THE MIGRATION OF NORWEGIAN HERRING TO ICELANDIC WATERS AND THE ENVIRONMENTAL CONDITIONS IN MAY–JUNE, 1961–1964

By

OLE J. ØSTVEDT

Fiskeridirektoratets Havforskningsinstitutt

INTRODUCTION

Since 1949 the migrations of herring in the Norwegian Sea have been intensively studied. It has been shown that the time and place of their migration to the spawning grounds along the west coast of Norway are closely related to hydrographical conditions, particularly temperature (DEVOLD 1951). During the feeding migration in summer the hydrographical conditions are also important in determining the distribution and formation of herring shoals (DEVOLD 1963, JAKOBSSON 1963), but several scientists have shown that there is also a connection between plankton conditions and the migration pattern of feeding herring. Reviews of work on the plankton/herring relationship have been given by PAVSHTIKS (1956) and JAKOBSSON (1958, 1962).

The most extensive investigations on the migrations of Norwegian herring in the Norwegian Sea in relation to plankton have been carried out by PAVSHTIKS (1956). She found that after spawning the older age groups were feeding mainly on the wintering stock of *Calanus finmarchicus* in the coastal or Atlantic water, and later in spring in the water of the East Icelandic Current; they thus followed the shift in spawning time of *C. finmarchicus*. The migration routes of the herring were closely related to the seasonal changes in distribution and production of plankton. Annual fluctuations in time of the biological spring may, therefore, cause a change in the feeding migration of the herring.

The Norwegian investigations on herring migration in the Norwegian Sea during May and June have been conducted since 1951 in collaboration with Denmark (until 1961), Iceland and U.S.S.R. (from 1957). During the years 1961–1964 the Norwegian part of the joint work has been confined to the areas from the Faroes along the east and north-east coast of Iceland to Jan Mayen. The observations on herring, temperature and zooplankton during these years provide the material for the present

study which demonstrate the migration of Norwegian herring to the north-east coast of Iceland in relation to environmental factors. A summary of the work has been given annually in the joint reports to the Herring Committee of ICES (JAKOBSSON and ØSTVEDT 1961, ANON 1964a, 1963 and 1964b).

MATERIAL AND METHODS

In 1962, 1963, and 1964 the investigations were carried out along the same sections with stations 20 or 40 miles apart (Figs. 3, 5 and 10) and during approximately the same period (in 1962: 26 May—8 June, 1963: 22 May—5 June, and 1964: 27 May—10 June). Additional observations were made each year until about 20 June. In 1961 the first survey on the east and north-east coast of Iceland was undertaken during the period 7—17 June.

Measurements of temperature and salinity have been made at each station at standard depths down to 500 meters. Surface temperature (at 4 m) was measured by termograph. Zooplankton was collected in vertical hauls from 50—0 m. In 1961 and 1962 a Juday net (diameter 80 cm, silk no. 0) was used, in 1963 and 1964 replaced by a standard Hensen net (diameter 70 cm, silk no. 3). The volume of each sample was measured by the displacement method and stage composition of *C. finmarchicus* determined by counting 100 individuals of the species (short cut method, HALLGRIMSSON 1958). The percentage occurrence of copepodite stages I—III combined, is shown on the figures as 25 percent, 50 percent and 75 percent isolines.

During these investigations herring shoals were located with sonar and echo sounders and drift nets were frequently used for sampling the herring.

RESULTS

1961

The distributions of herring and temperature at 20 m depth in the period 7—17 June are shown in Fig. 1. Herring shoals were recorded 60—70 miles north-east of Langanes on 9 June. During the following week the herring evidently moved north-westward and dense concentrations were recorded north of Melrakkasletta in the second half of June. According to JAKOBSSON and ØSTVEDT (1961) the temperature at 20 m depth on the north-east coast of Iceland was somewhat above average (mean temperature for the period 1950—60 as given by STEPHANSON (1962). In the area where the herring occurred, the temperature at 20

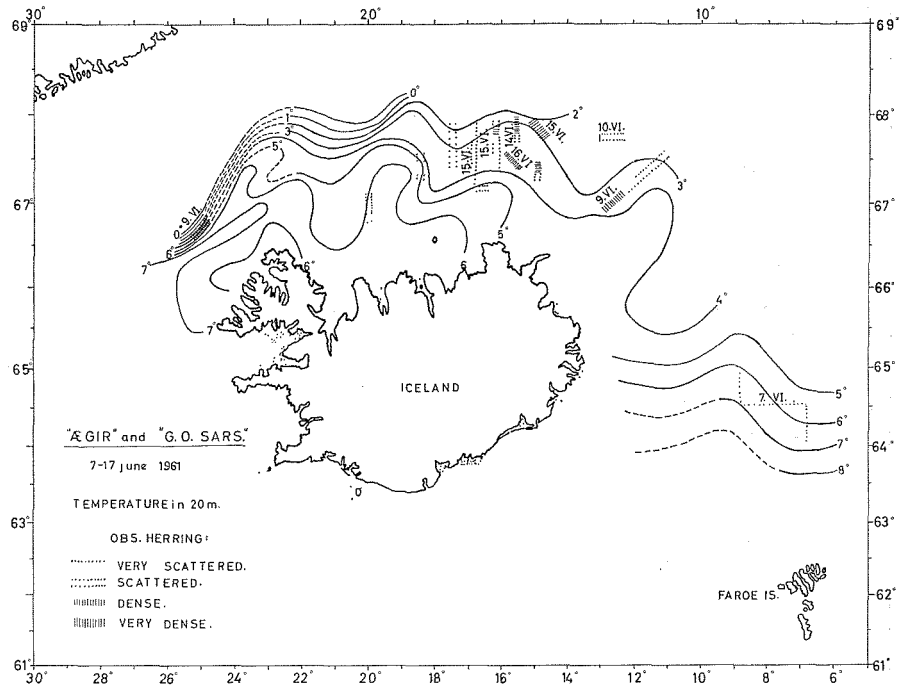

Fig. 1. Herring distribution and temperature at 20 m, 7—17 June 1961 (from JAKOBSSON and ØSTVEDT 1961).

m varied from 2° to 4°C. Off the north coast of Iceland the zooplankton was also more abundant than in previous years, while off the east coast it was about normal. During June the herring shoals were generally encountered in areas with low zooplankton densities and less than 25 percent of *C. finmarchicus* in stages I—III, i.e. in areas where the older stages predominated, presumably the wintering stock (Fig. 2).

According to JAKOBSSON (1962), 24.8 per cent of the Icelandic herring catch in 1961 was taken in the area north of Melrakkasletta during three weeks in June—July. Later in the summer the herring migrated to the traditional fishing grounds on the east coast of Iceland where young copepodites (stages I—III) of *C. finmarchicus* predominated in the beginning of June. In July copepodites had probably metamorphosed to older stages, constituting more suitable food for the herring.

