Part II. Zooplankton-herring Correlations in the English Fisheries.

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With 24 Figures in the Text.

CONTENTS.

INTRODUCTION.

THE English fisheries which were investigated with the Plankton Indicator in 1931, 1932, and 1933 were divided into three areas, i.e., those off Shields, the Humber mouth and the East Anglian coast (this last fishery was also sampled in 1930). All the samples in the Shields area lie between 56° 00′ N. Lat. and 54° 20′ N. Lat., whilst the majority (80%) lie in the area between 54° 45′ N. Lat., and 55° 30′ N. Lat. and a line parallel to and some 40 miles from the coast. This is an area of some 1600 square miles. In the Southern Bight Lat. 53° 00′ N. was taken as a division between the Humber and the East Anglian areas. The distribution of all the samples is shown in Figs. 1 to 4. With the exception of the samples obtained by the Ministry of Fisheries research ship *Onaway* in June, 1931, and four samples obtained by H.M.S. *Cherwell* in September, 1933, all those in the Shields area have been collected by individual drifters engaged in the fishery. The Humber and East Anglian samples were obtained from both drifters and gunboats of the Fishery Protection and Mine Sweeping Flotilla alongside drifters fishing. The manner of collecting these samples has been described in Part I (p. 153).

The greater part of this work refers to the ecological relations of the herring to the copepod *Calanus finmarchicus** (Günn.) and to the pteropod *Limacina retroversa*† (Flemming).

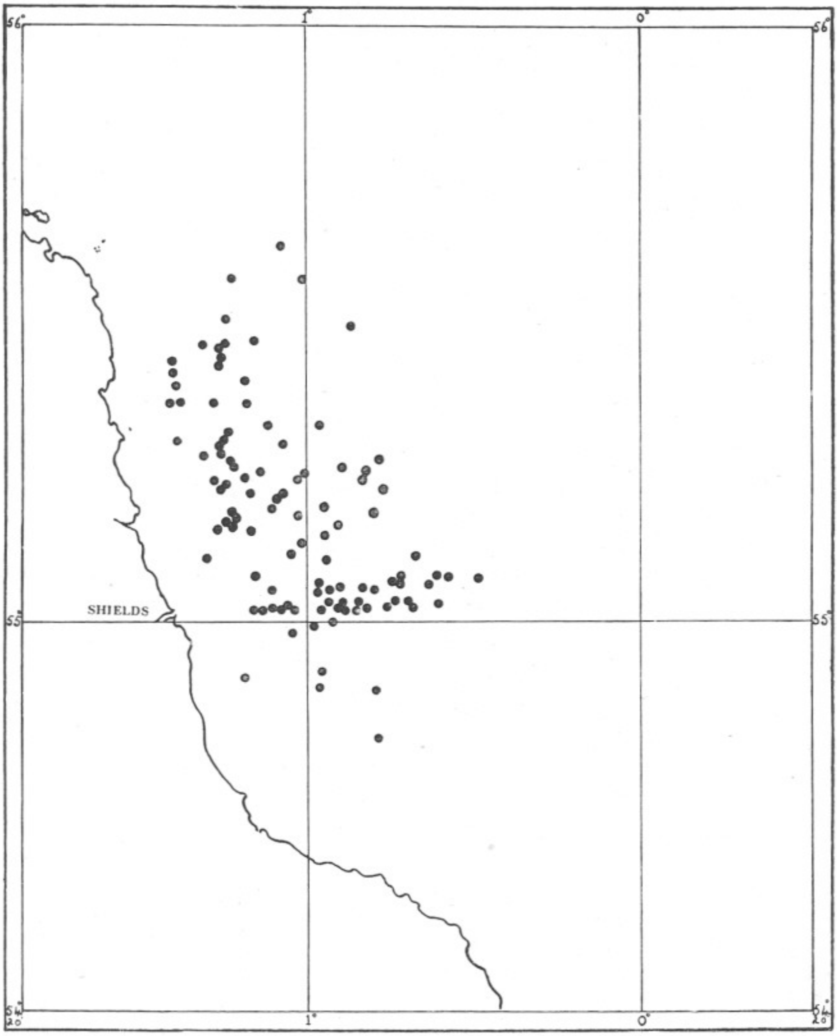


FIG. 1.—Showing the distribution of the Indicator samples in the Shields fishery in 1931 (29th June to 8th September).

In the first two years of the Scottish work (1930 and 1931) and the first year at Shields (1931) complete analyses of the plankton samples

* Throughout this paper the term Calanus is used to imply *Calanus finmarchicus* (Günn.).

† No other species have been identified, but at times differences in form have been noticed and it is possible that occasionally other species of the genus have been included in the general term Limacina used throughout the paper.

were made. Little sign of correlation between the herring and zooplankton forms other than Calanus and Limacina could be detected. Originally attempts were made to correlate the herring catches with total copepoda,

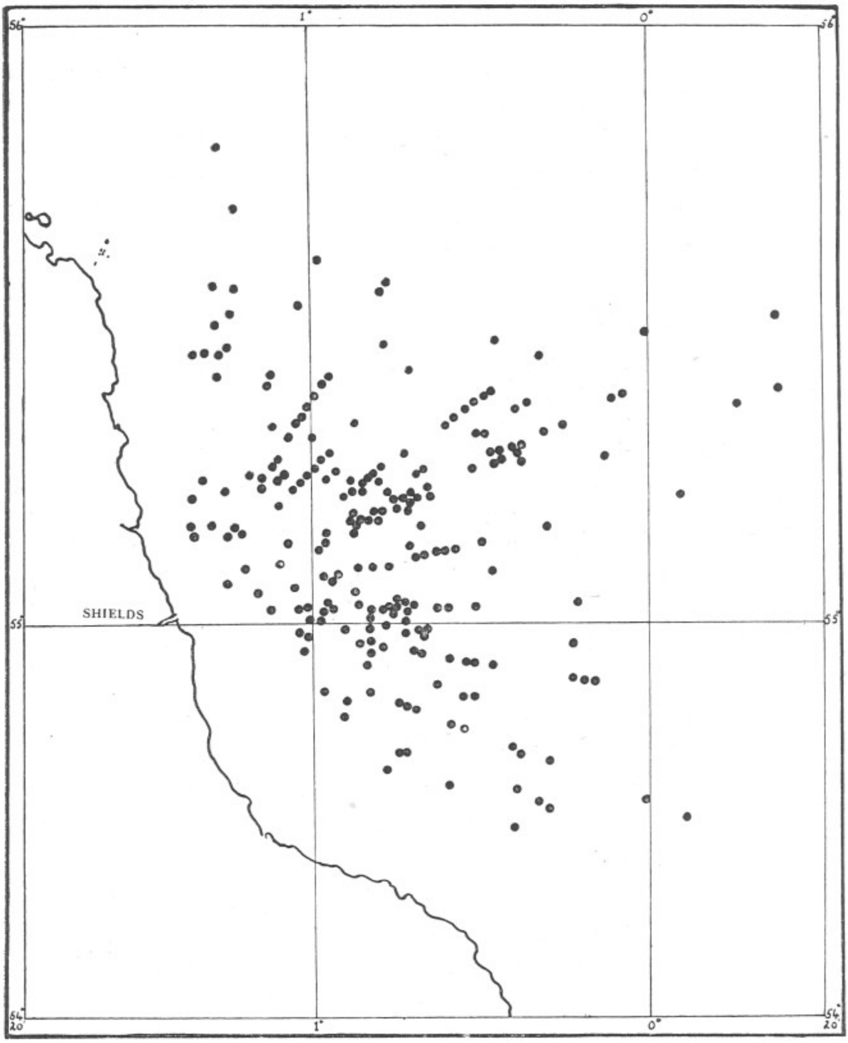


Fig. 2.—Showing the distribution of the Indicator samples in the Shields fishery in 1932 (3rd May to 14th September) Excluding one catch with position doubtful.

and positive correlations were found if we adopted a system of weighting the different species of copepoda approximately according to their relative mass. But it was then found that Calanus, having so great a mass compared with the other forms, overweighted these together to such an extent that total copepod correlations were usually almost equivalent to Calanus correlations. In 1932 and 1933 the analyses were restricted to Calanus, total Copepoda, Limacina and the phytoplankton as described

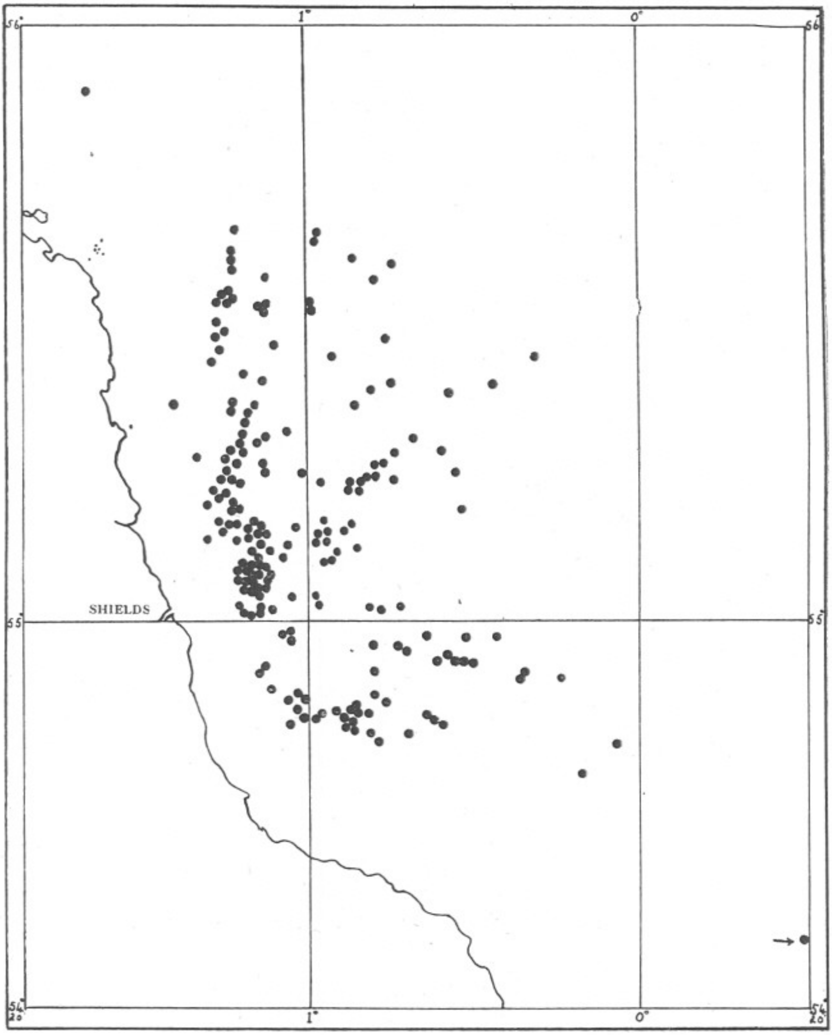


FIG. 3.—Showing the distribution of the Indicator samples in the Shields fishery in 1933 (1st May to 1st September).

on p. 159 of Part I. Fridriksson (1935) using the standard Indicator in Icelandic waters found, as far as his experiments went, no correlation with zooplankton other than Calanus (as quoted on p. 173 of Part I).

TABLE I.

SUMMARY OF DATA RELATING TO THE CALANUS-HERRING CORRELATIONS BASED ON THE RESULTS OF ALL DRIFTERS USING THE INDICATOR IN THE SHIELDS FISHERIES IN 1931, 1932 AND 1933.

Period and Year.	No. of Samples.	Calanus range.	Average Calanus.	Herring range in crans.	Average Herring in crans.	Calanus-herring Correlations. Total No. of herring in crans corresponding to lower and higher Calanus values.		Average No. of herring in crans corresponding to lower and higher Calanus values.		Percentage Increase or Decrease of the catch on the "higher" side compared with the catch of the whole series.
						Lower.	Higher.	Lower.	Higher.	
1931.										
June	30	12–350	87	0·8–60·0	12·8	165·8	218·0	11·1	14·5	+13·6
29 June/15 July* .	21	0–216	64	1·0–70·0	18·0	207·5	170·8	19·8	16·3	− 9·7
16–31 July . .	37	0–625	76	1·0–59·0	19·1	458·1	247·2	24·8	13·4	−29·9
1/15 Aug. . .	17	0–260	93	1·0–47·0	11·8	141·0	60·0	16·6	7·1	−40·3
16 Aug./8 Sept.* .	29	0–280	68	0·0–30·0	8·2	115·5	123·0	8·0	8·5	+ 3·1
Totals 1931 . .	134	0–625		0·0–70·0		1087·9	819·0	80·3	59·8	
1932.										
1–15 May . .	16	0–900	197	0·0–10·3	2·2	4·4	30·8	0·6	3·8	+75·1
16/31 May . .	43	0–2150	474	0·0–17·0	3·5	43·6	106·0	2·0	4·9	+41·7
1–15 June . .	50	45–3215	864	0·0–17·0	4·1	98·8	107·8	4·0	4·3	+ 4·4
16/30 June . .	45	0–3350	912	0·0–16·0	4·4	94·5	104·0	4·2	4·6	+ 4·8
1–20 July* . .	32	0–545	189	0·0–21·0	4·9	63·0	95·0	3·9	5·9	+20·3
1–15 Aug. . .	11	0–1045	175	1·5–40·0	10·5	82·8	32·5	15·1	5·9	−43·6
16–31 Aug. . .	17	0–550	121	0·1–16·0	4·7	25·9	54·0	3·0	6·4	+35·3
Totals 1932 . .	214	0–3350		0·0–40·0		413·0	530·1	32·8	35·8	
1933.										
1–15 May . .	12	10–1360	647	0·5–15·0	6·3	33·5	42·5	5·6	7·1	+11·8
16–31 May . .	11	2–525	170	0·5–13·0	6·0	26·5	39·0	4·8	7·1	+19·1
1–15 June . .	40	0–2200	200	0·0–13·0	2·1	34·6	48·0	1·7	2·4	+16·2
16–30 June . .	38	0–1800	389	0·0–41·0	8·6	183·0	142·0	9·6	7·5	−12·6
1–15 July . .	25	65–2800	1022	1·0–70·0	15·7	154·0	237·5	12·3	19·0	+21·3
16/31 July . .	25	0–4340	648	0·0–65·0	13·2	92·5	237·5	7·4	19·0	+43·9
1–15 Aug. . .	28	0–325	71	0·0–56·0	7·8	65·4	151·6	4·7	10·8	+39·7
16 Aug./1 Sept.* .	11	0–205	67	0·0–5·0	1·0	3·1	7·4	0·6	1·3	+40·5
Totals 1933 . .	190	0–4340		0·0–70·0		592·6	905·5	46·7	74·2	
Totals 1931–33 .	538	0–4340		0·0–70·0		2093·5	2254·6	159·8	169·8	

* Wherever possible, the periods selected have been limited to half-months of 15 or 16 days. Occasionally, in order to include as much of the data as we could, we have included a few days which would have otherwise been omitted at the beginning or the end of a period.

Calanus-Herring Correlations.

We will first describe briefly the distribution of Calanus and the nature of its relationship with the herring, and then discuss the significance of the correlations. The seasonal distribution of the samples is shown in Tables I and III whilst Figs. 6, 8, 10, 12 and 14 show their distribution in space during each period of the season in the Shields fishery.

Shields : 1931.

We were unable to begin work in this area before the 29th June so that we have no samples for the early part of the fishery which began at the end of April. Between the 7th and the 28th June however, thirty trials were made with the standard Indicator alongside drifters fishing in this area, by Mr. Michael Graham and Dr. W. G. Hodgson of the Ministry of Agriculture and Fisheries, on a cruise of the R.S. *Onaway*.* We are indebted to them for kindly placing at our disposal their records of Calanus numbers together with the corresponding catches of herring.

The average numbers of Calanus for June, July and August were 90, 70 and 80 respectively (see also Column 4, Table I). In May of the same year Gardiner (1933), using the Indicator in the area for studying the vertical distribution of Calanus, found it at similar depths a little more numerous on the whole than we did later.† From June on to the early part of September a weekly average of under 100 Calanus was the rule.

From the 7th June onwards, we have material (134 samples) for correlating the numbers of Calanus caught by the Indicator with the associated catches of herring. The method and the reasons for its adoption have been explained in Part I (p. 161). The series of samples was divided into half-monthly periods as nearly as possible.‡ The samples for each period were then arranged in ascending order of Calanus numbers and divided into two equal sets : one half containing the lower Calanus numbers of the series and the other the higher numbers (these will in future be termed "poorer" and "richer" Calanus samples). Against each was placed the corresponding catch of herring in crans§ : thus we can estimate the total or average catch of herrings in the poorer Calanus water and compare it with that in the richer. Reference should be made to the examples on pp. 162–3 in Part I. Table I summarises the essential data obtained in this way for all such period tables in the Shields fishing during the three years, and Figs. 5, 7, 9, 11, 13 and 15 (in the next section, pp. 190 to 201) illustrate these tables in a graphical form.

* See page 51, Report on Sea Fisheries for 1931 (1932).

† See also p. 219. ‡ See footnote to Table I.

§ A cran is a commercial measure of herring by volume. It is equivalent on an average to approximately 1,000 fish, but at different times and in different fisheries it may vary from somewhat less to considerably more.

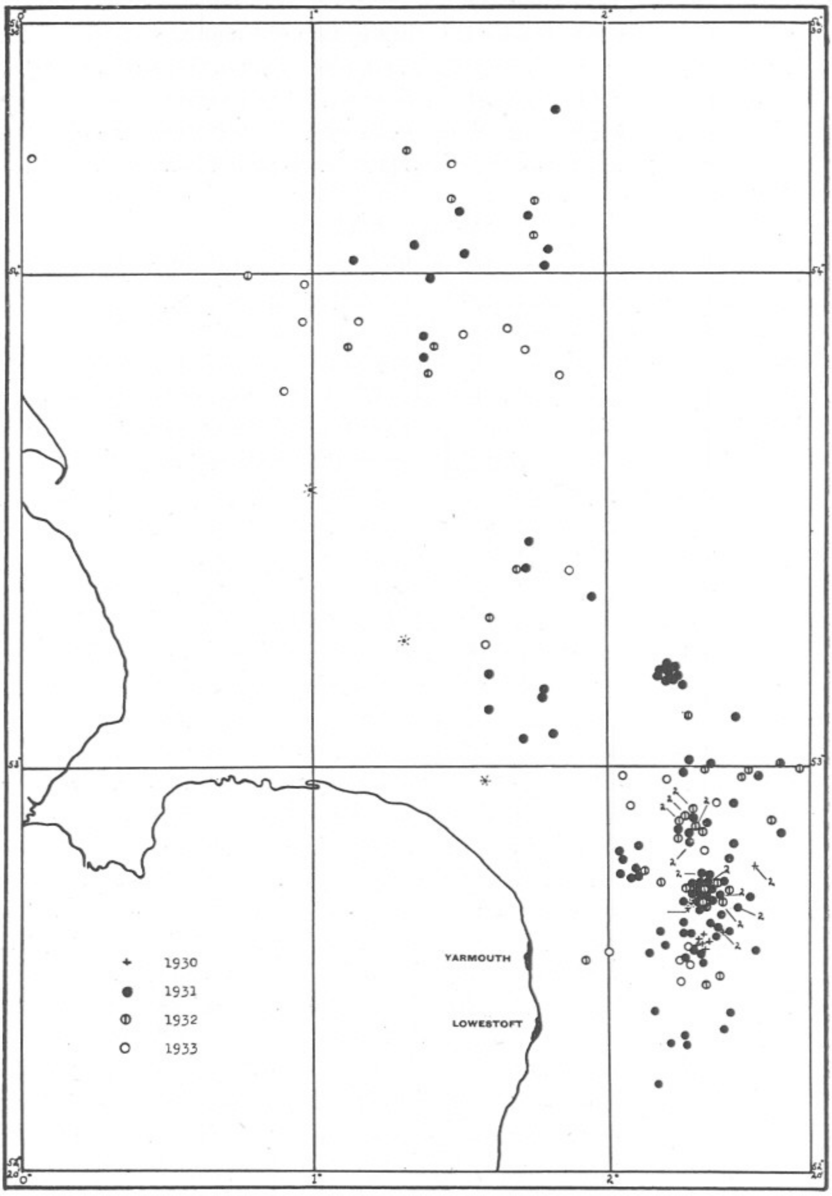


FIG. 4.—Showing the distribution of the Indicator samples in the Humber and East Anglian fisheries during the years 1930–33. Two catches associated with one plankton sample shown thus——2. Light vessels indicated thus *.

The tables in full, together with records of those remaining samples that could not usefully be grouped into tables (see p. 187) and the details of the catches in the Humber area and the Southern Bight, are to be filed in the British Museum (Natural History) and the Library of University College, Hull, and will be available for future workers if required. The series of maps (Figs. 6, 8, 10, 12 and 14) shows the spatial distribution of the Calanus samples over the three years, with the upper and lower halves of the series contrasted by different signs in each period. Alongside these maps are shown also charts of the distribution of the herring catches, the upper, intermediate and lower catches being distinguished by different symbols in each period.

Table I and Fig. 5 show that in June, 1931, when the R.S. *Onaway* samples were taken, a positive correlation was suggested. Thirty samples showed a total of 165·75 crans of herring taken in the poorer Calanus waters and 218·0 crans in the richer Calanus waters, giving an average of 11·1 and 14·5 crans respectively. In the following three half-months the data suggested an increasingly negative correlation (July and the first half of August). Details of the tables (see Figs. 5 and 7) show that the heavier catches were to be found near the lower end of the Calanus series; particularly is this so in the second half of July. The period 16th August–8th September suggested a small positive correlation. So far the general indications appear to be negative, 1087·9 crans being caught in the poorer Calanus waters and 819·0 crans in the richer Calanus waters, but it will be seen later that the use of such totals is subject to objection.

