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The Continuous Plankton Recorder Survey: plankton in the ICNAF Area, 1961 to 1971, with special reference to 1971

by

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INTRODUCTION

Material collected by the Continuous Plankton Recorder (Hardy, 1938 and Glover 1967) has been used to study the variability in the distribution of the plankton in the ICNAF area from 1959 onwards. Accounts of variation in abundance in the North-eastern Atlantic and North Sea have been presented for every year since 1946 for Annales Biologiques of ICES. In 1959, the survey was extended into the western North Atlantic and this paper attempts to show the kind of data presentation that could be offered, annually, for the ICNAF area. In particular, the distribution of the plankton in 1971 is discussed here with respect to the annual and seasonal fluctuations in abundance since 1961.

There have been several reports on Recorder collections in the ICNAF area; Henderson (1965 and 1968) and Bainbridge and Cooper (1971) investigated the distribution of gebastes larvae; Glover and Robinson (1968) and Robinson (1968) described the distribution of plankton in the western Atlantic at the time of the NORWESTLANT survey in 1963; Colebrook (1971) has discussed the distribution and abundance of the plankton from Recorder results in the north Atlantic and Robinson (1970) has analysed the seasonal variability of phytoplankton in the same area.

METHODS

Continuous Plankton Recorders are towed at a depth of 10m by merchant ships, Ocean Weather Ships and Coast Guard Cutters of the United States Navy once in each month along a number of standard routes (Figure 1). The rolls of silk are cut into sections representing 10 miles of tow and alternate sections, bearing the plankton from 3 cubic metres of water, are analysed. The methods of analysis have been described by Rae (1952) and Colebrook (1960). The present Recorder survey has been in operation since 1948 and since then plankton has been collected and the results have been processed in exactly the same way. Some clear patterns in distribution, abundance and time of occurrence have been established in the North Sea and the eastern Atlantic where there is a longer time series of results than in the ICNAF area.

The area of the survey has been subdivided into a grid of rectangles (each 1^{o} of latitude by 2^{o} of longitude) with diagonal subdivisions to follow the 100 fathom depth contour to differentiate between oceanic and shelf areas. These statistical rectangles can be grouped into larger areas; for the purpose of this paper each large area corresponds with ICNAF areas 1-5 (Figure 1). The data are processed by computer according to the scheme outlined in the following paragraphs.

Monthly data processing

a) A chart is drawn by the Calcomp Graph Plotter every month showing the routes sampled during that month.

b) Each 10-mile sample is allocated to a statistical rectangle and a chart produced showing the number of samples per statistical rectangle for each month.

c) The mean number of each species is calculated for the statistical rectangle in which it occurred in every month and the results are output by the line printer in quasi chart form.

d) the mean number of each species is calculated for each of the five main ICNAF sub-areas.

Some species are more abundant in samples taken at night because of the diurnal vertical migration of some zooplankton; for these, the data processing system is repeated for samples taken at night only.

Annual data processing

a) For each species in each ICNAF sub-area, a matrix is produced by the computer showing the mean number per month for the period 1961 onwards. Contoured representations of each standard area matrix are produced by means of line-printer graphic methods as well as the matrix of basic data. (Figure 2).

b) For each species in each ICNAF area in which it is sufficiently abundant, the annual fluctuations in abundance are calculated for the period 1961 onwards; the data are available as tables of log-transformed counts, as standardized deviates (from the long-term means) and as graphs drawn by the Calcomp Graph Plotter. (Figure 3).

c) Long-term monthly means of abundance for the ICNAF sub-areas are calculated and the results output by the line-printer in table form and also as graphs drawn by the Calcomp Plotter. These results can be used for comparison with area monthly means for a particular year (Figures 8 to 11).

d) Estimates of the "timing" of the seasonal cycle of abundance of each species in each standard area are calculated using the method described by Colebrook and Robinson (1965) and the results produced in table form and as graphs drawn by the Calcomp Plotter.

e) A chart showing the annual distribution of each species for every year from 1959 onwards together with an anomaly chart showing its variation from the long-term mean chart (Figure 7).

f) Product moment correlations are calculated for (i) the annual fluctuations in abundance of species, (ii) the annual fluctuations in the "timing" of species between all possible pairs of ICNAF sub-areas, and (iii) the annual fluctuations of abundance of the species within each sub-area.

g) The latent roots, vectors and principal components of all the correlation matrices are derived by Householder's method (Figure 4).

The results from this routine data processing have been used to describe the distribution of the plankton in the ICNAF sub-areas 1-5 in this report. During 1971, Recorders sampled 1,092 miles in sub-areas 1, 2315 miles in sub-areas 2, 13,244 miles in sub-area 3, 3,345 miles in sub-area 4 and 1,258 miles in sub-area 5.