1962

In 1962 the investigation started in the last week of May and dense concentrations of herring were observed on 30 May between 40 and 110 nautical miles north-east of Langanes (Fig. 3). The shoals were mainly

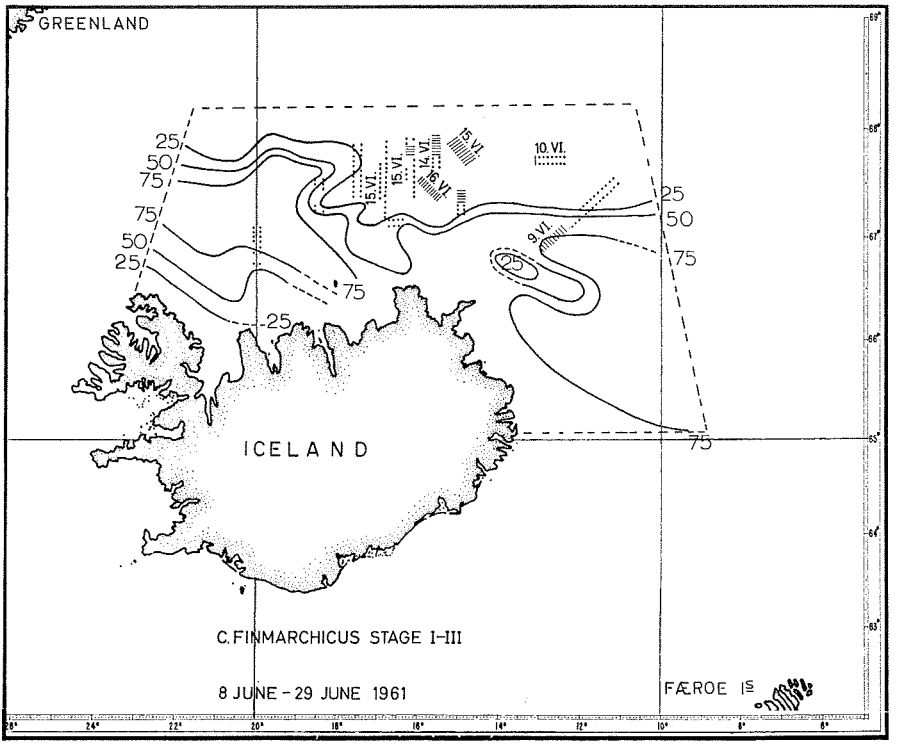

Fig. 2. Herring distribution (legend—see Fig. 1) and percentage distribution of copepodites stages I—III of *C. finmarchicus*, 8—29 June 1961.

found in waters colder than 3°C, extending into watermasses of temperature below 2°C (ANON 1964a). The herring quickly moved in a northwesterly direction and on 5 June dense concentrations were recorded north-east of Kolbeinsey. Samples of herring taken from drift net catches contained mainly Norwegian spring spawners, but it showed that the Icelandic spring spawners were also present and thus had already migrated to the north coast probably from the west, and had mixed with the Norwegian spring spawners migrating from east. During the first half of June 1962 the concentrations of Norwegian spring spawners were found much further west than in 1961.

The quantitative distribution of zooplankton off the north coast is shown in Fig. 4. In the cold waters, scarce in plankton, the wintering stock of *C. finmarchicus* was predominant while in the coastal and mixed waters off the north coast of Iceland *C. finmarchicus* in stages I—IV was abundant and the spawning had probably occurred.

In accordance with the observations in 1961 it was again found that

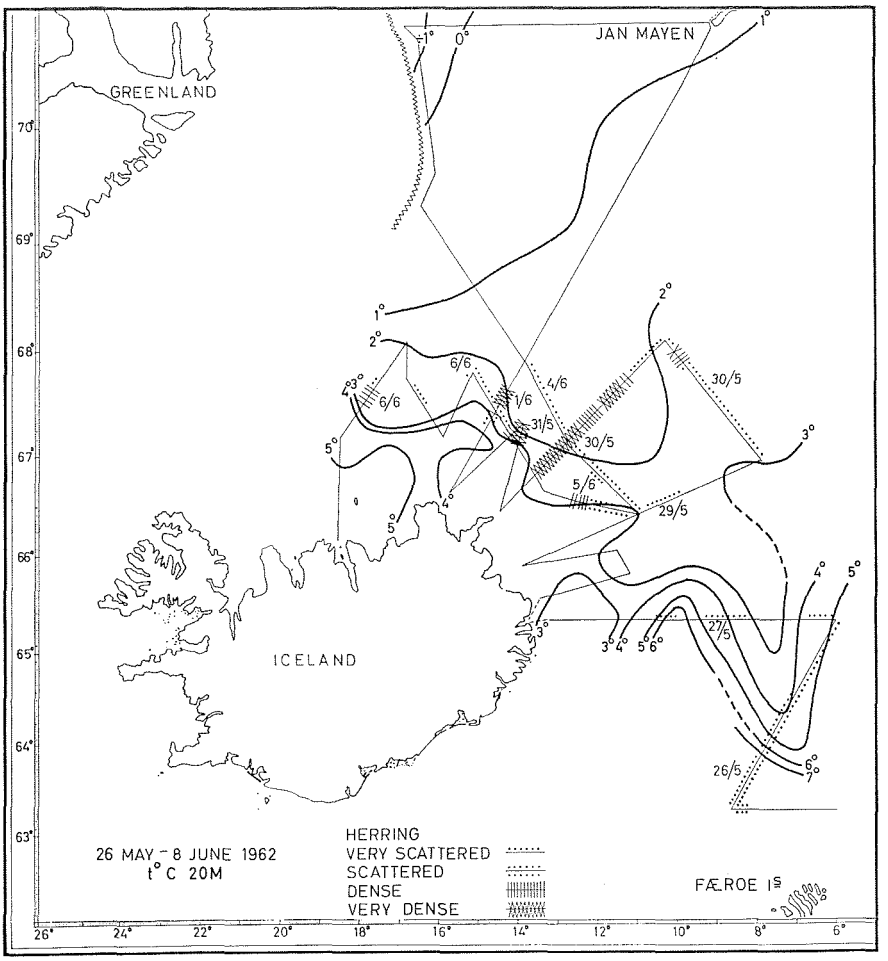

Fig. 3. Herring distribution and temperature at 20 m, 26 May—8 June 1962.

the Norwegian herring during the migration to the north-east coast of Iceland were mainly located in the cold water areas east and north-east of Langanes, where the zooplankton was relatively scarce, but with a high proportion of wintering stages of *C. finmarchicus*.