Shields : 1932.

A series of 218 samples was obtained, extending throughout the fishery from the beginning in early May, until the end of August, except for a period (July 21st to August 6th) during which all those drifters using the Indicator went north to the Scottish fishery. Calanus is by far the most important copepod throughout most of the season; its maximum period of abundance was in June (averaging about 1000 per disc) and where comparison is possible (see Table I and Fig. 21) it is much more abundant than in 1931 except at the end of August. The same, however, does not hold for the herring which were mainly scarce in 1932 (Table IV and Fig. 16).

The nature of the correlations between Calanus and the herring is seen in Table I and Figs. 9 and 11. From early May to mid-July they were markedly positive, although much less so in June than in May or July. The second week of August (providing only 11 samples) shows a marked negative correlation, but the latter half of August is again positive. The season as a whole shows a positive correlation, a total of 413·0 crans being caught in the poorer Calanus waters and 530·0 crans in the richer: in this respect 1931 and 1932 differ, but they show similarity in that the largest negative correlations occur in the first half of August in both years.

Shields: 1933.

We obtained this year a complete series of observations from the end of April to the end of August, although the number of samples (193) was somewhat lower than in 1932. Calanus was again the most important copepod, but its distribution in time was a little different from that in 1932. In early May it was quite dense in our samples and averaged about 650 per disc: the number of samples was, however, rather small. Its numbers then decreased steadily until early June when an average of only 41 was found. By the end of the first week in July the numbers had increased to over 1000 and such numbers were maintained till the end of the third week; a sudden drop then produced an average of less than 100 throughout August. It seems probable that on the whole Calanus was richer this year than in 1932 and the landings of herring appear to have been a little heavier (Figs. 16 and 21). The correlations proved to be positive with the exception of the period 16th–30th June (in particular the third week of June) which was decidedly negative (Table I and Figs. 13 and 15). Taking the season as a whole there is a marked positive correlation: 592·6 crans being caught in the poorer Calanus waters and 905·5 crans in the richer waters which were sampled. The most striking difference from the previous years is that the negative correlation so marked in the first half of August of 1931 and 1932, is not apparent this year.

Shields: 1931–33.

The Shields area has been sampled more intensively and for a longer period than those off the Humber and East Anglia, and for that reason we must discuss it in more detail. The totals at the feet of columns 7 and 8 in Table I show that over the three years 2093·5 crans were caught in the poorer Calanus waters (as shown period by period) and 2254·6 crans in the richer waters. As a whole this suggests a general positive correlation between Calanus and the herring, but the figures so obtained are subject to the criticism that they are seriously weighted by the number of samples we were able to obtain in any one period. Thus an average of 18 crans in the first half of July, 1931, is only represented (and so weighted) by 21 samples whereas the average of 2 crans in the first half of June, 1933, is represented by 40 samples and thus is given nearly twice the weight of the previous example. Consequently, in order to evaluate the relationship over the three years and to include all the fluctuations in the abundance of the fish, we thought it advisable to give the results the same weight for each period, as though an equal number of samples was obtained in each. Columns 9 and 10 show the *average* number of crans obtained in lower and higher Calanus waters. They can be taken to be a measure of the results which would be obtained if a constant number of boats had fished a constant number of times in each half-month. Totals obtained from these columns show that in 1931 the correlation was negative with 80·3 crans in the poorer Calanus waters against 59·8 crans in the richer waters. 1932 and 1933 are both positive with figures of 32·8 and 46·7 crans in the poorer waters and 35·8 and 74·2 crans in the richer. The whole shows 159·8 crans in the poorer waters and 169·8 crans in the richer. Now our sampling in the year 1931 was incomplete; the only samples we have for the first half of the season are those taken by the R.S. *Onaway* during June. The sum of the two complete seasons 1932 and 1933, comprising 411 samples taken throughout the two seasons, gives 79·5 crans and 110·0 crans in the poorer and richer Calanus waters respectively.

There are 20 half-monthly periods* in the Shields area and of these 15 show a positive correlation: in itself this might be taken as indicating a 3 to 1 chance that any correlation would prove positive.† A similar ratio of 3 to 1 in the Scottish waters would tend to confirm this possibility, but there is some evidence to show that in the Shields area the negative correlations are limited to a short period. Up to the end of June over the three years, only one result in nine is negative. The first half of July shows one negative and two positive; the second half of July shows one negative and one positive; August 1st–15th shows two negative and one positive whilst all the results from the second half of August are positive. The positive correlation tends to give place to a negative one and then to a positive one again.

The Shields material can be considered in another way. So far we have been using together all the samples collected by different boats in any one period. Now we have seldom had more than five boats using the indicator at one time in this area, and most of the boats have worked over several periods in one or more years. Thus it is possible (as it is not in the other areas) to obtain correlations based upon "Individual Boat" returns, a list of which is shown in Table II. The data have been treated in the same manner as the preceding, but sometimes more irregular periods had to be employed, some extending to as much as one month, or overlapping from one month to the next. This was necessary because the number of samples per individual boat per half-month is sometimes very low. We have omitted from the table any correlation containing less than ten samples, having decided, as in the Scottish area, that ten is the lowest number upon which a correlation may be satisfactorily based.

* See footnote to Table I.

† It must be borne in mind that only three results are possible for a correlation of this type: positive, negative and identity.

TABLE II.

SUMMARY OF DATA RELATING TO THE CALANUS-HERRING CORRELATIONS BASED ON THE RESULTS OF THE INDIVIDUAL DRIFTERS (A–G) USING THE INDICATOR IN THE SHIELDS FISHERY IN 1931, 1932 AND 1933.

Drifter.	Month and Year.	No. of samples.	Calanus-herring Correlations. Total crans of herrings corresponding to lower and higher Calanus values.		Average crans of herrings corresponding to lower and higher Calanus.		Per cent gain or loss.
			Lower.	Higher.	Lower.	Higher.	
A.	1–15 July, 1931	11	94·8	116·8	17·2	21·2	+10·0
	16–31 July, 1931	17	190·1	90·1	22·4	10·6	−35·7
	1 Aug.–8 Sept.,1931	22	54·5	102·0	5·0	9·3	+30·4
	1–31 May, 1932	18	10·4	22·1	1·2	2·5	+36·2
	1–15 June, 1932	13	17·9	26·1	2·8	4·0	+18·8
	16 June–8 July, 1932	15	34·0	65·5	4·5	8·7	+31·7
	1–31 Aug., 1932	17	26·8	48·0	3·2	5·7	+28·4
	29 April.–15 May, 1933	14	35·5	46·5	5·1	6·6	+13·4
	16 May–20 June, 1933	18	37·5	50·0	4·2	5·6	+14·3
	1–31 Aug., 1933	11	14·3	59·3	2·6	10·8	+61·2
	Total Boat A	156	515·8	626·4	68·2	85·0	..
	Average Boat A	16	51·6	62·6	6·8	8·5	+20·9
B.	16–31 July, 1931	10	123·0	111·0	24·6	22·2	− 5·1
	1 Aug.–1 Sept., 1931	20	120·0	117·0	12·0	11·7	− 1·3
	16–31 May, 1932	11	3·8	23·4	0·7	4·3	+71·8
	1–15 June, 1932	11	20·3	38·8	3·7	7·1	+31·4
	16 June–16 July, 1932	12	5·0	25·5	0·8	4·3	+67·2
	Total Boat B	64	272·1	315·7	41·8	49·6	..
	Average Boat B	13	54·4	63·1	8·4	9·9	+32·8
C.	29 July–1 Aug., 1931	17	166·4	121·9	19·6	14·3	−15·4
	1–31 May, 1932	11	12·0	31·5	2·2	5·7	+44·8
	1–30 June, 1932	14	39·0	24·3	5·6	3·5	−23·3
	1–31 July, 1932	10	14·5	29·0	2·9	5·8	+33·3
	Total Boat C	52	231·9	206·7	30·3	29·3	..
	Average Boat C	13	58·0	51·7	7·6	7·3	+ 9·9
D.	12–31 May, 1932	16	19·8	50·8	2·5	6·3	+44·0
	1–15 June, 1932	10	14·8	21·3	3·0	4·3	+18·1
	16 June–13 July, 1932	19	37·8	23·0	4·0	2·4	−21·8
	1–30 June, 1933	21	55·0	72·5	5·2	6·9	+13·7
	1–15 July, 1933	11	69·0	52·0	12·6	9·5	−14·0
	16 July–1 Aug., 1933	15	38·0	102·0	5·1	13·6	+45·7
	Total Boat D	92	234·4	321·6	32·4	43·0	..
	Average Boat D	15	39·1	53·6	5·4	7·2	+14·3
E.	18 May–15 June, 1932	12	20·0	28·5	3·3	4·8	+17·5
	16 June–10 July, 1932	14	40·0	49·0	5·7	7·0	+10·1
	Total Boat E	26	60·0	77·5	9·0	11·8	..
	Average Boat E	13	30·0	38·8	4·5	5·9	+13·8
F.	1–30 June, 1933	22	83·5	39·5	7·6	3·6	−35·8
	1–31 July, 1933	15	134·0	201·0	17·9	36·8	+20·0
	1–15 Aug., 1933	10	20·0	70·0	4·0	14·0	+55·6
	Total Boat F	47	237·5	310·5	29·5	44·4	..
	Average Boat F	16	79·2	103·5	9·8	14·8	+13·3
G.	1–30 June, 1933	20	40·5	82·0	4·1	8·2	+33·9
	Grand total	457	1592·2	1940·4	215·3	271·3	..

The drifters will not be referred to by name but by the letters " A " to " G," since boat owners and skippers may not wish the details of their fishing to be made public. Of the seven boats working for us at different times, six showed a positive relation between Calanus and the herring over the whole time of sampling: one boat C, showed a small negative result.* If the average catches† for the seven boats are added on either side (i.e., totals corresponding to the lower and higher Calanus numbers), as might be expected, a marked positive result is found. Altogether the samples of the seven boats have been arranged into 31 boat-periods: of these 23 proved positive and 8 negative. Here again is the ratio of three positive results to one negative one, but again the negative results are seasonal: May shows positive results only, in June nine out of eleven are positive, in July less than half are positive whereas in August four out of five are positive. The negative period is July, and mainly in the second half of the month, but it will be remembered that the previous results suggest August 1st–15th as the most negative period. It is possible that the difference between these results is due to the insufficiency of samples in August to provide half-monthly individual boat results, and the probable overweighting of the negative tendencies in early August by the definitely positive ones in late August when these periods are combined. In weighing up these results we must not forget that no negative correlations were found in the late July and August periods of 1933.

The Shields material may also be considered with regard to the spatial relationships between Calanus and the herring. We have already referred to the series of charts (Figs. 6, 8, 10, 12 and 14) showing the distribution of the Shields samples during each half-month for the three seasons. They have been arranged in pairs, one of each pair showing the broad distribution of Calanus and the other that of the associated catches of herring. In the Calanus charts the open circles indicate the lower and the filled-in circles the upper halves of the Calanus series respectively (based on the correlation tables described on p. 161 of Part I and p. 183 of this part). In the herring charts a little more detail is shown: the catches have been arranged in an ascending series as with Calanus, and then divided into three sections such that the open circles show the lower half of the catches, whilst the upper half (shown as shaded and filled-in circles) has again been divided, into two sections, the shaded circles representing the third quarter and the filled-in circles the top (fourth) quarter of the ascending series of catches.‡ This series of charts represents the first continuous survey of conditions on a herring ground over three

* This is found to be positive when treated another way. (See p. 215.)

† See note on p. 187.

‡ Odd numbers and the coincidence of several identical values of Calanus or herring at the half or three-quarter points in the ascending series may (as in the period 1–15 May, 1932) necessitate the halves or quarters of the series being only approximate.

seasons and permits a broad comparison to be made of the spatial distribution of Calanus and the herring period by period. To further this comparison, histograms representing the period correlation tables (see p. 183) have been arranged facing each appropriate pair of charts (Figs. 7, 9, 11, 13 and 15). The sets of spatial diagrams and histograms should be

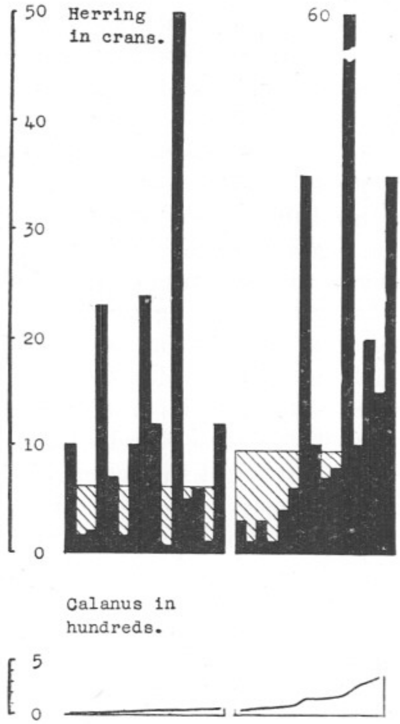


FIG. 5.—Histogram showing (in black) the individual catches of herring in June, 1931, arranged from left to right in the order of the ascending values of Calanus in the associated plankton Indicator samples. The series is divided into halves, the left half representing the catches in the poorer Calanus water and the right half the catches in the richer Calanus water. The average catches of herring in each half are shown as shaded histograms. Below are graphs showing the associated Calanus values.

considered together. At first sight the correspondence between the distribution of the herring and that of Calanus may not appear to be a close one, but a study of the histograms will show that usually the highest catches of herring are taken in the highest Calanus areas. In the small spatial charts it has been impossible to indicate the relative sizes of the catches in the higher Calanus water.

In general the series of charts and histograms needs little description in the text, but certain features seem worthy of mention. As a whole there is a fair correspondence in the spatial distribution of the higher Calanus samples and the higher catches except in certain periods when the charts show how inadequate has been the sampling of the area (e.g. the period 1–15 August, 1932) and when (particularly with a generally high or low average value of Calanus) the higher Calanus values are distributed widely over the whole area (this is particularly well shown in the two June periods of 1932 during which the positive correlations were almost negligible).

In 1931 the samples showed Calanus to be very sparse and evenly scattered in the area during July and the first half of August: in early July there appeared to be a concentration of herring in the centre of the area, but in late July and early August the herring also were fairly evenly spread and relatively large numbers were on the grounds. At the end of the season (16 August–8 September) there was a definite concentration of Calanus near the coast and some concentration of the herring in that region also: the correlation for this period was only slightly positive. The spatial distribution of Calanus as a whole during July and August does not suggest that it would be possible for the herring to locate dense patches even if the feeding urge was great, and we do indeed find by correlation a generally negative association during these periods (but see also p. 223).

In early May, 1932, we had relatively few scattered samples, but individually the association between the samples and their catches was very good. Later in May there is definitely a concentration of herring in the richer Calanus area. The June periods have been mentioned above. In July we obtained no samples after the 20th, but up to that date there is a good correspondence, six out of eight of the highest catches being found in the higher Calanus zones (mainly on the eastern side of the fishing area). The late August samples (for reference to early August, see above) suggest that both Calanus and the herring were more abundant in the northern part of the fishery.

In 1933 the correspondence is closer. In May there were relatively few scattered samples, with both Calanus and the herring irregularly distributed. In early June, whilst both are still diffuse, there is a rather closer agreement in distribution. The period 16–30 June shows an interesting feature. We see in the corresponding histogram in Fig. 13 that the correlation for this period was negative, but that when split into two sub-periods the first (16–22 June) is negative and the second (23–30 June) is positive, there being many more Calanus in the second sub-period than in the first. Referring to the charts, the southern group of samples and the most northerly ones in general represent the first sub-period whilst the second sub-period has samples mainly in the centre of the area. It seems possible

[*text continued on p. 202.*]

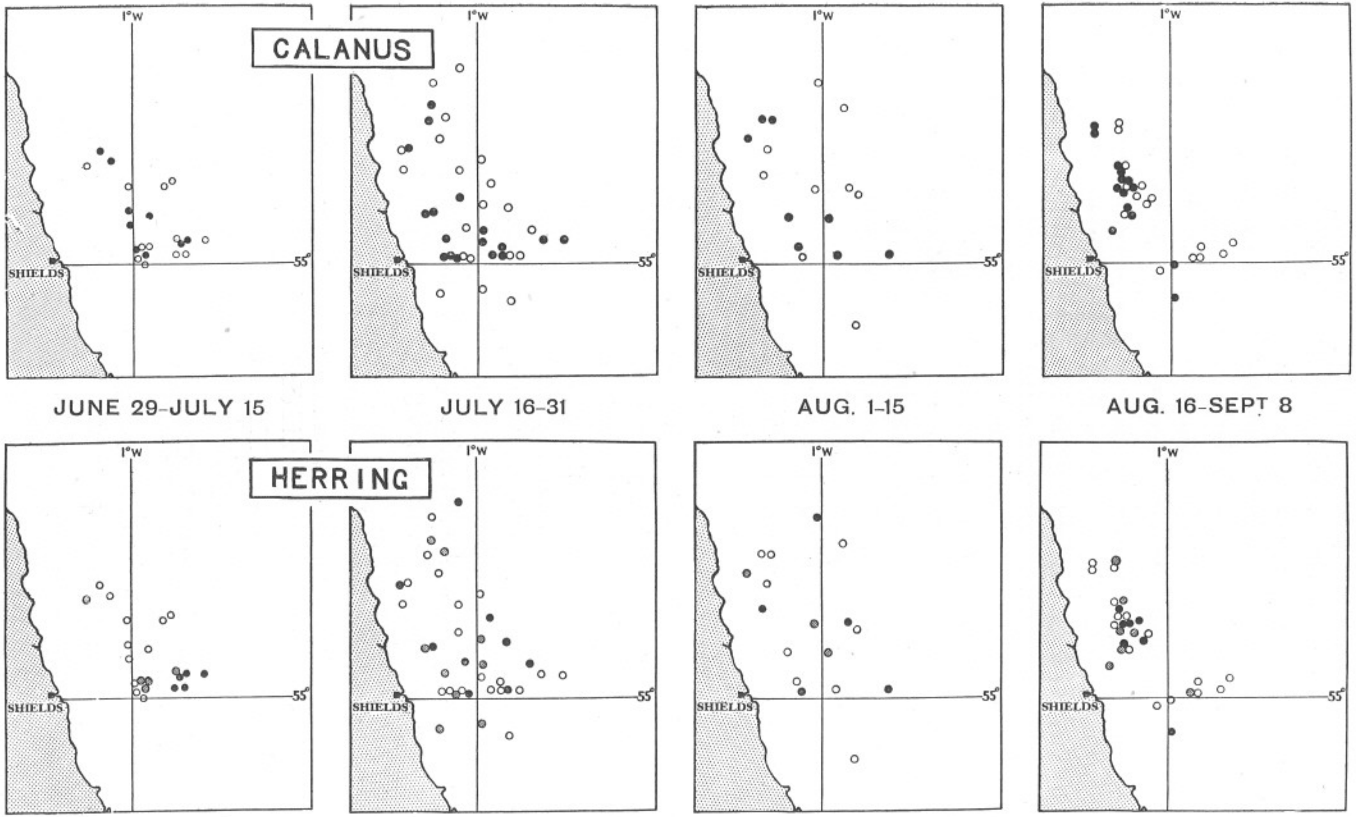


Fig. 6.—Charts showing the half-monthly distribution of Calanus as sampled by the Indicator in July and August, 1931, and below them the associated catches of herring. In the Calanus charts those samples falling in the upper half of an ascending series of Calanus values are shown as blacked-in circles and those in the lower half as open circles. In the herring charts the catches have been arranged in an ascending series as with Calanus but divided into three sections: the lower half of the catches shown as open circles, and the upper half again divided into two quarters shown as shaded and blacked-in circles, the latter representing the highest values.

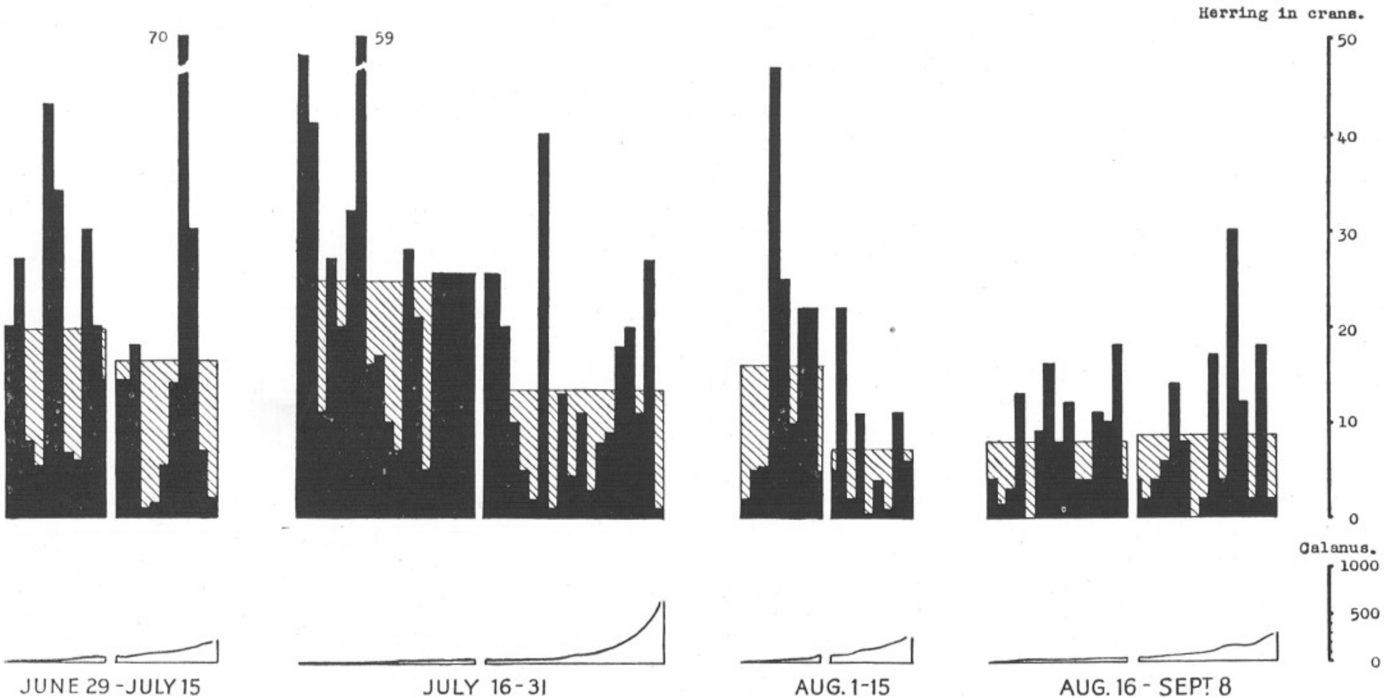


FIG. 7.—Histograms showing (in black) the individual catches of herring in the half-monthly periods corresponding to the charts in Fig. 6, arranged in each period from left to right in the order of the ascending values of Calanus in the associated plankton Indicator samples. Each series is divided into halves, the left half representing the catches in the poorer and the right half the catches 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 period tables drawn up for correlation purposes. For discussion see text.

