.

TABLE XIII.

Occurrences of Diatoms.

Area.	Year.	April 16–30.	May 1–15.	May 16–31.	June 1–15.	June 16–30.	July 1–15.	July 16–31.	Aug. 1–15.
59° to 60° N.	1931				0	0	Rh.++ Ch.+ Tha.+	Rh.+ Par.+	
	1932					0	0	0	0
	1933				0	Ch.++	0		
58° to 59° N.	1931					Rh.+ Ch.+ Tha.+ N.+ Cra.+	Rh.+++ Ch.++ Tha.++ N.+	0	0
	1932						0	0	Ch.+
	1933	Ch.+++ Tha.+++ N.+++ Cosc.+			0	0	0	0	0
56° to 58° N.	1931								0
	1932			Rh.++ Ch.+++ Tha.+++ N.+++	0		Rh.++ Tha.+	0	0
	1933				0	Rh.++ Ch.+ Thx.+++ N.+++	0		0

Explanation of Symbols.

0 No diatoms recorded from samples taken.
\+ Present but not exceeding 1000 cells per disc.
++ Moderately abundant, 1,000–25,000 cells per disc.
+++ Abundant, exceeding 25,000 cells per disc.

Rh. Rhizosolenia spp., Ch. Chætoceros spp., Tha. Thalassiosira spp., N. Nitzschia spp., Thx. Thalassiothrix spp., Cosc. Coscinodiscus spp., Cra. Coscinosira spp., Par. Paralia spp.

Halosphæra is recorded in the area 56° to 58° N. in 16–31 May and 1–15 June, 1932, these being the only occurrences of this form. Phæocystis is found in all the areas N. of 58° N. in the Scottish Eastern Fishery, but is not very common. It is not recorded in 1930 or 1932, and is only recorded once in 1933 (Area 58° to 59° N., 16–31 July). Most of the records of its presence refer to 1931, when it is recorded for the area N. of 60° N. in July, for the area 59° to 60° N. in 1–15 July, and for the area 58° to 59° N. for 16–30 June and July, being most abundant and occurring most often in 1–15 July. It is probable that this form was rather more widespread than these records indicate, as it is very difficult to be certain of its presence if the discs have been stored for some time before examination, but it is unlikely that any instances of its occurrence in large quantity have been missed.

Dinoflagellates are fairly abundant during the period covered by these investigations, and the figures for Ceratium species, which form the bulk of the records, are set out in Table XIV below. The numbers are given as hundreds of Ceratium and are to the nearest 100.

TABLE XIV.

DINOFLAGELLATES: CERATIUM SPECIES, IN HUNDREDS.

AVERAGE NUMBERS PER SAMPLE PER HALF MONTH.

Indices denote the number of samples averaged.

Year.	Area.	May 16–31.	June 1–15.	June 16–30.	July 1–15.	July 16–31.	August 1–15.	August 16–31.
1930	N. of 60° N.		195^{5}	—	—	0^{1}		
	59° to 60° N.			420^{8}				
	S. of 59° N.					815^{4}	71^{10}	
1931	N. of 60° N.			302^{15}	486^{8}	316^{5}		
	59° to 60° N.		530^{2}	357^{9}	192^{10}	281^{11}		
	S. of 59° N.			44^{8}	257^{11}	387^{17}	454^{11}	
1932	N. of 60° N.			514^{10}	406^{13}	1049^{8}		
	59° to 60° N.			458^{18}	605^{9}	899^{21}	1000^{1}	
	S. of 59° N.	7^{3}	678^{1}	—	276^{16}	442^{14}	503^{28}	465^{6}
1933	N. of 60° N.			804^{7}	717^{3}			
	59° to 60° N.		71^{9}	338^{17}	637^{5}			
	S. of 59° N.		2^{3}	42^{11}	315^{15}	425^{11}	567^{2}	457^{3}

	Area.	1930.	1931.	1932.	1933.
Average per area in years and totals	N. of 60° N.	162^{6}	357^{28}	607^{31}	778^{10}
	59° to 60° N.	420^{8}	290^{32}	685^{49}	308^{31}
	S. of 59° N.	283^{14}	314^{47}	415^{68}	275^{45}
	Whole area	297^{28}	318^{107}	544^{148}	345^{86}

There is, on the whole, a tendency for the abundance to be greater N. of 59° N. than to the south of this line, and for the abundance to increase to some extent with the passage of time in any one season. The general average level increases up to 1932 but drops in 1933 and only in the area N. of 60° N. do the figures increase steadily over the four years. It is possible that the 1933 season might have shown higher figures had the material been more extensive, as the figures available indicate higher numbers in the northern part of the area than at the corresponding periods in any of the previous years. The relatively limited material at the beginning of the season suggests low numbers, while there are signs of a diminution of abundance after mid-August.