RESULTS

Annual and seasonal fluctuations in abundance

Annual and seasonal distributions can be summarized conveniently by considering the distributions of the major components of the plankton in the ICNAF sub-areas. Figure 2 gives the annual and seasonal fluctuations in abundance for phytoplankton, total copepods, Euphausiacea, copepodite stages V-VI and I-IV of *Calanus finmarchicus* for sub-area 3. This type of diagram is provided in computer printout for all species in all sub-areas in which they occur.

The estimate of phytoplankton was obtained from a visual assessment of the green coloration of the filtering silks. The main phytoplankton season occurs in the spring (Figure 2a, April and May) and, although there was marked year-to-year variation in the timing and abundance of its start, there was no consistent trend within the eleven-year period. However, there is some evidence that the spring outbreak declined at a progressively earlier date from 1965 onwards. Dominant spring species were Thalassiosira spp., Chaetoceros spp. and Thalassiothrix longissima. From 1968 onwards, there has been an autumnal peak which was not apparent in previous years, except 1964. This may be related to changes in the abundance of copepods (Figure 2c) which, from 1967 onwards, became much less numerous from August to December than in the preceding years. Also, there was a spring outbreak in copepod production which indicated a trend of earlier production from 1963 onwards.

The diagrams for copepodite stages V-VI and I-IV of Calanus finmarchicus should be compared. The overwintering adult stages appeared at 10m in February and disappeared in May or June. The timing of their occurrence has been stable but there have been considerable fluctuations in their abundance and length of season. In 1968 they occurred early and were abundant until June but were extremely scarce in 1970. There was considerable variation in the time of production of copepodite stages I-IV with a trend of earlier production from June 1961 to May 1971.

The abundance of the Euphausiacea was more variable than that of other organisms illustrated in Figure 2. The adults usually appear in samples taken at 10m in February or March and disappear in June (Jones, 1969); thereafter, they are replaced by young stages which will appear as adults the following spring. Adults were particularly numerous in 1961, 1962, 1967 and 1968 in spring, while young stages were abundant in 1963 and 1964 in the autumn.

Figure 3 shows the annual fluctuations in abundance of the same five organisms in sub-areas 1-4 for 1961 to 1971. Eleven years is too short a period to detect trends in the fluctuations in abundance such as have been identified in north-eastern Atlantic and the North Sea over a period of twenty-five years. (Colebrook, 1971; Glover, Robinson and Colebrook 1972). An attempt to analyse these patterns of annual fluctuations in abundance has been made by calculating the Principal Components of the array of data formed from annual fluctuations in abundance of all the species occurring in each sub-area, (Williamson, 1961). The first components (Figure 4) for sub-areas 1-4 express 30, 37, 46 and 50% and the second components 20, 26, 20 and 27% respectively of the total variation in the annual fluctuations in abundance. Fourth order polynomials have been fitted to the graphs to indicate trends in annual fluctuations in abundance.

The first components for sub-areas 2 and 3 are similar with numbers below the long-term mean from 1962 and 1963 onwards. Also the first component for sub-area 4 indicates a downward trend with the graph below the long-term mean from 1968 onwards. Similar trends are obvious in the first component for sub-area 1 and the second component of sub-area 2 with a peak from 1965 to 1967 and troughs on either side in 1963 and 1970 while the trend lines for the first component of sub-area 4 and the second component for sub-area 3 differ from these two with the peak two years earlier in 1964 and 1965. The annual fluctuations in abundance of young fish (Sebastes spp., Clupeidae, Ammodytidae, Mallotus spp. and Scopelidae) are given in Figures 5 and 6. Fourth order polynomials have been fitted to the graphs so that the fluctuations in abundance may be compared with the principal components of the annual fluctuations in abundance of the plankton given in Figure 4. There are close relationships between these two parameters in the following instances; Sebastes spp. and the first components for sub-areas 1 and 4 and the second component for sub-area 2; Clupeidae and the first component for sub-area 4; Ammodytidae and the second components for sub-areas 3 and 4; Mallotus spp. and the first component for sub-area 3 and Scopelidae and the second component for sub-area 3. Thus eight out of ten trend lines fitted to the graphs of the annual fluctuations in abundance of young fish in ICNAF sub-areas 1-4 show similar annual fluctuations in abundance to the first or second components of the annual fluctuations in abundance of the plankton in the same sub-areas.

Geographical Distributions in 1971

The charts in Figure 7 (above) give the distributions in the ICNAF area of the phytoplankton and the two major components of the zooplankton, (Copepoda and Euphausiacea) for 1971. The distributions of individual species, or groups of species, are available on request in the form of quasi-synoptic charts produced by the line-printer. Atlas charts giving the long-term mean distributions of species in the North Atlantic have been published (Edinburgh, Oceanographic Laboratory, 1973). Phytoplankton and copepods were both found in greatest abundance over the Grand Banks and other coastal areas. Euphausiacea, however, were numerous in the Labrador Sea as well as in the coastal areas south of Newfoundland and Nova Scotia.