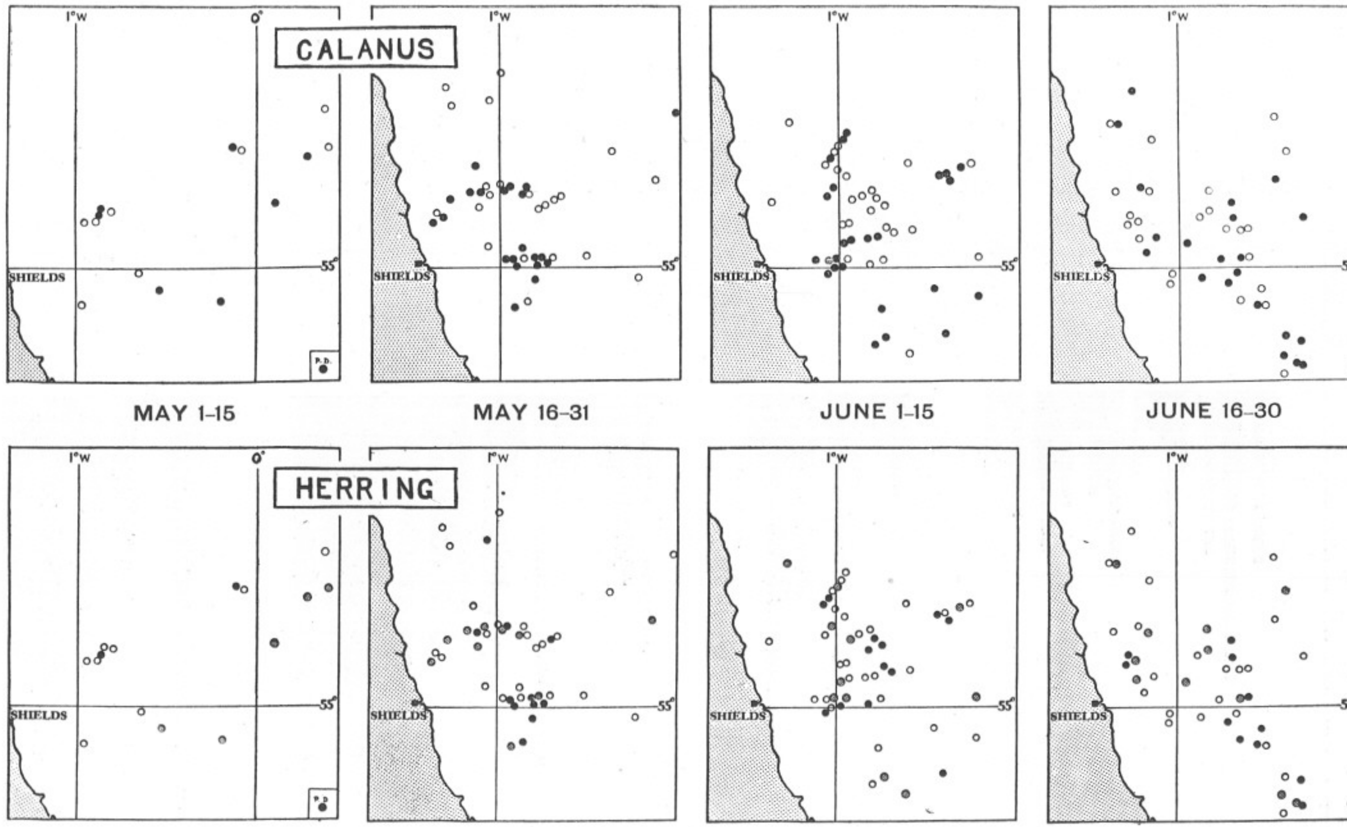


FIG. 8.—Charts showing the half-monthly distribution of Calanus as sampled by the Indicator in May and June, 1932, and below them the associated catches of herring. In the Calanus charts those samples falling in the upper half of an ascending series of Calanus values are shown as blacked-in circles and those in the lower half as open circles. In the herring charts the catches have been arranged in an ascending series as with Calanus but divided into three sections: the lower half of the catches shown as open circles, and the upper half again divided into two quarters shown as shaded and blacked-in circles, the latter representing the highest values. P.D. indicates position doubtful.

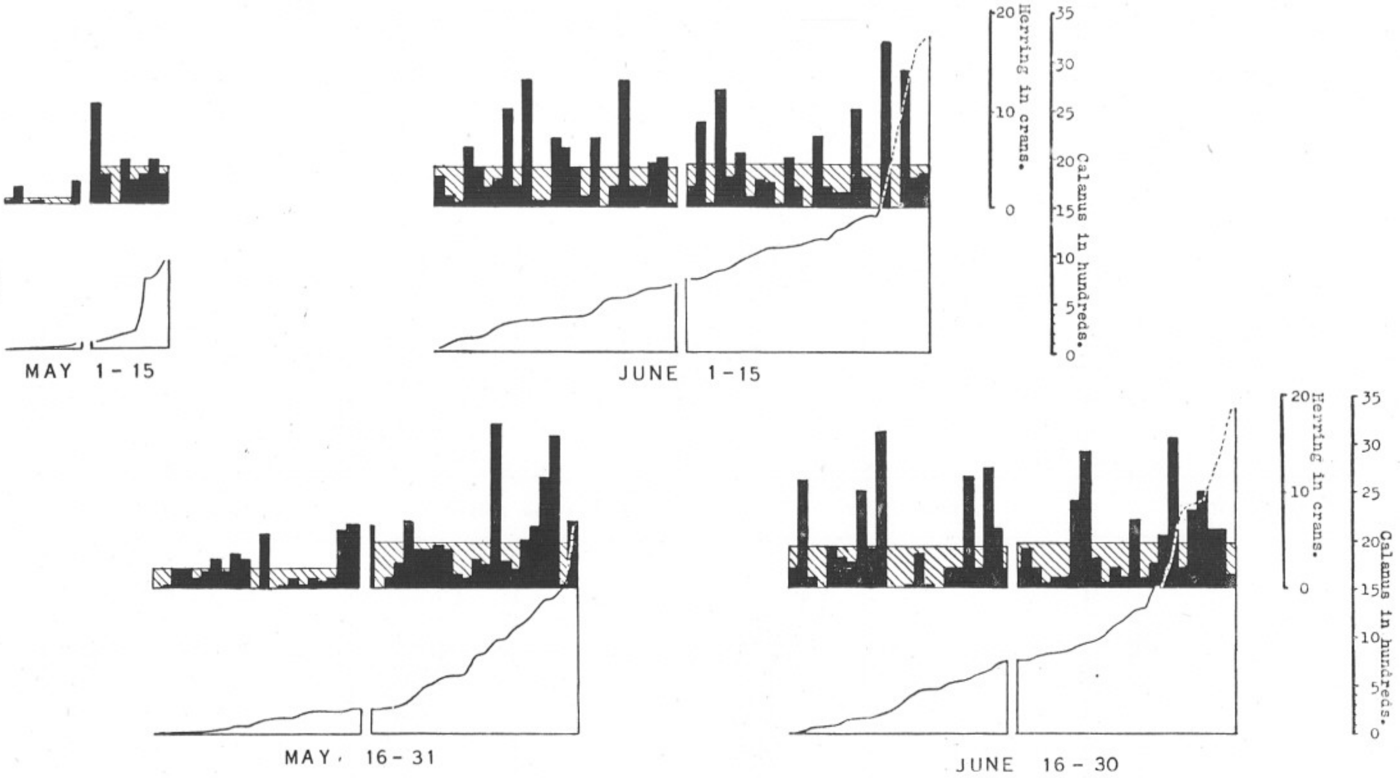


FIG. 9.—Histograms showing (in black) the individual catches of herring in the half-monthly periods corresponding to the charts in Fig. 8, arranged in each period from left to right in the order of the ascending values of Calanus in the associated plankton Indicator samples. Each series is divided into halves, the left half representing the catches in the poorer and the right half the catches 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 period tables drawn up for correlation purposes. For discussion, see text.

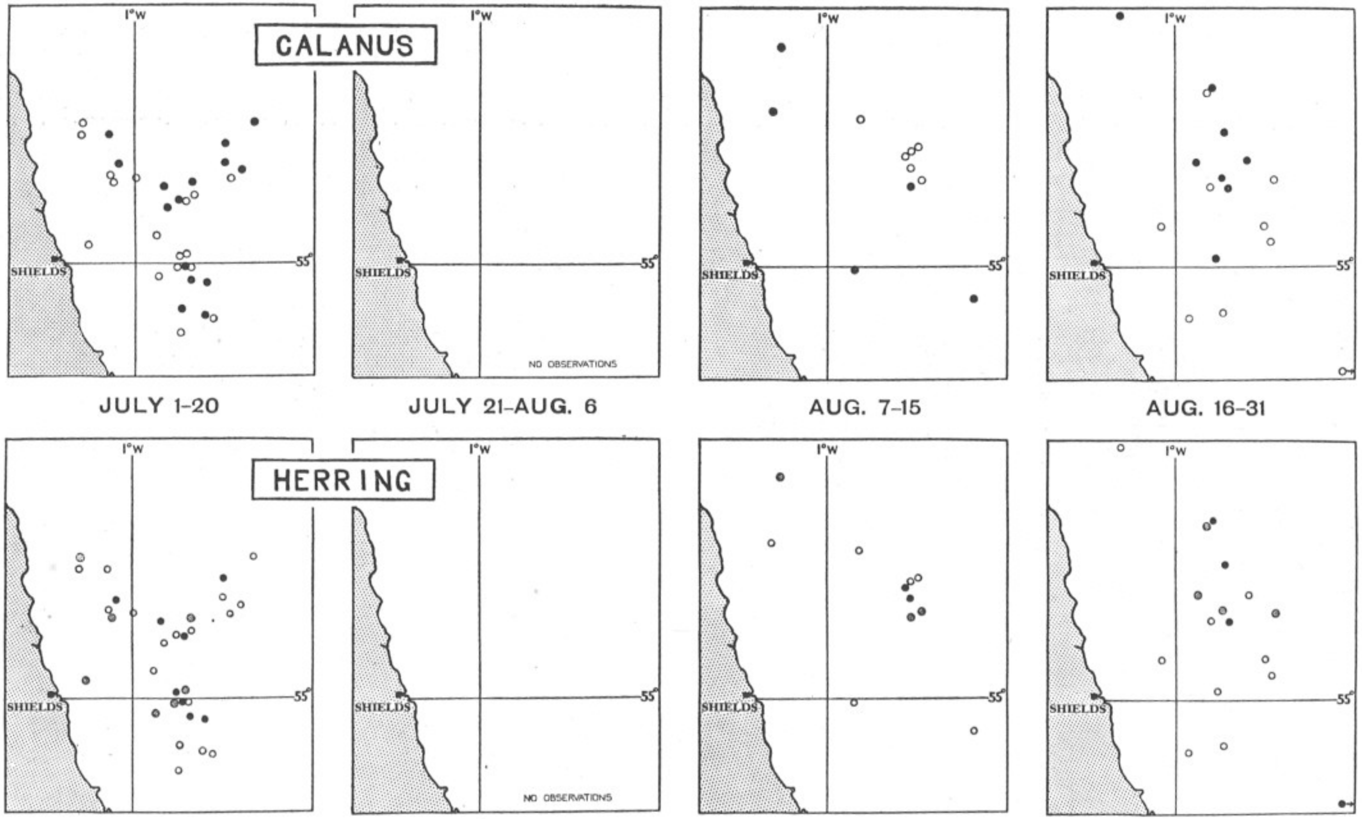


Fig. 10.—Charts showing the half-monthly distribution of Calanus as sampled by the Indicator in July and August, 1932, and below them the associated catches of herring. In the Calanus charts those samples falling in the upper half of an ascending series of Calanus values are shown as blacked-in circles and those in the lower half as open circles. In the herring charts the catches have been arranged in an ascending series as with Calanus, but divided into three sections: the lower half of the catches shown as open circles, and the upper half again divided into two quarters shown as shaded and blacked-in circles, the latter representing the highest values.

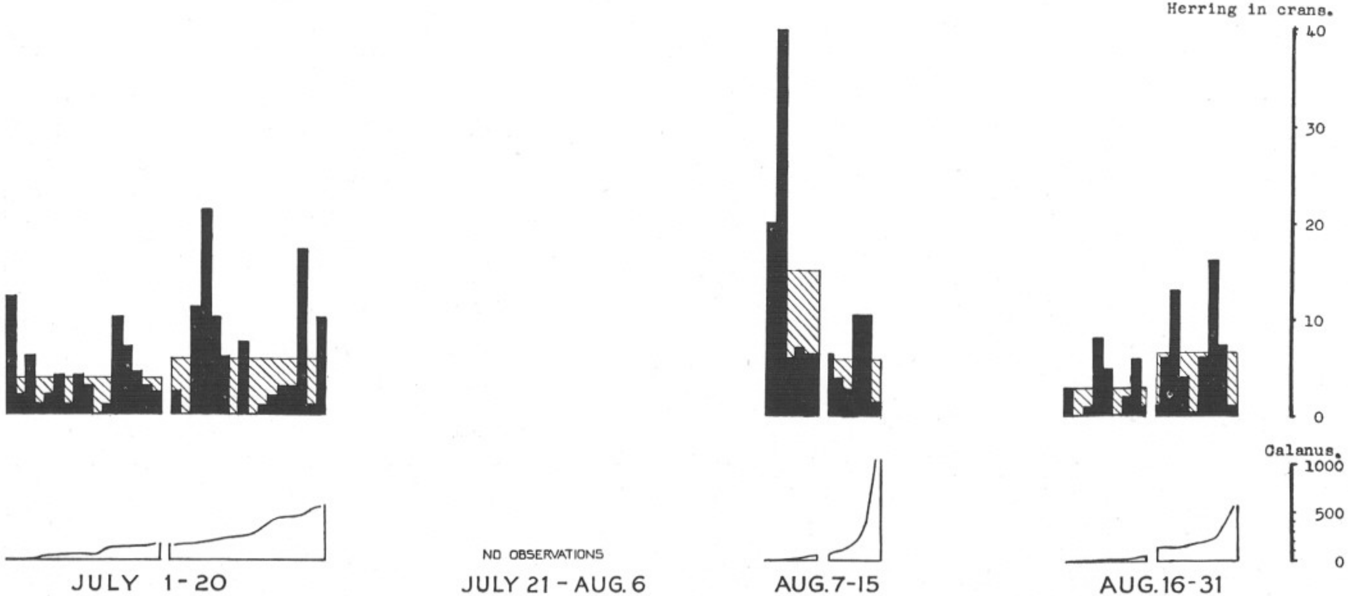


Fig. 11.—Histograms showing (in black) the individual catches of herring in the half-monthly periods corresponding to the charts in Fig. 10, arranged in each period from left to right in the order of the ascending values of Calanus in the associated plankton Indicator samples. Each series is divided into halves, the left half representing the catches in the poorer and the right half the catches 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 period tables drawn up for correlation purposes. For discussion, see text.

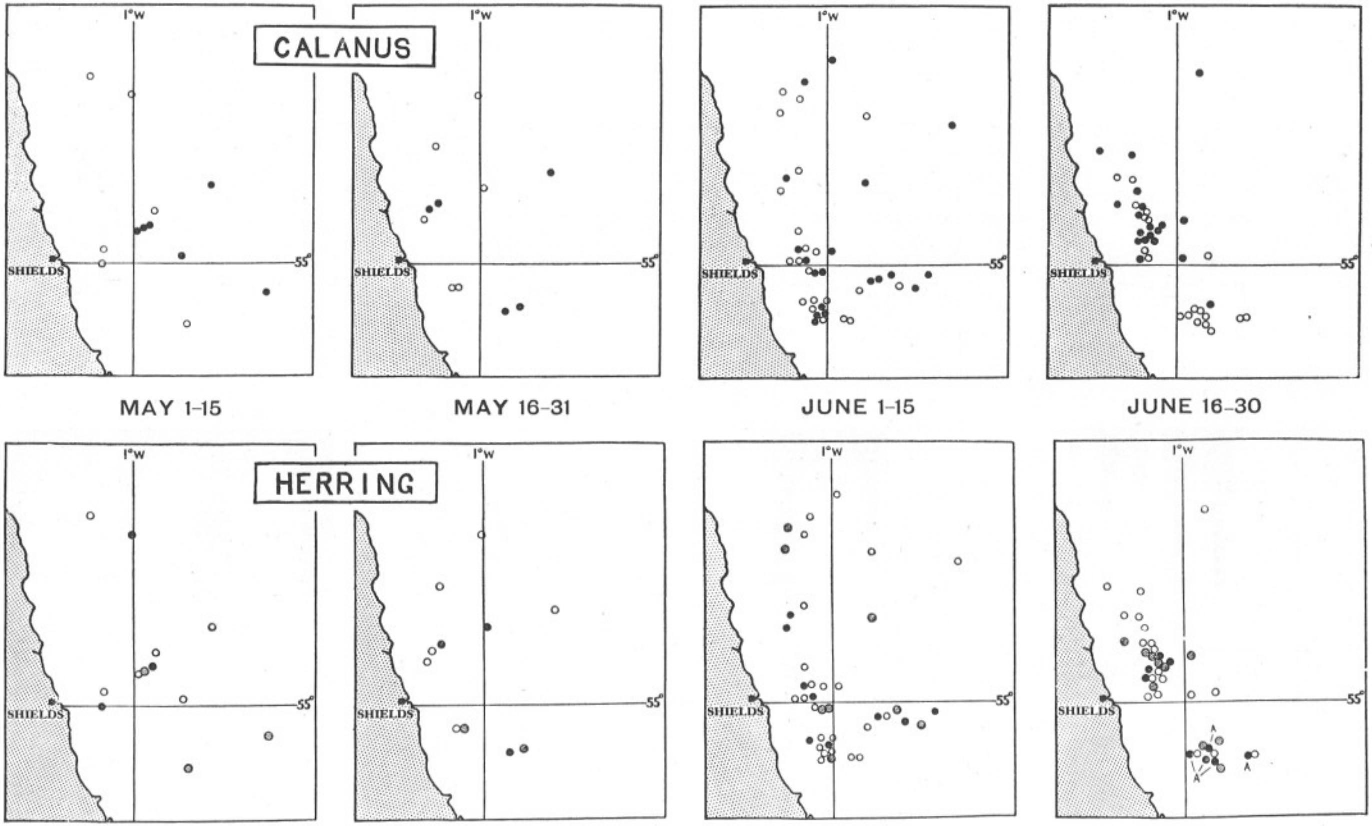
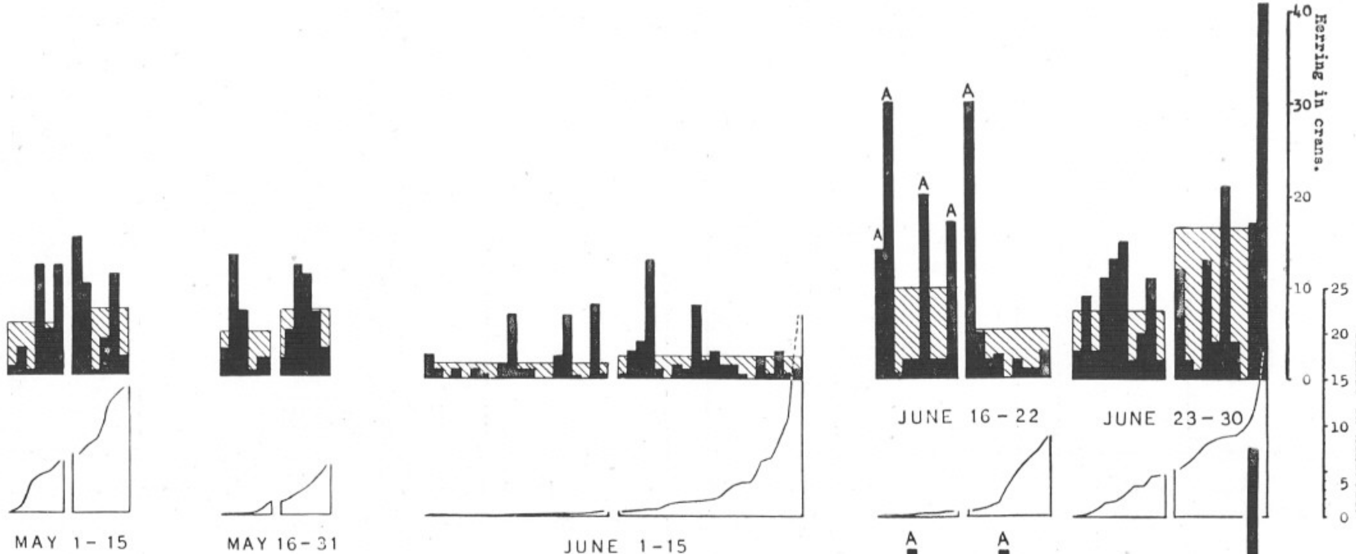


Fig. 12.—Charts showing the half-monthly distribution of Calanus as sampled by the Indicator in May and June, 1933, and below them the associated catches of herring. In the Calanus charts those samples falling in the upper half of an ascending series of Calanus values are shown as blacked-in circles and those in the lower half as open circles. In the herring charts the catches have been arranged in an ascending series as with Calanus, but divided into three sections: the lower half of the catches shown as open circles, and the upper half again divided into two quarters shown as shaded and blacked-in circles, the latter representing the highest values.



