RIT FISKIDEILDAR VOL. II — NR. 5

A Study of the Plankton-Herring Relationship off the SW-Coast of Iceland.

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CONTENTS:

I. INTRODUCTION.

Already before the end of the last century many scientists (Goodsir 1843, Brook 1886, and Hensen 1893) had suggested that the movement of the adult herring at certain seasons is greatly influenced by the distribution of their food or other organisms in the plankton. This hypothesis was further supported by Paulsen (1906) who investigated the plankton in Icelandic waters. Later, Hardy (1922) designed a special instrument to study the relationship between the herring and its food. This instrument, known as the prototype plankton Indicator, was designed for use by fishermen from commercial ships, hence the essential requirement was that the device should be "simple, strong, easily handled and rapid in use" (Hardy, 1926).

Following preliminary experiments Hardy (1926) instigated a large scale survey from the University College, Hull. The standard Indicator, a modified form of the original prototype was used for this work in which a great number of herring drifters assisted by towing the Indicators while taking part in the Scottish, Northumbrian and East-Anglian fisheries (Hardy *et al.*, 1936). During this extensive survey the understanding of the plankton-herring relationship in the North Sea was greatly furthered.

The plankton herring relationship in Icelandic waters has mainly been studied during the north coast summer fishery. While investigating the herring and its food off the north coast of Iceland, Fridriksson (1944) found a close correlation between the plankton maxima and the herring concentrations, using Hardy's standard indicator. Einarsson (1951) using a Hensen net for his plankton sampling also found a plankton-herring correlation. Although Einarsson's surveys were mostly concentrated on the herring grounds north of Iceland, he also surveyed the south-western areas in late June 1951 (*loc. cit.* p. 155, Fig. 8). By collecting information from various commercial crafts Einarsson (*loc. cit.* pp. 156–160) was able to estimate the distribution of the herring as well as demonstrate a plankton-herring correlation in these south-westerly regions. It should be noted here that while the north coast herring fishery (purse seine net) takes place during July and August, the south-west coast fishery (drift net) extends from August to December. Thus Einarsson's survey of 1951 did not take place during the usual drift net season.

Since 1947, several plankton surveys have been carried out off the SW-coast by members of the staff of the Fisheries Department of the University

Research Institute in Iceland. However, the analyses of this material have neither been completed nor were these surveys particularly designed to investigate the plankton-herring relationship with the exception of the material collected in 1948 (HALLGRÍMSSON 1954, unpublished). The material on which the present paper is based was collected during two surveys in 1954 and 1955. Both surveys were carried out on the Ægir during the first half of September of each year; the immediate objective was to investigate the distribution of the herring on the fishing grounds using the Kelvin-Hughes Asdic Whalefinder and the Simrad echosounder.

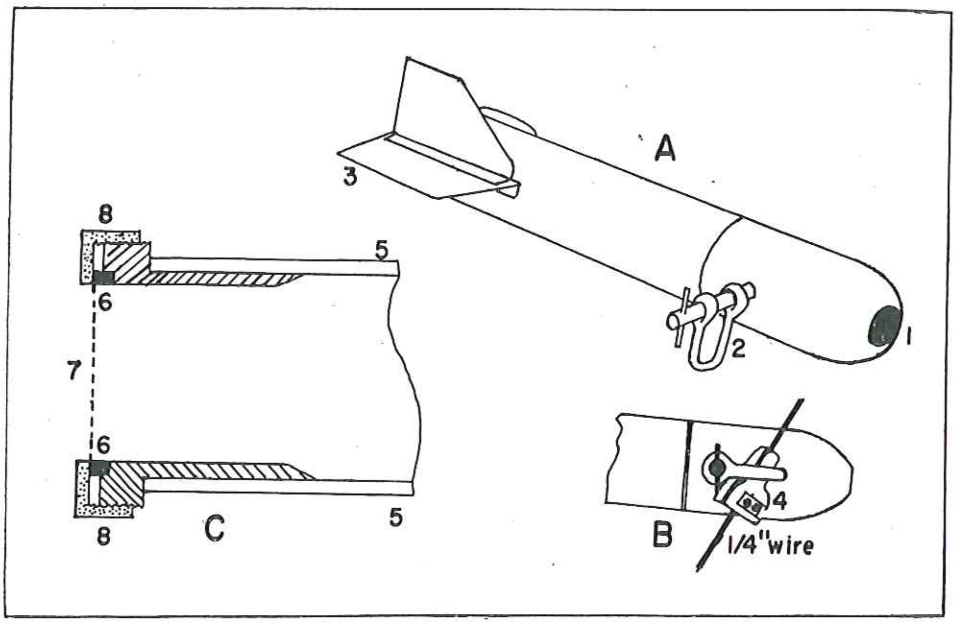


FIG. 1. *The multidepth small Indicator (A and B altered after Glover, 1953, Text fig. 4). A. Perspective sketch: (1) Sampling aperture ½" diameter in cast bronze-nose, (2) towing shackle, (3) stabilising fins. B. Side view showing the Indicator in a towing position resting on a brass stop (4) which is secured by two screws to the towing wire. C. A section of the rear end, from a drawing kindly provided by Mr. R. S. Glover; (5) copper barrel of Indicator (6) brass ring on which silk disc (7) is mounted, (8) screwed cap holding brass ring in position.*

In 1954 two methods were used for sampling the plankton, one of which, vertical Hensen net hauls, has been used extensively in Icelandic waters since 1948 (EINARSSON 1951) while the other, multidepth high speed horizontal sampling, had not previously been used there.

The method of horizontal sampling which was used was developed by the Edinburgh laboratory of the Sscottish Marine Biological Association.

GLOVER (1953) has described the prototype multi-depth sampler which has since been modified in a number of ways. I am indebted to the Scottish Marine Biological Association for the loan of gear and for permission to publish here a brief description of their apparatus. The multi-depth plankton Indicator (Fig. 1) was used in the present work: this is a modified version of the small Hardy Plankton Indicator without diving planes and fitted with a laterally-placed towing eye. The plankton is sampled through an aperture of ½ inch diameter at the front end and is filtered on to a silk disc of 60 meshes to the inch at the rear end. The Indicators were towed at a speed of 8 knots on a ¼ inch diameter wire rope shackled to an Isaacs-Scripps cable depressor of cast bronze, weighing 34 pounds. The wire was fitted with stops on which the Indicators rested during towing (see Fig. 1). During 1954, five Indicators were used simultaneously at depths of 2, 8, 15, 23 and 30 meters, but in 1955 samples were taken at 2, 15 and 30 meters only. At each station the Indicators were towed for 1.4 nautical miles by the ship's log. The grids of stations sampled in 1954 and 1955 are shown in Figs.2 and 19 respectively.

II. STORAGE AND ANALYSIS OF SAMPLES.

As each Indicator came to the ship's side it was unshackled from the towing wire and the silk disc mounted on its brass ring was removed. The discs were then labelled and placed with their plankton in small paper envelopes of the type used by philatelists. These were then stored in a jar, which contained on its bottom a pad of cotton wool, soaked in 4% formaldehyde supersaturated with borax. A similar pad of cotton wool was placed on top of the discs and the jar, closed by an airtight lid. The samples were stored in this way for a month after which they were transferred to corked specimen tubes. When transferred, the silk was torn off the brass rings and the silk discs stored with the plankton in the tubes.

For analysis the samples were transferred from the tubes to a perspex dish, the diameter of the dish, 1¼″, being exactly the same as that of the Indicator disc. The dish was then placed on a mechanical stage of a microscope and the samples analysed by:

(I) ***Subsample.***

Using a magnification of approximately 80 giving a field diameter of 1.90 mm., one traverse was made across the diameter of the dish. Thus the traversed area was $\frac{1}{13}$ of the total area of the dish. Zooplankton organisms seen in this traverse were counted; phytoplankton was noted as present (+), abundant (++) and very abundant (+++). All the organisms occurring were either grouped or indentified as follows:

Dinoflagellates	*Euchaeta norvegica*
(Dominant spp. were noted)	*Paracalanus parvus*
Diatoms	*Pseudacalanus elongatus*
(Dominant spp. were noted)	*Acartia spp.*
Calanus finmarchicus	*Oithona spp.*
Stage VI males and females	Harpacticids
Stage V	Cladocera
Stages I—IV	Gastropoda
Temora longicornis	Nauplii
Metridia lucens	Cyphonautes larvae

(II) ***Overall Search.***

Using the same magnification as above the entire dish was searched and counts were made of *Calanus finmarchicus* stages V and VI and other large copepods (*Euchaeta norvegica* and *Metridia lucens*).