1963

The distribution of temperature and herring, east and north-east of Iceland in the period 21 May—5 June are shown in Fig. 5. Herring were recorded in two regions; in the southernmost region (between lat. 64°N and 65°N and about long. 6°W) only small shoals were found. Here the herring seem to be present nearly all the year round, mostly scattered

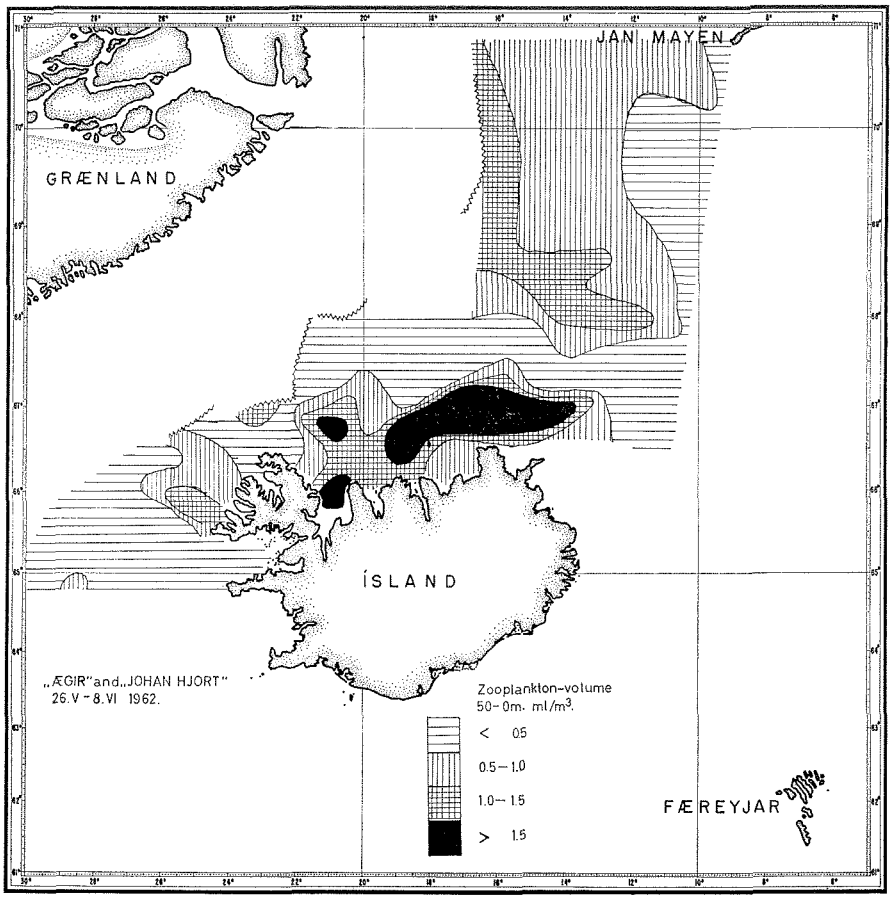

Fig. 4. Zooplankton volume, ml/m³ in 50—0 m, 26 May—8 June 1962 (from ANON 1964a).

over a wide area; further north, dense concentrations were found about 150 nautical miles north-east of Langanes in watermasses colder than 2°C. The vertical distributions of the herring shoals in relation to temperature are shown in Fig. 6. The shoals were found from the surface to 300 m, in water with the temperature ranging from 5° to 0°C. In the 0—200 m layers the temperature was below the average for the last ten years and the 3° isotherm was situated 120 nautical miles further south-eastwards than in 1962 (ANON 1963).

The quantitative distribution of zooplankton in the period 22 May to 5 June is shown in Fig. 7. Off the north-east coast of Iceland the zooplankton was generally scarce as compared with previous years and considerably more scarse than in 1962. The areas abundant in plankton

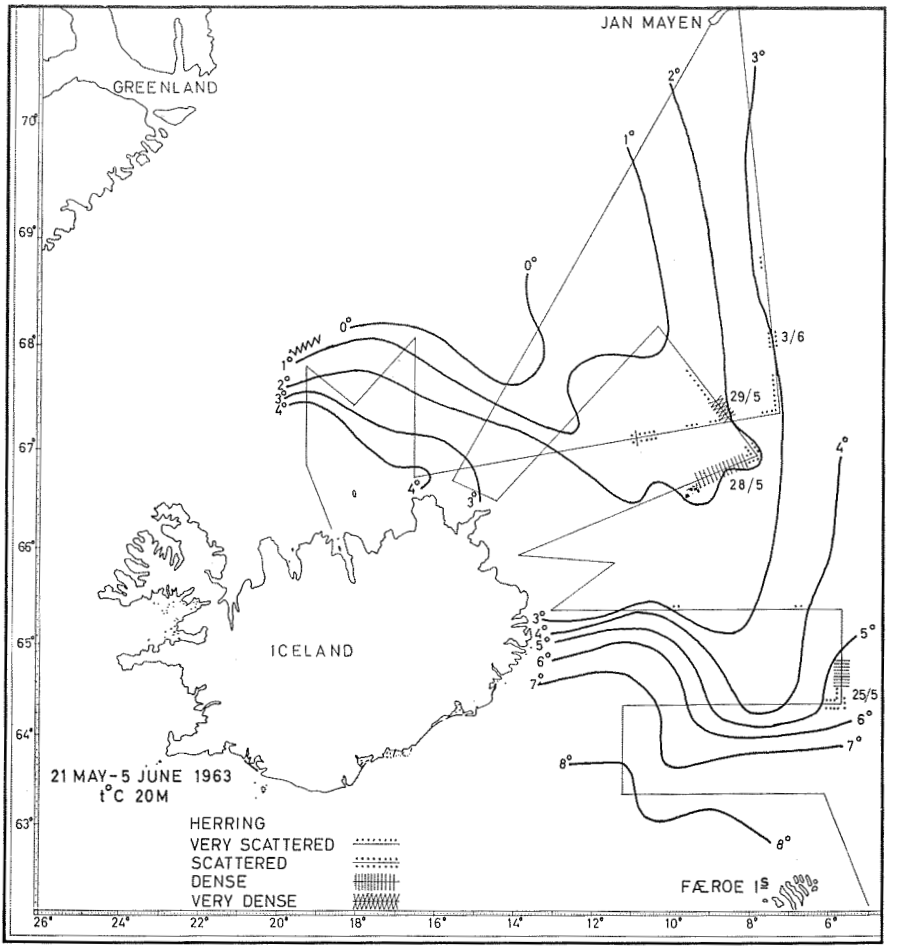

Fig. 5. Herring distribution and temperature at 20 m, 21 May—5 June 1963.

(above 1.5 ml/m³) were also situated much further off the coast than in 1962. In both years *C. finmarchicus* was the most numerous species in the plankton population also along the coast, where the densities were low. In the cold waters (besides *C. finmarchicus*) *C. hyperboreus*, *Pseudocalanus minutus*, *Themisto* spp. and *Sagitta* spp. were numerous. As in previous years the herring were found in watermasses where the older stages of *C. finmarchicus* predominated (Fig. 8).