The anomaly charts (Figure 7, below) compare the distribution in 1971 with the long-term mean distribution (1958-1970); the average number per sample for each statistical rectangle is expressed as a percentage of the thirteen year mean for that rectangle. For the phytoplankton, numbers were higher than usual to the east and south of the Grand Banks with an area of low numbers to the north and also south of Greenland. Copepods tended to show the reverse distribution with numbers lower than usual to the east and south of the Grand Banks; they were also below average in the Labrador current but abundant in the Labrador Sea. Euphausiids were abundant in the coastal waters south of Newfoundland, but below average in most other areas.

Plankton in the ICNAF areas 1-5 in 1971

The results are presented in the same way as those published annually in Annls biol. Copenh., (Glover, Colebrook and Robinson, 1962). For each month, for ICNAF sub-areas 1-5, the mean number per Recorder sample (of $3m^3$) has been calculated for the dominant members of the plankton and young fish. The results are shown in Figures 8-11 in which the data for 1971 are presented as histograms (gaps in the baseline indicate there was no sampling during that month). A measure of the normal seasonal cycle is provided by line graphs of the average number per sample during the period 1959 to 1970 or 1971). Both the monthly means for 1971 as well as the long-term means for the plankton were calculated from logarithmic transformations of the original counts; the means for the young fish are calculated from the untransformed data.

Figure 8 shows the results for phytoplankton and total copepods. The spring outbreak of phytoplankton in sub-area 1 occurred in June and July, about a month later than usual. Numbers were high in April in sub-areas 2, 3 and 4 suggesting that the spring outbreak was slightly earlier than usual in these areas; also it was unusually abundant in sub-area 1 in October, sub-area 2 in July and November, sub-area 4 in October and sub-area 5 in November and December. Numbers of copepods were above average in the early months of the year in all areas; in particular April to September in sub-area 1, May and June in sub-area 2, January, March, April and June in sub-area 3, January and April in sub-area 4 and January and March in sub-area 5. (There was no sampling for four months in sub-area 4 and five months in sub-area 5). Numbers were lower than usual at the end of the year in sub-areas 1, 2 and 3, but high in sub-area 5.

Adult Calanus finmarchicus (Figure 9, left) were more numerous than usual in sub-area 1 with two major peaks (April/May and August/September). They were below average in most months until May in sub-areas 2, 3 and 4 but were generally more abundant in these areas in the second half of the year (June and August to

September in sub-area 2; August to December in sub-area 3; June to October in sub-area 4). It was abundant in the months sampled until September in sub-area 5.

Euphausiids (Figure 9, right) were generally below average or close to the long-term mean except in sub-area 1 in May, sub-area 2 in October, sub-area 3 from August to October and in December and sub-area 4 in April and June. However, they were more abundant than usual in most months sampled in sub-area 5.

Copepodite stages I-IV of *Calanus finmarchicus* (Figure 10, left) were abundant in spring in all areas sampled (June and July in sub-area 1, May and June in sub-area 2, January, February and May in sub-area 3 and April in sub-area 4. However, they were below average in most months in all sub-areas from July onwards except July in sub-area 1 and August in sub-areas 3 and 4. Numbers were low in all months when samples were taken in sub-area 5.

Young stages of *Sebastes* spp. (Figure 10, right) were scarce in all areas. High numbers occurred for a short period in sub-area 1 (in May, a month earlier than usual) and in June in sub-area 2. Young stages of Ammodytidae, Clupeidae and *Mallotus* spp. (Figure 11) are only found in appreciable numbers in sub-areas 3, 4 or 5. Ammodytidae were present for one monthly only in sub-areas 3 and 4; Clupeidae were abundant in January, March, July, November and December in sub-area 3, in January and April in sub-area 4, and in November and December in sub-area 5. *Mallotus* was also abundant in sub-area 3 in August, October and December.

CONCLUSIONS

The main results of the sampling in the ICNAF area from 1961 to 1971 may be summarized as follows:

(a) In sub-area 3 the end of the spring outbreak of the phytoplankton has occurred progressively earlier over the period 1965 to 1971. This may be correlated with the earlier outbreak of copepods, and copepodite stages I-IV of *Calanus finmarchicus* from 1963 onwards.

(b) The autumnal peak of the phytoplankton production has increased since 1968 while there has been a decline in the abundance of copepods over the same period.

(c) there has been a decline in the abundance of copepods in sub-areas 2, 3 and 4.