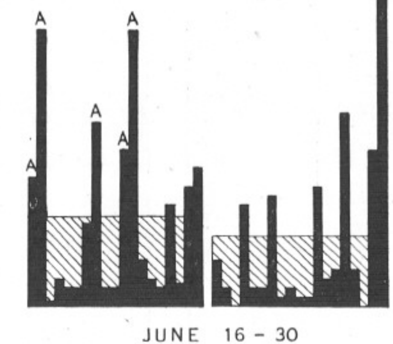


FIG. 13.—Histograms showing (in black) the individual catches of herring in the half-monthly periods corresponding to the charts in Fig. 12, arranged in each period from left to right in the order of the ascending values of Calanus in the associated plankton Indicator samples. Each series is divided into halves, the left half representing the catches in the poorer and the right half the catches 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 period tables drawn up for correlation purposes. In the period June 16–30 the high catches in the poorer Calanus water (marked "A," see also distribution chart in Fig. 12) are all taken in the first week of the period. The period is shown divided into two weeks (sub-periods), June 16–22 and June 23–30 as well as the whole period June 16–30. For discussion, see text.

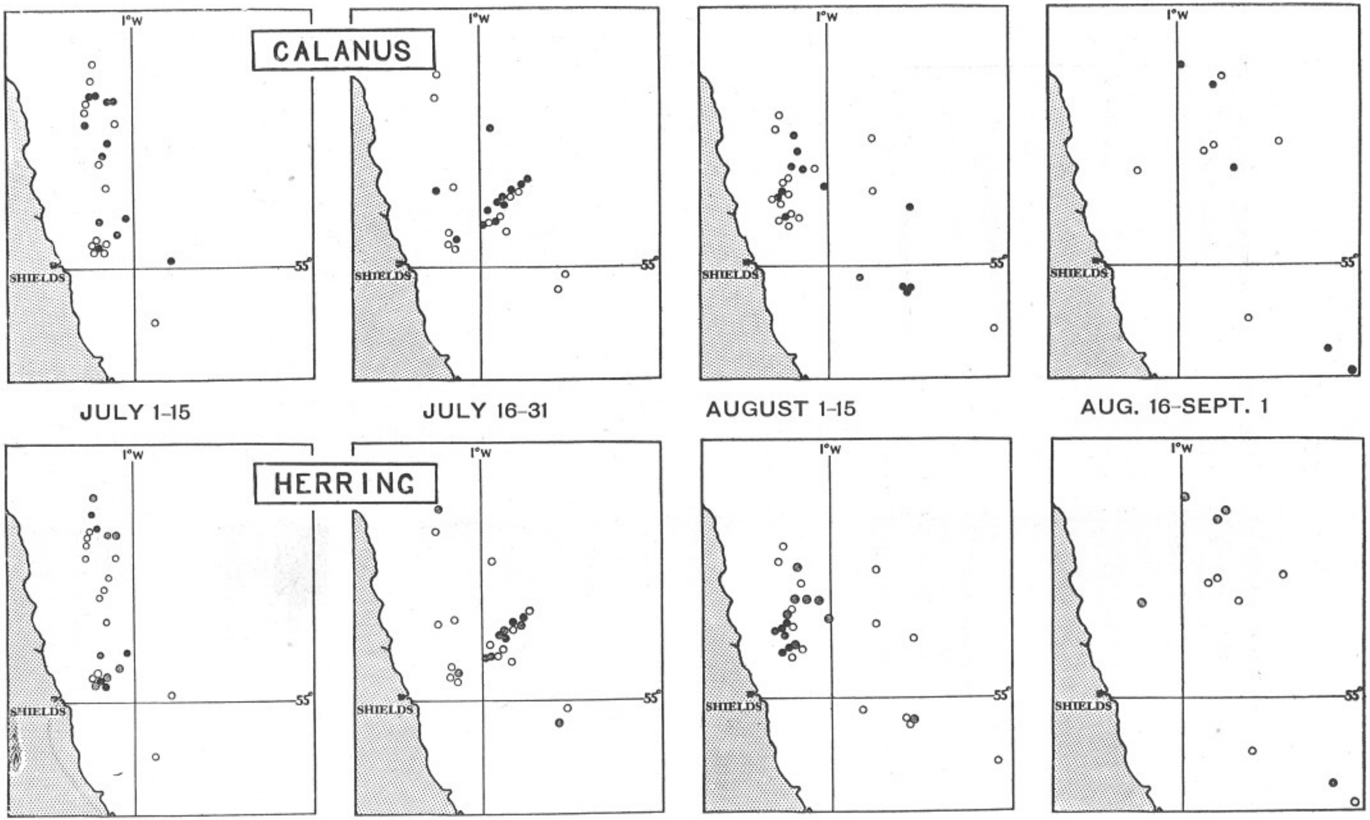


FIG. 14.—Charts showing the half-monthly distribution of Calanus as sampled by the Indicator in July and August, 1933, and below them the associated catches of herring. In the Calanus charts those samples falling in the upper half of an ascending series of Calanus values are shown as blacked-in circles and those in the lower half as open circles. In the herring charts the catches have been arranged in an ascending series as with Calanus, but divided into three sections: the lower half of the catches shown as open circles, and the upper half again divided into two quarters shown as shaded and blacked-in circles the latter representing the highest values.

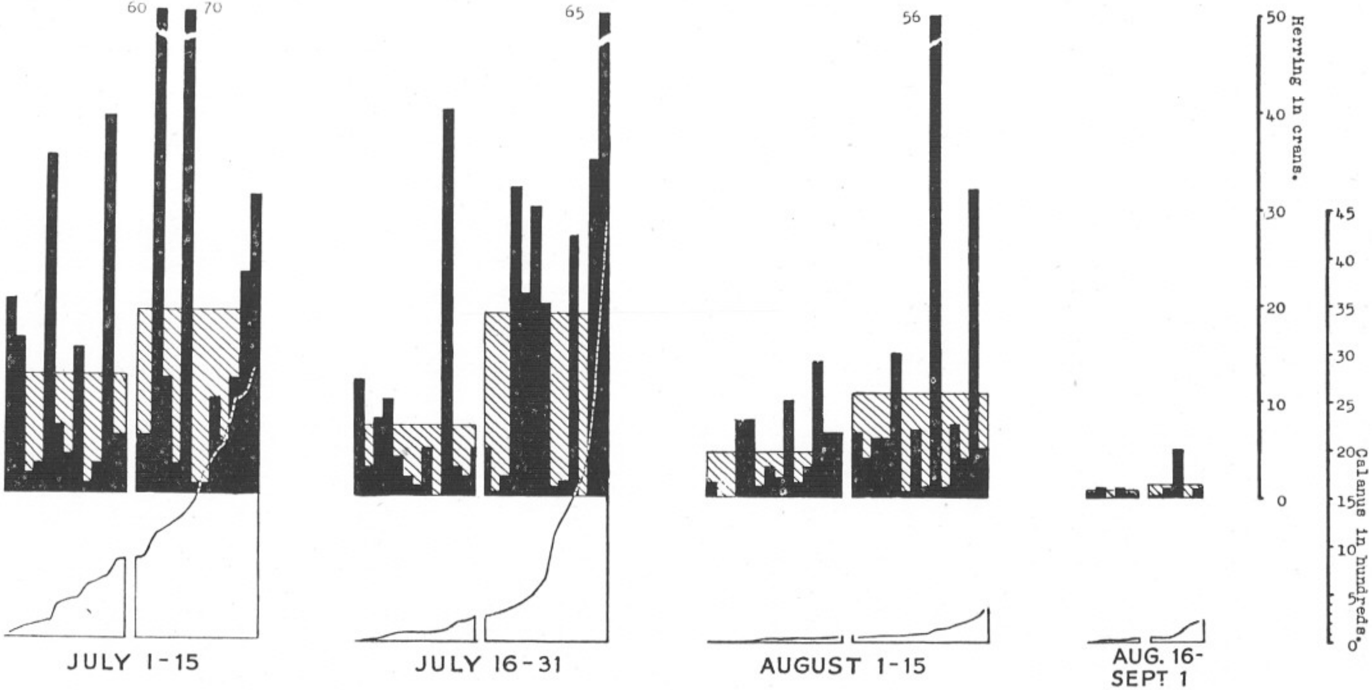


Fig. 15.—Histograms showing (in black) the individual catches of herring in the half-monthly periods corresponding to the charts in Fig. 14, arranged in each period from left to right in the order of the ascending values of Calanus in the associated plankton Indicator samples. Each series is divided into halves, the left half representing the catches in the poorer and the right half the catches 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 period tables drawn up for correlation purposes. For discussion, see text.

that a shoal entering the area in the third week of June did not find the richer Calanus zone (more central) during that week and a negative correlation resulted, whilst in the fourth week the higher catches were definitely to be found in the richer Calanus waters, a positive correlation resulting. In early July again there is a general correspondence and in the later part of the month we find the best example of coincidence, the herring being mainly limited to a small area of relatively dense Calanus. In early August there is some correspondence, with the herring limited more to the western side of the fishery : later in the month the samples are too few and scattered to reveal any relationship, although the correlation diagram suggests a marked positive association.

From consideration of all the foregoing results, we are able to conclude that over the three years 1931–33, there is on the whole a positive correlation between Calanus and the herring the commercial significance of which will be discussed presently. There are certain negative results, and in 1931 and 1932 these are mainly confined to July and August : these may be accidental variations in the general relationship perhaps arising out of inadequate methods of investigation, but they probably have a more significant meaning. This matter will also be discussed later.

Humber Area : 1931–33.

Towards the end of the Shields season there is a tendency for the drifters to move in towards the coast and some move southwards towards the Humber mouth. The area fished at this time is quite distinct from that of the earlier Shields fishery which we have been considering and which is often being fished at the same time : we have delimited this area by the lines of latitude 53° 00′ N. and 54° 20′ N. During August and September we have received samples taken in this area by drifters sailing from both Shields and Yarmouth. Table III shows details of the correlations from this ground.

In September, 1931, Calanus was even scarcer than it was further north, but 16 samples show a positive correlation. There are only 19 samples spread over October, November and December, and no useful correlations can be made for even a whole month.

In 1932 Calanus appeared to be scarce, but since only eight samples were returned in September the positive correlation, whilst suggesting a confirmation of the previous year's result, must not be given much weight. There are only four records from October to December.

Calanus was scarce in 1933 and the material not suitable for correlation purposes : there are only nine samples for September and the results are heavily weighted by a single large catch of 142 crans.

TABLE III.

SUMMARY OF THE DATA RELATING TO THE CALANUS-HERRING CORRELATIONS BASED ON THE RESULTS FROM ALL DRIFTERS USING THE INDICATOR IN THE HUMBER AND EAST ANGLIAN FISHERIES IN 1930, 1931, 1932 AND 1933.

Period and Year.	Number of samples.	Calanus range.	Average Calanus.	Herring range.	Average herring.	Total number of herring in crans corresponding to lower and higher Calanus values.		Average number of herring in crans corresponding to lower and higher Calanus values.	
						Lower.	Higher.	Lower.	Higher.
				Humber Area.					
September, 1931 . . .	16	0–32	12	0·0–95·0	20·9	127·4	206·8	15·9	25·8
October, 1931 . . .	7	0–84	36	1·0–102·0	28·3	33·0	165·0	9·4	47·1
November, 1931 . . .	6	0–1	0	2·5–53·0	24·4	†	†	†	†
December, 1931 . . .	6	0	0	8·0–43·0	15·7	†	†	†	†
September, 1932 . . .	8	0–530	81	1·0–20·0	4·1	10·4	22·5	2·6	5·6
October, 1932 . . .	1	10	10	50·0	50·0	†	†	†	†
November 1932, . . .	1	0	0	36·0	36·0	†	†	†	†
December, 1932 . . .	2	10	10	3·0–50·0	26·5	†	†	†	†
September, 1933 . . .	9	4–105	31	0·3–142·0	16·6	143·5	5·4	31·9	1·2
October, 1933 . . .	2	10–12	11	0·0–1·0	0·5	†	†	†	†
				East Anglian Area.					
October, 1930 . . .	7	0	0	12·0–41·0	26·4	*	*	*	*
November, 1930 . . .	3	0–1	0	5·0–12·0	8·3	†	†	†	†
October, 1931 . . .	26	0–100	17	1·0–82·0	19·1	352·3	143·5	27·1	11·0
November, 1931 . . .	40	0–34	3	0·0–76·0	13·3	*	*	*	*
July, 1932	2	0	0	0·0–0·2	0·1	†	†	†	†
October, 1932 . . .	7	0	0	4·0–38·0	14·3	*	*	*	*
November, 1932 . . .	17	0	0	4·0–42·0	11·2	*	*	*	*
December, 1932 . . .	2	0–1	0	11·8–21·5	16·6	†	†	†	†
June–November, 1933 . .	6	0–40	7	0·0–4·0	1·1	†	†	†	†

* There were too few samples with Calanus present in these periods for correlation purposes.
† Correlation tables were not made for periods containing less than seven samples.

East Anglian Area : 1930–33.

The division between this fishery and the Humber fishery is quite arbitrary. As drifters move south fishing may be carried out by a fairly regularly distributed fleet over both areas. As the two together are large, we felt justified in separating a northern (Humber) area characterised by a relatively richer zooplankton and younger earlier spawning herring from a southern (East Anglian) region with a poorer plankton fauna, and a fishery composed of older late spawning fish. The fisheries are also separated in time, the Humber fishery taking place mainly before the East Anglian fishery attains its peak. The position of the samples is shown in Fig. 4 and details of analyses in Table III.

Only one period in this area gives sufficient data to provide a correlation: Table III shows this to be strongly negative. In the remaining periods either the data are too scanty or Calanus is too scarce, but we may note that a positive correlation with Calanus would not be expected in the East Anglian area in October, November and December, since the work of Hardy (1924) and Savage (1931) showed that the herring during this time were not feeding.

TABLE IV.

SHOWING THE AVERAGE CATCHES OF HERRING IN CRANS FOR THE WHOLE FLEET AND THE BOATS USING THE INDICATOR, PER HALF-MONTH IN THE SUMMER SHIELDS FISHERY FOR 1931, 1932 AND 1933.

Date.	1931.		1932.		1933.	
	Fleet.	Indicator boats.	Fleet.	Indicator boats.	Fleet.	Indicator boats.
1–15 May	7·4	–	4·2	2·2^{16}	3·9	6·3^{12}
16–31 May	10·4	–	3·1	3·5^{43}	3·6	6·0^{11}
1–15 June	4·4	2·0^{6}*	3·9	4·1^{50}	3·5	2·1^{40}
16–30 June	14·1	15·5^{24}*	3·7	4·4^{45}	6·7	8·6^{38}
1–15 July†	17·0	18·0^{21}	5·2	4·7^{28}	12·2	15·7^{25}
16–31 July	18·1	19·1^{37}	11·1	6·9^{4}	9·3	13·2^{25}
1–15 August	8·6	11·8^{17}	6·7	10·5^{11}	4·5	7·8^{28}
16–31 August	7·0	9·0^{22}	3·9	4·7^{17}	6·3	1·0^{11}
1–15 September	11·5	5·9^{7}	9·3	6·3^{4}	4·8	–
16–30 September	9·4	–	7·9	–	14·6	–

The index figures against the catches of the Indicator boats denote the number of catches for the period.

THE COMMERCIAL SIGNIFICANCE OF THE CALANUS CORRELATIONS.

We may now consider the practical significance to the industry of the Calanus results and in doing so we must confine ourselves to the Shields fishery since we have just seen that in the autumn fishery further south the Calanus are scarce and the herring are not feeding.‡

* Results supplied from the R.S. *Onaway* (see p. 183).

† This period in 1931 is 29th June–15th July.

‡ In a later part (IV) it will be seen that the Indicator can have considerable commercial value in the Autumn East Anglian fishery on account of the phytoplankton indications.

At first sight it may seem unreasonable to regard the samples collected by at most five boats at one time as representative of the fishery. Mr. Leach, the Ministry of Fisheries District Inspector at Shields, having kindly provided us with the details of the landings at Shields for the three years, we are able to show (Fig. 16) that the average catches of the Indicator boats do follow those of the whole fleet very closely* (see details in Table IV). It is difficult to believe that they are not fairly representative in other matters.

Fig. 16 also enables us to compare the course† and magnitude of the fishery in the three years. The 1931 season (which followed a very poor season in 1930) was much more productive than either of the succeeding years. The total and average catches are as follows:

1931.	Total of	57,000 crans,	i.e. average of	9·4	crans for	6125	landings.
1932.	,,	25,000	,,	5·7	,,	4407	,,
1933.	,,	33,000	,,	6·3	,,	5295	,,

Accounts in *The Fishing News* show that the larger and better fish appeared somewhat later in each successive year.

In 1931 the Shields herring were small until mid-July, when we read that "the more mature fish are appearing in better proportion" and "many fine fish showing well-developed roes and melts are in the average shot." The quality remained mixed, but seemed to improve as time passed, the season ending on the 6th October. The ports near to Shields on the East coast also showed this improvement over the previous year.

In 1932 *The Fishing News* records that fish were small until mid-July when the quality became somewhat better, but they were still very "mixed" and remained so until mid-August when the best fish of the season so far were obtained. The quality remained good until the end of the fishery (8th October). Catches at the neighbouring ports were much poorer than in 1931.

In 1933, again according to *The Fishing News,* the fish appear to have been very small up to 12th August: then there was an "enormous improvement in quality." Towards the end of the season the fish were again "poor." At the adjacent ports the catches were even poorer than in 1932: small and poor quality fish were exceptionally evident.

It may be of interest here to quote from the Report on Sea Fisheries for 1933 (1934), page 25: for the Hartlepool fishery up to September "complaints were general of the scarcity and poor quality of the fish brought in. During the early part of July herrings were small and oily and exceptionally small fish were landed in August. . . ." Again, at Grimsby as "at so many other stations along the East coast, complaints were made of the poor quality of the fish" (p. 26).

In Part I of this account (p. 162) we have shown how the correlations can be evaluated for commercial purposes as percentage gains and losses.

* The average catches for the whole fleet are based on steam drifters in 1931, but in 1932 and 1933 they also include the landings of the few motor drifters. The drifters using the Indicator were all steam.

† Figs. 6, 8, 10, 12 and 14 show broadly the distribution of the shoals of herring in each half-month period over the three years.

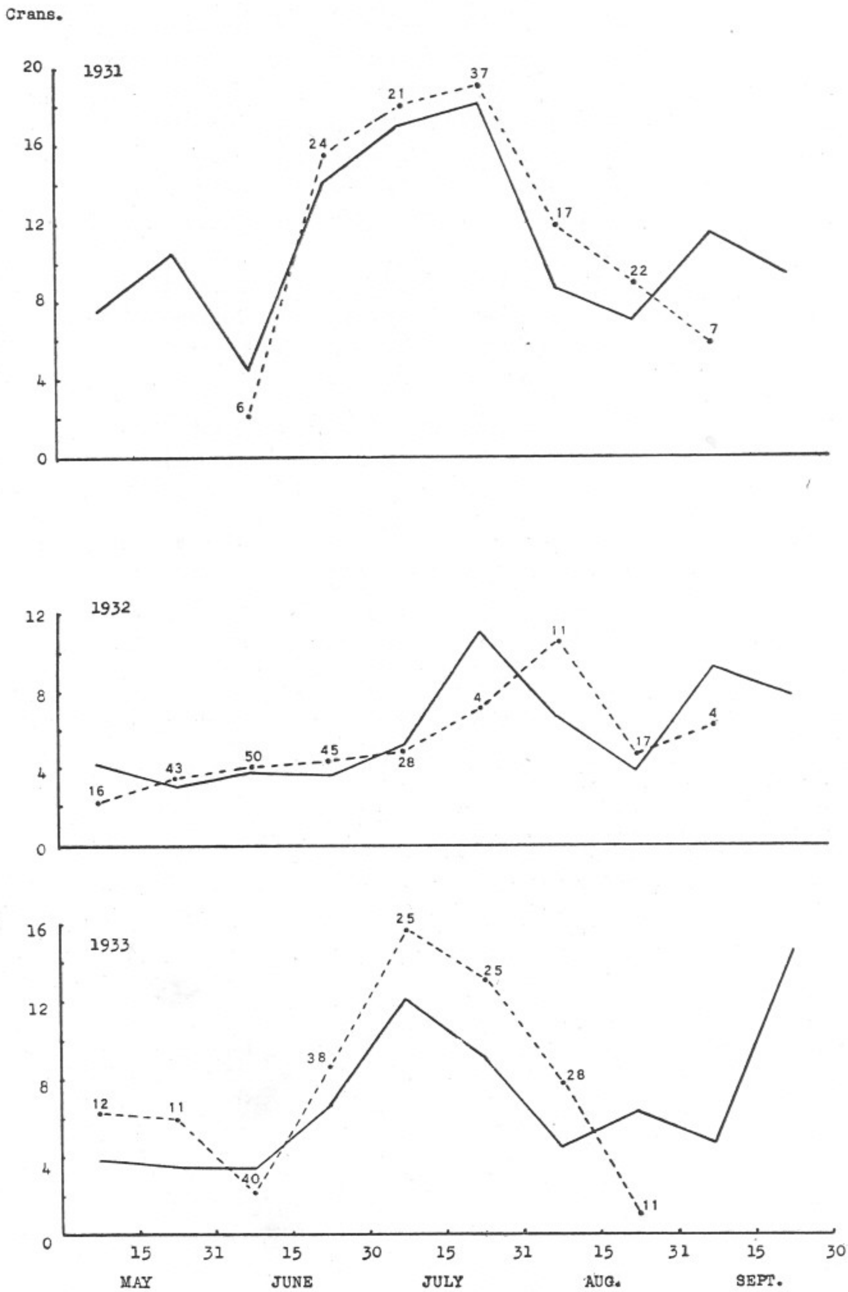


FIG. 16.—Showing for the Shields fishery the average catches per half-month obtained by the drifters using the Indicators (broken line) and those for the whole fleet (continuous line). The index figures denote the number of samples on which the Indicator averages are based.