The herring shoals observed north-east of Langanes at the end of May, seemed to move westwards, penetrating the East Icelandic Current. When the observations were repeated in the period 11—21 June, dense concentrations were found on 19 June in the area north and north-east of

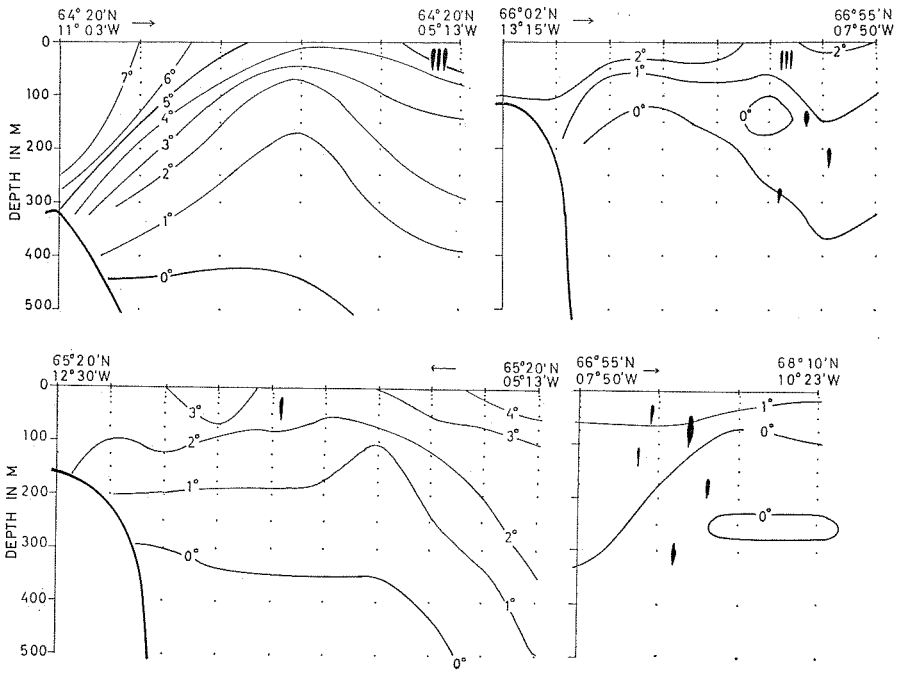

Fig. 6. Temperature sections and herring distribution east and north-east of Langanes 24—29 May 1963.

Langanes between lat. 67°N and 68°N at long. 16°W (Fig. 9). The percentage distribution of *C. finmarchicus*, stages I—III, shown in Fig. 9, indicates that during the migration to the north-east coast the herring followed the transition area between the cold water, containing a stock of wintering *C. finmarchicus* in stages IV—VI, and the mixed coastal water, containing young *C. finmarchicus* (stages I—III). In 1963 the westward migration of the Norwegian herring was delayed at least two weeks, compared with 1962 (ANON 1963).

1964

The investigation started 5 days later than in 1963. On 4—5 June, during the survey of the area east of Langanes, dense concentrations of herring were recorded 60 nautical miles off Langanes (Fig. 10). The herring were mainly observed in waters with a temperature of 2°—3°C, on the western side of the East Icelandic Current, and seemed to be moving rapidly further westwards. On 8 June, dense concentrations were recorded north off Langanes, from lat. 67°30' N to 68°30' N and between

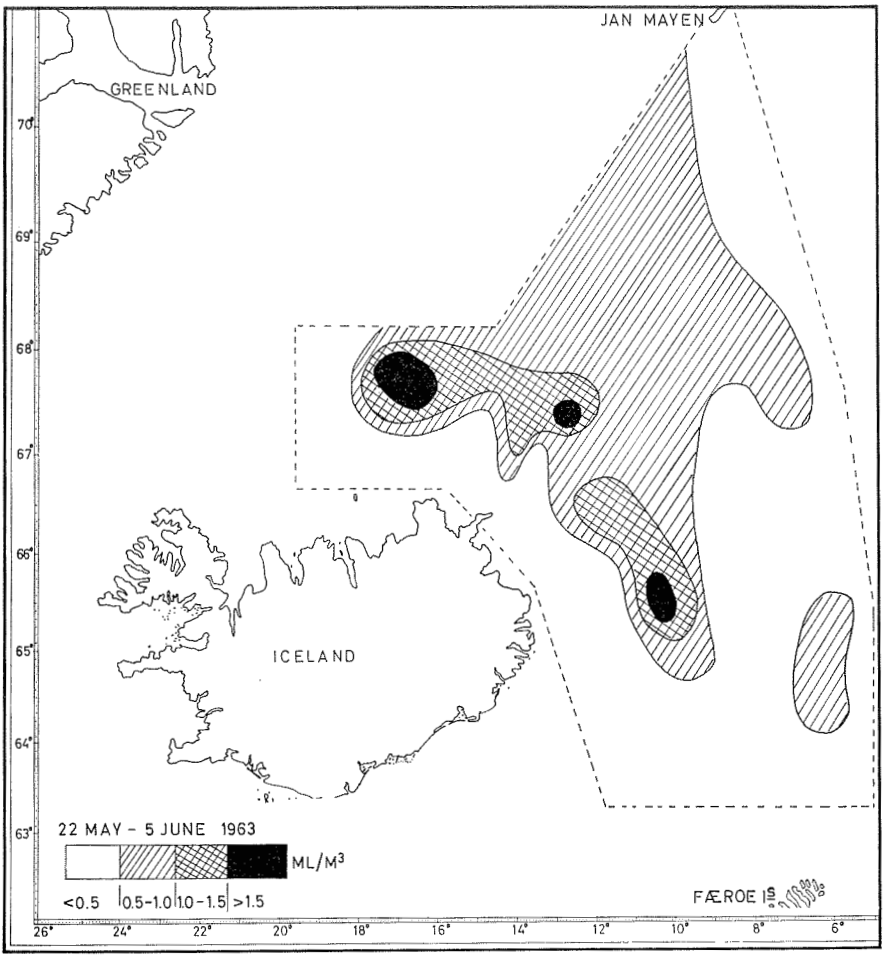

Fig. 7. Zooplankton volume, ml/m³ in 50—0 m, 22 May—5 June 1963.

long. 12°W and 16°W. Drift net samples in this area consisted exclusively of old Norwegian spring spawners with a mean length of 37.5 cm.

The temperature at depths down to 200 m off the north coast of Iceland was generally 1°C above average and 2°C higher than in 1963 (ANON 1964b). In this area the zooplankton was more scarce than in 1963, plankton volumes above 1.5 ml/m³ being recorded at only a few stations (Fig. 11). In all areas with high plankton concentrations, *C. finmarchicus* predominated.

The percentage distribution of *C. finmarchicus* stages I—III, shown in Fig. 12, indicates that only to the north of latitude 66°30' did the stock consist of less than 25 percent young copepodites. South of lat. 66°30' N

