1978
Rapp. P.-v. Réun. Cons. int. Explor. Mer, 172: 397–404. 1978.

THE PLANKTON IN THE NORTHWESTERN NORTH SEA, 1948 TO 1974

V. Bainbridge†, D. C. T. Forsyth and D. W. Canning
Institute for Marine Environmental Research
Prospect Place, The Hoe, Plymouth PL1 3DH, England

INTRODUCTION

This paper summarizes and brings up to date a series of papers describing the plankton of the northwestern North Sea in relation to the environment and distribution of herring (see Bainbridge and Forsyth, 1972). Figure 308 shows the areas of the survey and also the migration routes of the herring which spawn at scattered localities from the Shetland Islands to the east coast of Scotland during August and September. The herring then travel east to overwinter along the edge of the Norwegian Rinne and migrate westward to feed during spring and early summer.

During the postwar years there have been some dramatic changes in the Scottish herring fishery of the northwestern North Sea. The drifter fleet, operating from Shetland and the Buchan ports, declined from over 400 boats in 1948 to less than 40 in 1969, and by 1974 it was reduced to a single drifter working out of Lerwick. The herring stock is now exploited mainly by purse-seine vessels which have increased from a single vessel in 1966 to a fleet of 30 in 1975. In addition, continental trawlers fish for herring in the same area.

Throughout the 1960's the Shetland fishery continued to prosper, while the Buchan fishery failed almost every year and by the end of the decade had virtually disappeared. In the seventies the Shetland fishery has steadily declined but was still a viable fishery for purse-seine vessels in 1974. Scientists at the Marine Laboratory, Aberdeen (for example, Saville, 1967) have monitored the fluctuations in the herring stock and have provided details of its distribution, abundance, and age composition over the years.

METHODS

The plankton data used in this paper are based on samples collected by the herring fishermen, supplemented at times by sampling from the research ships of the Department of Agriculture and Fisheries for Scotland. Beginning in 1948 at Buchan and in 1957 at Shetland, herring-drifter fishermen were asked to tow a Plankton Indicator (Glover, 1953) on their way to or from the fishing grounds. The tow, of ten minutes' duration at full speed (8 knots), theoretically sampled $0{\cdot}3\ m^3$ of water. Only samples taken between 1700 and 0500 hr GMT were used in order to reduce the variability due to diurnal migrations. For fuller details of the methods of sampling and analysis, see Bainbridge and Forsyth (1972).

† 24 June 1974.

SEASONAL CYCLES IN THE PLANKTON OF THE FISHING GROUNDS

The data for the years 1957 to 1974 were combined, and the average weekly variations of three of the main elements of the plankton are shown in Figure 309, which brings up to date Figure 4 of Bainbridge and Forsyth (1972) who combined data for the years 1957 to 1967.

In the Buchan area, Copepoda used to decrease in July but recovered in late August after the summer maximum of the dinoflagellates. (The increase of dinoflagellates in September is entirely due to one week in 1971 when there were exceptionally high numbers of *Ceratium* spp.) *Spiratella* reached a peak in late August and thereafter declined.

The relationships between the timing of the seasonal cycles were much the same in the Shetland area, although there were differences in the overall numbers between the two areas. The addition of data for the years 1968–1974 has made little difference to the apparent form of the seasonal cycles in the two areas, but there are big differences in the numbers of organisms at Shetland, reflecting large increases in numbers of dinoflagellates and decreases in copepods and *Spiratella* during the past seven years; these changes are discussed below.