These percentages have been used to estimate the probable advantages and disadvantages of using the Indicator as a means of locating the herring. As happened throughout the Scottish areas, the Shields samples for 1931 and 1932 were obtained with the Indicator when drifters were fishing without using it to find better fishing grounds. During 1933, however, the skippers had a knowledge of the probable benefits of fishing in waters rich in Calanus and though they were not provided with the proper means of examining the discs, they could recognise Calanus and to some extent use the Indicator for locating better water. It seems reasonable to suppose that had they been using the Indicator as in 1931 and 1932, more shots would have been made in less productive water, and the estimated gains and losses would have been larger. It is noteworthy that as shown in Fig. 16, although in all the three years the average catches of the Indicator boats were as a whole higher than the averages at the port, in 1933 this difference was appreciably larger than in the previous years.

As will be seen, the percentages just referred to can also be used as a general measure of the correlation between Calanus and the herring. This method has the advantage over any other method of presentation in that, being based upon a constant of 100, the fluctuations in the fishery can be eliminated and the results can be applied to the prices of fish in order to give some idea of the monetary value of the instrument.*

In Table I, column 11, are shown the resulting percentage gains and losses based on the catches discussed on page 185 *et seq.* In Fig. 17 they have been expressed in graphical form for the Shields area. These graphs suggest how the efficiency of the Indicator (efficiency in terms of its indication of the presence of herring) may vary throughout the seasons. Extreme caution must be used when considering the individual period results: reference to Figs. 5, 7, 9, 11, 13 and 15 shows that in several periods a single high or low catch may by its position weight unduly the resulting gain or loss. It is the average results for all the twenty periods (a gain of 12·7%) combined with the apparent periodicity of the losses, which is significant. Also the average for each half-month over the three years (shown graphically in Fig. 17 by the broken line) may give some indication of the expected seasonal variations in that it bears some relation to the known variations in the feeding habits of the herring in these waters (see later, p. 218). The results for 1931 represent only a part of the season and when the two complete years 1932 and 1933 are considered alone, the average gain is seen to be 21·2%. It is perhaps even more important to note that by avoiding unsuitable water as revealed by the plankton indications, it should have been possible for a similar quantity

* Prices tend to vary with the abundance of the fish. As a result it is quite probable that a gain made in using the Indicator during a poor period of fishing, may balance or even exceed any possible loss resulting during a period of heavy fishing when the ruling prices are poor.

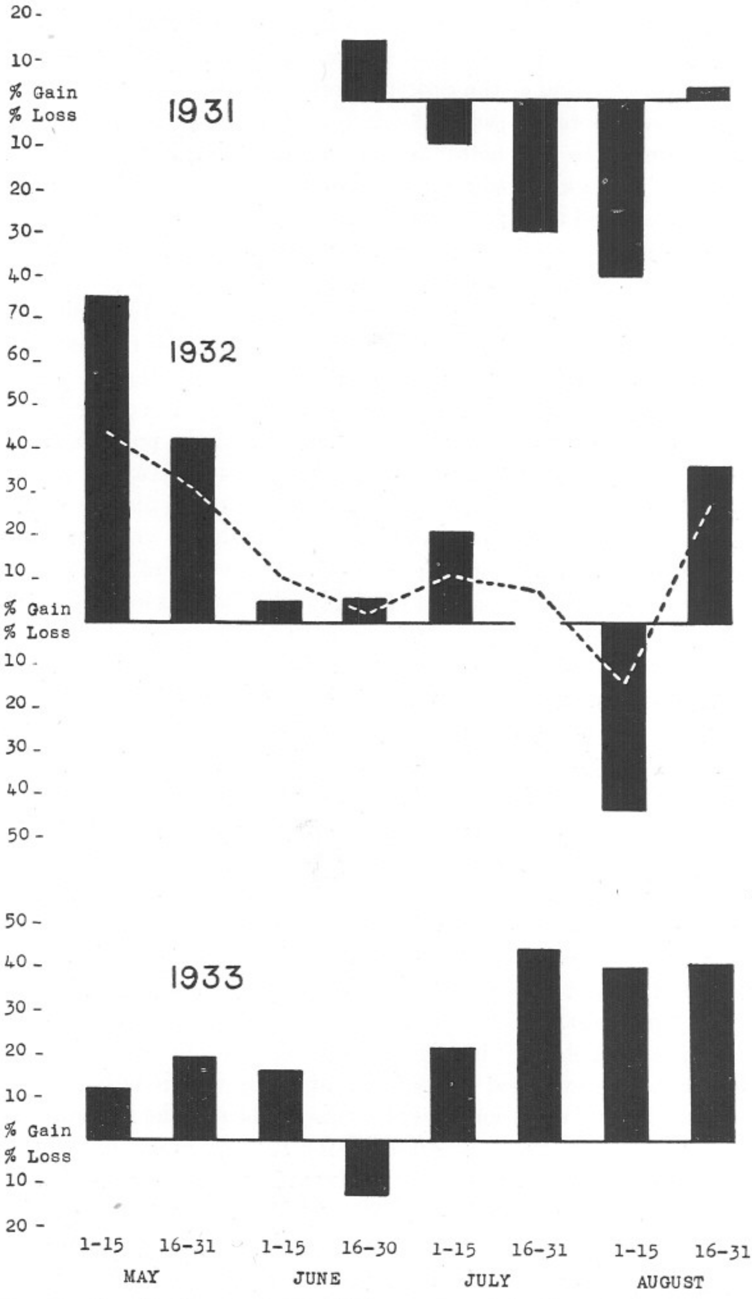


FIG. 17.—Graphical representation of the sequence of the theoretical percentage gains and losses (see text) per half-month period during the three years 1931–33 in the Shields fishery. The dotted line in the central (1932) graph represents the average gain or loss for each half-month over the three years.

of fish to have been caught in the majority of the periods with a total expenditure of less fuel and also fishing time ; i.e. with either a smaller fleet or a similar fleet working on fewer days.

Since the percentage gains and losses of less than 10% might be commercially and statistically insignificant, they have been termed "Neutral." Of the twenty half-monthly periods there are twelve which show gains of over 10% (ranging from 11·8% to 75·1%), four neutral periods and four periods showing losses of more than 10% (ranging from 12·6% to 43·6%). These may be set out as follows :

% Gains.	Neutral.	% Losses.
75·1	4·8	– 12·6
43·9	4·4	– 29·9
41·7	3·1	– 40·3
40·5	– 9·7	– 43·6
39·7		
35·3		
21·3		
20·3		
19·1		
16·2		
13·6		
11·8		

This table should be compared with a similar one prepared for the Scottish fishery shown on page 253, where we see that the ratio of percentage gains, neutrals and percentage losses is 11 : 5 : 2 for the "primary" periods.

It has already been stressed that the particular values of the individual periods are of little significance by themselves in that individual catches may be weighting the results. This is shown in Figs. 5, 7, 9, 11, 13 and 15 where the details of the catches for all the periods are shown graphically. We see here that both high and low catches occur in both the richer and the poorer Calanus waters, but on the average there are more higher catches in the richer waters than in the poorer.

Acting on the suggestion of Prof. R. A. Fisher, we have estimated the Standard Error for each of the mean percentage gains shown above. The results may now be expressed as follows :

Year.	No. of periods.	Theoretical mean gain.	Standard error of mean.	Corresponding value for "t."
1931–33	20	12·7%	±6·7%	1·90
1932–33	15	21·2%	±7·5%	2·82

We are greatly indebted to Prof. Fisher for his kind assistance and advice.

We can estimate the frequency with which the larger and smaller catches occur in the richer and poorer Calanus waters respectively. The following table shows this for the three years 1931, 1932 and 1933 separately, for the three years combined and for the two complete years 1932 and 1933 combined, together with the percentages of the catches of 0·0, 0·1–5·0, 5·1–10·0, 10·1–20·0 and over 20·0 crans in the poorer and richer waters respectively.

	Herring catch range. Crans.	Numbers of catches. Poorer Calanus water.	Richer Calanus water.	Percentage of catches. Poorer water.	Richer water.	Total.
1931	0	1	1	1·5	1·5	1·5
	0·1–5·0	14	**24**	21·6	**37·0**	29·3
	5·1–10·0	**15**	13	**23·1**	20·0	21·6
	10·1–20·0	13	**17**	19·9	**26·1**	23·0
	20·0 and over	**22**	10	**33·9**	15·4	24·6
1932	0	**13**	8	**12·4**	7·6	10·0
	0·1–5·0	**65**	60	**61·9**	57·2	59·6
	5·1–10·0	18	**21**	17·1	**20·0**	18·5
	10·1–20·0	8	**15**	7·6	**14·2**	10·9
	20·0 and over	1	1	1·0	1·0	1·0
1933	0	**10**	6	**10·8**	6·5	8·7
	0·1–5·0	**50**	49	**53·7**	52·6	53·1
	5·1–10·0	**14**	11	**15·1**	11·9	13·5
	10·1–20·0	**14**	13	**15·0**	13·9	14·5
	20·0 and over	5	**14**	5·4	**15·1**	10·2
1932–33	0	**23**	14	**11·6**	7·1	9·4
	0·1–5·0	**115**	109	**58·1**	55·0	56·5
	5·1–10·0	32	32	16·2	16·2	16·2
	10·1–20·0	22	**28**	11·1	**14·1**	12·6
	20·0 and over	6	**15**	3·0	**7·6**	5·3
1931–33	0	**24**	15	**9·1**	5·7	7·4
	0·1–5·0	129	**133**	49·1	**50·6**	49·9
	5·1–10·0	**47**	45	**17·8**	17·1	17·4
	10·1–20·0	35	**45**	13·4	**17·1**	15·3
	20·0 and over	**28**	25	**10·6**	9·5	10·0

Fig. 18 shows graphically for the years 1931, 1932 and 1933 a derivative of this table : i.e. graphs of the percentage of all the catches each year which fall below the given values of 0·1, 5·1, 10·1 and 20·1 crans for the poorer and richer Calanus waters. The essential difference between the year 1931 and the two succeeding years is well shown in this figure where we see clearly that the presence of the higher catches in the richer water and the lower catches in the poorer water generally throughout 1932 and 1933 was reversed on the whole in 1931 (particularly between July 1st and August 15th) ; but we must also note, that for our investigations, the year 1931 was an incomplete season, the bulk of the samples being obtained after the middle of June. Fig. 18 should be compared with Fig. 4 in Part III, page 257, where graphs similarly derived are shown for the Scottish area.

Thus we see that for the combined years 1932–33 there were fewer lower catches and more higher catches in the richer water than in the poorer water. A similar distribution is found for the Scottish fishery (see page 253, Part III). This method of treatment brings out an interesting difference between these fisheries for these two years. In the Shields fishery 1932–33 only 9·4% of the total catches were blank and only 5·3% exceeded 20 crans, whereas in the Scottish fishery, 1932–33, as many as 17·7% were blank and 18·6% of the total catches exceeded 20 crans. This is discussed further in the section on the Scottish fishery, page 256.

If now we consider the Shields 1931 figures, we see that the catches

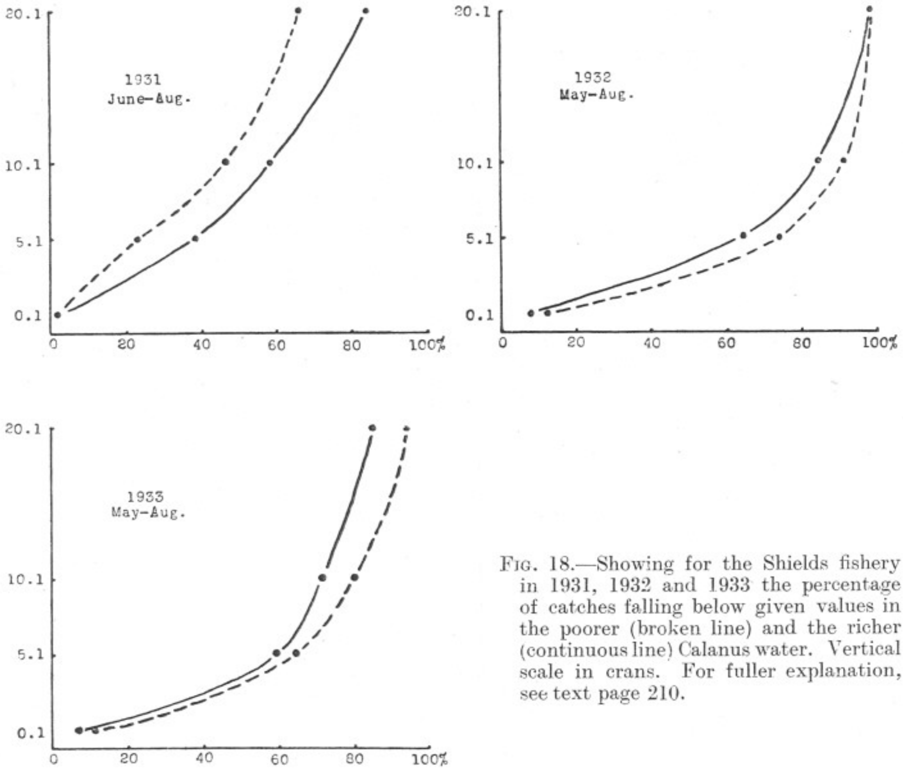


Fig. 18.—Showing for the Shields fishery in 1931, 1932 and 1933 the percentage of catches falling below given values in the poorer (broken line) and the richer (continuous line) Calanus water. Vertical scale in crans. For fuller explanation, see text page 210.

were much higher than in the following years in this area, or even in the Scottish fishery (i.e. considering the samples obtained by us). Only 1·5% of the catches were blank and 24·6% exceeded 20 crans. This condition is even more marked between the 1st July and the 15th August (the period characterised by marked losses) when the distribution of the catches is as follows :

Herring catches range.	Percentage of total catches 1st July—15th August, 1931.
0·0 crans.	0·0
0·1–5·0 ,,	24·0
5·1–10·0 ,,	20·0
10·1–20·0 ,,	25·2
20·0 and over	30·8

The area fished during this period was relatively near the coast and must have contained a much denser concentration of herring than occurred usually on the east coast north of the Humber. No blank catches occurred, 56% of the catches were over 10 crans and 30·8% exceeded 20 crans. In particular at this time Calanus was relatively very scarce (see Table I).

TABLE V.

(For details, see text.)

Period and Year.	Theoretical percentage Gain or Loss to be obtained by avoiding the lowest quarter, half, two-thirds and three-quarters of the waters sampled.				Average of (a), (b) and (c).
	Lowest quarter. (a)	Lowest half. (b)	Lowest two-thirds.	Lowest three-quarters. (c)	
1–15 May, 1932	+25·3	+75·1	+33·0	+48·0	+49·5
,, 1933	+25·4	+11·8	−30·9	−10·5	+ 8·9
16–31 May, 1932	+18·0	+41·7	+61·4	+91·4	+50·4
,, 1933	−10·8	+19·1	+38·5	+17·6	+ 8·6
1–15 June, 1932	+ 1·1	+ 4·4	+ 3·2	+16·9	+ 7·5
,, 1933	+14·8	+16·2	− 8·4	−32·2	− 0·4
16–30 June, 1931	+ 8·3	+13·6	+61·0	+61·2	+27·7
,, 1932	− 3·5	+ 4·8	+ 8·1	+24·7	+ 8·7
,, 1933	+ 0·4	−12·6	+ 7·9	+22·8	+ 3·5
29 June–15 July, 1931	− 4·7	− 9·7	+ 3·1	+18·9	+ 1·5
1–20 July, 1932	+ 6·8	+20·3	− 7·0	− 6·3	+ 6·9
1–15 July, 1933	+ 3·7	+21·3	+11·0	−23·8	+ 0·4
16–31 July, 1931	−18·6	−29·9	−31·8	−41·0	−29·8
,, 1933	+16·0	+43·9	+68·8	+61·8	+40·6
1–15 Aug., 1931	−13·4	−40·3	−52·8	−61·9	−38·5
,, 1932	−41·2	−43·6	−39·8	−28·4	−37·7
,, 1933	+17·4	+39·7	+66·5	+96·3	+51·1
16 Aug.–8 Sept., 1931	+ 8·3	+ 3·1	+15·5	+32·2	+14·5
16–31 Aug., 1932	+11·0	+35·3	+22·4	+29·9	+25·4
16 Aug.–1 Sept., 1933	+11·1	+40·5	+83·3	+109·5	+53·7
Average all results	+ 3·8	+12·7	+15·7	+21·4	+12·6
Average excluding 1–15 Aug.	+ 6·6	+17·6	+19·9	+24·8	+16·3

It seems reasonable to suggest that these shoals did not consist of feeding fish, but of fish collected for spawning and moving about the area irrespective of the Calanus distribution (but see also page 223).

Now instead of dividing the series of samples in each period into two equal sets (half having the lower Calanus numbers and the other half having the higher ones), we can divide each series of samples into (*a*) the lower three-quarters and the higher quarter and (*b*) the lower quarter and the higher three-quarters. It is now possible to obtain two further series of percentage gains and losses showing the results to be expected if (*a*) the fishermen were able to find for each catch waters containing Calanus of a similar value to those in the top quarter of the series and (*b*) they were only fortunate enough to obtain waters similar in average Calanus

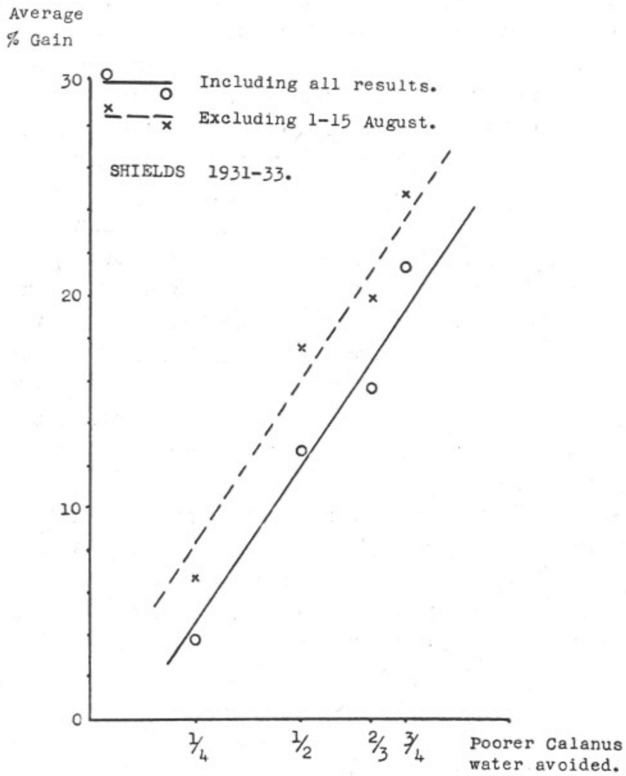


Fig. 19.—Showing the theoretical estimated average gains which might have been obtained by the Indicator boats had they avoided the poorer quarter, half, two-thirds or three-quarters of the Calanus waters in the Shields fishery, 1931–33. For fuller explanation, see text. Averages based on all results are shown as circles, and those based on all results except those for the first half of August are shown as crosses.

content to those represented by the top three-quarters of the series. Table V shows these results (and also one based on correlating Calanus and herring in the bottom two-thirds and the top third of the series) together with those of the lower and higher halves, for comparison. It will be seen that on the whole, these results become higher as we pass from the avoidance of the bottom quarter, half, two-thirds and three-quarters of the Calanus numbers. This is expressed most suitably by averaging each column: we thus find increasing gains of 3·8%, 12·7%, 15·7% and 21·4%: or if we exclude the period August 1st–August 15th, the gains are 6·6%, 17·6%, 19·9% and 24·8%.

These results are expressed in graphical form in Fig. 19, where it is seen that the points lie close to a straight line, a feature which would seem to be of considerable ecological interest. It is also of economic importance, for we see that over four ranges of Calanus values we can deduce an increasing gain in the catch based on aiming at an increasing density of Calanus, or, inversely, avoiding more and more of the water poor in Calanus. In other words, this means that not only in a broad way is the catch associated with the higher half of the Calanus samples larger than that with the lower half, but the correlation of which this is evidence extends further throughout the whole range of the Calanus samples on the average (not in all periods), and that if the fisherman aimed at a much higher value of Calanus, on this evidence he would make much higher gains*; but against this must be borne in mind the relative scarcity of the dense Calanus samples shown at the higher end of the table. If too high a value is aimed at he may well waste too much time and fuel trying to find suitable water, just as if the careless fisherman aims at a lower average he will usually find this easily, but gains, if any, will be proportionately lower.