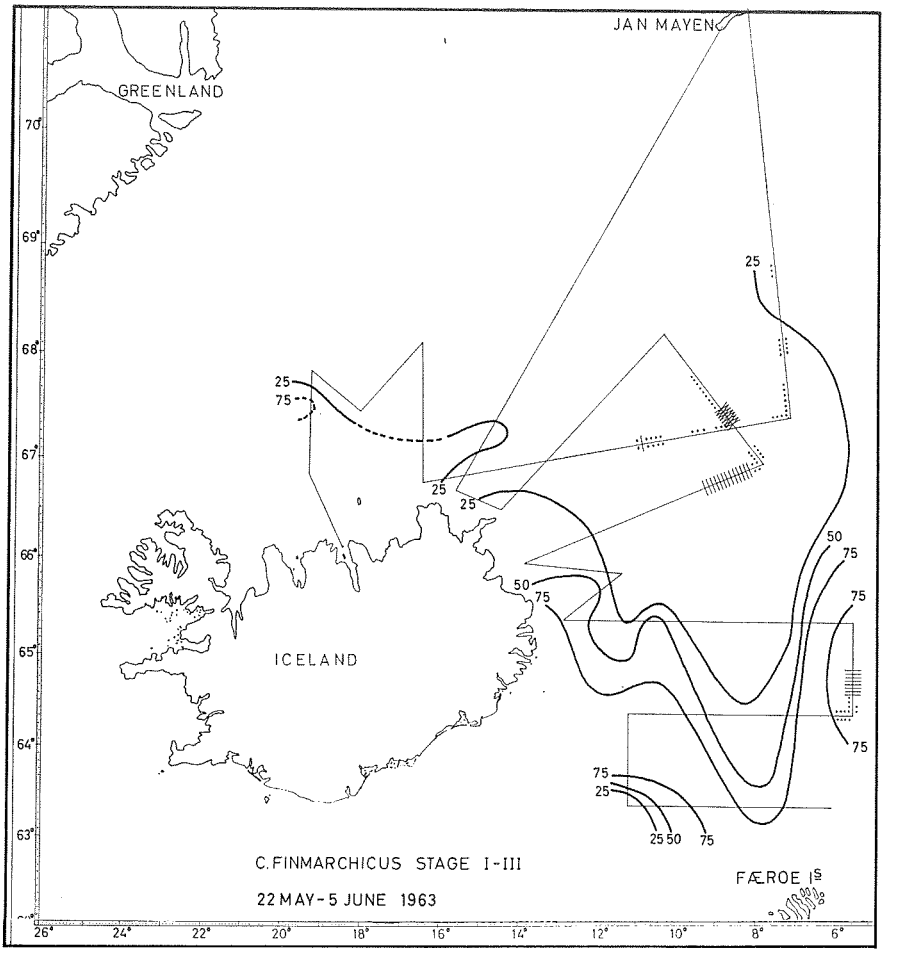

Fig. 8. Herring distribution (legend—see Fig. 5) and percentage distribution of copepodites stages I—III *C. finmarchicus*, 22 May—5 June 1963.

the spawning of *C. finmarchicus* had apparently occurred somewhat earlier than in 1963 when the stages IV—VI predominated over a much wider area. This fact may be ascribed to the higher temperature in 1964 and an early formation of a thermocline in the upper water layers off the east and north-east coast of Iceland, which resulted in an unusual early spring bloom of phytoplankton (ANON 1964b). Further evidence of this was provided by the continous transparency recordings. In 1964 much lower concentration of particles were recorded than in 1963, indicating a different situation in the phytoplankton (BERGE, personal communication). The initiating effect of phytoplankton blooming on the

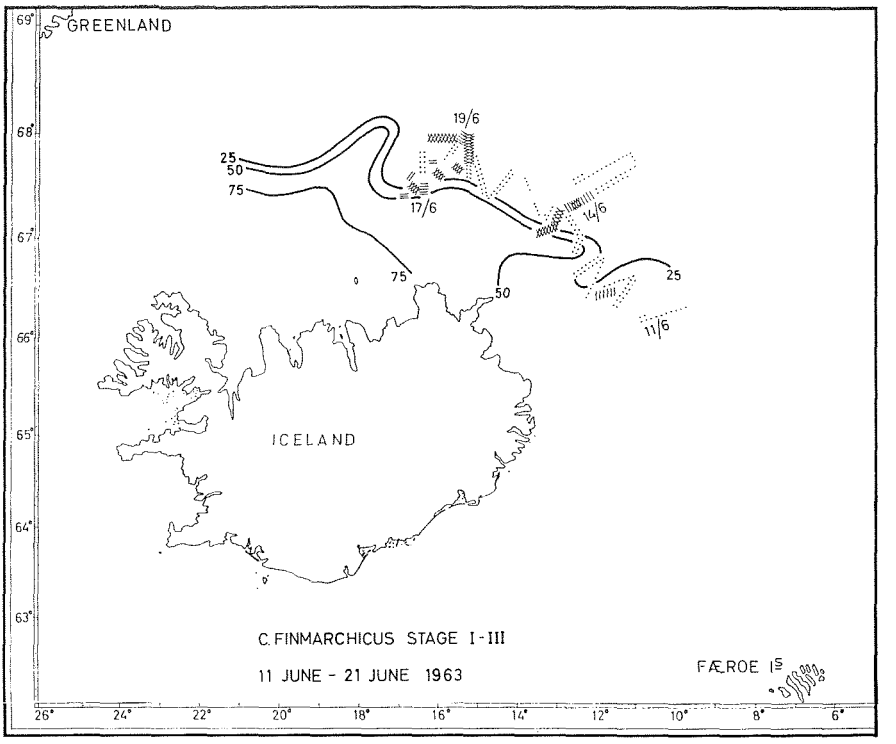

Fig. 9. Herring distribution (legend—see Fig. 5) and percentage distribution of cope podites stages I—III of *C. finmarchicus*, 11—21 June 1963.

spawning of *C. finmarchicus* has been shown by several workers (SVERDRUP 1953, MARSHALL and ORR 1959).

In the period 11 to 20 June the temperature increased rapidly along the north-east coast and this was followed by an extension of the spawning area of *C. finmarchicus* (Fig. 13). The herring observed north of Langanes on 8 June either moved further northwards or dispersed (ANON 1964b), but during the first half of June a purse-seine fishery, by both Icelandic and Norwegian vessels took place further from the north coast of Iceland than in any previous years. On 10 June dense concentrations of herring were recorded close to the east coast of Iceland. In contrast to the herring sampled off the north coast younger individuals were also present, constituting from 5—35 per cent of the samples from drift net catches. No observations of these herring shoals were reported until they were found off the east coast. It should be noted that the invasion into the coastal waters took place when young copeodites (stages I—III) of *Calanus* were still predominant in this area.