(d) the annual fluctuations in the young stages of Sebastes spp., Ammodytidae, Clupeidae, Mallotus spp. and Scopelidae all show strong correlations with the first or second components of the annual fluctuation in abundance of the permanent plankton. Bainbridge and Cooper (1971) suggested that there were four independent populations of Sebastes in the North Atlantic, three of which occurred in the ICNAF area: these were distinguished by their spawning times which appeared to be related to the seasonal cycle of copepods. Three different patterns of annual fluctuation of abundance of Sebastes can be identified (Figure 5) in sub-areas 1-2, sub-areas 3 and 4 and sub-area 5; this is further evidence in support of the conclusions of Bainbridge and Cooper.

(e) Young stages of Sebastes spp. and Ammodytidae were scarce in 1971, while Mallotus spp. and Clupeidae were more abundant than usual. Copepods were abundant in the first half of the year in all areas; numbers remained high throughout the year in sub-areas 4 and 5 but were below average in sub-areas 2 and 3 from June onwards.

This paper does no more than provide examples of descriptive data presentation from the CPR survey which could be made available as a routine. The paper does not attempt to deal with the analysis and interpretation of variability in the plankton.

ACKNOWLEDGMENTS

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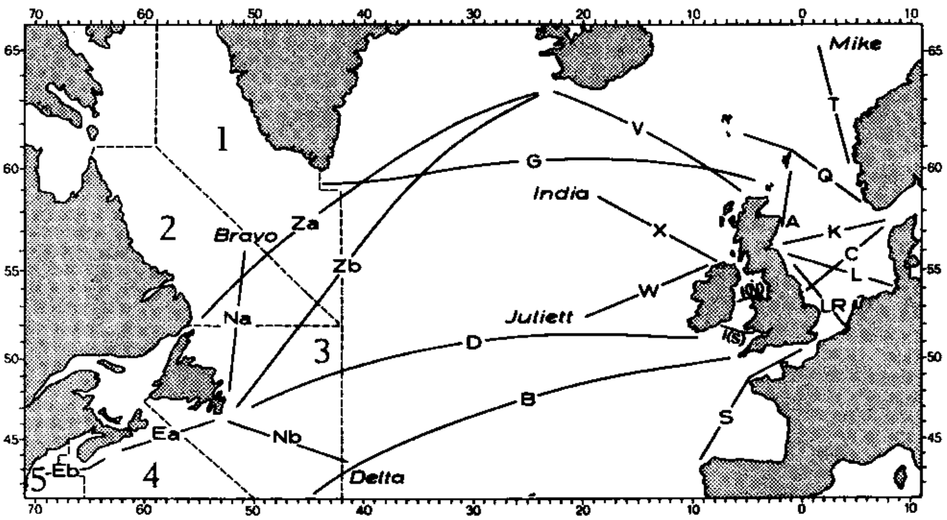

Fig. 1. The Continuous Plankton Recorder Survey during 1971. The routes are identified by code letters and the Ocean Weather Stations by their international names. Za indicates the position of tows along the Z route in summer and Zb in winter. The boundaries of ICNAF subareas 1-5 are outlined.