(III) ***Eyecounts of the whole dish were made of:***

Sagittae	Amphipods
Meganyctiphanes norvegica	Young fish
Thysanoessa inermis	

III. COMPOSITION OF THE PLANKTON.

Calanus finmarchicus was of the far greatest importance although *Meganyctiphanes norvegica* ranged high in bulk in some of the samples. All the copepodite stages of *Calanus* were found, but the abundance of each stage varied greatly; stage IV and V being most abundant. Adult males were very rare. The occurrence of stages I, II and III in September suggests that there are at least two generations of Calanus per year. HALLGRÍMSSON (1954 and personal communication) judging by various unpublished data, thinks that there may be 3 generations per year in Icelandic waters. The life history of *Calanus finmarchicus* in Icelandic waters has, however, not been worked out, — the issue being complicated because a varying proportion of the plankton is almost certainly carried into Icelandic waters by currents from other regions.

Although few in numbers, the Euphausiids were found to make up the bulk of some of the samples; a selection of the Euphausiids was identified by Mr. GLOVER in 1954 and by Mr. HALLGRÍMSSON in 1955 and with one exception *(Thysanoessa inermis)* all were found to be *Meganyctiphanes norvegica*.

A fair number of *Temora longicornis* and *Oithona* spp. was encountered. The other species listed occurred only in few samples and were few in number.

In the phytoplankton the Dinoflagellates were dominant. Most abundant were *Ceratium* spp. especially *C. longipes*, *C. fusus*, *C. furca* and *C. arcticum* (checked 1954 by MR. GLOYER, 1955 by MRS. ÞÓRUNN ÞÓRÐARDÓTTIR). *Peridinium* spp. and *Dinophysis* spp. were also frequently present.

Large *Coscinodiscus* spp. were quite common but otherwise few diatoms were present.

IV. METHOD OF PLOTTING.

Fig. 2 shows the division of the fishing grounds covered by the 1954 survey. With the exception of area I and II these were also covered in 1955 (see fig. 19).

Fig. 3 shows the echosoundings represented by perpendicular lines along the ship's course.

Plots of the arithmetic mean of the counts in the Indicator samples at all depths (five in 1954 and three in 1955) were made for *Calanus* stages V and VI and I—IV and *Temora longicornis*. In addition plots were made of *Calanus* stages V and VI and phytoplankton at 8 and 30 meters and of *Oithona* spp. (arithmetic mean) in 1954. Similar distribution diagrams of phytoplankton at 2 and at 15 and 30 meters combined were made in 1955. Plots of total number of Euphausiids per station were made. Corrections were made for the different numbers of samples per station in the two successive years.

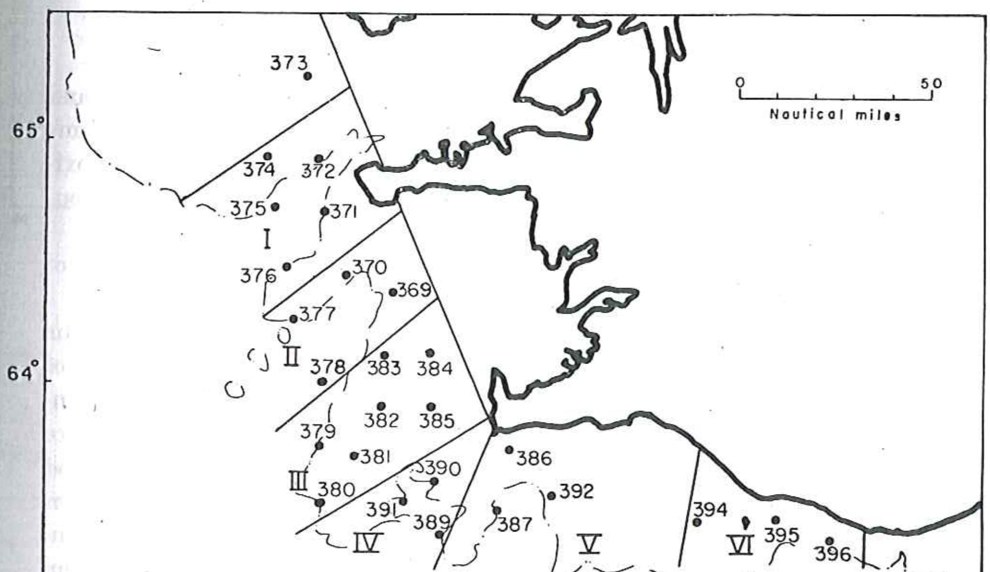


FIG. 2. *Grid of stations sampled in 1954. Positions of stations are shown by dots with serial numbers. Fishing grounds are denoted by roman numerals I—VI.*

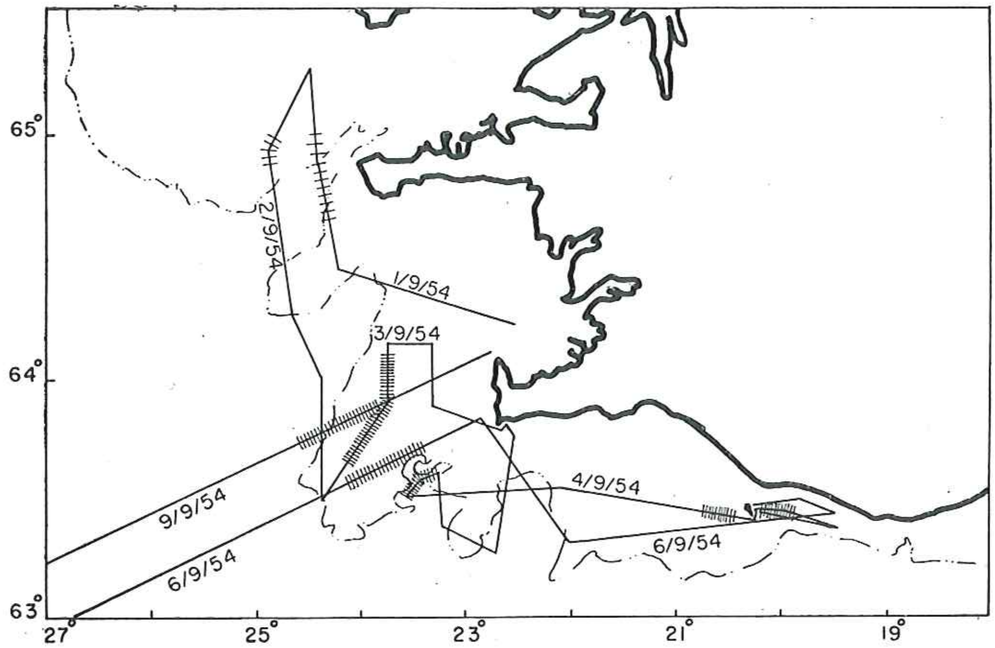


FIG. 3. *Echosounding during the 1954 survey. The density of echosoundings is shown by perpendicular lines along the ship's route. Dense shoals are indicated where the lines are shown close together.*

In the case of the plots for Euphausiids, contours were drawn for 3, 9 and 27 organisms per station (5 samples) but for all other zooplankton organisms contours were drawn for 10, 30 and 90 organisms per sample. Since approximately 0.33 cubic meters of sea water were filtered by each Indicator, contours correspond to 30, 90 and 270 organisms per m^3 of sea water.

In the plots of the phytoplankton, contours were drawn to show areas of present (+), abundant (++) and very abundant (+++).

CUSHING (1953) has discussed the use of contours. He showed that contour limits should be spaced in accordance with the coefficient of variation of the gear used. BARNES (1951) has shown that with the small Indicators sampling at one depth without a depressor, replicate hauls taken in the same place may differ from each other by as much as × 3.

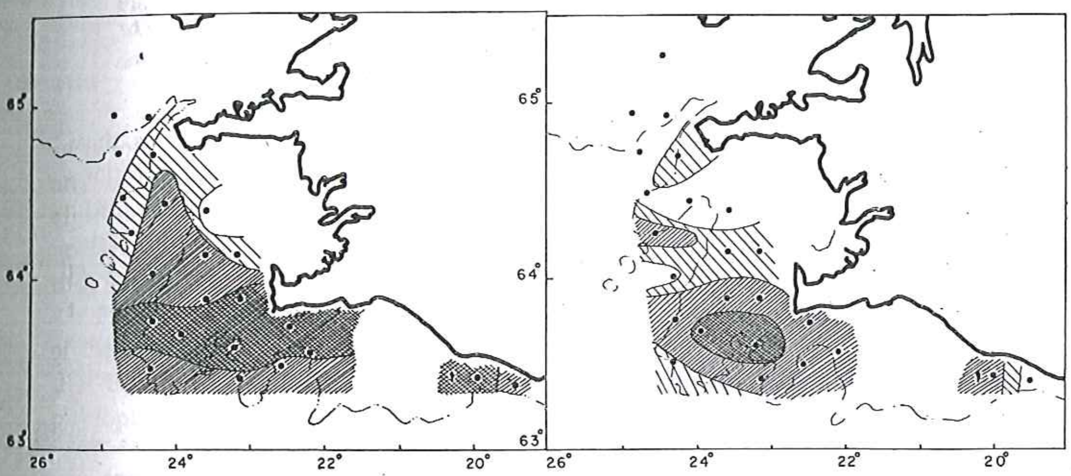
The spacing of contour limits must also depend on the number of observations from which the contours are drawn. Since a fairly large number of samples is used and no contour line should be dependent on a single observation, the levels which have been used here, –10–30–90– (i. e. in the ratio 1:3:9:27 etc.), are expected to be sufficiently separated to give confidence in the contours.