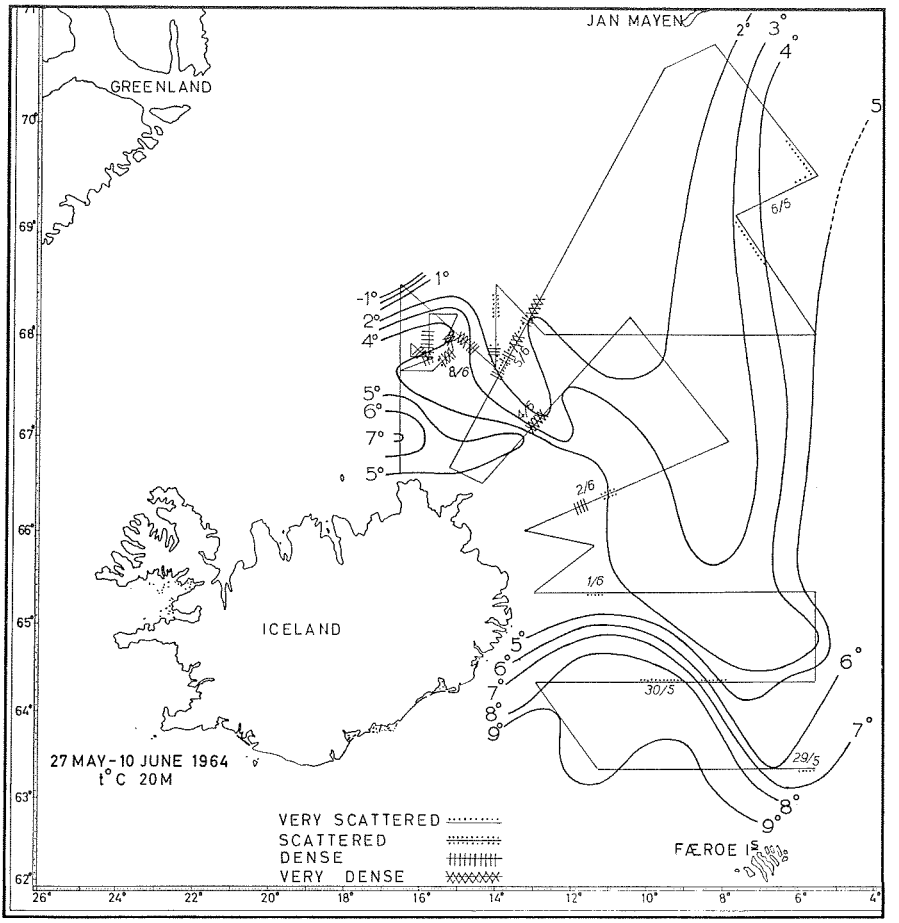

Fig. 10. Herring distribution and temperature at 20 m, 27 May—10 June 1964.

The migration pattern of the herring into North Icelandic waters in early June was similar to that in 1963, but such dense concentrations of herring, as those recorded in the first half of June close to the east coast, have usually not been observed before the beginning of July.

DISCUSSION

In the years 1961—1964 the herring were first recorded east or north-east of Langanes at the end of May and early June. During the first or second week of June the herring shoals migrated further westwards, being mainly confined to the areas between lat. 67°N and 68°N and as far west as about long. 16°W or 18°W.

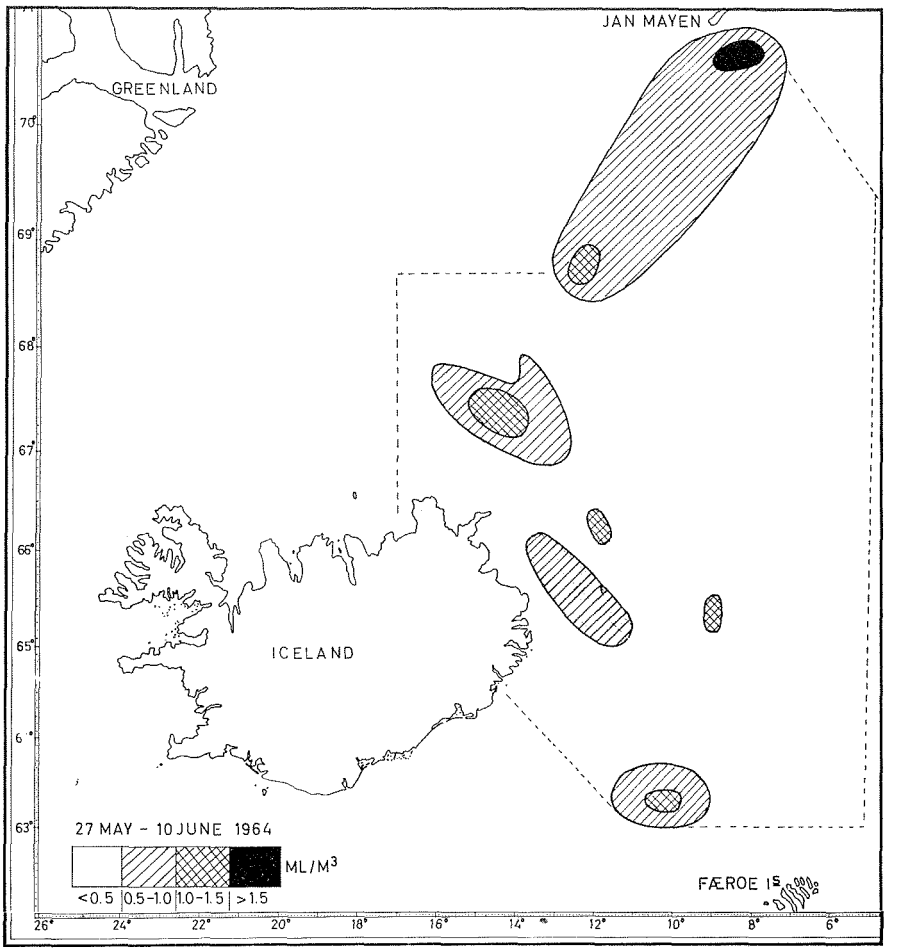

Fig. 11. Zooplankton volume, ml/m³ in 50—0 m, 27 May—10 June 1964.

In 1961 and 1962 an early influx of Icelandic spring spawners from the west was observed on the north coast of Iceland. In contrast in June 1963 and 1964, there was only insignificant, or no, migration of Icelandic spring spawners to the north coast.

During the period 1961—1964 the migration pattern of the Norwegian spring spawners to the north-east coast of Iceland in May and early June was rather similar, but variations in time were observed from year to year. In 1962 dense concentrations of herring were recorded at long. 18°W already on 5 June, but the main invasion was still west of long 14°W. In 1964 herring were observed at long. 16°W on 8 June. In 1963 no herring shoals were found west of long. 16°W until 17 June,

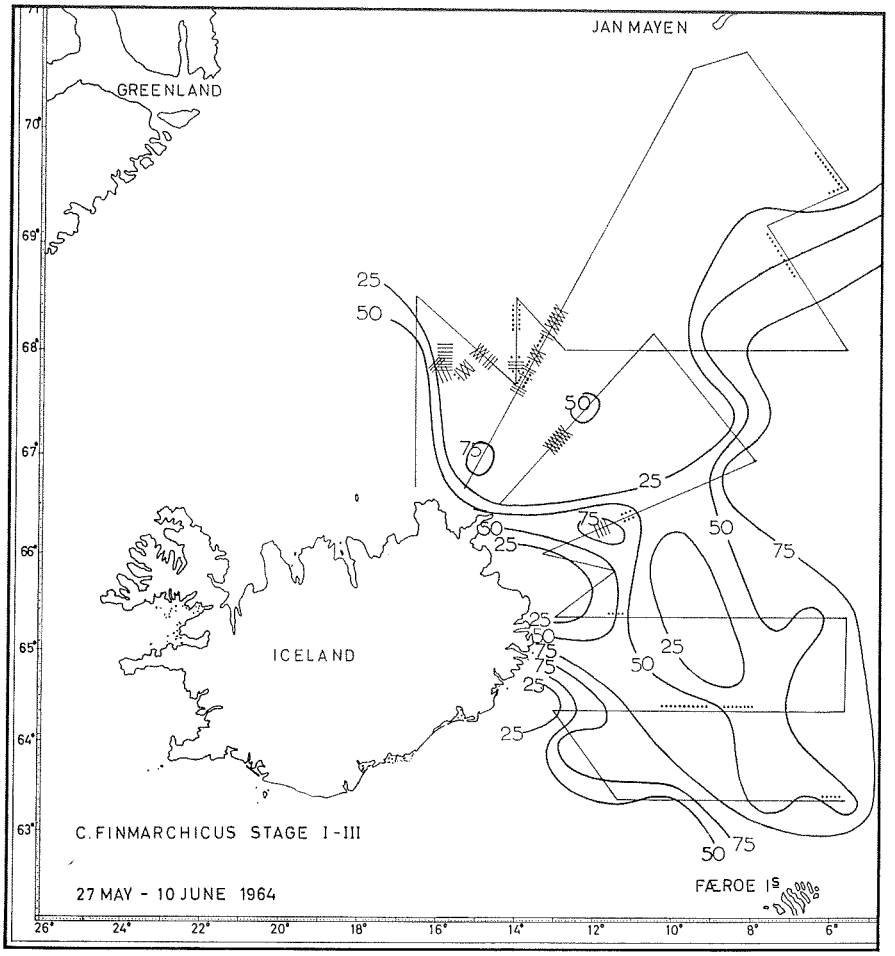

Fig. 12. Herring distribution and percentage distribution of copepodites stages I—III of *C. finmarchicus*, 27 May—10 June 1964.