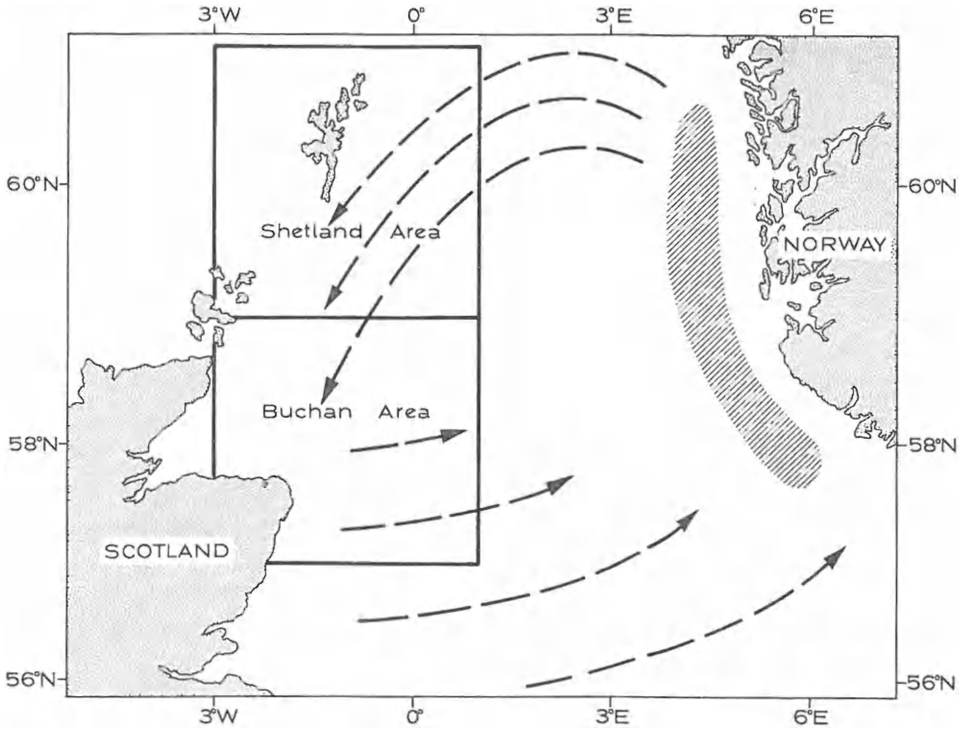

Figure 308. Schematic diagram of the migratory pattern of the Buchan spawning stock of herring during the 1950's (adapte Harden Jones, 1968). The hatched area represents the overwintering grounds. Superimposed on the chart are the twc subdivisions used for the Plankton Indicator survey.

Again combining data for the years 1957–1974, the species composition of the Copepoda is illustrated in Figure 310. The principal species in the Buchan area were *Calanus finmarchicus*, *Temora longicornis*, and *Acartia clausi*, while around Shetland, they were *Calanus* and the combined genera *Paracalanus parvus* and *Pseudocalanus elongatus*. In both areas, maximum numbers of *Calanus* were found in June followed by a gradual decline at Buchan and a sharp one at Shetland. The Buchan area was dominated by *Acartia* and *Temora* with an early peak of *Calanus*, while the Shetland area was dominated by *Calanus* with a secondary peak of *Paracalanus* and *Pseudocalanus*.

ANNUAL VARIATION OF THE PLANKTON

The analysis of annual variations in the plankton during the fishing season follows the system used by Glover (1957) and Williamson (1961), who adopted a standard season of 12 weeks coinciding roughly with the main summer fishery; that is, June, July, and most of August. The data for the Buchan area from 1948 to 1974 are compared and contrasted with data for the Shetland area from 1957 to 1974.

CORRELATION ANALYSIS

The data were transformed [$y = \log_{10}(x+1)$ standardized to zero mean and unit variance in to eliminate differences in the level of abunda various entities; patterns of annual fluctuation then be easily compared between species. Son amples are shown in Figure 311. Cladocera, *T* and *Centropages hamatus* show similar but irr patterns of variation over the years at both B and Shetland. The dinoflagellates in both areas the same trend with a period of low abundanc the years 1964 to 1967 and increasing nearly year thereafter. *Acartia* in the Buchan area sh marked trend of increasing abundance, especia the last four years, but irregular variations i Shetland area. *Calanus* shows clearly, in both that following the early years of high average nun there has been a steady and dramatic fall i level of abundance, starting in 1959 at Bucha six or seven years later in Shetland waters. molluscs *Spiratella* and *Clione* had annual vari very similar to one another as might be exp from their close predator/prey relationship. fluctuations, although somewhat irregular, b