V. RESULTS 1954.

(A) *Horizontal distribution of the plankton.*

Fig. 4 shows the distribution of *Calanus* stages I—IV at all dephts. It is clear that these stages were widely if not evenly distributed over the area; there was a dense patch which extends across areas III, IV and V and perhaps all the way to VI. This is surrounded by a large area with a moderate number of young *Calanus* which extends far north into area II.

Fig. 5 shows the distribution of *Calanus stages* V and VI at all depths. The dense patch of the late stages in area III is much less extensive than that of the young stages. The evidence of this patch is, however, supported by the existence of a large area showing moderate numbers of *Calanus* in the neigh-

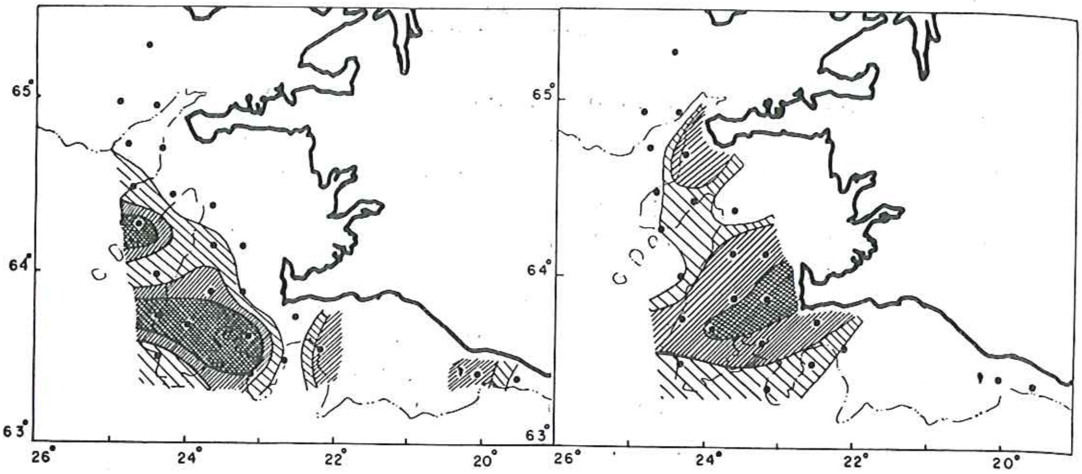


FIGS. 4 AND 5. *Horizontal distribution of Calanus finmarchicus stages I—IV (left) and V and VI (right) during the 1954 survey. Contours are drawn for 10, 30 and 90 animals using the arithmetic mean per samle for the 5 depths: 2, 8, 15, 23, 30 m. at each station. Wide hatching: 10–30 animals per samle, close hatching: 30–90 animals per sample, double hatching: >90 animals per sample.*

bouring stations in areas III, IV and V. There is some evidence of moderate numbers of *Calanus* in area VI where few samples were taken.

Although the densest patches of both juvenile and the late stages of *Calanus* coincided, the extension of moderate numbers of the juveniles (stages I—IV) into area II should be noted.

Figs. 6 and 7 show the distribution of the late stages of *Calanus* at 8 and 30 meters, respectively. Although each shows the characteristic maximum in area III, there were striking differences between the distribution at the two

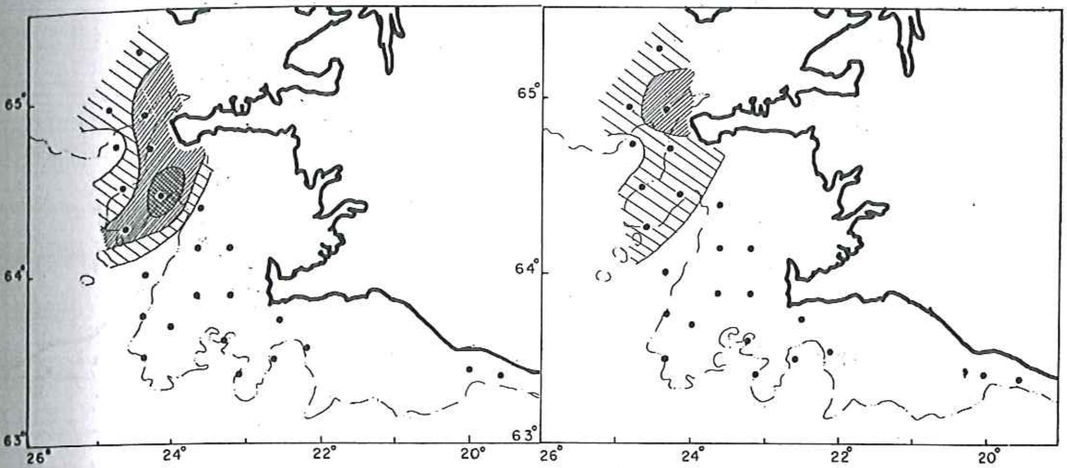


FIGS. 6 AND 7. *Horizontal distribution of Calanus finmarchicus stages V and VI at 8 meters (left) and at 30 meters (right) during the 1954 survey. Contour limits are drawn as in figs. 4 and 5.*

depths. In area III the dense patch was further off shore at 8 meters than at 30 meters. This may be associated with the fact that the offshore stations were taken late at night, i. e. from 2040 (station 379) to 0050 (station 381) whereas the inshore stations were taken after sunrise (0400) from 0507 (station 383) to 0815 (station 385). Even more striking differences are observed in areas I and II. Again the patch was further off shore at 8 meters than at 30 meters. This difference cannot, however, be correlated with diurnal phenomena since all the stations concerned were taken at more or less the same time on two successive days (1510—1832 hrs.).

As shown in figures 8 and 9 the phytoplankton maximum at 8 meters was at station 370 (see fig. 2 for reference). This coincided with the absence of adult *Calanus* at that depth although there were moderate numbers of adults at 30 meters, where there was little phytoplankton. At stations 377 and 371, areas II and I, the phytoplankton is "abundant" at 8 meters at both stations but at one of these stations (377, offshore) *Calanus* is abundant at 8 meters and at the other (371, inshore) it is in moderate numbers at 30 meters and absent at 8 meters.

It appears that at the inshore stations the vertical gradients of the distribution of *Calanus* stages V and VI and of the phytoplankton were inversely related. At the offshore stations this is not so. There the vertical gradients were the same i. e. more of both *Calanus* and of phytoplankton at 8 meters than at 30 meters. It was found, although not shown here, that this holds also for the juvenile stages I—IV at the corresponding stations. There were even relatively greater numbers of stages I—IV than of V and VI at 30 meters at the inshore stations. It is impossible, from this material to ascribe these re-



Figs. 8 and 9. *Horizontal distribution of phytoplankton at 8 meters (left) and at 30 meters (right) during the 1954 survey. Phytoplankton absent: blank, P. present: wide hatching, P. abundant, close hatching, P. very abundant: cross hatching.*

sults to a definite ecological interrelationship. The distribution as such may fit any of the current zoo-phytoplankton interrelationship hypotheses (see e. g. Harvey 1934, Hardy 1936 and Bainbridge 1953) depending on the interpretation of the data. Hydrographical conditions may also have influenced the distribution.