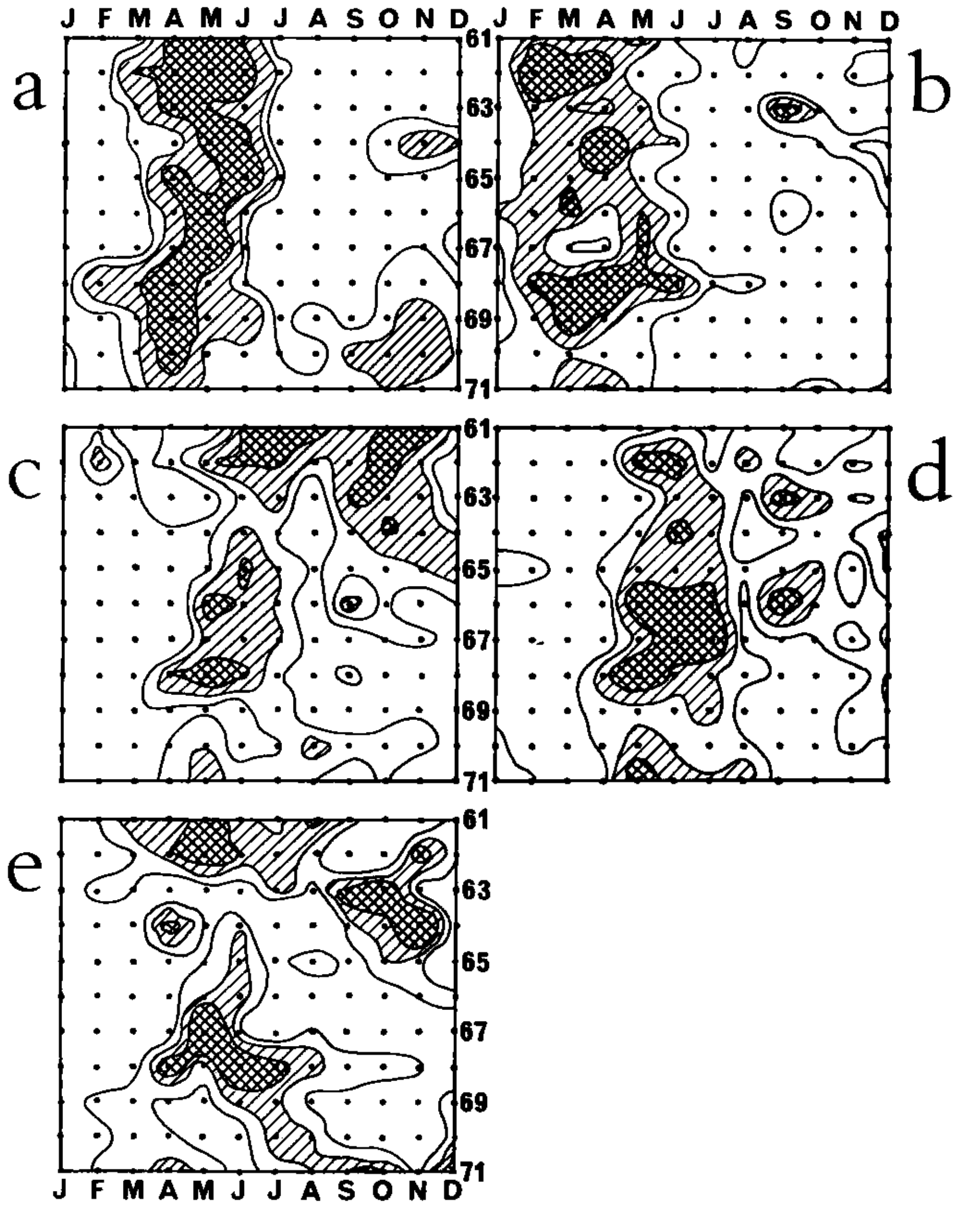

Fig. 2. Contour diagrams of the annual and seasonal fluctuations in abundance of (a) phytoplankton, (b) copepodite stages V-VI of Calanus finmarchicus, (c) total copepods, (d) copepodite stages I-IV of C. finmarchicus, and (e) Euphausiacea in ICNAF Subarea 3. Contour levels for phytoplankton are shown on an arbitary scale at 2, 4, 6 and 12. Contour levels for the remaining diagrams are drawn at 6, 11, 19 and 30 per sample of $3m^3$ for (b), 179, 272, 396 and 600 for (c), 23, 43, 83 and 155 for (d) and 2, 3, 4 and 6 for (e).

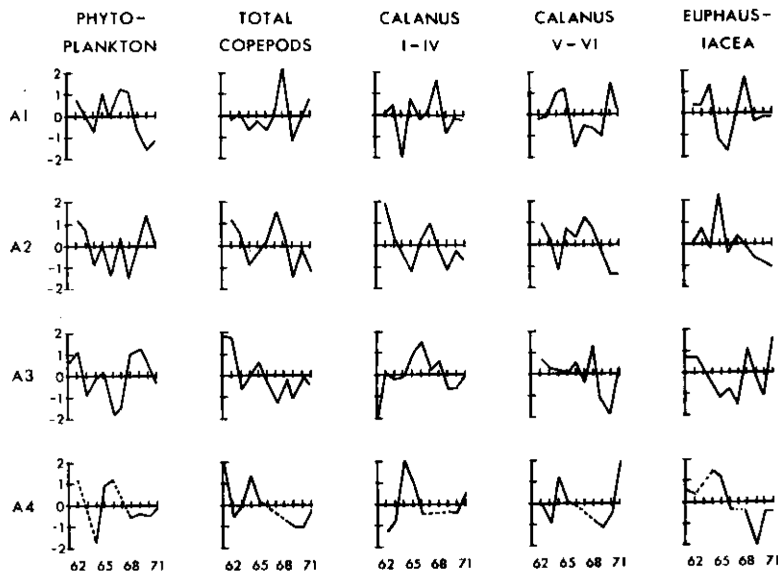

Fig. 3. Graphs of the annual fluctuations in abundance of total phytoplankton, total copepods, copepodite stages I-IV of Calanus finmarchicus, copepodite stages V and VI of C. finmarchicus and Euphausiacea in ICNAF Subareas 1-5 for the period 1961-1971. Each graph is shown as a standized variable about a mean of zero. The ICNAF Subareas are indicated by A1, A2, etc.