The Western Fishery.

The samples available from this section of the Scottish Fishery are restricted in both space and time, so that the few results which can be obtained may hardly be regarded as significant, except in that they afford confirmatory evidence of the Calanus-herring correlations. Few of the samples were obtained by drifters, the majority having been secured by cruisers of the Fishery Board for Scotland. (The instrument was towed close to a drifter's fleet of nets, and the catch ascertained subsequently. We are indebted to the Fishery Board for Scotland for arranging for their Fishery Cruisers to take samples for us in these waters.) Only the latter, located in the waters of the Little Minch and North Minch where they form groups on various dates, are available in sufficient numbers to form correlation tables. There are six dates when groups of samples were secured, and the results of the correlations, in terms of percentage gain or loss, are shown below in Table XV. The number of samples, five, on each of the September, 1930, dates is too small to consider these two results even as secondary results in the sense in which this term is used for the Eastern Fishery, but, for reasons given below, a combination of these two tables into one gives a misleading result, so they are quoted separately. The six sets of samples fall into three half-month periods, and these results are also shown.

TABLE XV.

Abridged Correlation Tables. Calanus.

Year.	Date.	No. of samples.	Average Calanus.	Average catch. (crans)	Percentage gain or loss.	Percentage gain or loss. Half-months.
1930	22 Sept.	5	161	1·0	+ 5·3	− 72·0
	26 Sept.	5	18	5·8	+ 28·4	
1931	1 July	22	72	1·1	− 18·0	+ 5·4
	2 July	44	174	2·2	+ 7·9	
	26 Aug.	15	983	3·2	+ 27·5	+ 12·6
	27 Aug.	16	827	1·8	− 3·4	

The combination of the two September dates into one table for the half-month, which gives a loss of 72·0%, is found on examination to be unjustified. All the samples from the 22nd September fall on the higher Calanus side, and on this date a low average catch is associated with a high Calanus average (and a high Limacina average), while all the samples from the 26th September, when the Calanus average was low (Limacina also), with an increased catch, fall on the lower Calanus side. Thus the combination gives a loss, although each day indicates a gain if treated separately.

The two other half-month periods, which may more justifiably be formed from the days concerned, show gains of 5·4% and 12·6%, and average 9·0% gain, or if the individual days are used, an average gain of 3·5% is shown. (This becomes a gain of 8·0% if the two 1930 results are included.)

These results, as far as they go, provide further support for the positive Calanus-herring correlations established in the Scottish Eastern and Shields Fisheries, and indicate that increased catches would have been obtained in the Scottish Western Fishery by using the Indicator on the basis of the Calanus correlations. The average percentage gain indicated by the above results is smaller than in the other fisheries, but there are too few results to provide a reliable estimate of this figure. It should, however, be remembered that a small percentage gain in catch on a poorly supplied market may mean a relatively greater monetary return than that accruing from a greater gain when the market is well supplied; and the average catch in this fishery was low over the years concerned. The observations of Herdman and Riddell (1913) on Calanus and the herring-shoals in the Hebrides, quoted in Part I (p. 148), are of interest in considering the results for this area.

Limacina was abundant, particularly in 1931, and Table XVI shows that over half of the total samples were taken in water of over 500 Limacina per disc. Table XVI also indicates the possibility of a negative correlation between Limacina and herring, but the information is inconclusive, as in the Eastern Fishery.

TABLE XVI.

Limacina-Herring Correlations.

Indices denote the number of catches averaged (crans).

Limacina.	1930.	1931.	1932.	1930–1932.
0–99	$5{\cdot}8^{5}$	$2{\cdot}5^{28}$	$1{\cdot}5^{4}$	$2{\cdot}9^{37}$
100–249	—	$0{\cdot}9^{8}$	—	$0{\cdot}9^{8}$
250–499	$2{\cdot}4^{2}$	$2{\cdot}2^{10}$	$20{\cdot}0^{2}$	$4{\cdot}8^{14}$
500–999	$0{\cdot}0^{3}$	$2{\cdot}0^{20}$	$2{\cdot}5^{2}$	$1{\cdot}8^{25}$
1000 and over	—	$2{\cdot}0^{39}$	—	$2{\cdot}0^{39}$
100 and over	$1{\cdot}0^{5}$	$1{\cdot}9^{76}$	$11{\cdot}25^{4}$	$2{\cdot}3^{85}$
0–499	$4{\cdot}8^{7}$	$2{\cdot}2^{46}$	$7{\cdot}7^{6}$	$3{\cdot}0^{59}$
500 and over	$0{\cdot}0^{3}$	$2{\cdot}0^{59}$	$2{\cdot}5^{2}$	$1{\cdot}9^{64}$