The results of this survey show, however, that the horizontal distribution of *Calanus* was uneven in the area investigated at the time of the survey and that the younger stages extended in moderate numbers further north into the phytoplankton area than did the late stages. There were also striking differen-

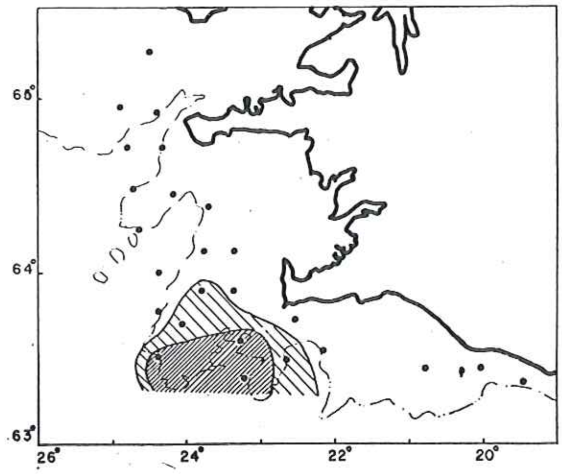


Fig. 10. *Horizontal distribution of Euphausiids during the 1954 survey (mainly M. norvegica). Total of all depths. Contours drawn for 3, 9, 27 etc. animals per station. Blank: 0–3 Euphausiids per station, wide hatching: 3–9 Euphausiids per station, close hatching >9 Euphausiids per station.*

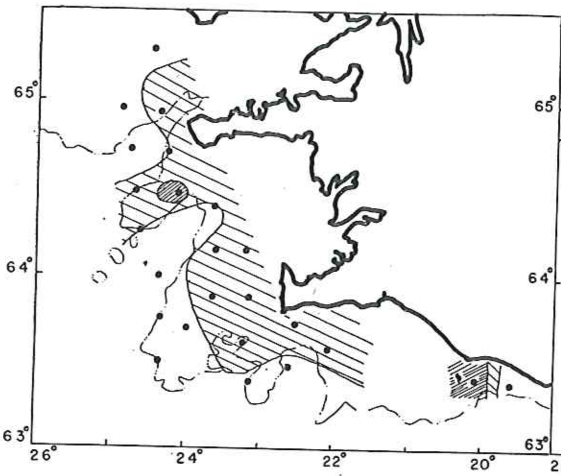


FIG. 11. *Horizontal distribution of Oithona spp. during the survey in 1954. Arithmetic mean of 5 depths. Contour limits as in fig. 4.*

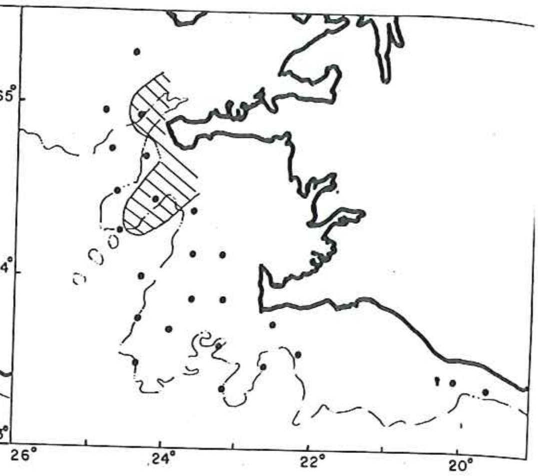


FIG. 12. *Horizontal distribution of Temora longicornis during the survey in 1954. Arithmetic mean of 5 depths. Contour limits as in fig. 4.*

ces in the distribution of *Calanus* at 8 and 30 meters. These differences could sometimes be correlated with diurnal phenomena and sometimes with spatial differences; this will be discussed further in section V.B.

As shown in fig.10 the Euphausiids were limited to a few stations in areas III and IV. There were, however, well defined density gradients which strongely support the existence of a patch of Euphausiids (mainly adult *Meganyctiphanes norvegica*) in the southern part of area III extending into area IV. It will be noted that this dense patch of the Euphausiids almost coincided with that of *Calanus*, stages V and VI (fig. 5).

As shown in fig. 11 *Oithona* spp. were present in practically all the coastal stations although generally few in numbers.

The distribution of *Temora longicornis* is shown in fig. 12. It was nowhere abundant and was mostly limited to the phytoplankton area (areas I and II); elsewhere *Temora* was scarce.

Other groups named in the section III were too few in numbers and were present at too few stations for distribution diagrams to be made.

(B) ***Vertical distribution.***

This survey was in no way designed to investigate vertical migrations of the planktion. Samples were, however, taken simultaneously at 5 depths throughout the survey so that the method as such is bound to give some information regarding vertical distribution. Figures 8 and 9 show that the phytoplankton was present in greater numbers at 8 meters than at 30 meters.

Similarly figures 6 and 7 show difference in the distribution of *C. fin-*

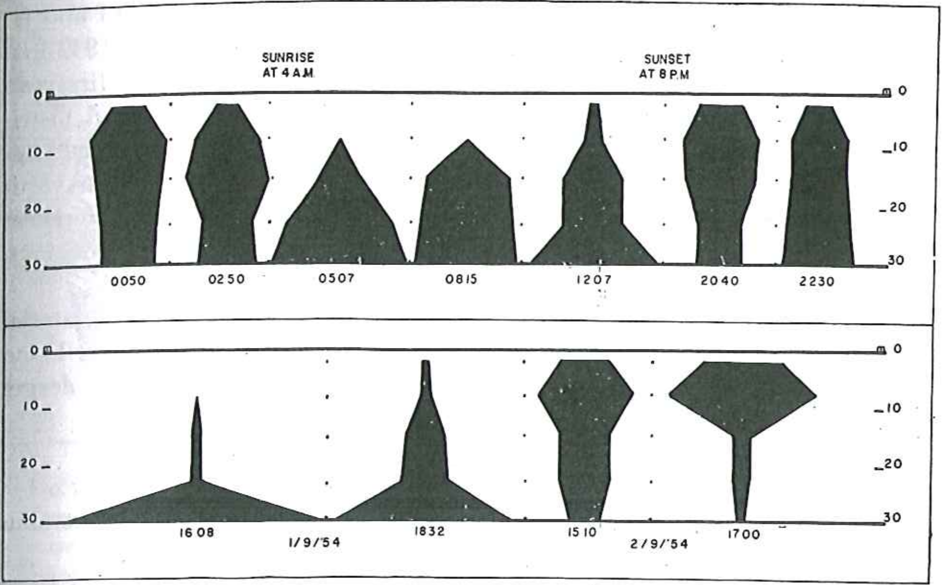


FIG. 13. *Percentage vertical distribution of stages V and VI of Calanus finmarchicus in September 1954, from 2—30 meters depth. Sampling depths (2, 8, 15, 23, 30 meters) are shown by black dots. — Top half: The seven stations are arranged in chronological order as noted below each. All were taken in area III within 24 hrs. Botom half: The four stations are arranged in chronological order. They were taken in areas I and II (stations 370, 371, 376 and 377) on two successive afternoons as denoted in the figure.*

marchicus, stages V and VI of the two depths. Fig. 13 shows the percentage vertical distribution i. e. regardless of fluctuations in total abundance between stations.

All the stations in the upper half of figure 13 were taken in area III and these are arranged in chronological order. Marked diurnal changes are obvious. Just after midnight *C. finmarchicus* was evenly distributed with a slight maximum at 8 meters. An hour before sunrise this maximum had shifted to 15 meters and an hour after sunrise (at 0507) it was at 30 meters with none at 8 and 2 meters. At noon the maximum was still at 30 meters and only a few *Calanus* were found at 2 and 8 meters. Forty minutes after sunset (2040) the even distribution was regained. The existence of an even distribution during darkness was further confirmed by the last station, taken 1½ hour before midnight. It should be pointed out, however, that the day stations were taken at the inshore end of area III and the night stations were taken further off shore. The existence of a geographical difference in vertical distribution is not therefore excluded. In other areas there were either too few *Calanus* or the stations were not evenly distributed throughout the 24 hours.

In the lower half of figure 13, the vertical distribution of *Calanus*, stages

V and VI, is shown at 4 stations which were close together in areas I and II. The 4 stations were taken on two successive days between 1510 and 1832 hrs. so there can be no question of diurnal differences. The first two stations which were taken in inshore waters show a similar vertical distribution with a marked maximum at 30 meters. The third and the fourth stations were taken in more off-shore waters. Both stations showed similar vertical distributions but this time the maximum was at 8 meters. No differences in weather conditiones were observed, the sky being overcast on both days. All four stations are in a phytoplankton area.

Although there appeared to be a diurnal vertical cycle in the material taken from area III (above) it is possible, as the material from areas I and II shows, that there was a real geographical difference, *Calanus* being deeper nearer the shore than it was at the off-shore stations.

(C) ***The "Hensen net" samples.***

Plankton samples were taken with a Hensen net at 25 of the 26 stations sampled by the multidepth high speed Indicators in 1954.