In column 6 of Table V, the average of columns 2, 3 and 5 is shown. It seemed likely that the average of all these results would give an even better estimate of the potential value of the Indicator over the three years than that given on page 207, since it is based on estimates obtained from the same material under a more exhaustive analysis: the figure obtained, however, a gain of 12·6%, is almost identical with the previous one (12·7%).

The table also shows another and related feature, to which Prof. R. A. Fisher has kindly drawn our attention. If for each half-monthly table the ascending series of Calanus values is divided into four consecutive quarters, and the catches associated with each quarter are averaged, we can then obtain for each quarter an estimate of its mean catch as a percentage of the mean catch of the whole table. This has been done for each half-month and a mean percentage obtained for each quarter over the three years. The approximate results are as follows: First (lowest) quarter, 87%; second quarter, 86%; third quarter, 95% and the fourth (highest) quarter, 121%.† It would appear that the differences between the means of the catches associated with the lower two (and to

* There is almost certainly a limit to this.

† It may be observed that these four figures do not total 400 as they should theoretically. This is due to certain approximations made in calculating the percentages for a table consisting of an odd number of samples.

some extent the third) quarters are of little significance, whereas the mean of the fourth quarter is significantly different from these three. On the whole the correlations must depend on the relatively high catches associated with the fourth quarter, i.e. the quarter containing the highest Calanus samples. This again would seem to be of considerable ecological and economic importance, and again emphasises the importance of the fishermen endeavouring to locate the richest Calanus water, even where this necessitates the expenditure of a little more fuel.

As we saw on page 187 the Shields material can also be used on an Individual Boat basis. In all there have been seven such boats, here denoted by the letters A–G. The following table shows the number of periods and samples on which the results for each boat have been based, and the average estimated percentage gain.

Boat A	10 periods	156 tests	averaged 20·9% gain	
,, B	5 ,,	64 ,,	,, 32·8%	,,
,, C	4 ,,	52 ,,	,, 9·9%	,,
,, D	6 ,,	92 ,,	,, 14·3%	,,
,, E	2 ,,	26 ,,	,, 13·8%	,,
,, F	3 ,,	47 ,,	,, 13·3%	,,
,, G	1 ,,	20 ,,	,, 33·9%	,,

Of the seven fishing boats, all show a gain over the total period of using the Indicator. With regard to Boat C, reference to page 189 shows that by considering the actual number of crans caught during the four periods, or the sum of the average catches during each period, one gains the impression that over the whole time an appreciable negative correlation resulted. The table above records in opposition an average gain of nearly 10%. This emphasises certain fundamental differences in the methods of obtaining results. Conclusions based upon the actual average catches for each period will give estimates of the probable gain or loss to the fishermen in crans of herring, but it will not give an idea of the probable monetary gain or loss through the season. On the whole the price of fish varies inversely with its abundance, and for this reason it is more satisfactory to base our ideas of the real value of the Indicator on the proportionate gain or loss, than on the actual gain or loss in crans (thus it is reasonable to suggest that the Boat C would have gained appreciably in time or money by using the plankton indications, although he might have obtained fewer herring).

The average gains and losses for the year as obtained from these Individual Boat results are different from those in which all the boats are massed together. The years 1931 and 1932 gave a higher average for the

Individual Boat data than for all the boats taken together, but in 1933 the average is slightly lower. Thus :

	1931.	1932.	1933.
Average % gain or loss averaging all boats	−12·6	+19·7	+22·5
Average % gain or loss averaging individual boats	− 0·5	+27·2	+20·8

It may be that the difference in 1931–32 is due to the fact that when dealing with the individual boats the differences in catching power of the boats and their methods and locations are not disturbing the results as they may be when the boats are combined. If this is so then the relative similarity shown in 1933 might be due to the boats having at least one more feature in common than in the earlier years : in this year they were already adopting the plankton indications as a guide to locating the herring.

The mean gain for the thirty-one individual boat periods over the three years is 19·3% as against 12·7% shown by the previous estimations for the " All Boat " results. The Standard Error is ±5·13% with a consequent value for " t " of 3·76.

By means of percentages it is possible to estimate more exactly the probable gains and losses obtained by using the Indicator. By averaging the percentages for each half-month (Table V. All boats, with Calanus divided into lower and higher halves) we find that off Shields high probable gains decrease from early May to the end of June, rising in the first half of July and then dropping to the end of the first half of August when there may be a substantial loss, followed by a gain in the period August 16th–31st. The order of the magnitude of these gains and losses is suggested in the following table :

Date.	May.		June.		July.		August.	
	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–31
Average % gain or loss	+43·5	+30·4	+10·3	+1·9	+10·6	+7·0	−14·7	+26·3

Our records in the Shields area end in early September (although the season may last into October).

Further information regarding the correlations and feeding habits off Shields in July and August is desirable, but at the present time it seems inadvisable to use the Indicator for positive correlations with Calanus during the first part of August.* On the whole, our information suggests the possibility that not only are the herring at this time not following Calanus, but that they may even be avoiding it and other food : further

* A number of Indicators were used commercially during 1934, 1395 and 1936, and this advice was given to the skippers of the boats using the instrument.

work may confirm this, but the series of positive correlations found in July and August in 1933 suggests very strongly that it will not be possible to formulate any general rule applicable to all years, and that in certain years (perhaps occurring in cycles) it may be possible to use the Indicator

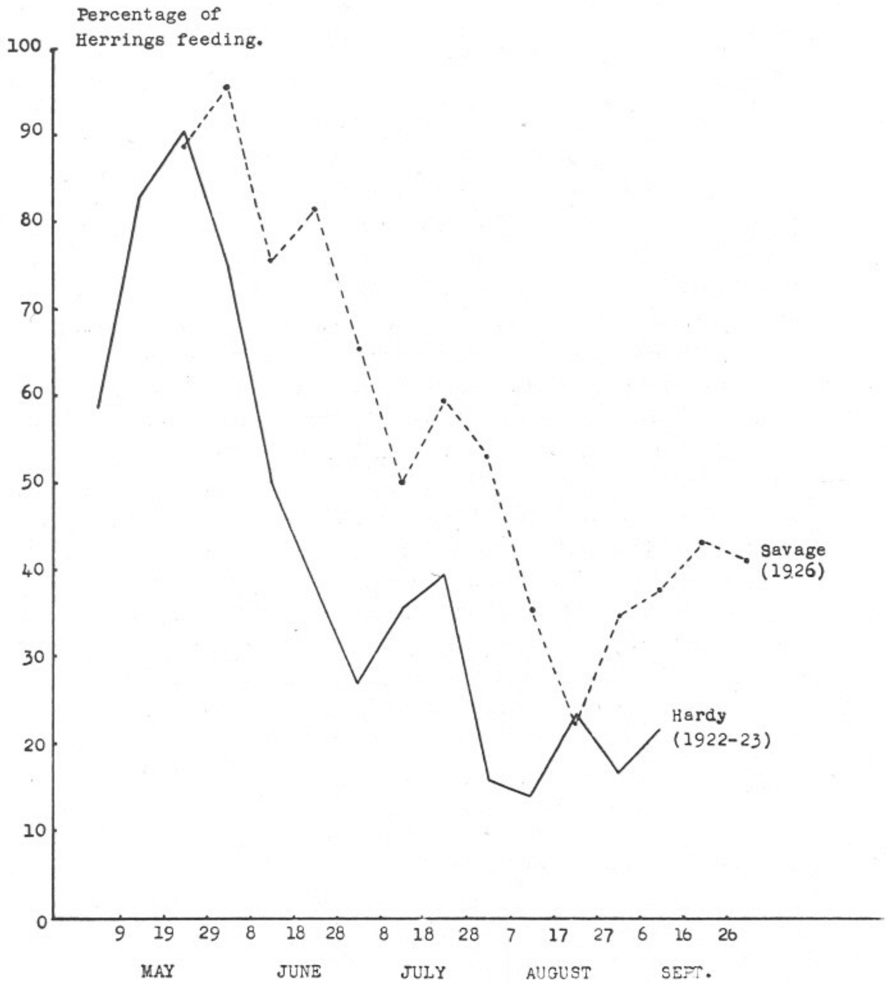


FIG. 20.—Showing the changes in the percentages of feeding herring in the Shields area for 1922–23 and 1926 as shown by Hardy (1924) and Savage (1931) respectively. See footnote on page 218.

throughout the season. Further, since herring are fish which spawn on the sea bed and are known to prefer some types of bottom to others and to spawn in fairly definite places, it is possible that when the shoals assemble for spawning they will do so in relation to fixed geographical features, and that as a result, any correlation between the herring and Calanus will vary according to the apparently accidental presence or absence of Calanus in the waters over the spawning grounds and the correlations would be positive or negative accordingly. Again, if this were found to be correct, it would not be possible to formulate any general ruling for the use of the Indicator at this period.

Calanus and the Feeding of the Herring.

The principle on which the Indicator work was based was that during the feeding season, herring would tend to follow the organisms on which they are feeding. During the late spring and summer the principal of these is *Calanus finmarchicus* (see Hardy, 1924 ; Savage, 1931 ; Jespersen, 1928). At times Calanus exceeds the other copepods in actual numbers in the stomach contents of the herring, but even when it is not so abundant, its large size compared with the other common species in the area suggests that it is still of great importance in the food. Now Hardy (1924) showed how the proportions of herring feeding in the Shields area increased rapidly in April to a maximum in May and then fell off towards the end of the season with a final spurt of feeding off Shields and the Yorkshire coast in September, followed by a period with little or no feeding, which condition also holds in the Yarmouth fishery until the end of the year.

In 1926, Savage (1931) found substantially similar results : these together with those of Hardy are shown graphically in Fig. 20.* It will be seen that the trend shown by these graphs is broadly similar to that of the average percentage Gains and Losses as shown by the Indicator over the three years 1931–33 (see p. 216 and Fig. 17). The prevalent gains in the early part of the season correspond with the high percentage feeding at that time : the " losses " or negative correlations in July and August correspond with the slackened feeding found by Hardy and Savage, and it seems possible that the positive correlations found in August off Shields and in September off the Humber would correspond with the spurt of feeding found for the same areas at the end of the season. From October onwards, the impossibility of correlation as brought out by the marked scarcity of Calanus, agrees with the almost entire absence of feeding found off Yarmouth at that time.

Thus there is a general agreement between the separate data found by different workers in this area, but the information for 1931–33 has interesting variations, both between the different years and within the years. It is important to obtain, if possible, some idea of the significance of these

* Hardy's results have been re-graphed in ten-day periods from the figures in Savage's paper (1931, see p. 13). These results are recalculated from the data in Hardy's 1924 paper.

variations : Are they, as suggested on page 202, due to accidental variations in the efficiency of the instrument as a means of correlating herring and Calanus, or have they a different and more important significance ? We are indebted to Mr. R. E. Savage, of the Ministry's Laboratory at Lowestoft, who has kindly placed at our disposal data, as yet unpublished, from his Shields herring stomach examinations in the years 1931–33. The relation between our results and Mr. Savage's can best be shown by means of a series of graphs. Table VI and Fig. 21 show a comparison of

TABLE VI.

Showing the Numbers of *Calanus finmarchicus* per 100 Herring Stomachs, in 10-day Periods for the Shields Area 1931–33,* together with the Average Numbers found in the Plankton for the same Periods.

10-day period ending.	Numbers of *Calanus finmarchicus* per 100 stomachs. 1931.	1932.	1933.	Numbers of *Calanus finmarchicus* in plankton. 1931.	1932.	1933.
29th April . .	73,387	—	166,200	—	—	470^{1}
9th May . .	128,012	1,423	36,114	—	321^{8}	824^{9}
19th May . .	85,442	10,759	24,939	—	244^{21}	366^{7}
29th May . .	46,740	27,005	20,686	—	415^{23}	199^{6}
8th June . .	55,717	24,708	6,861	41^{6}	800^{32}	49^{21}
18th June . .	12,646	14,645	15,997	—	896^{33}	336^{27}
28th June . .	26,463	37,321	18,111	99^{24}	$1{,}030^{32}$	276^{26}
8th July . .	5,540	16,292	22,790	84^{11}	265^{22}	$1{,}001^{18}$
18th July . .	12,741	2,927	11,912	36^{16}	183^{13}	$1{,}205^{20}$
28th July . .	255	11,603	31,134	69^{25}	114^{2}	372^{12}
7th August . .	2,010	1,601	5,703	115^{16}	380^{1}	91^{24}
17th August . .	2,913	1,492	3,273	89^{10}	185^{13}	56^{12}
27th August . .	6,479	2,444	5,947	59^{15}	109^{11}	40^{1}
6th September .	2,777	2,524	6,416	92^{9}	2^{6}	84^{8}
16th September .	3,953	251	13,978	24^{2}	—	—
26th September .	—	536	—	—	—	—
6th October . .	—	—	0	—	—	—

The index figures show the number of samples on which the average is based.

the numbers of Calanus found by Mr. Savage in herring stomachs for each 10-day period throughout the season, and the numbers of Calanus found by the Indicator in the plankton at a depth of 7–10 metres. There is a general agreement between these results. We see that on the whole when Calanus is more abundant at 7–10 metres it is eaten in greater quantity by the herring, and when it is scarce, usually little is found in the herring stomachs.† Table VI shows that the two aberrant points

* This information was kindly supplied by Mr. R. E. Savage of the Ministry of Agriculture and Fisheries.

† Seeing that Savage found such large numbers of Calanus in the herring stomachs in May, 1931, it seems likely that there must also have been a large number in the plankton, suggesting a much greater number than that found by the Indicator later in the year (see also p. 183).

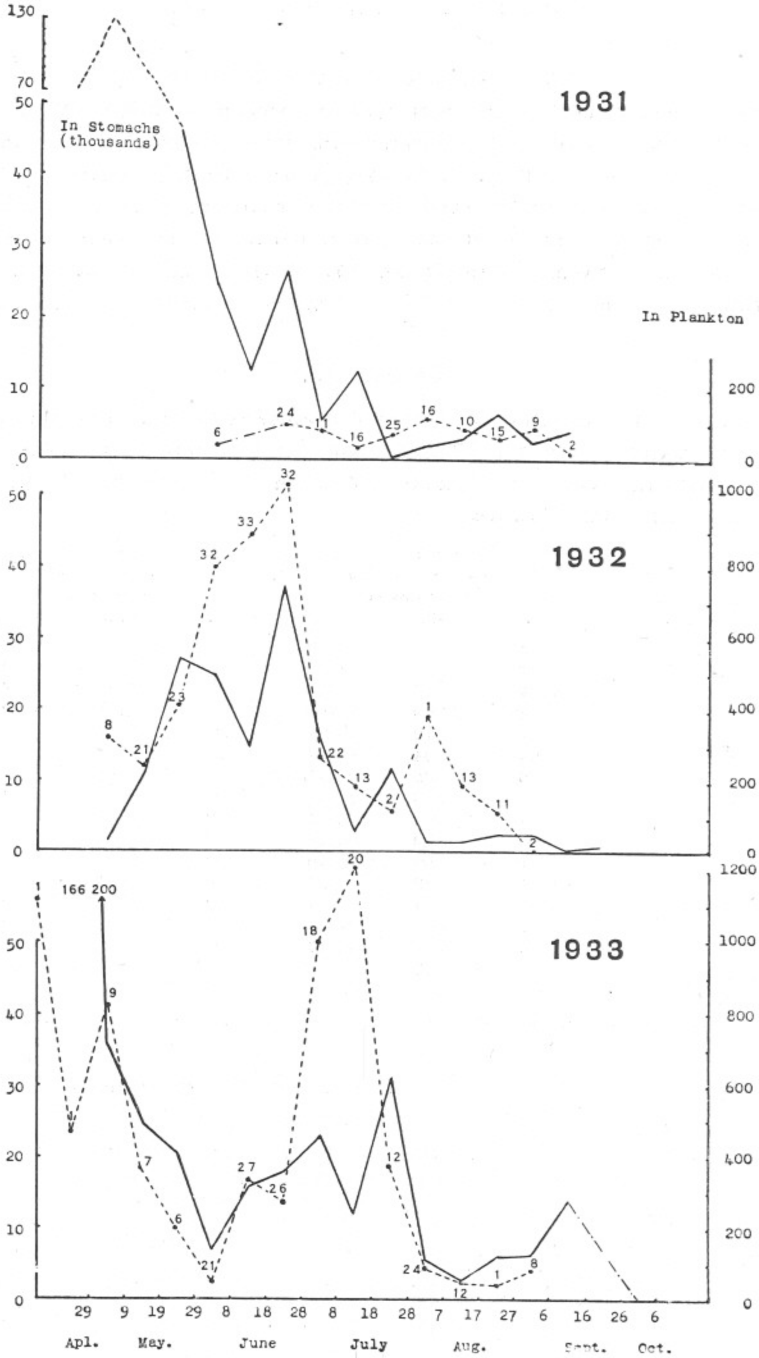


FIG. 21.—Showing the variations in the numbers of the available Calanus as found by the Indicator at 7–10 metres (Calanus per disc: broken line) and in the numbers eaten by the herring (Calanus per 100 herring stomachs: continuous line) for each ten-day period in the Shields fishery, 1931–33. The latter figures have been kindly supplied to us by Mr. R. E. Savage of the Ministry of Agriculture and Fisheries, from his as yet unpublished material.

in these graphs occur when two high feeding periods coincide with (1) a period in 1931 comprising only six plankton samples taken (by the R.S. *Onaway*) on one night and (2) a period in 1933 when only one sample was obtained. When we consider that the stomachs were not necessarily obtained at the same time and in the same places as the Indicator samples we could not expect a very marked correlation between the variations of each. The degree of correlation between the two factors is shown in

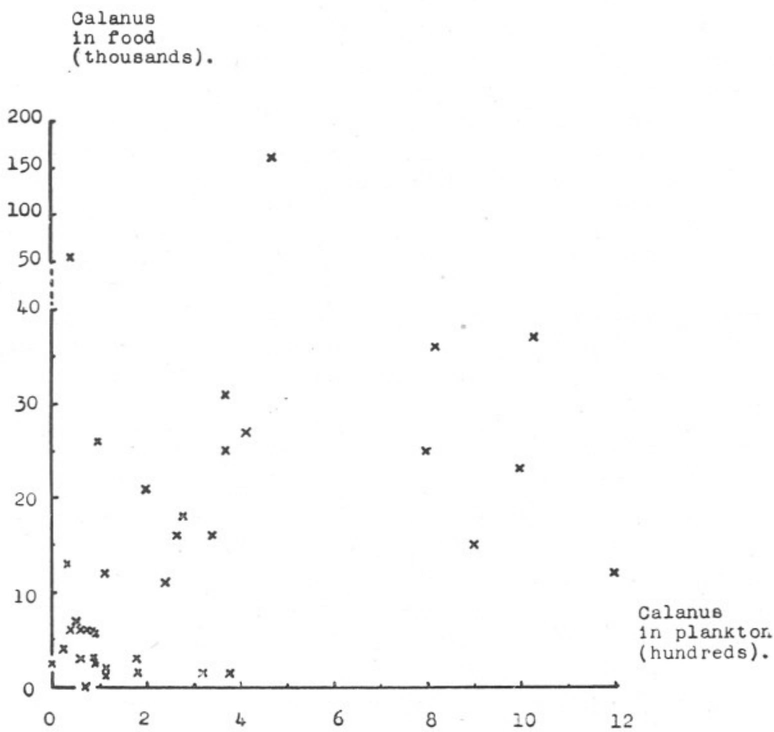


Fig. 22.—Showing for the Shields fishery, 1931–33, the relation between the intensity of feeding of the herring upon Calanus (as shown by the analyses of stomach contents) and the available supplies of Calanus at 7–10 metres (as found by the Indicator samples). The former figures have been kindly supplied to us by Mr. R. E. Savage of the Ministry of Agriculture and Fisheries, from his as yet unpublished material.

Fig. 22 derived from Fig. 21 and Table VI. Regarding these graphs we may note further that in 1932 the period of most intensive feeding was a month later than in 1931, and in 1933 there was a second period of intensive feeding about three weeks later than in 1932.

Now, Hodgson (1925) has shown that the usual course of the fishery at Shields is as follows: In April and early May catches are made of fish just recovering from the spring spawning; these are mainly four-year-olds and are succeeded by the typical fat Shields herring, which are small, only three years old, and in particular, virgin fish. They form an important part of the catch and appear to come mainly for feeding purposes. (Hodgson points out that there is usually an abundant zooplankton at this time.) They appear towards the end of May and are found to be growing up to the end of September. In July and August, these fish are displaced by the vanguard of the autumn-spawning herring, of which the main body supplies the autumn fishery in the Southern Bight. The Shields representatives of these herring are mainly four years old and about to spawn for the first time, though older fish may appear later. This generalised statement of events which we may imagine to vary within limits, is important in any consideration of the ecology, and in particular, the feeding relationships of the herring, since most observers are agreed that the herring cease to feed at spawning time (Hardy, 1924, and Savage, 1931, etc.). Giard (1903) and Brook and Calderwood (1885), however, suggest that the herring may feed hard immediately after spawning.

A possible explanation of the negative correlations found in July and August of 1931 and 1932, might be that they were caused by the presence of spawning fish in the shoals : if spawning herring do not feed then large catches might be taken irrespective of the distribution of the food : the second wave of positive association following on the negative one might be due to the feeding of post-spawning fish as suggested by Giard, etc. (loc. cit., above). We have no accurate information about the constitution of the herring shoals at these times, although reports in *The Fishing News* (see p. 205) suggest that spawning did occur about July in 1931 and in August in 1932, and moreover that in 1933 (when no negative correlations were found) spawning fish were not so evident as in the previous years and on the whole appeared even later.