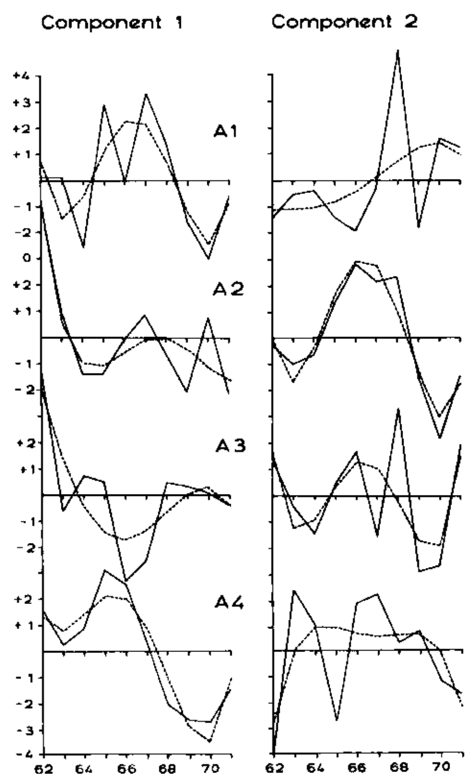

Fig. 4. Graphs of first and second components of the annual fluctuations in abundance of the species occurring in the ICNAF Subareas 1-4. Each graph is shown as a standardized variable about a mean of zero. The ICNAF Subareas are indicated by A1, A2, etc.

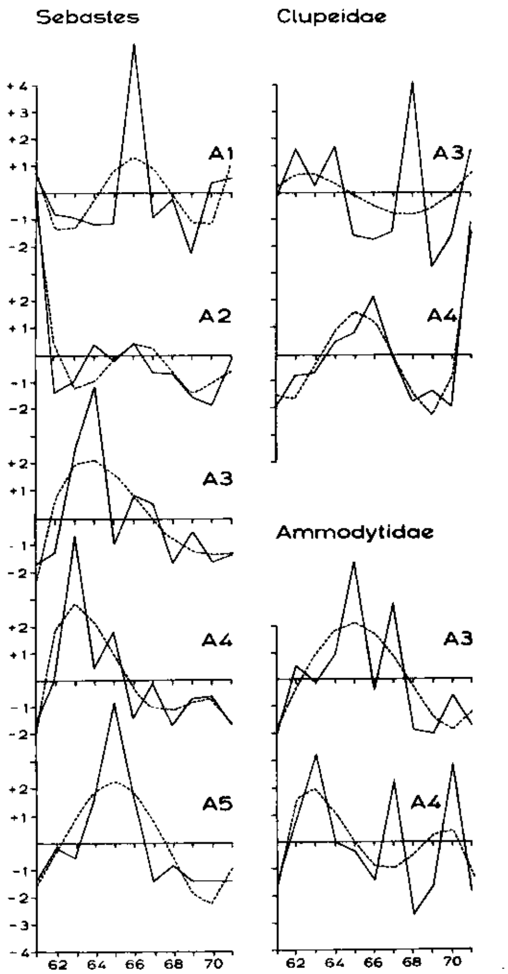

Fig. 5. Graphs of the annual fluctuations in abundance of Sebastes spp. in Subareas 1-5, Clupeidae and Ammodytidae in Subareas 3 and 4 for the period 1961-1971. Each graph is shown as a standardized variable about a mean of zero. Fitted trend lines are shown by the dashed lines. The ICNAF Subareas are indicated by A1, A2, etc.

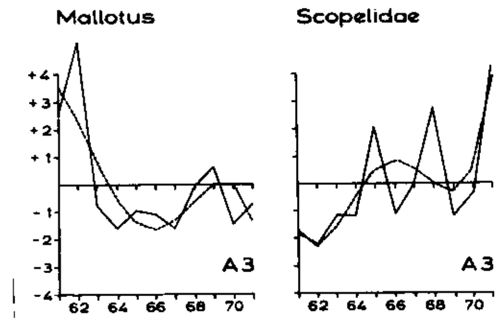

Fig. 6. Graphs of the annual fluctuation in abundance of Mallotus spp. and Scopelidae in ICNAF Subarea 3 for the period 1961-1971. Fitted trend lines are shown by the dashed lines.