When sampling with the Hensen net, the ship was stopped, the net lowered to a depth of 50 meters and then hauled vertically. The plankton was immediately transferred to a measuring cylinder with a known amount of sea water and its displacement volume read. This method has been used for quick estimation of plankton quantity on Icelandic research vessels since 1948 when the Hensen net was chosen in preference to the standard Indicator as the main plankton collector. By 1954 a terminology suited for the north coast area during the early summer had been evolved: More than *20 ml.* was termed *"much plankton", 10—20 ml. "appreciable amount" and 0—10 ml. "little plankton"*. Sometimes, however, this last category was divided into *0—1 ml.* or *"no plankton" and 1—10 ml.* or *"little plankton"*. None of the samples taken during the survey 1954 contained more than 20 ml.; one contained 13,5 ml. (station 390 in area IV) ,twelve contained 1—10 ml. and twelve 0—1 ml. Thus using the standard classification for Hensen net samples the whole area of the survey would appear to be more or less devoid of plankton. A new set of contours was therefore used with limits at displacement volumes of *0—1; 1.5—4.5; 5.0—14.5 and 15—24.5 ml.* (fig. 15).

The overall distribution of the plankton as shown by the Hensen net samples resembled that found by the Indicators. The patch of *Calanus* which coincided with the herring shoals in areas III and IV can be seen by both methods (figs. 4, 5, 14 and 15). One big difference in the overall plankton distribution is that the Indicator samples showed abundant *Calanus* in area VI where the echosounder and the asdic also indicated heavy concentrations of herring. The Hensen net failed, however, to reveal the presence of plankton in this area.

A rough qualitative inspection of the Hensen net samples showed that the bulk of the samples (like the Indicator samples from 1954) was made up of

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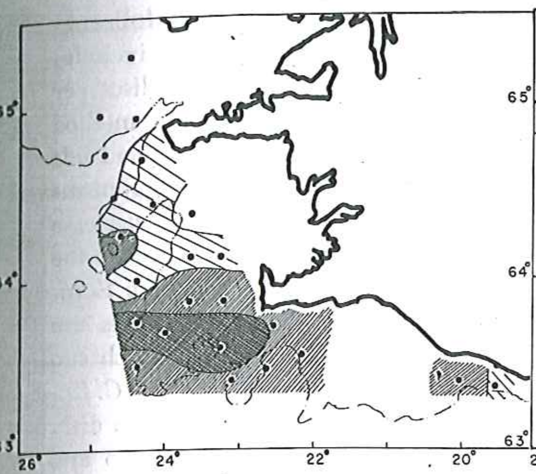


FIG. 14. *Horizontal distribution af Calanus finmarchicus during the 1954 survey; all stages and all five depths. Contours are based on the total numbers counted in five subsamples each being an estimate of 1/13 of the numbers present in one Indicator sample. Blank: 0–10 Calanus counted in five subsamples; close hatching: 30–90 Calanus counted in five subsamples; cross hatching: >90 Calanus counted in five subsamples.*

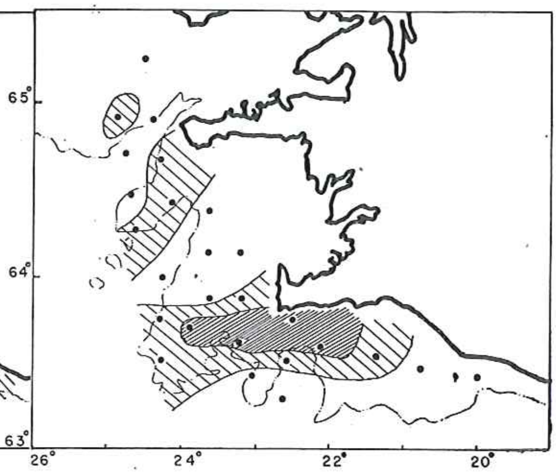


FIG. 15. *Horizontal distribution of plankton during the 1954 survey as shown by the displacement volumes of Hensen net-hauls from 50—0 meters depth. Calanus finmarchicus formed the bulk of the material. Contours are drawn to show: Blank: 0–1.0 ml. displacement volume; wide hatching: 1.5–4.5 ml. displacement volume; close hatching: 5.0–14.5 ml. displacement volume; cross hatching: 15–24.5 ml. displacement volume.*

Calanus. There is, however, one very striking difference in the composition of the two sets of samples. Of the paired samples taken at the 25 stations, only one Hensen net sample contains Euphausiids (station 381 where two *M. norvegica* were found). On the other hand Euphausiids are present in the Indicator samples at 7 of the 25 stations. Moreover, the distribution of these stations and the number present at each is such that a clearly and well defined Euphausiid patch is shown by the Indicator samples. The importance of this difference may be of the greatest concequences since the Euphausiids sometimes form the bulk of the herring food in this area and may therefore be very important in the ecology of the herring.

On the basis of this comparison it will be seen that (a) there is a better correlation between distribution of herring and that of *C. finmarchicus* shown by Indicator than by Hensen net samples, and (b) the Indicator samples revealed a very close correlation between the greatest concentrations of herring and the Euphausiid patch whereas the Hensen net samples completely failed to show any Euphausiid patch.

It must be stressed that whereas the Hensen net samples are easily measured at sea and their rough qualitative composition ascertained, the full analyses of the Indicator samples, as carried out in the present work, includes the counting of all adult *C. finmarchicus* present per disc with five discs per station. This is a laborious and slow process at sea. A reasonably quick method of analysing the Indicator samples would be to count (a) the Euphausiids and other equally large organisms by eye and (b) the other major organisms present (e.g. *Calanus*) in one traverse of the dish and consider the traverse as a quantitatively valid subsample. This method is in fact employed at the Oceanographic Laboratory of the Scottish Marine Biological Association Edinburgh (GLOVER 1957). The only difference is that the Scots sometimes use eye counts of *Calanus* and other equally large copepods; a method which can only be applied by highly skilled workers. Figure 14 shows the total *C. finmarchicus* (all stages) at all depths as found by a single traverse of each dish. The results show a very close correlation with those of figures 4 and 5 and do not differ significantly in any place. The contours are drawn at 10, 30 and 90 animals per subsample per 5 discs instead of animals, per sample per disc. The same conclusions would be drawn, namely, that patches of *Calanus* existed in those areas where echotraces revealed herrings. There is thus every reason to believe that the subsamples are quantitatively valid and it should be possible to do this type of analyses of the Indicator samples, reasonably rapidly.

The relationship between Hensen net and Indicator samples is represented graphically by a scatter diagram (fig. 16). Only stations in phytoplankton-free areas are included in this diagram. For each of these stations, the volume of the Hensen haul (abscissa) was plotted against the number of *Calanus* (all stages) found in the subsamples of the Indicator catches. The regression line was then calculated and is shown in fig. 16. The scale in figure 16 is arbitrary and therefore the slope of the regression line in no way reflects the absolute catching power of these two instruments. This could only be done accurately if the Hensen samples were analysed in detail. It is, however, the relative correlation of the catches of these two instruments which is important. In order to estimate this, the coefficient of correlation was calculated; this gave $r = 0.633$. The probability of obtaining this value from uncorrelated data is less than one in a hundred and the correlation shown by the scatter diagram may therefore be considered significant. Nevertheless there is a wide scatter of dots and the correlation is to a considerable degree dependent on a single station which gave the greatest displacement volume in the Hensen net material and the highest number of *Calanus* in the Indicators. It would be unwise, therefore, to place too much emphasis on this single survey: more paired sampling is clearly required to establish the relationships between the two methods.