Further, with regard to the variations in the individual years, it seems to be important to note that if Hardy's suggestion should be borne out that a crustacean diet may be necessary to the ripening of the gonads prior to spawning (Hardy, 1924, p. 18) certain differences over the three years in regard to the distribution of Calanus may be significant. Reference to Fig. 21 shows that in 1932, the season of maximum abundance of Calanus as shown by our plankton samples was probably a month later than in 1931* and that in 1933 whilst Calanus was abundant in April, there was a marked period of scarcity in late May and early June followed by a maximum in mid-July, i.e. some three weeks later than the maximum in 1932. If a period of intense feeding on crustacea should be necessary prior to spawning, it is possible that the late arrival of the Calanus in 1933,

* See also p. 183 and footnote on p. 219 referring to Mr. Savage's results.

which probably covered a wider area of the North Sea than the relatively small one under consideration, may, indirectly, have been the cause of a later spawning in this area, i.e. it may have affected the stock of fish normally entering this area in order to spawn.

It is interesting to note that (1) large numbers of Calanus were taken later each year, (2) the period in the fishery during which small herrings were caught was longer each successive year and (3) that in 1931, whilst there was a period of poor or negative correlation in July and August, in 1932 this was shorter and in 1933 high positive correlations were found at this time. It may be too speculative to suggest that the negative correlations in 1931 and 1932 were due to the presence of non-feeding, spawning herring and that the absence of negative correlations in August, 1933, was due to delayed spawning, but it is evident that some change did occur in the nature of the correlation in 1933 as compared with 1931 and 1932.

An alternative explanation might lie in the following consideration. A study of the histograms representing individual and average catches of herring together with the graphs of the associated numbers of Calanus, shown in Figs. 5, 7, 9, 11, 13 and 15, gives interesting information regarding the strengths of stock of both Calanus and the herring on the grounds during the three seasons and also suggests that there may be at times a reduction in the Calanus stock by the grazing action of the herring when present in very large numbers.* Turning to Fig. 7 (July and August, 1931) we see exceptionally large numbers of herring on the grounds and the Calanus stock has the appearance of being grazed very low. Judging by the numbers of Calanus found in the herring stomachs (figures kindly supplied by Mr. R. E. Savage)—see Fig. 21—we can see that in the earlier part of the season the herring were eating enormous numbers of Calanus, but subsequently the numbers found in the stomachs became very low. This fall in the numbers of Calanus in the stomachs coincides with the greatly increased numbers of herring taken in the fishery in June (see Fig. 16) and suggests that there were not enough Calanus on the grounds to feed so large a stock of fish. It may indeed be that the negative correlations found in July and August, 1931, were not necessarily due to the advent of non-feeding spawning herring, as has been suggested above, but to the presence of hungry herrings searching all over the area for Calanus to feed upon, and thus accounting for their widespread distribution in late July and early August. If the ratio of herring to Calanus is exceptionally large then the Calanus in the samples of plankton associated with the larger catches of herring may be small because the stock in the locality has been greatly reduced by the feeding of the latter.

* That the stock of Calanus on the Shields grounds is intensively grazed, has been suggested by Savage in 1931.

Again in Fig. 15 we see that the herring on the grounds in July, 1933, presented a higher average than at any time in the three seasons other than July and August, 1931. Looking at the curves of the Calanus numbers we see a gradual reduction passing from the first half of July, 1933, to the second half of August. The number of herrings on the grounds also diminished in August, but it was still fairly high in the first half. The herring-Calanus ratio as a whole was lower than in 1931, and positive correlations held over the two months. In most other periods the quantities of herrings are not so large and the curves of Calanus show that its stock was not reduced to a low level over the whole area, regions of richer Calanus remaining in parts, and in these periods the herring-Calanus correlations were mainly positive.

These diagrams do suggest the possibility that the herring can seriously reduce the Calanus stock by grazing, and that if the herring-Calanus ratio is very high (as in late 1931) a positive feeding relationship between the two forms might appear as a negative correlation owing to the extensive reduction of the prey (Calanus) in those localities where the predators (the herring) are most abundant. The negative correlation in early August, 1932, might also be explained thus, the herring-Calanus ratio being high but against this we must consider the following point. Although the reduction in the Calanus stock in early July, 1932 (Fig. 11), is as marked as that in early August, 1933 (Fig. 15), yet the stock of herring on the grounds in 1932 was nothing like so strong as that which might possibly be held to have brought about such a reduction in 1933. If the marked reduction in the Calanus stock in 1932 cannot reasonably be attributed to the grazing of the herring we must be prepared to recognise that the low numbers of Calanus in 1931 and late 1933 may also be due (at least in part) to other reasons. With the inadequate information at our disposal we can go no further: whatever may be our explanation, we must remember that both analyses of the shoals of herring and correlations between the herring and the plankton in this experiment are subject to the movements of the fishing fleet which may produce apparent variation in the constitution of the shoals of fish and also of the plankton.

Seasonal Differences and Hydrological Considerations.

It is worthy of note that other changes have occurred in this area over the three years 1931–33, and it may be that these also can be associated with those previously mentioned. We have already (p. 186) shown that the numbers of Calanus during the fishing season seem to have been increasing during the three years,* whereas the numbers of the other

* It is perhaps also of interest to note that our records (see Part III) suggest that in the waters off the East Coast of Scotland, the numbers of Calanus increased markedly over the three years, and, to a lesser extent, those of Limacina also.

copepoda on the whole decreased. On page 222 we saw that the periods of maximum abundance of Calanus extended later each year, likewise (as shown by Mr. Savage's figures) the period of most intensive feeding on Calanus (p. 220). In the Shields area (p. 232) the amount of phytoplankton decreased from 1932 to 1933, whilst in the Southern Bight it has been increasing in bulk each year (see Savage and Hardy, 1935, and Hardy in collaboration with Henderson, Lucas and Fraser, 1935). Limacina (see Table on p. 227) was progressively scarcer each year during the period of observations,* although it attained higher maxima at the end of the season in 1931 and 1933 than it did in 1932 (p. 236). Herring catches in the vicinity of Shields decreased on the whole (p. 205) and as far as we have information available (see p. 205) it appears that the period when small unripe fish were to be caught extended later each year in these waters. The period of marked negative correlation between Calanus and the herring (see Indicator results, p. 182), so evident in July and early August in 1931, was less extensive in 1932 and in 1933 during the corresponding period the correlations were markedly positive. Reference to the Hydrological Bulletin for 1927–33 (1928–34) shows that on the whole in the centre of the Shields area, temperatures and salinities have been increasing since 1927–28.† For the northern North Sea, Tait (1935) has shown how the salinities have been increasing markedly during recent years, culminating (as far as information is up to date) in the year 1934.

It seems likely that all these factors are not entirely unconnected and it may not be unreasonable to suggest further a connection with the Atlantic inflow which is known to have been increasing steadily over that time. The Report of the Ministry of Agriculture and Fisheries for 1933 (1934, section on Hydrography) shows how the easterly component of the Channel inflow through the Dover Straits has decreased steadily since 1930. This " is to be ascribed to an extra strong southward push of the waters from the north." " Only throughout January was there an inflow from the Channel anything approaching a bold stream." The recovery of drift bottles, liberated in Scotland in 1933, on the Suffolk coast also points to a very strong Atlantic inflow in 1933 round the north coast of Scotland (Scottish Fishery Board Reports, 1934). Russell (1935a) has reviewed past information concerning the value of certain plankton animals as indicators of unusual water currents and with reference to the increasing strength of the Atlantic inflow into the North Sea in these years it is interesting to note a number of instances of unusual organisms penetrating into the North Sea during that time.

* See footnote on p. 224.

† Information from the Meteorological Office Records for Shields (1931–33) for these years shows that higher maximum atmospheric temperatures were attained each year and that the period of maximum temperature persisted later, i.e. for a longer time, each successive year.

In September, 1933, we found *Dolioletta gegenbauri* (Uljanin) apparently moving southwards in the North Sea in the latitude of Aberdeen (Lucas, 1933).* It seems possible that some of the doliolids which have been found by the Scottish Fishery Board to be penetrating further into the North Sea from 1928–33, are the same form (Scottish Fishery Board Reports, 1929–34). Kramp (1934) refers to the unusual occurrence of *Rhizostoma octopus* and *Chrysaora hysoscella* in Danish waters in 1933 (see also the finding of *Clione limacina*, *Limacina helicina* and *Sepia officinalis* referred to by Kramp, loc cit.). In addition to doliolids the reports of the Scottish Fishery Board for 1930–33 refer to other unusual organisms entering the North Sea during these years. Chief amongst these are: Larval Wrasse (*Ctenolabrus rupestris*) in September, 1930, and *Ommatostrephes sagittatus* on the Shetland herring grounds in 1930 and 1931 together with unusually large numbers of medusæ as Laodicea, Tiaropsis, Cosmetira, Mitrocoma and Obelia species in 1931 (see also Lucas and Henderson, 1936). *Cyclosalpa bakeri* in November, 1932, and the floating barnacle, *Lepas fascicularis* in July 1933, were also recorded off the Bressay Shoal.

Russell (1935b) has shown that many of these forms, with others, may be considered when present in the North Sea to be indicators of the presence of Atlantic water. In another paper (1935a) he demonstrated how the fluctuating movements of *Sagitta elegans* and *Sagitta setosa* since 1930 in the waters off Plymouth also demonstrated the gradually increasing strength of the Atlantic pulse in the north during those years: the predominance of the *Sagitta elegans* in 1930 gave place to a dominance of *Sagitta setosa* late in 1931. From 1930 to 1934 the proportionate dominance of *Sagitta setosa* at Plymouth on the whole tends to agree with the abundance of *Rhizosolenia styliformis* (also an indicator of Atlantic water) in the Dogger Bank region. The abundance of both increased from 1930 to 1933 and both seem to have been rather less abundant in 1934.

It is thought important to note, where possible, broad changes of the above nature which may be associated over a term of years, and which apparently include such diverse planktonic forms as copepods, doliolids, pteropods and the phytoplankton, the pelagic herring and the physical conditions of the environment, whilst there are probably many other factors which we are not at present able to enumerate. We have noted what seem to be important changes in the Shields herring fishery during the years under review and we must consider the possibility that these changes (and other similar changes in fisheries in these waters) may be a reflection of more general changes occurring in the North Sea as a whole.

The Limacina-Herring Correlations.

Whilst in 1931, both for the Scottish and Shields areas, we considered that we had good evidence of a negative correlation between Limacina and the herring, we had later to qualify this view. Our first results were based upon a table combining all the results then available, without any regard being paid to variations within the season. In the Shields area for

* Young *Luidia sarsi* (echinoderm larvæ) were also found in these waters during the same period.

the three years 1931–33 we have the following average catches of herring (in crans) for different ranges of Limacina.

		1931.	1932.	1933.	1931–33.
Limacina	0–99 .	18·89^{50}*	3·98^{185}	8·21^{170}	7·59^{405}
,,	100–249 .	14·26^{21}	4·68^{19}	4·94^{12}	8·61^{52}
,,	250–499 .	9·84^{16}	12·09^{11}	3·86^{4}	9·85^{31}
,,	500–999 .	8·93^{9}	3·33^{3}	10·08^{3}	8·05^{15}
,,	1,000 and over	5·19^{8}	2·75^{1}	1·00^{4}	3·71^{13}

In this table we see that whereas 1931 showed a marked negative correlation as a whole, 1932 showed an optimum catch in the region of 250–499 Limacina and 1933, although showing an optimum (almost certainly not significant) at 500–999, is on the whole more similar to 1931 than 1932. We might also note at this stage that whereas in 1931 52% of the samples showed concentrations of more than 100 Limacina, in 1932 and 1933 the numbers of such samples were much lower; this is due partly to the fact that we have no samples before June 29th in 1931, whereas in the other years we have samples from early May onwards, and at these times Limacina was scarce, but there is also a significant difference in the numbers of Limacina appearing after June in the three years in this area. This is best shown by considering the percentage of samples with more than 100 Limacina from the end of June, together with the average catches of herring for the different ranges of Limacina from this date (including one sample on June 29th, 1931). In this way we find:

		1931.	1932.	1933.	1931–33.
Limacina	0–99 .	18·89^{50}*	4·7^{42}	11·9^{72}	12·2^{164}
,,	100–249 .	14·26^{21}	5·8^{9}	6·5^{7}	10·7^{37}
,,	250–499 .	9·84^{16}	12·9^{9}	5·0^{3}	10·3^{28}
,,	500–999 .	8·93^{9}	3·3^{3}	10·1^{3}	8·1^{15}
,,	1,000 and over	5·19^{8}	2·8^{1}	1·0^{4}	3·7^{13}
Percentage greater than 100		52%	34%	19%	

On the whole very similar results are obtained, but there is this difference that although in 1933 Limacina attains at the end of the season a higher average than throughout 1932 (see p. 236), yet throughout the period for which we have samples, the percentage with more than 100 Limacina is less than in the two previous years, in fact the percentage decreases steadily from 1931 to 1933, so that during the fishing season its effects (whether good or bad) might be expected to decrease, since the area of water in which it was abundant became less and less. If we consider the correlation over the three years we find an almost perfect

* The indices denote the number of samples.

negative relationship after June, whereas, including all results from May onwards, the relationship was of a different type, the maximum average being associated with 250–499 Limacina. This demonstrates well the unsatisfactory nature of correlating results without reference to variation during the passage of time. The catches in May and June of 1932 and 1933 were low, and were associated with a low Limacina population, thus affecting the general correlation. The ecologist must always be prepared to distinguish between correlations in time and in space. Organisms which

TABLE VII.

SHOWING THE AVERAGE CATCHES OF HERRING IN CRANS CORRESPONDING TO LOWER AND HIGHER LIMACINA NUMBERS. THE HIGHER OF THE TWO CATCHES IS SHOWN IN HEAVY TYPE.

Year.	Area.	Period.	Average catch with Limacina 0–99.	Average catch with Limacina 100 and over.	Sign of Correlation.
1931	Shields	29 June–15 July	$17{\cdot}6^{20}$	**$27{\cdot}0^{1}$**	+
,,	,,	16–31 July	**$23{\cdot}6^{21}$**	$13{\cdot}2^{16}$	—
,,	,,	1–15 August	$10{\cdot}5^{4}$	**$12{\cdot}2^{13}$**	+
,,	,,	16 Aug.–8 Sept.	**$11{\cdot}2^{5}$**	$7{\cdot}6^{24}$	—
,,	Humber	1–30 Sept.	**$26{\cdot}7^{6}$**	$17{\cdot}4^{10}$	—
,,	,,	1–31 Oct.	$16{\cdot}0^{6}$	**$102{\cdot}0^{1}$**	+
,,	Yarmouth	1 Sept.–31 Oct.	**$19{\cdot}3^{25}$**	$13{\cdot}5^{1}$	—
1932	Shields	1–15 June	**$4{\cdot}1^{49}$**	$3{\cdot}0^{1}$	—
,,	,,	16–30 June	$4{\cdot}3^{34}$	**$4{\cdot}6^{11}$**	+
,,	,,	1–20 July	$4{\cdot}2^{20}$	**$6{\cdot}2^{12}$**	+
,,	,,	1–15 Aug.	$5{\cdot}3^{3}$	**$12{\cdot}4^{8}$**	+
,,	,,	16–31 Aug.	**$4{\cdot}9^{15}$**	$3{\cdot}5^{2}$	—
1933	,,	1–15 June	**$2{\cdot}1^{37}$**	$2{\cdot}0^{3}$	—
,,	,,	16–30 June	**$9{\cdot}0^{35}$**	$2{\cdot}7^{3}$	—
,,	,,	16–31 July	**$14{\cdot}0^{18}$**	$11{\cdot}1^{7}$	—
,,	,,	1–15 Aug.	**$8{\cdot}0^{26}$**	$4{\cdot}3^{2}$	—
,,	,,	16 Aug.–1 Sept.	$0{\cdot}5^{3}$	**$1{\cdot}1^{8}$**	+
,,	Humber	1–31 Sept.	**$18{\cdot}6^{8}$**	$0{\cdot}3^{1}$	—

The indices denote the number of catches on which the average is based.

may be correlated positively in time (their numbers rising and falling similarly during a season), may yet be negatively associated in space, and *vice versa* : perhaps this has particular application in pelagic ecology, in which all the forms are not only liable to sudden fluctuations in actual numbers, but also to sudden migrations, both active and passive.

If now we examine the results in half-monthly periods corresponding to those used in the Calanus section, we find a considerable amount of variation. Table VII shows the correlations obtained by comparing the average catches associated with samples of less than 100 and more than 100, respectively. For the Shields area in May, 1932, and in May and the first half of July, 1933, no correlations are possible : also in 1931 there are no analyses of Limacina corresponding to the Calanus material from the R.S. *Onaway*. Of the remaining groups, eight are negative and six are positive, and whilst the 1931 and 1933 groups are mainly negative, those in 1932 are mainly positive. Such information as we are able to obtain from the Humber and Yarmouth areas is equally unsatisfactory: the data for both these areas is shown in Table VII.

We may now consider for the Shields area the progress of the fishery and the samples of Limacina through the season, and we see that in 1931 and 1933, as Limacina increases the catches decrease, whereas in 1932 the rise and fall of the catches and Limacina coincide very well (see Figs. 16

TABLE VIII.

Showing the Numbers of Limacina per 100 Herring Stomachs* compared with the Numbers found in the Plankton, in 10-day Periods, in the Shields Area, 1931 and 1932.

10-day period ending.	Numbers of Limacina per 100 stomachs. 1931.	1932.	Numbers of Limacina in the plankton. 1931.	1932.
9th May	—	83	—	2^{8}
19th May	—	38	—	1^{21}
29th May	—	0	—	3^{23}
8th June	—	0	—	5^{32}
18th June	—	0	—	22^{33}
28th June	—	32	—	72^{32}
8th July	100	48	9^{11}	79^{22}
18th July	0	0	41^{16}	125^{13}
28th July	0	54	118^{25}	23^{2}
7th August	2,696	0	293^{16}	225^{1}
17th August	2,346	13	186^{11}	339^{13}
27th August	4,441	27	507^{14}	53^{11}
6th September	8,795	29	$1{,}341^{9}$	2^{6}
16th September	24,884	95	$1{,}980^{2}$	—

The index figures denote the number of samples on which the plankton averages are based.

and 24). I think that this last factor is important; the negative correlations between Limacina and the herring in 1931 and 1933 may have been due to associations in time, as may also the positive correlation in 1932. Such an association may or may not be significant; we have not sufficient information to test this effectively. It is well known that herring will feed on Limacina (Hjort, 1912; Hardy, 1924; Savage, 1931) sometimes so much as to cram their stomachs and produce in cured fish the well-known condition of "black gut." Mr. Savage, of the Ministry of Fisheries Laboratory, Lowestoft, has kindly supplied us with the details of the feeding of herring on Limacina at Shields in 1931; a comparison

* These figures have been kindly supplied by Mr. R. E. Savage of the Ministry of Agriculture and Fisheries.

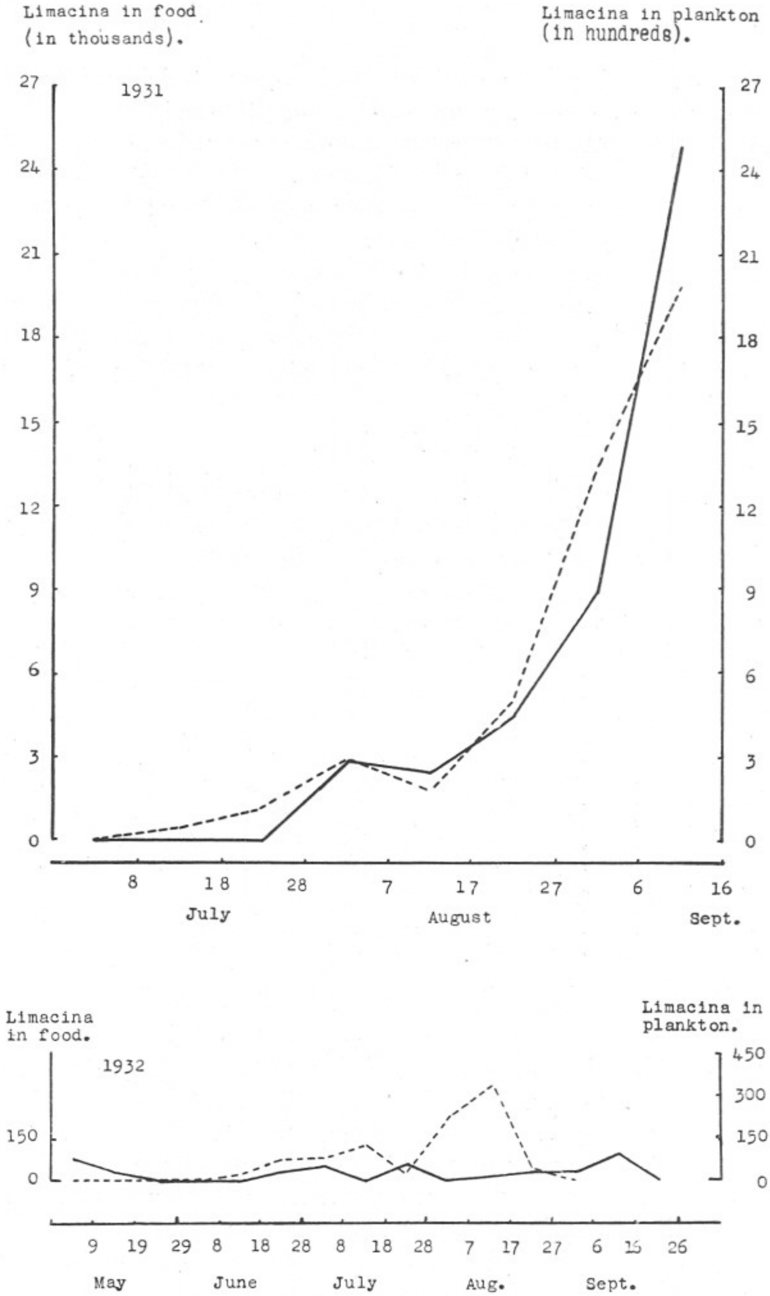


FIG. 23.—Showing the sequence of Limacina in the plankton (numbers per disc: broken line) and that in the food of the herring (numbers per 100 stomachs: continuous line) during ten-day periods in 1931 and 1932. It should be noted that the horizontal scale differs in the two years. We are indebted to Mr. R. E. Savage, of the Ministry of Agriculture and Fisheries, Lowestoft, who kindly supplied to us his as yet unpublished data relating to the feeding of the herring during these three years.

of the increase of feeding on Limacina with the increase of the organism in the plankton (sampled by our Indicator) is shown in Table VIII and Fig. 23 (1931). There is such a remarkedly close relationship between the two graphs that it is difficult to resist surprise that we do not find a marked positive relation between Limacina and herring during such times as it is reasonably abundant. In 1932 (see Fig. 23) Limacina was much scarcer in the plankton and Mr. Savage found very little of it in the food and no significant seasonal variation in the quantity. Yet we saw that in 1931 the correlation was mainly negative, whilst in 1932 it was mainly positive. We cannot at present account for these discrepancies, and although it is possible that normally the association between the herring and Limacina would be based upon a positive feeding relationship, there may yet be a negative association between the herring and dense concentrations of Limacina due to the avoidance by the herring of some at present unknown factors associated with large quantities of the latter. It must of course be borne in mind that the negative correlations in 1931 may well be due to similar factors to those producing the negative correlations between the herring and Calanus, although the abundance of Limacina occurred later in the season than the periods of negative correlation with Calanus. It is worthy of note here that there appears to be no association, either negative or positive, between the distribution of Calanus and that of Limacina : they may at times occur together in large numbers and at others they may be most abundant in different parts of the area.