The samples available are too restricted in space and time to enable any reliable information to be obtained relating to the distribution and abundance of the plankton generally. The Calanus averages are, however, noted in Table XV.

https://doi.org/10.1017/S0025315400011280 Published online by Cambridge University Press

NOTES ON SOME SAMPLES FROM IRISH WATERS.

In 1931, between the 24th of May and the 8th of June, eight samples, with associated catches of herring, were obtained from the north and west coasts of Ireland. These samples were characterised by a very great abundance of Limacina, the average being 51,866 Limacina per sample, with a maximum of 96,600 in one sample. Only one sample had less than 100 Limacina, and the associated catch was 46·0 crans, while the average for the remaining seven catches was 4·9 crans. The Calanus average was less than 100. No correlations can reasonably be drawn up for these samples, in four of which no accurate count of Calanus was obtained owing to the large numbers of Limacina present.

SUMMARY.

(1) In the Scottish Eastern and Western Fisheries 459 Plankton Indicator samples have been analysed and the results studied for evidence of correlations between the zooplankton and the 533 associated catches of herring. (See Part IV for the phytoplankton correlations.)

(2) In the Eastern Fishery, 1930–33, out of twenty half-month area-periods considered of primary value, fifteen show positive Calanus-Herring correlations and five negative. The area-periods of secondary value confirm this three to one ratio, there being eight positive and three negative results indicated. (A three to one ratio was also found in the Shields Fishery. Part II.)

(3) An attempt to estimate the commercial value of the Indicator, when used to locate the richer Calanus waters, shows that if in each period (1931–33) the fishing had taken place in the richer Calanus waters a gain of $24{\cdot}5 \pm 7{\cdot}7$ % over the catch secured by fishing at random should have resulted.

(4) Poor catches may be secured in the richer Calanus waters and good catches in the poorer Calanus waters, but the good catches are secured more frequently in the richer Calanus waters.

(5) A seasonal fluctuation in the degree of Calanus-Herring correlation is suggested, and the irregularity at the end of the season is tentatively associated with the arrival of shoals of spawning fish.

(6) The results of the Western Fishery, although few, in general support those of the Eastern Fishery.

(7) A negative correlation between the herring and large numbers of Limacina is suggested, but the evidence is inconclusive.

(8) The abundance and distribution of Calanus, Limacina, and a number of other plankton forms are discussed.

POSTSCRIPT.

A few samples were obtained in July, 1935, by H.M.S. *Foyle*, and two correlation tables of primary value have been compiled. These samples were all taken north of lat. 59° 55′ N. and so the tables may be compared with those for the area N. of 60° N. for the earlier years.

TABLE XVII.

SUMMARY OF DATA RELATING TO THE CALANUS-HERRING CORRELATIONS IN THE AREA NORTH OF 59° 55′ N. FOR JULY, 1935.

Period.	No. of samples.	Average Calanus.	Average catch.	Total catch in water of Lower Calanus numbers.	Total catch in water of Higher Calanus numbers.	Average catch in water of Lower Calanus numbers.	Average catch in water of Higher Calanus numbers.	Percentage gain or loss on total catch.
1–15 July	10	88	12·7	120·75	6·50	24·1	1·3	– 89·8
16–31 July	12	50	16·6	7·25	191·50	1·2	31·9	+ 92·7

Calanus reaches a higher average in 1–15 July than it did in 1931 and 1932, but is less abundant in 16–31 July than in the earlier years. Limacina is more abundant than in the corresponding periods in 1931–33, and the two correlations with this organism give negative results, supporting the suggested relation between Limacina and Herring (p. 265, also Table X).

TABLE XVIII.

LIMACINA-HERRING CORRELATIONS.

Period.	Average catch (crans) with Limacina 0–99.	Average catch (crans) with Limacina 100 and over.
1–15 July	$15{\cdot}9^{8}$	$0{\cdot}125^{2}$
16–31 July	$46{\cdot}0^{4}$	$1{\cdot}8^{8}$

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