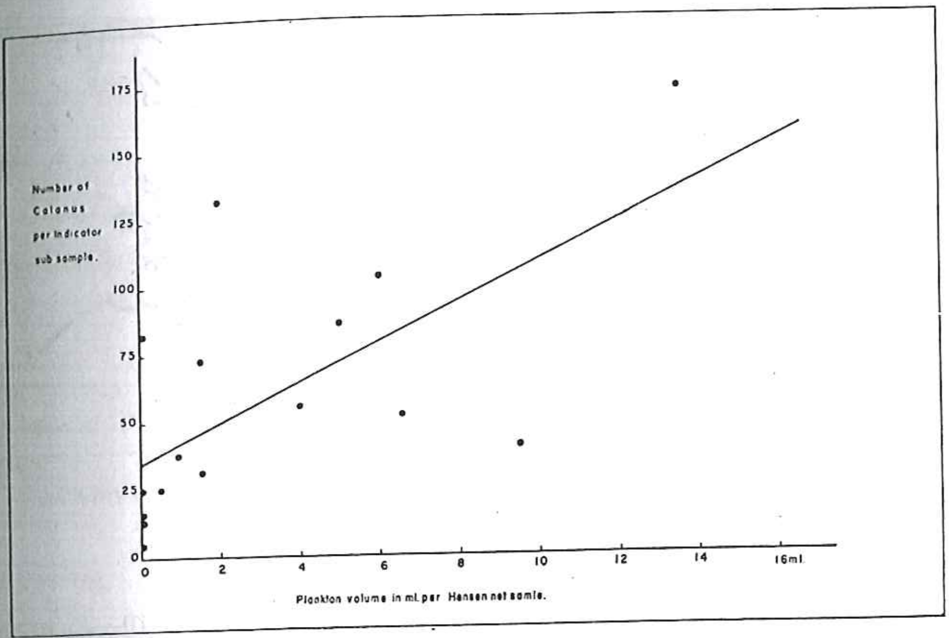
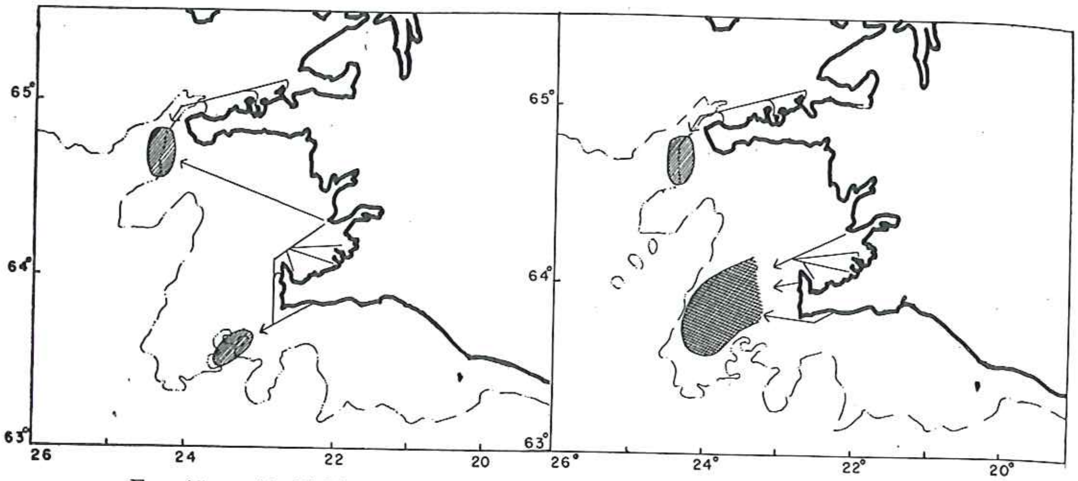


FIG. 16. *Scatter diagram to show the regression of Indicator catches of Calanus on Hensen net displacement volumes. The diagonal line is the calculated regression line (see text).*

(D) ***Distribution of Herring.***

As already stated in the Introduction, the primary purpose of the survey was to estimate the distribution of herring with the aid of the echosounders and asdic "whale finder". Our findings were intimated to the fishing fleet 3 times a day.

The distribution of herring as shown by the echosounders during the 1954 survey is represented in fig. 3. The main concentrations were found in areas III and IV although a small but very dense patch was found in area VI. Herrings were also recorded in area I. Strictly speaking, the echosounders only detect fish shoals but by circumstantial evidence it is most probable that these were in fact herring shoals. Unfortunately, no exact information of catches and fishing localities was available but every morning the commercial craft intimated their approximate catches over their radio transmitters. These were noted and figs. 17 and 18 are based on information obtained in this way. Fig. 17 shows that before 3rd of September 1954 the fleet had not discovered the main herring concentrations in area III. On the morning of the 3rd September the fleet was told of our findings as usual. Our broadcast started by describing the Ægir's route during the previous 12 hours and then went on (in translation): "... few herring echos have been observed except in the area between the places 17 nautical miles W of Geirfuglasker and 23 nautical miles



FIGS. 17 AND 18. *Fishing areas before (left) and after (right) 3rd September 1954. Close hatched: average catch, per drifter per shot of 60 nets, 100 crans. Cross hatched: average catch, per drifter per shot of 60 nets, 200 crans.*

W off Garðskagi, where quite good soundings were recorded at 10—25 meters . . . ".[1])

The following night only 10 boats out of some 50 fishing in area IV went to area III. All these 10 boats got excellent catches of more than 200 crans each as opposed to about 100 crans which was the average catch per shot in areas I and IV.

During the week preceding 4th September 1954 the total landings were 1,903,601 kgs or approximately 19 thousand barrels. During the following week the total catch was almost twice as much, 3,712,495 kgs or approximately 37 thousand barrels. This increase of 18,000 barrels was mainly due to high catches in area III. For yet another two weeks (till 25th September) this area yielded excellent catches giving total landings of 45,000 and 40,000 barrels respectively. After the 25th the catches were much smaller giving total landings of 634,635 kgs or only 6346 barrels; the number of boats being approximately the same throughout the period.

From this it is clear that the information given by the research vessel assisted the fishing fleet and the success of the fleet provides an additional confirmation of the assumption that the shoals detected by echosounder in area III were herring.

1) That is, in area III.

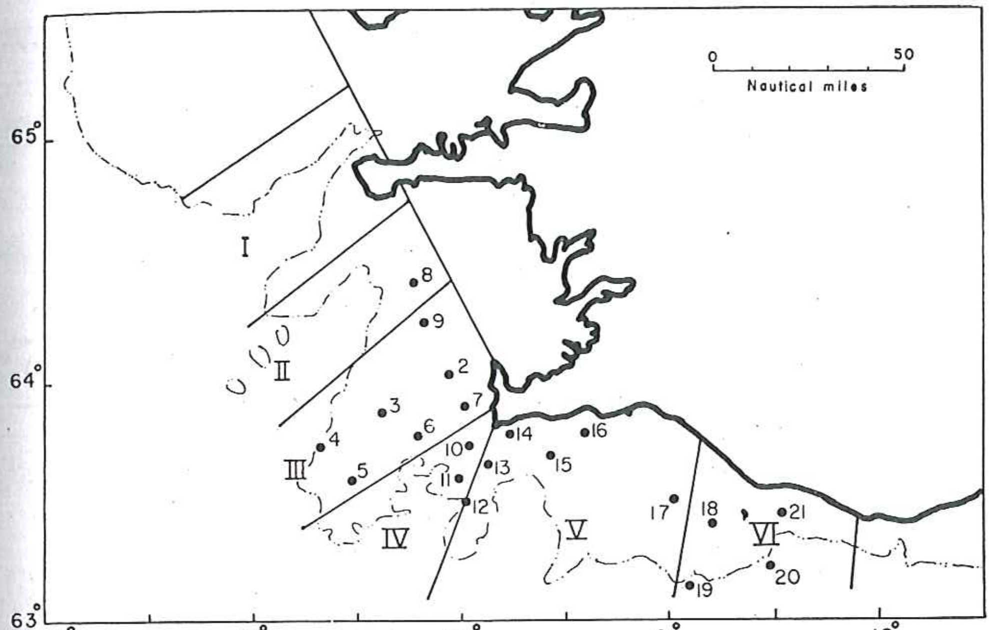


FIG. 19. *Grid of stations sampled in 1955. The division of the fishing grounds is shown by roman numerals.*