It is clear that considerably more information is required, not only in regard to correlations between Limacina and herring, but also concerning the physiology of both organisms. It would be interesting to know, for instance, what is the actual food value of Limacina to the herring. The fact that large numbers are sometimes found in the stomachs does not necessarily imply that it is of high value to the herring as food. The difficulty of curing fish with " black-gut " suggests the inability of the herring to digest Limacina. Whatever may be the result of such researches, it seems evident that at present Limacina cannot be used as an indicator of herring catches, but it may be that further investigation with the Indicator will show that when Limacina is very abundant poor catches may be expected, especially if it is widely distributed. Results during 1930–33 from the Scottish and Irish areas also suggests this possibility. The average catch for all discs having over 500 Limacina is 4·94 crans (117 samples), and that for discs with over 1000 is 4·37 crans (70 samples), whilst the average for discs with less than 500 Limacina is 9·97 crans (1109 samples). Although this is not borne out area by area and period by period in detail, the consensus of results does suggest a negative effect on the size of the catches associated with *large* numbers of Limacina.

Notes on the Plankton taken with the Indicator off the East Coast of England.

Shields Area.

In the introductory paper two important factors are mentioned which qualify the value of the plankton material collected : (1) the Indicator hauls were horizontal and limited to a depth of 7–10 metres and (2) it is likely that considerable variation in the quantity of the plankton at this level may be due to the changes in its vertical distribution from time to time. In the plankton-herring correlations discussed in the foregoing pages these qualifications, whilst being kept in mind, need not be allowed to weigh too heavily : the correlations are found by using the Indicator in this particular manner and they appear in spite of the limitations of the method. In attempting to study the ecology of the plankton from this material it is necessary to give full weight to these factors.

Whilst the value of the material is limited in this way, with regard to certain organisms it is quite extensive. In the Shields area 545 samples have been taken, spaced fairly regularly in time over two and a half fishing seasons. In addition there is the advantage that all were collected in the fishing area, whilst fishing was in operation. For this reason notes on the more salient changes in the plankton over the period of investigation may be of value in supplementing the work of previous investigators and perhaps for reference in relation to future work.

Our work in this area, it will be remembered, began on the 29th June, 1931, and extended to the 8th September of that year ; in 1932 it extended from early May to the 1st September with a gap from the 21st July to the 6th August, and in 1933 we obtained samples in an almost complete series from the 29th April (there was also one sample on the 13th April) to the 1st September. In 1931 the samples were completely analysed, but in the following years, as already mentioned, the zooplankton analyses were limited to *Calanus finmarchicus*, total Copepoda and Limacina together with notes on the abundance of other organisms.* Table IX gives the numbers of these forms week by week together with those of the Dinoflagellates. The sequence of the variations is shown in Fig. 24 in graphical form. The chief points of interest arising out of these tables may be summarised as follows :

Diatoms and Phæocystis. There were no records in 1931 for the early part of the season, but 1932 and 1933 were characterised by the abundance of phytoplankton in May and early June. It seems probable that 1932 produced the greater concentrations of diatoms,

* For part of 1932 there are also analyses of Temora, the Cladocera, Sagitta and other forms.

TABLE IX.

SHOWING THE AVERAGE NUMBERS OF VARIOUS PLANKTON ORGANISMS PER QUARTER MONTH IN THE SHIELDS AREA.

Month.	May.				June.				July.				August.				Sept.
Quarter.*	1.	2.	3.	4.	1.	2.	3.	4.	1.	2.	3.	4.	1.	2.	3.	4.	1.
Number of samples.																	
1931					6	—	5	19	9	12	18	19	10	7	13	9	7
1932	7	9	24	19	23	27	25	20	15	13	4	—	—	11	8	9	4
1933	5	7	5	6	16	24	18	20	12	13	11	14	18	10	2	7	2
Dinoflagellates, in thousands.																	
1931									2	7	5	29	36	45	65	39	39
1932	14	14	7	10	10	3	3	5	5	7		—	—	8	8	10	
1933	1	0	0	2	1	3	4	8	2	4	6	13	13	16	18		
Calanus finmarchicus.																	
1931					41	—	117	94	99	39	19	130	90	98	66	77	59
1932	290	72	270	731	749	962	965	845	205	175		—	—	175	194	39	
1933	961	422	249	104	41	306	195	564	1,030	1,015	1,077	293	74	66	67		
Copepoda other than Calanus.																	
1931									3,454	2,546	1,813	1,652	875	1,045	1,621	1,061	1,264
1932	506	492	505	990	1,346	1,320	2,143	938	1,421	1,107		—	—	697	963	596	
1933	321	267	37	146	180	1,134	1,221	975	1,125	1,274	745	852	841	885	699		
Limacina.																	
1931									5	28	106	163	292	235	232	851	1,659
1932	2	2	1	5	4	26	35	101	75	100		—	—	365	101	32	
1933	10	13	0	9	2	32	20	35	16	33	18	149	19	236	810		

* The numbers 1, 2, 3 and 4 represent the periods 1st–7th day, 8th–15th day, 16th–22nd day and 23rd day to the end of the month in question.

two-thirds of the discs obtained in the first part of May being coloured green. The chief forms were *Nitzschia closterium*, Chætoceros species and Thallassiosira spp. with local concentrations of *Rhizosolenia styliformis* and the flagellate Phæocystis. Fish were scarce at this time even compared with the general low average for the year. In 1933 there are two records of dense phytoplankton off Shields (i.e. two discs deeply coloured green by the diatoms), although less dense associations were frequent during early May and early June, but not in the second half of May: the principal forms were Thallasiosira and Chætoceros species and *Rh. hebetata*. The

TABLE X.

Showing the Average Numbers of Plankton Organisms per Quarter Month in the Shields Area, 1931.

Month	July.				August.				Sept.
Quarter*	1.	2.	3.	4.	1.	2.	3.	4.	1.
No. of samples	9	12	18	19	10	7	13	9	7
Dinoflagellates in thousands	2	7	5	29	36	45	65	39	39
Sagitta . .	1	5	15	13	9	7	32	57	23
Podon . .	60	38	31	19	9	1	1	0	7
Evadne . .	342	54	3	0	2	0	0	0	3
Calanus . .	99	39	19	130	90	98	66	77	59
Paracalanus and Pseudocalanus	652	310	170	271	115	57	280	260	276
Centropages .	204	523	441	361	177	247	153	175	147
Temora . .	137	191	126	279	68	225	549	130	230
Acartia . .	1,117	1,064	638	492	342	400	579	474	572
Oithona . .	556	165	188	106	32	33	28	21	32
Total Copepoda	3,553	2,585	1,832	1,782	965	1,143	1,687	1,138	1,323
Limacina .	5	28	106	163	292	235	232	851	1,659
Lamellibranch Larvæ . .	93	642	916	385	57	1	30	31	14

phytoplankton will be further considered in relation to the herring in Part IV of this series of papers.

Dinoflagellates. In our samples these are mainly Ceratium species,† due probably to the differential catching power of the 60-mesh silk used on the discs. The year 1931 was easily the dominant year, an average of over 60,000 being found in August. In 1932 and 1933 the average figures were similar on the whole, but whereas the highest numbers in 1933 were towards the end of the season (as in 1931), in 1932 they were obtained in May with a secondary maximum occurring in August. An average of 27,000 in September, 1933, is the highest found in the two years.

* The numbers are used as in Table IX.

† The evidence from 1931 suggests that in August and particularly in September, Peridinium and Dinophysis increase in abundance relatively and actually.

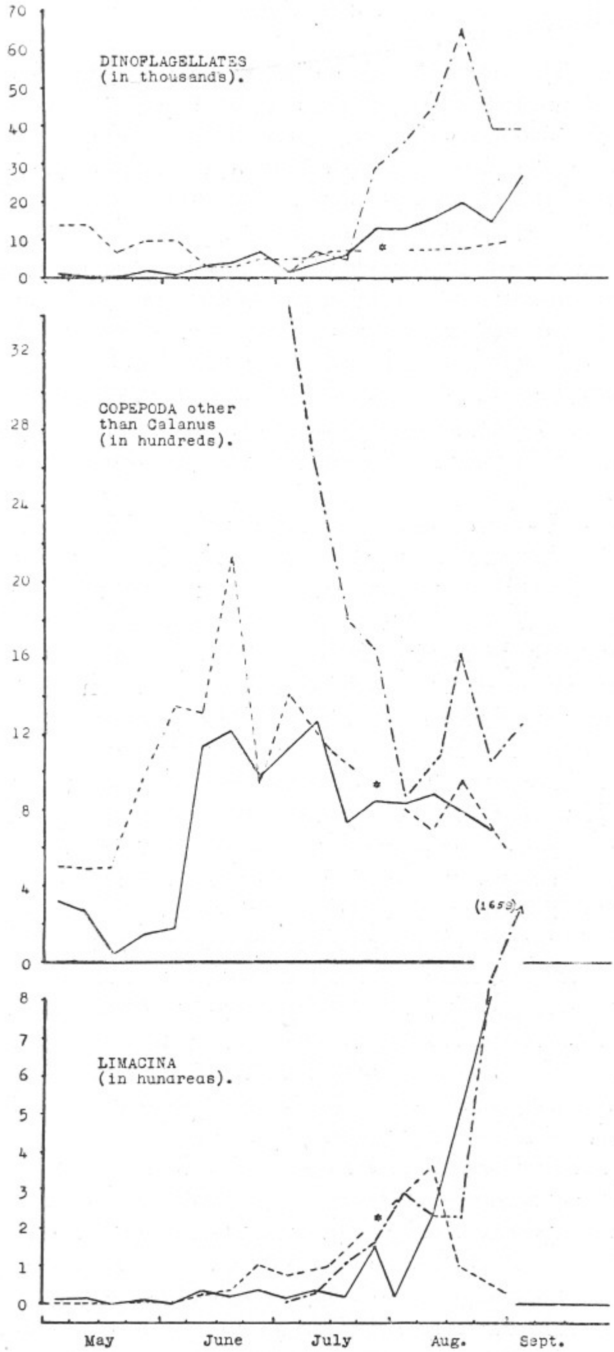


FIG. 24.—Showing the seasonal variations in the numbers of Dinoflagellates, Copepoda other than Calanus, and Limacina in the Shields area during the years 1931–33. (1931:—dots and dashes; 1932:—broken line; 1933:—continuous line). * indicates a gap in the otherwise continuous series of observations for 1932.

Copepoda. The seasonal distribution of Calanus has already been described (see pp. 183–186) and Figs. 6, 8, 10, 12 and 14 show its spatial distribution at 7–10 metres, in consecutive half-months together with that of the herring. The distribution in time of the other copepoda is not dissimilar from that of Calanus in 1932 and 1933, but in 1931, whereas Calanus is scarce throughout the period of our results, at the beginning of that period the other Copepoda were very numerous, more numerous, in fact, than on any other occasion in the three years. How long this abundance lasted, unfortunately we cannot say. On the whole a broad similarity can be detected, a period of Calanus abundance in each year being followed by a scarcity ; the other copepods were abundant at the same time in 1932 and 1933, and then followed a drop in the numbers which was however very small compared with the drop in the Calanus population.

From the end of June onwards in 1931 we have the records of the numbers of the different copepods (see Table X). In early July, Acartia, Paracalanus and Oithona were very numerous : as the numbers of these forms decreased, Temora and *Centropages hamatus* became the chief features of the copepod fauna, although Paracalanus and Acartia had a small secondary maximum at the end of August. In 1932, Temora appeared to be very abundant during the first half of July, but the number of samples analysed for Temora in 1932 is not very large.

Cladocera. In 1931 the Cladocera as a whole decreased rapidly from the end of June, Evadne being more abundant at first and later Podon being the dominant form, although latterly the numbers of both were very low. In 1932 the maximum period occurred during the first half of June. Cladocera were not counted in 1933, but notes of their abundance were kept and these suggest a maximum density in late June.

Echinoderm Larvæ. In late June and early July an interesting feature was the appearance of large numbers of brightly coloured Echinoplutei. These were found both in 1932 and 1933 in large numbers, and to some extent in 1931, but not so numerous during the period of observation (from the end of June onwards). When these forms were abundant, the discs presented a brick-red appearance.

Limacina. The distribution of Limacina has been dealt with on page 227 ; 1931 was undoubtedly the year of its maximum abundance, but while under the period of observation it appears to have been scarcer in 1933 than in 1932, there were signs in 1933 that it was increasing and that it might attain a much greater density at the end of August and in early September than had been found at any part of the season in 1932.

TABLE XI.

Showing the Average Numbers of Various Plankton Organisms in the Humber and East Anglian Area, 1931–33.

1. *In the Humber Area*, 1931–33.

	1931.				1932.				1933.		
	Sept.	Oct.	Nov.	Dec.	Sept.	Oct.	Nov.	Dec.	Sept.	Oct.	Nov.
Dinoflagellates in thousands .	10	3	0	0	1	0	0	0	2	1	–
Calanus	12	36	1	0	18	10	0	10	31	11	–
Copepods other than Calanus	1027	1084	105	11	1040	1290	60	100	825	405	–
Limacina	348	457	1	0	26	0	0	0	30	10	–
Number of samples . .	16	7	6	6	6	1	1	2	9	2	–

2. *In the East Anglian Area*, 1931–33.

	1931.				1932.				1933.		
	Sept.	Oct.	Nov.	Dec.	Sept.	Oct.	Nov.	Dec.	Sept.	Oct.	Nov.
Dinoflagellates in thousands .	9	1	0	–	–	0	0	0	–	1	0
Calanus	56	16	3	–	–	0	0	5	–	20	0
Copepods other than Calanus	3008	796	19	–	–	223	69	60	–	218	0
Limacina	0	9	0	–	–	0	0	0	–	35	0
Number of samples . .	1	24	35	–	–	5	14	2	–	2	1

Humber and East Anglian Areas.

The number of samples obtained in these areas is in most of the months very small, too small for more than the briefest notes to be made. The results are tabulated in Table XI. The progressive impoverishment of the plankton as the season advances is seen in each area and in each year.

The Plankton Community as a Whole and the Feeding of the Herring.

Hardy (1924) and Savage (1931) in their work on the food of the herring have indicated broadly the succession of food types taken. Hardy found that in the herring, after feeding intensively upon Ammodytes in the early Spring, the diet becomes almost entirely planktonic and in particular, crustacean.

Oikopleura was eaten in May, June and July but mainly in May. The Cladocera, whilst very unimportant compared with forms such as Oikopleura and Calanus, did figure in the food lists and were most numerous in mid-June. Copepods supplied food from March to December, but mainly in June, July and August, particularly in July. We do not know whether Limacina was very abundant in the plankton of that year or not ; it only supplied a relatively small proportion of the food, and that mainly in July and August. Sagitta was fairly important increasing to a maximum in July and August. Savage (1931) found a period of intensive feeding upon Calanus in May, 1926, whilst Temora seemed to be taken mainly in early July with a small peak in early September. Centropages was important in late August and September (particularly off the Yorkshire coast). Paracalanus and Pseudocalanus had maxima in June, but were much more abundant in the food of the Yorkshire coast herring in the period September and October. Savage's findings for the other species are mainly in agreement with those of Hardy. The maxima are Oikopleura in June, Cladocera in June (mainly) followed by a peak composed of Podon in July and a small secondary maximum of Evadne in September and October. Sagitta was most abundant in August and Limacina, which was very abundant in the plankton, increased rapidly in the food in September reaching a maximum in October off the Yorkshire coast.

These findings in general agree very well with the sequence of planktonic forms as found by the Indicator at 7–10 metres' depth. From unpublished information supplied to us by Mr. Savage, we may say that there is a very close agreement between the sequence of different food species in 1932 and the actual sequence in the plankton as shown by the Indicator results. On page 219 we have already commented upon the close agreement found for Calanus in the three years 1931–33 (see Fig. 20), and on page 231 we have demonstrated (1) the marked similarity in the increase of Limacina in the plankton and that in the herring stomachs for 1931 and (2) the marked scarcity of Limacina in the stomachs in 1932 when that form was much less abundant in the plankton samples than in 1931 (see Fig. 23). Both Savage and Hardy are agreed in showing how the feeding decreases with the passage of time, and with the movement of the fishery further south. Whatever this may be due to, there is little doubt that, considering the scarcity of the plankton at this time in the Southern Bight compared with the vast shoals of herring gathered there, very little feeding would be possible however much the herring might desire planktonic food.

SUMMARY.

1. The 704 samples of plankton, taken with the Plankton Indicator by drifters fishing in the Shields, Humber and East Anglian fisheries in the years 1931–33, together with a few off East Anglia in 1930, have been examined and correlated with the associated catches of herring. In addition a series of half-monthly charts has been prepared showing the spatial relations of the waters richer in *Calanus finmarchicus* and the higher herring catches (pp. 183–204).

2. Out of 20 half-monthly periods in the Shields fishery (May to August), 15 show a positive correlation between the abundance of the herring and its food Calanus, and 5 show a negative correlation. The negative correlations tended to occur in July and early August and it is thought that they may possibly be associated with shoals of fish about to spawn (pp. 187 and 222).

3. Poor catches may be made in rich Calanus waters and good catches in poor Calanus waters, but more usually the better catches are made in the richer Calanus waters. There is some evidence that the positive correlations depend most on the general presence of the *highest* catches in the waters *richest* in Calanus (pp. 207–215).

4. An attempt is made to estimate the commercial value of the Indicator if used to locate the richer Calanus waters. The theoretical gain or loss which drifters would be expected to have incurred had they fished only in the richer Calanus waters, is estimated for each period. This is expressed as a percentage gain or loss over the actual catch made when fishing at random. The average of the percentage gains and losses for 1931–33 gives an average gain of $12{\cdot}7 \pm 6{\cdot}7\%$, or omitting the incompletely sampled year 1931, the average gain is $21{\cdot}2 \pm 7{\cdot}5\%$ (pp. 204–209).

5. The histories of individual drifters using the Indicator are followed through the fisheries and the theoretical results of fishing in the richer waters are calculated for each drifter; they all show that substantial gains (averaging $19{\cdot}3 \pm 5{\cdot}1\%$ over the three years) are to be expected by always avoiding the poorer Calanus water (pp. 215–216).

6. Up to a point it is demonstrated that the richer the Calanus water found the greater may be the expected gain (p. 214).

7. Results off the Humber in September suggest a positive Calanus correlation, but in the East Anglian fishery no satisfactory correlations can be made owing to the scarcity of Calanus and to the fact that the herring are no longer feeding in the late Autumn (p. 202).

8. Observations are made upon the possible grazing effects of the herring upon the stocks of Calanus in the area (pp. 223–224).

9. There are indications that the herring may avoid waters containing large numbers of Limacina, but no definite conclusions have been reached (pp. 226–231).

10. Changes in the fisheries and the plankton are tentatively linked with hydrological changes over the period of the investigations (pp. 224–226).

11. The feeding of the herring in relation to the plankton is considered and notes on the general plankton ecology are included (pp. 232–239).

POSTSCRIPT.

Thirty-six Indicator samples were taken in 1935 by the Boat "A" mentioned above, whilst using the Indicator to locate shoals of fish. Correlations between Calanus and the herring have been made as before and the following data obtained :

Period.	Samples.	Average catch (crans). Lower Calanus.	Higher Calanus.	% Gain or Loss.	Av. Cal.	Av. Limacina.
12th–31st May	10	5·5	3·6	—20·4	11	0
1st–15th June	10	3·2	3·9	+ 9·2	375	3
16th June–1st July	10	2·7	29·8	+83·4	2,455	10
7th–14th July	6	9·6	14·8	+21·3	672	67
Totals	36	21·0	52·1	..	..	..
Averages	..	5·2	13·0	+23·4	..	..

An average gain of 23·4% was made. Limacina was scarce during the whole of this period, though increasing in July, whilst Calanus would appear to have had its maximum in late June.

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