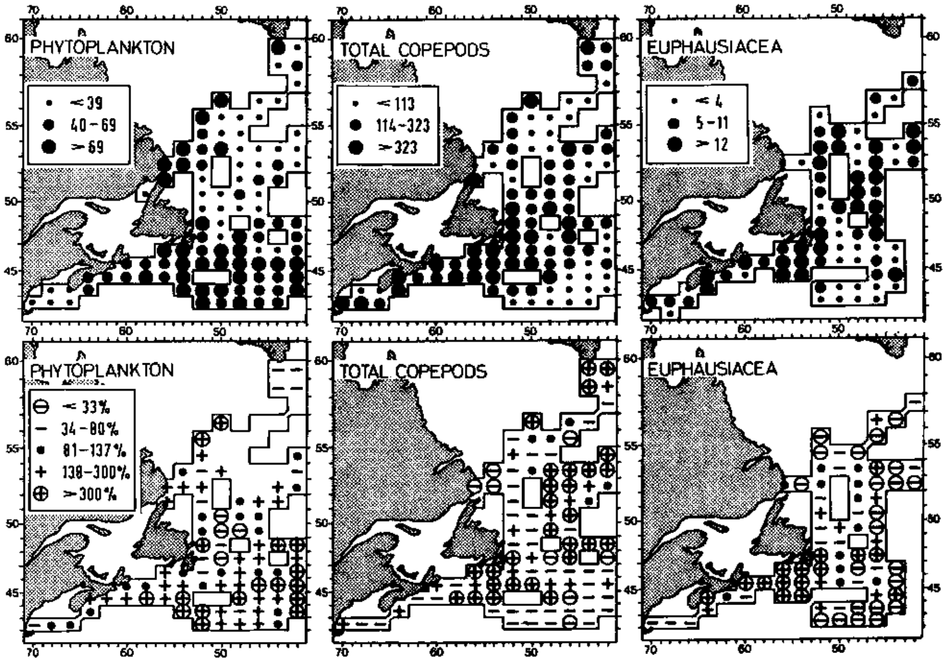

Fig. 7. Above, charts showing the geographical distributions of total phytoplankton, total copepods and Euphausiacea in the ICNAF Area in 1971. The symbols show the average numbers of organisms per sample for each statistical rectangle for total copepods and Euphausiacea (see key at top left of each chart); the phytoplankton scale is an arbitrary measure of the coloration of the samples. The distribution chart for Euphausiacea was constructed from samples taken at night only. Below, anomaly charts of the distribution of total phytoplankton, total copepods and Euphausiacea in 1971. The symbols represent the average numbers per sample for each rectangle expressed as a percentage of the thirteen-year mean.

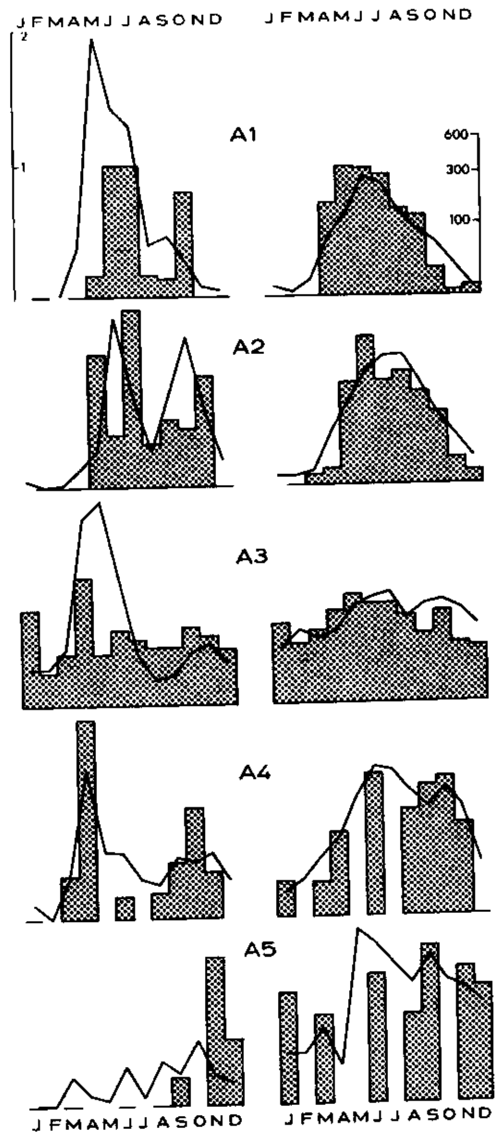

Fig. 8. Histograms showing average numbers per Recorder sample of phytoplankton (left) and total copepods (right) in ICNAF Subareas 1-5 in 1971. The line graphs show the mean value for the period 1959-1971. For further details, see text.