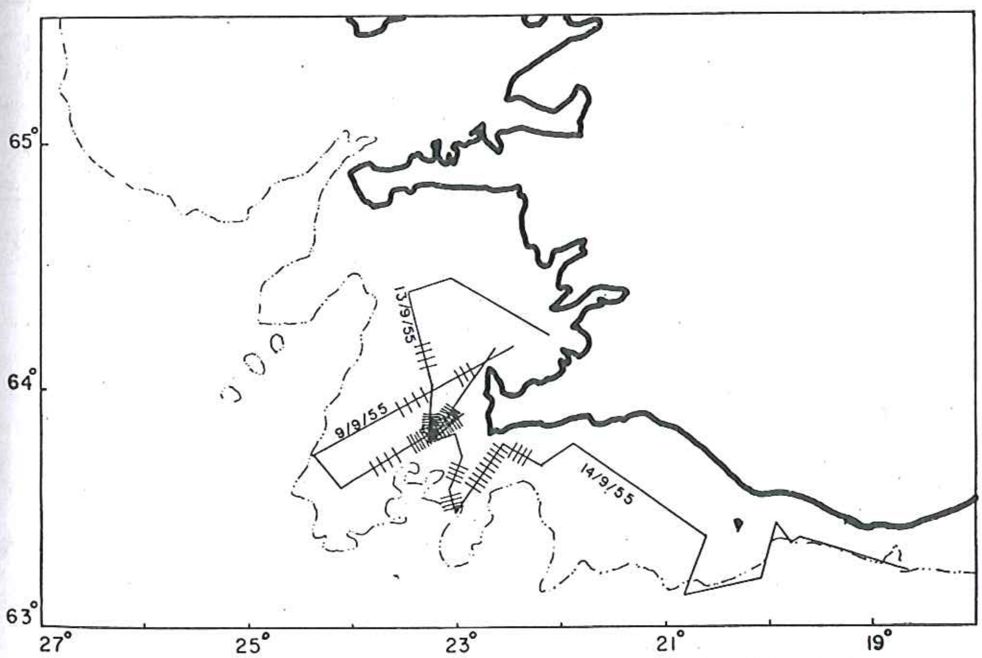


FIG. 20. *Echosoundings during the 1955 survey. See legend for fig. 3.*

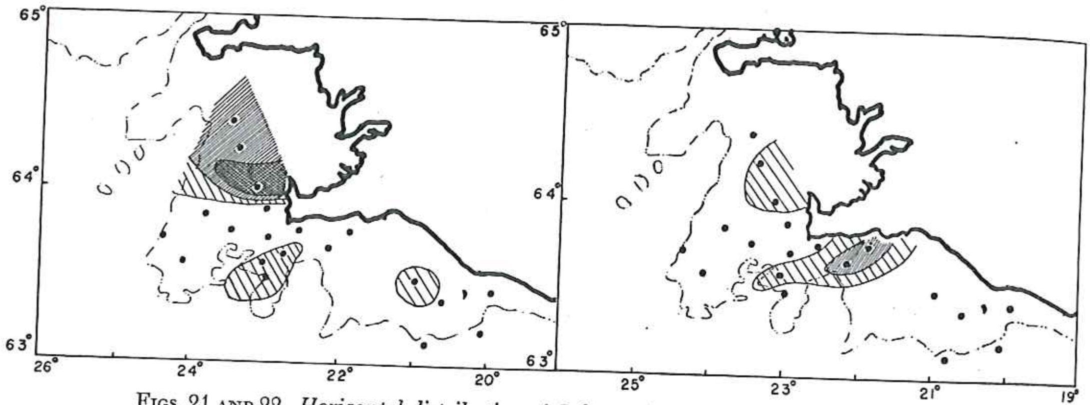
VI. RESULTS 1955.

(A) *Horizontal distribution of the plankton.*

Figure 21 shows the distribution of the younger stages of *Calanus* taken in the Indicator samples in 1955 when *Calanus* were much fewer in number than in the previous year.

In particular this applies to the southern part of area III. There is a dense patch of the younger stages in the northern part of area III and another in area IV and V where the juveniles are, however, very few in number.

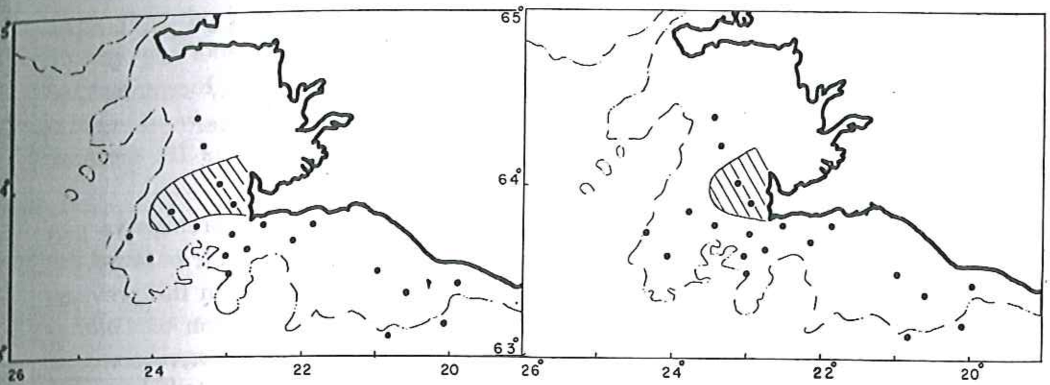
Figure 22 shows that there are also two patches of the late stages of *Calanus*. The patch of the late stages in area III is smaller and not as dense as the juvenile one. In areas IV and V the adult patch is on the other hand denser and more extensive than that of the younger stages. Thus, although the distirbution of both the adults and the juveniles was limited to more or less the same two patches, their relative abundance in each was inversely related. The patch in area III consisted mainly of the younger stages whereas the patch in area V consisted of adults with only a few juveniles.



FIGS. 21 AND 22. *Horizontal distribution of Calanus finmarchicus stages I–IV (left) and V and VI (right) during the 1955 survey. Contours, at the same intervals as in fig. 4, were drawn for the arithmetic mean at three depths (2, 15, 30 meters).*

Since no sampling took place at 8 meters it is somewhat difficult to compare the horizontal distribution of *Calanus* at different depths.

The phytoplankton was noted as present at only 3 stations at 2 m and at two stations at 15 and 30 meters as shown in figs. 23 and 24 resp. It will be noted that this phytoplankton patch near the northeastern limit of area III and extends well into the dense juvenile *Calanus* patch whereas the main adult concentration was in the phytoplankton-free areas IV and V. It should, however, be noted that the adult *Calanus* were also present although few in numbers in the phytoplankton patch in area III (fig. 21, 22 and 23).



FIGS. 23 AND 24. *Horizontal distribution of phytoplankton 1955 at 2 meters (left) and at 15 and 30 metres combined (right). Hatching as in fig. 8 and 9.*

Again, it is impossible from this material to ascribe these results to a definite ecological interrelationship but the evidence from both years suggests that there were relatively higher numbers of the younger *Calanus* stages in the phytoplankton area although adults were also present in small numbers.

Figure 25 shows the distribution of Euphausiids which were found at a few stations in areas III and IV. The maximum density lay in area III, in between the two *Calanus* patches. Although the Euphausiid maximum thus fell slightly southwest of both the phytoplankton and the "juvenile" *Calanus* patches, there was considerable overlapping. In fact Euphausiids were present at two of the three phytoplankton stations.

Fig. 26 shows the distribution of *Temora longicornis*. As in 1954 the plotted distribution of this species was limited to the phytoplankton areas.

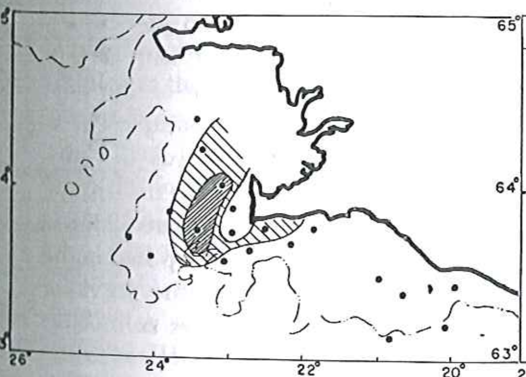


FIG. 25. *Horizontal distribution of Euphausiids during the 1955 survey. Hatching as* in fig. 10.

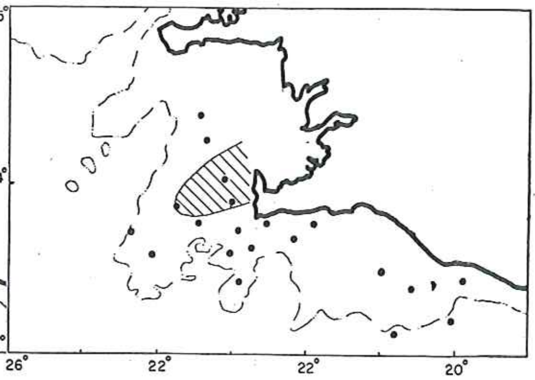


FIG. 26. *Horizontal distribution of Temora longicornis during the 1955 survey. Arithmetic mean of 3 depths. Hatching as in fig. 4.*

Although noted present elsewhere the numbers were less than 10 per sample per station.

Other organisms named in section III occurred at too few stations and were too few in numbers for distribution diagrams to be made.

(B) ***Vertical distribution.***

The method of sampling in 1955 does not give such a comprehensive picture of the vertical distribution of the plankton as that of 1954, because the sampling took place at only 3 depths, compared with 5 depths in the previous year. Fig. 27 shows, however, the percentage vertical distribution of *Calanus* stages V and VI at the only series of stations (9—16) which were conveni-

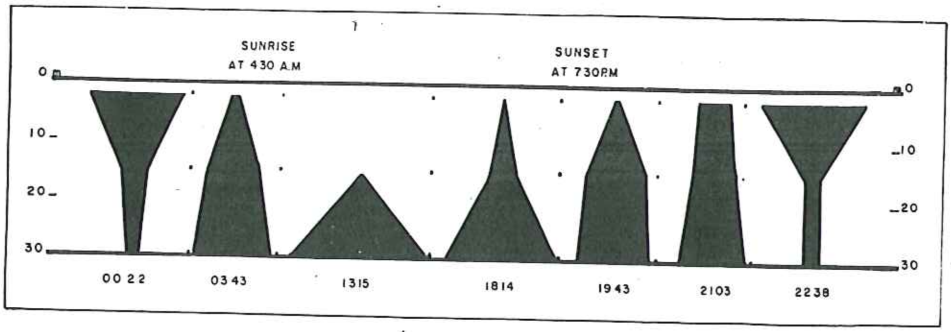


FIG. 27. *Percentage vertical distribution of Calanus finmarchicus stages V and VI during the 1955 survey. The seven stations were taken in areas III and IV within an interval of 24 hrs. The time is noted below each stations and the sampling depths at 2, 15 and 30 meters are shown by black dots.*

ently spaced throughout the 24 hours and where *Calanus* was sufficiently abundant. Diurnal migrations are quite clear. After midnight the maximum concentration (65%) was at 2 meters, at the next station, at 0343 just before sunrise, the maximum had shifted from 2 meters to 30 meters with a fair number still at 15 meters and a few at 2 meters. In the middle of the day (1315) there was a complete absence of adult *Calanus* in the samples at 2 and 15 meters but by 1814 hours they had started to move towards the surface. The distribution was fairly even throughout the evening but a maximum at 2 m was found again about an hour and a half before midnight (2238). Thus the differences in the *Calanus* distribution at different depths might be explained in terms of diurnal phenomena. On the other hand the previous year's results show that sometimes a difference *can* and sometimes *cannot* be related to diurnal phenomena.