and the invasion was delayed nearly two weeks as compared with 1962 and 1964. When these data are compared with the temperature conditions in June each year, there is apparently a close relationship. In 1961 the temperature in the surface layers (at 20 m) was a little above average on the north coast, while they were average off the east coast; in 1962 the temperature was close to the average values and in 1964 about 1°C above average and nearly 2°C higher than in 1963. It therefore seems that the herring during the average temperature years of 1961 and 1962 migrated to the north coast during the 1st or 2nd week of June. In the cold year of 1963 the invasion was delayed, while in the warm year 1964, it occurred early especially on the east coast.

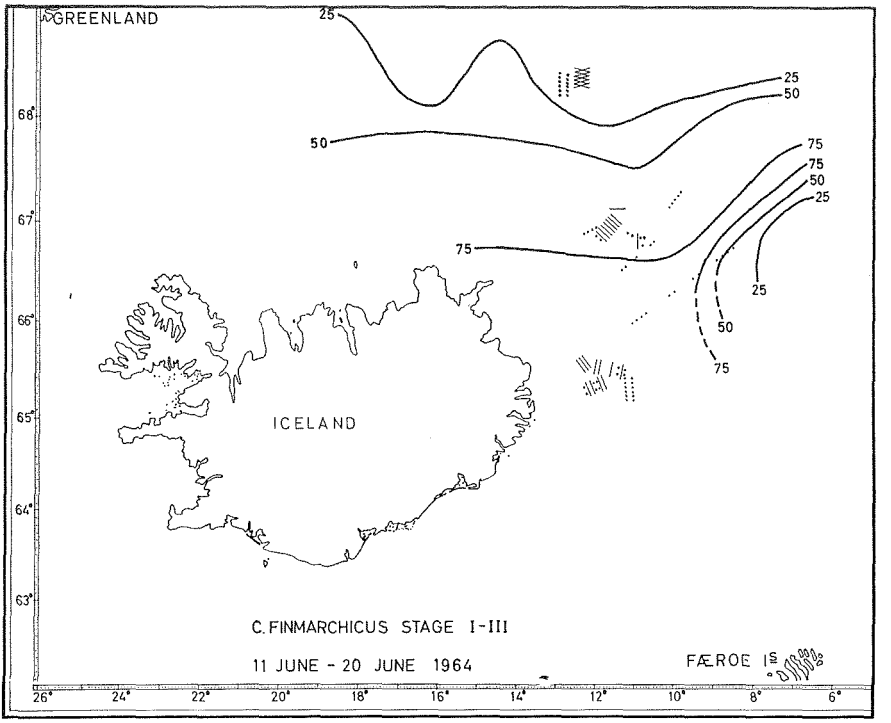

Fig. 13. Herring distribution and percentage distribution of copepodites stages I—III of *C. finmarchicus*, 11—20 June 1964.

In May-June herring shoals have been recorded in waters of temperature between 6° to 0°C and even below 0°C (Fig. 6). Although dense herring concentrations are mainly found in waters above 1°C there seems to be no clear evidence that the feeding migrations of herring are wholly governed by temperature conditions. During all the years investigated herring have been recorded east or north-east of Langenas crossing the East Icelandic Current. PAVSHTIKS (1956) also found that herring migrate into the cold waters (below 2°C) of the East Greenland Current.

On the Icelandic north coast fishing grounds changes in migration pattern of herring in July—August are closely related to temperature and feeding conditions (JAKOBSSON 1963). As temperature and plankton conditions are closely related, it cannot be doubted that the plankton conditions (or rather certain species of the plankton, in particular *C. finmarchicus*) are important for the migration pattern of feeding herring. BLAXTER and HOLLIDAY (1963) also emphasized the importance of size and type of plankton in the study of plankton/herring relationships.

PAVSHTIKS (1956) found that nauplii and young copepodites of *C. finmarchicus* are probably too small as food for the adult herring.

Although *C. finmarchicus* usually constitutes the bulk of the zooplankton population in the Norwegian Sea, other organisms, unacceptable as herring food, may also be very abundant. In this situation a possible positive correlation between the quantitative distribution of edible zooplankton forms and herring may be masked. The present data show that during May-June herring were mainly found in areas where zooplankton was relatively scarce. During June 1958 herring were also scarce in the areas of the Norwegian Sea, richest in zooplankton (LIE 1963). On the other hand JAKOBSSON (1963) demonstrated a positive correlation between herring and the abundance of zooplankton, in particular *C. finmarchicus* off the north coast of Iceland in July-August.

In May and early June, stages I—III of *C. finmarchicus* usually predominate in areas with high zooplankton concentrations along the east and north-east coasts of Iceland. The older stages, IV—VI, are most abundant in the cold water further off the coast. In the years 1961—1964 the migration routes of the Norwegian herring have been confined to areas with a high proportion of stages IV—VI. These results confirm the observations by PAVSHTIKS (1956) and GRUSOV (1961) that in spring and early summer the older age groups of the Norwegian herring feed on the wintering stock of *C. finmarchicus*, nauplii and young copepodites being too small to serve as food.

According to HALLGRIMSSON (1960) the growth condition for zooplankton in North Icelandic waters depends on the mixing processes of the water masses off the north-west coast. Furthermore the strong oceanic fronts and the favourable growth conditions for zooplankton near these fronts are the environmental factors which primarily affect the herring fishery north of Iceland. Several authors (FRIDRIKSSON 1944, EINARSSON 1957, JAKOBSSON 1960) have stressed the importance of the abundance of *C. finmarchicus* on the shoaling behaviour of the herring and consequently on the herring purse-seine fishery. There thus seems to be a close relationship between the distribution of herring on their feeding migration and *Calanus*. In early June, *C. finmarchicus* is usually more abundant in the coastal waters north and east of Iceland than in the East Icelandic Current proper. In the coastal waters the *Calanus* population is dominated by young copepodites (stages I—III) of the spring generation. As mentioned above during the present surveys herring have been observed in the cold East Icelandic Current evidently feeding on the wintering stock of *C. finmarchicus*. In 1964 the spawning of *C. finmarchicus* occurrend somewhat earlier than in 1963 and already in the first week of June herring were recorded in the coastal waters off Seydisfjord on the east

coast of Iceland, where young copepodites (stages I—III) of *C. finmarchicus* predominated. The coastal waters may nevertheless have provided better feeding conditions for the herring then the offshore waters where the wintering generation of *C. finmarchicus* was dying off after spawning. During the years 1961—1963 the difference in spawning time of the *C. finmarchicus* populations in the coastal and offshore waters may have been greater than in 1964. Until the spring generation of *C. finmarchicus* in coastal waters had developed to copepodite stages III—V, the herring have been mostly feeding on the wintering generation in the East Icelandic Current. Thus the migration of the herring into the coastal waters north and east of Iceland will depend on the time of spawning of *C. finmarchicus* in the different water masses as well as the density of the different copepodite stages.