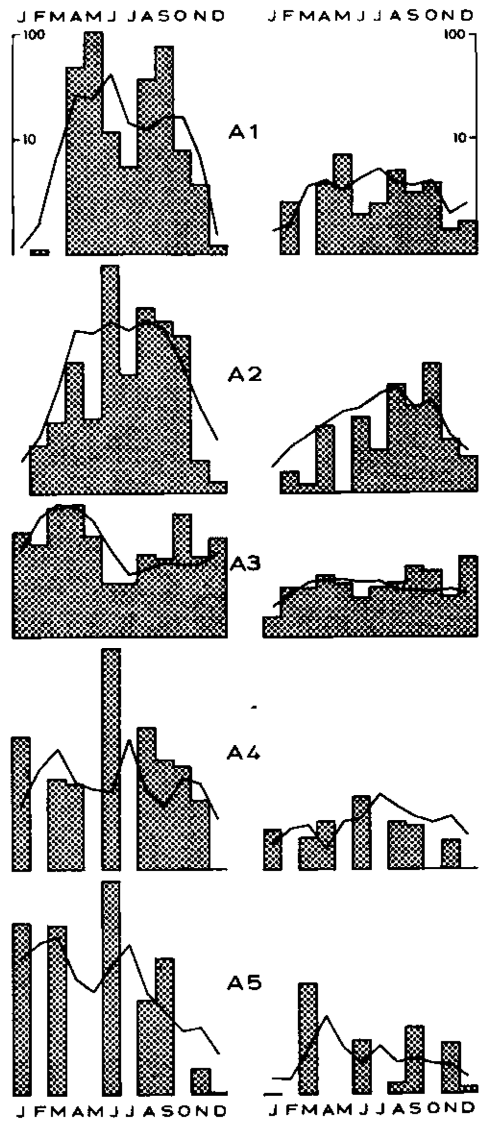

Fig. 9. Histograms showing average numbers per Recorder sample of copepodite stages V-VI of Calanus finmarchicus (left) and Euphausiacea (right) in ICNAF Subareas 1-5 in 1971. The line graphs show the mean values for the period 1959-1971. For further details, see text.

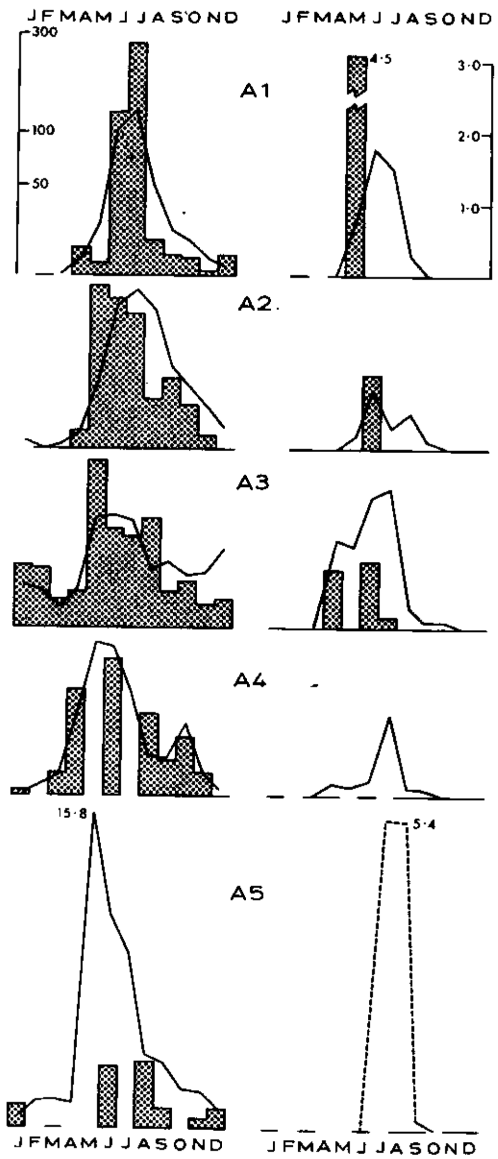

Fig. 10. Histograms showing average numbers per Recorder sample of copepodite stages I-IV of C. finmarchicus (left) and young stages of Sebastes spp. (right) in the ICNAF Subareas 1-5 in 1971. The line graphs show the mean values for the period 1959-71. For further details, see text.

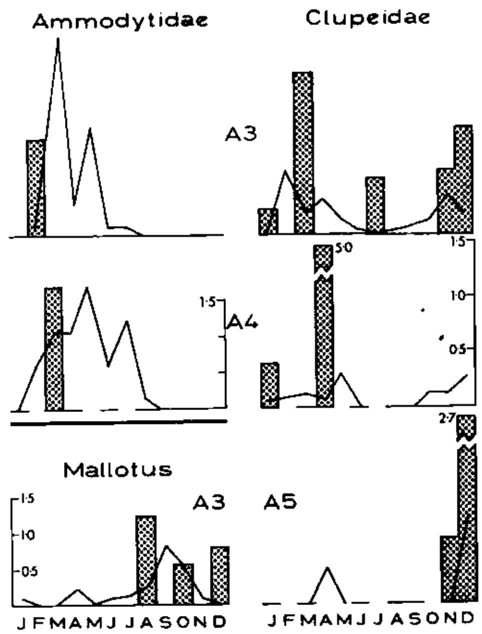

Fig. 11. Histograms showing average numbers per Recorder sample of young stages of Ammodytidae in Subareas 3 and 4, Clupeidae in Subareas 3, 4 and 5 and <u>Mallotus</u> spp. in Subarea 3 in 1971. The line graphs show the mean value for the period 1959-1970. For further details, see text.