(D) ***Distribution of Herring.***

Unfortunately no information is available about the localities of the commercial catches. Statistics on the total catch per harbour per week show, however, that the landings were of the same order as in the year before. Judging by previous experience it seems to be fairly safe to locate the main concentrations of herring by plotting the echosoundings along the ship course. This is shown in fig. 20. It will be seen that the main soundings were limited to areas III and IV and the extreme NW corner of area V.

VII. DISCUSSION.

From a comparison of figs. 3, 17 and 18 it is obvious that in 1954 there was good agreement between the echosoundings and fishing areas. It should be noted that there were no boats in area VI where echosoundings indicated very dense concentrations of herring.

CUSHING (1952) attempted a quantitative analysis of echosoundings when surveying of the NE-coast of England. By examining the recording paper under magnification he estimated the actual number of soundings. No attempt has been made here to estimate the number of soundings but their density was carefully compared and they are thought to be represented by a fair degree of accuracy in fig. 3 and 20.

In 1954 a very dense patch og phytoplankton was detected in area II with quite a dense extention into area I. This coincided with a complete absence of herring on the usual fishing grounds in area II although quite good fishing took place in area I. It thus appears that a very dense concentration of phytoplankton (Dinoflaggelates) may affect the herring distribution although moderate concentrations do not seem to do so directly. Although the main *Calanus* patch was found well away from the phytoplankton area there was considerable overlapping. Comparison of figs. 4, 5, 8 and 9 shows that this overlapping is more pronounced by juveniles. Figs. 21—24 show that this was even more obvious in 1955 than in the previous year. Here there were two *Calanus* patches. In one of these stages V and VI were dominant (area V) while in the other the younger stages were more abundant (area III). The juvenile patch extended well into the only phytoplankton area.

There is thus some suggestion from these data that the younger stages may be found in relatively greater numbers in phytoplankton areas than the adult *Calanus* stages.

Figs. 3, 4 and 5 show that in 1954 there was quite good agreement between the main herring concentrations and the *Calanus* patches, as shown by the Indicator samples. Both have their maxima and most extensive distribution in area III with an extension into area IV. In 1955 this was not quite so, as will be seen by comparison of figs. 20, 21 and 22. Although the two *Calanus* patches (figs. 21 and 22) coincided with herring concentrations the densest herring patch (area III) was recorded in a barren area between the two *Calanus* patches.

Figs. 10 and 25 show the distribution of Euphausiids (mainly adult *M. norvegica*) in 1954 and 1955 resp. In both years there was one well defined patch which lay near the maximum herring concentration. In 1954 the Herring, *Calanus* and the Euphausiid maxima coincided whereas in 1955 only Herring and Euphausiid maxima did so although herring was also found in the *Calanus* patches. The relative importance of the *Calanus* and Euphausiid gradients almost certainly varies greatly from year to year; these organisms are probably the most important food of the herring in Icelandic waters. The evidence suggests therefore that it may be profitable to study further, the distribution of Calanus and Euphausiids in relation to the shoaling habits and distribution of the herrings of the fishing grounds off SW-Iceland in the early autumn. At this point it is perhaps worth while to consider the three main types of shoaling behaviour of the herring in Icelandic waters.

During the late summer and the early autumn (second half of August and in September) the herring of the SW-coast are usually found in moderately large and dense shoals easily detected by echosounders but not detectable by the Asdic Whalefinder. On the other hand, the northcoast herring shoals are very easily detected on the Asdic Whalefinder and to a lesser degree by the echosounder because of the lesser horizontal spread (Jónsson and Stefánsson 1955). By November the shoaling behaviour of the SW-coast herring changes and they appear to aggregate in one or a few enormous shoals which often extend over several square miles each. One large shoal of this kind was e.g. detected in November 1956 area III some 20 miles off Reykjanes. This shoal was found in the same locality for at least a fortnight (15th—30th November). It had very marked vertical diurnal migrations extending from a depth of a few fathoms during darkness to 80—90 fathoms during daylight depending on the depth of the sea. It was estimated (Jakobsson 1956) that this huge shoal extended over some 20—25 square miles. The fact that the commercial drifters could only shoot a few nets at a time and haul them back almost instantly with excellent catches (3—10 crans per net) gives some measure of the density of the shoal. If the nets were shot and left for the more usual 3—6 hours, they sank, taking the floats with them because of the enormous weight of fish.

Considering the agreement that has been shown between the shoals of herring and certain zooplankton organisms in September it seems likely that the distribution of the relatively small herring shoals may be influenced by the density gradients of Euphausiid and of *Calanus*. Judging by various unpublished data as well as older material (Fridriksson 1944, Einarsson 1951) it seems likely that the dense shoals as well as the shoaling behaviour of the north coast herring as a whole, is greatly influenced by the sharp plankton density gradients of these waters.

On the other hand the reason for the formation of the large herring shoals in November and December is not easily understood. Inspection of unpublished data concerning herring samples collected by the staff of the University Research Institute in the late autumn shows that the herring stomachs contain very little food at that time of the year so it seems a fair assumption that the small quantities of plankton which may still exist on the fishing grounds in the winter do not influence the herring distribution to any extent (see also JAKOBSSON 1956, pp. 346–347). Samples from commercial catches consist of variable mixtures of spring and summer spawners (EINARSSON 1951a). Thus the formation of the enormous winter shoals is most likely neither influenced by their food nor by spawning behaviour. The answer may perhaps lie in some subtle reaction to environmental factors.

SUMMARY

(1) Plankton samples using high speed plankton Indicators, were taken at frequent intervals during herring surveys off the SW-coast of Iceland in September 1954 and 1955.

(2) It was found that *Calanus finmarchicus* and *Meganyctiphanes norvegica* were the dominant species. Their relative abundance varied within the surveyed area as well as between the two years.

(3) In both years some overlapping of *Calanus finmarchicus* and dinoflagellate patches was observed and in both years this overlapping was more pronounced for the younger stages. Concentrations of herring were found where there were moderate concentrations of phytaplankton but no herring was found where these concentrations were really dense.

(4) The differences in vertical distribution (figs. 6 and 7) suggest that in these surveys multidepth sampling is preferable to single depth sampling.

(5) The differences of the vertical distribution of *Calanus* were shown to be of two kinds:

- (a) resulting from diurnal migrations.
- (b) differences possibly correlated with the distribution of phytoplankton or other environmental factors.

(6) In 1954, the maximum herring concentrations coincided with both the *Calanus* and the Euphausiid maxima but in 1955 herring only coincided with the Euphausiid maximum and the main concentration of herring was found in between two patches of *Calanus*. Excellent agreement was found between the herring distribution as shown by an echosounding survey and as shown by commercial catches. Increasing density gradients of *Calanus* or Euphausiids usually coincided with herring concentrations. The direction of these gradients seems to be of more importance than the absolute concentration of the plankton organisms.

(7) In 1954, Hensen net samples were taken at 25 Indicator stations.

Brief inspection has shown that the composition of these samples is similar to that of the Indicator samples with one exception: Euphausiids were only present in one of the Hensen net samples as compared with seven Indicator stations. By plotting the Hensen net volumes, a considerable agreement is observed between the distribution of plankton as shown by Hensen net and by Indicators. A brief method of analysis of Indicator samples is suggested and it is illustrated that in this case the results from such an analysis would not differ significantly from those obtained by a thorough and laborious one. A statistical analysis suggests that the apparent relative correlation between Indicator and Hensen samples is linear and significant.

(8) It is suggested that a further study of the *Calanus* and Euphausiid distribution on the Herring grounds off SW-Iceland would help understanding the shoaling habits of the herring in that area.

(9) It is pointed out that there are three main types of herring shoals in Icelandis waters.

ACKNOWLEDGEMENTS.

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