During the years covered in these investigations the mature part of the Norwegian spring spawning stock has been dominated by the rich 1950 year-class. Until the 1959 year-class began to recruit the adult stock in 1964 recruitment was insignificant. It should be stressed therefore that in years with change in age composition the migration pattern of the herring may show considerably changes. The change in age composition observed in 1964 may therefore also have altered the migration pattern, when early in June herring were recorded in Icelandic coastal waters. It is known that in the summer the younger age groups of the Norwegian spring spawning stock usually have a more easterly distribution than the older ones (Fridriksson 1944, Pavshtiks 1956) and in 1964 the herring were mainly located east of Iceland. Also the shift in spawning time and place of the herring as observed on the Norwegian west coast (Devold 1963) may have to be taken into account when studying the feeding migration of the herring.

The data indicate that the time of the migration of the Norwegian herring to Icelandic waters as well as the migration routes are closely related to the biological seasons. Biological seasons are again associated with the hydrographical conditions and this may explain the apparent correlation between temperature and herring distribution observed several times also during the feeding seasons.

So far the present material is representative of "normal" years, it seems that the first invasion of Norwegian herring to Icelandic waters generally takes place in the first half of June. The herring pass through the East Icelandic Current east of Langanes in waters below 3°C. The shoals on migration are usually found in the cold waters near the strong temperature front north east of Iceland, feeding on the wintering stock of *C. finmarchicus* and other cold water forms such as *C. hyperborus*, *Themisto* and *Euphauciacea*.

It is tentatively concluded that the migration of the herring into the coastal waters, north and east of Iceland depends on the spawning time of *C. finmarchicus* in the different water masses as well as its density.

SUMMARY

The present material on zooplankton, temperature and herring have been collected in the Norwegian Sea, from the Faroes along the east and north-east coast of Iceland to Jan Mayen as a part of the Norwegian herring investigations, in collaboration with Iceland and U.S.S.R. during May and June 1961—1964.

Zooplankton was collected in vertical hauls from 50 m to the surface with a Juday net (1961—62) and a Hensen net (1963—64). Temperature was measured at standard depths from surface to 500 m. A termograph measured the surface temperature (at 4 m) throughout the cruises. Herring were located by horizontal and vertical accoustic fish detection devices (sonar, echo sounders).

The herring have been observed migrating across the East Icelandic Current east or north-east of Langanes in waters below 3°C. The distribution and migrations of herring in relation to temperature, plankton biomass (ml/m^3) and the distribution of the copepodite stages of *Calanus finmarchicus* are discussed.

REFERENCES

ANON, 1963. Joint Report of the Scientists attending the "Academican Knipowich" "Johan Hjort" — "Ægir" Meeting held at Akureyri, June 23rd — 24th 1963. *ICES Meeting*, 1963. [Mimeo.].

— 1964a. Report of the joint investigations on the distribution of herring in relation to hydrography and plankton in the Norwegian Sea, June/July 1962. *Ann. biol., 19* (1962):193—198.

— 1964b. Joint Report of the Scientists attending the "Academican Knipovich" — "G. O. Sars" — "Ægir". Meeting held at Seydisfjordur, June 22—23 1964. *ICES Meeting*, 1964, Doc. No. 76:5pp. [Mimeo.].

BLAXTER, J. H. S. and HOLLIDAY, F. G. T. 1963. The behaviour and physiology of herring and other clupeids. Pp. 261—393 in Russel, F. S., ed. *Advances in Marine Biology, 1.* New York and London.

DEVOLD, F. 1951. På jakt etter storsilden i Norskehavet. *Fiskets Gang, 20*:217—222.

— 1963. The life history of the Atlanto-Scandian herring. *Rapp. Cons. Explor. Mer, 154*:98—108.

EINARSSON, H. 1956. "Rannsóknir á átu, hitastigi og dreifingu sildar gerðar á rannsóknarskipinu Ægi sumarið 1955 (Observations on plankton, temperature and the distribution of herring, made from the research vessel "Ægir" during the summer of 1955). *Fjølrit Fiskideildar, 7*:1—21.

FRIDRIKSSON, A. 1944. Norðurlands-sildin (The Herring of the North-coast of Iceland). *Rit. Fiskid.*, *1*:1—390.

GRUSOV, L. N. 1961. Influence of plankton upon the pattern of feeding migrations of herring in the Norwegian Sea in 1959. *Trud. BALT NIRO, 7*:38—49.

HALLGRIMSSON, I. 1958. A short cut method for estimating zooplankton composition while at Sea. *Rit. Fiskid.*, *2*(6):1—6.

— 1960. Zooplankton investigations in Icelandic waters in 1958—1960. *ICES Meeting*, 1960, Doc. No. 92:6 pp. [Mimeo.].

JAKOBSSON, J. 1958. A study of the plankton herring relationship off the SW-coast of Iceland. *Rit. Fiskid.*, *2* (5):1—27.

— 1960. Síldargøngur og síldarleit sumarið 1960. (Herring concentrations and herring surveys in the summer 1960). *Ægir, 53* (20): 333—339.

— 1962. On the migrations of the North coast herring during the summer season in recent years with special reference to the increased yield in 1961 and 1962. *ICES Meeting*, 1962, Doc. No. 98:4 pp. [Mimeo.].

— 1963. Some remarks on the distribution and availability of the North coast herring of Iceland. *Rapp. Cons. Explor. Mer, 154*:73—82.

JAKOBSSON, J., and ØSTVEDT, O. J. 1961. Report of the joint meeting of the Norwegian and Icelandic scientists working onboard "G. O. Sars" and "Ægir" the first half of June in 1961. *ICES Meeting*, 1961, Doc. No. 149:3 pp. [Mimeo.].

LIE, U. 1961. Zooplankton in relation to herring in the Norwegian Sea, June 1959. *Fiskeridir. Skr. Havundersøk.*, *13*(1):1—14.

MARSHALL, S. M. and ORR, A. P. 1952. On the biology of *Calanus finmarchicus* VII: Factors affecting egg production. *J. Mar. Biol. Ass. U.K.*, *30*:527—547.

PAVSHTIKS, E. A. 1956. Seasonal changes in plankton and feedings migrations of herring. *Trud. PINRO*, *99*:3—123. [In Russian].

STEFANSSON, U. 1962. North Icelandic Waters. *Rit. Fiskid. 3*:1—269.

SVERDRUP, H. U. 1953. On conditions for the vernal blooming of phytoplankton. *J. Cons. int. Explor. Mer*, *18*:287—95.

Received 20 April 1965.
Printed 15 November 1965.