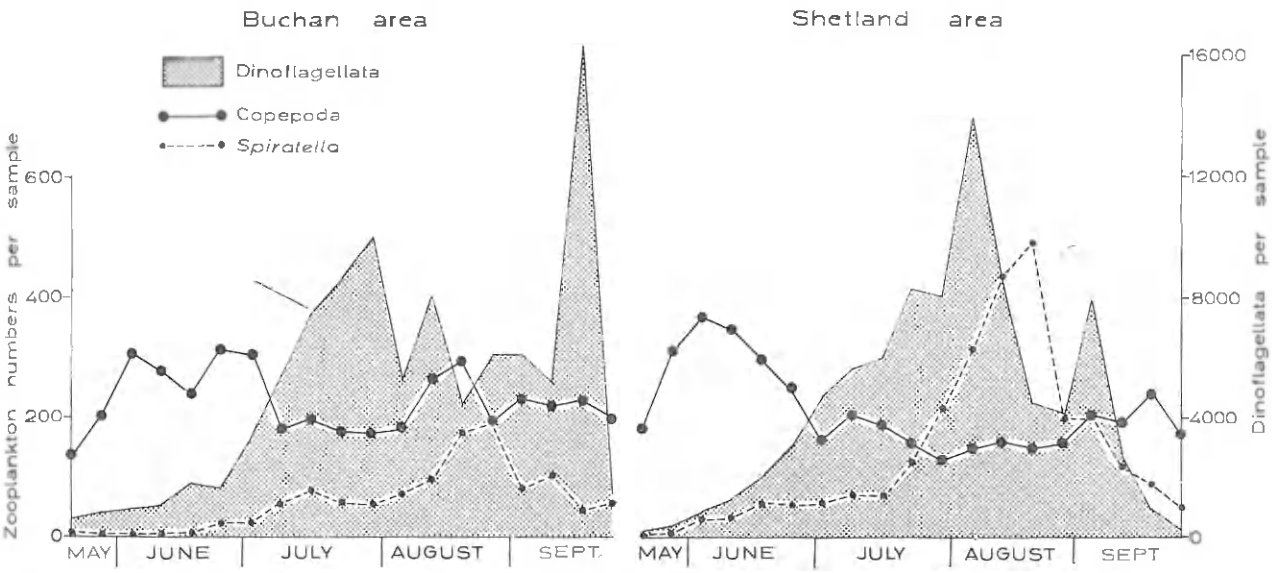

Figure 309. Fluctuations in the abundance of some major planktonic groups during the summer months in the Buchan and Shetland areas. Data are given as weekly averages for the 18-year period 1957–1974.

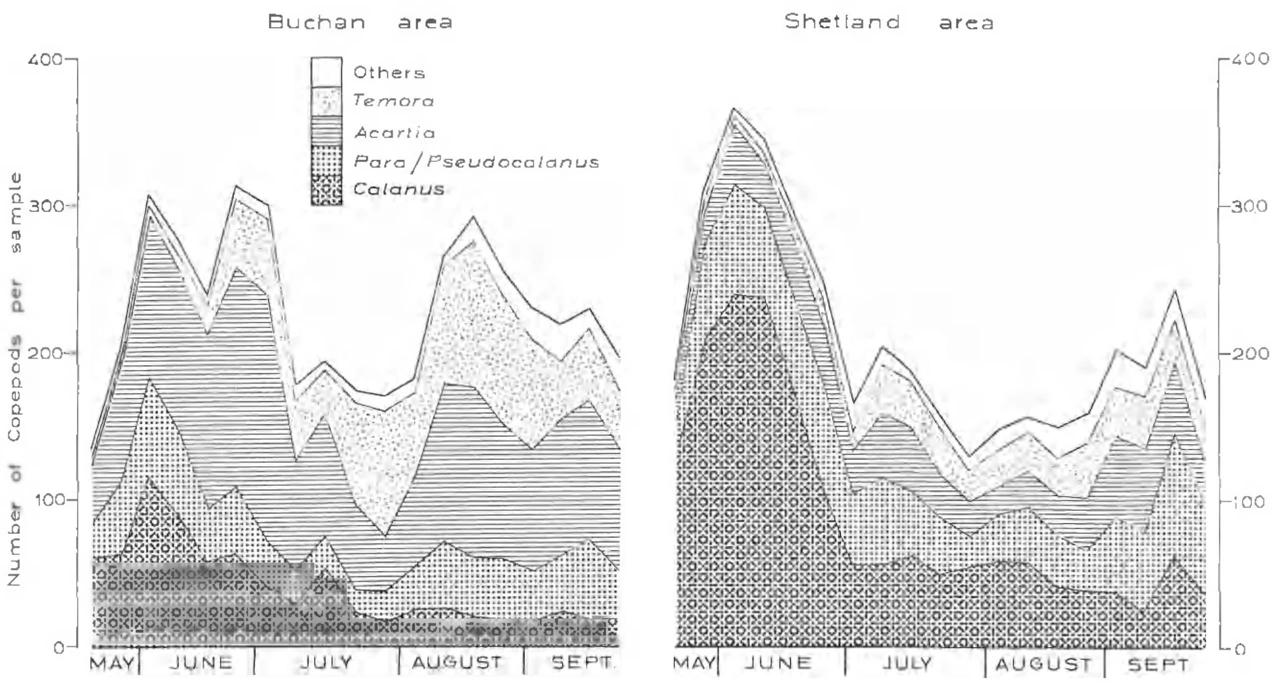

Figure 310. The average numbers of Copepoda during the summer months in the Buchan and Shetland areas. The graphs are divided to show the relative abundance of the commoner species. Data are averages for the 18-year period 1957–1974.

close resemblance to those of *Calanus* and, as with *Calanus*, the decline in numbers became apparent about six years earlier in Buchan waters than in the Shetland area.

PRINCIPAL COMPONENT ANALYSIS

Principal component analysis was applied to all 23 entities in the plankton, using the standard 12-week averages over the years 1948–1974 in the Buchan area

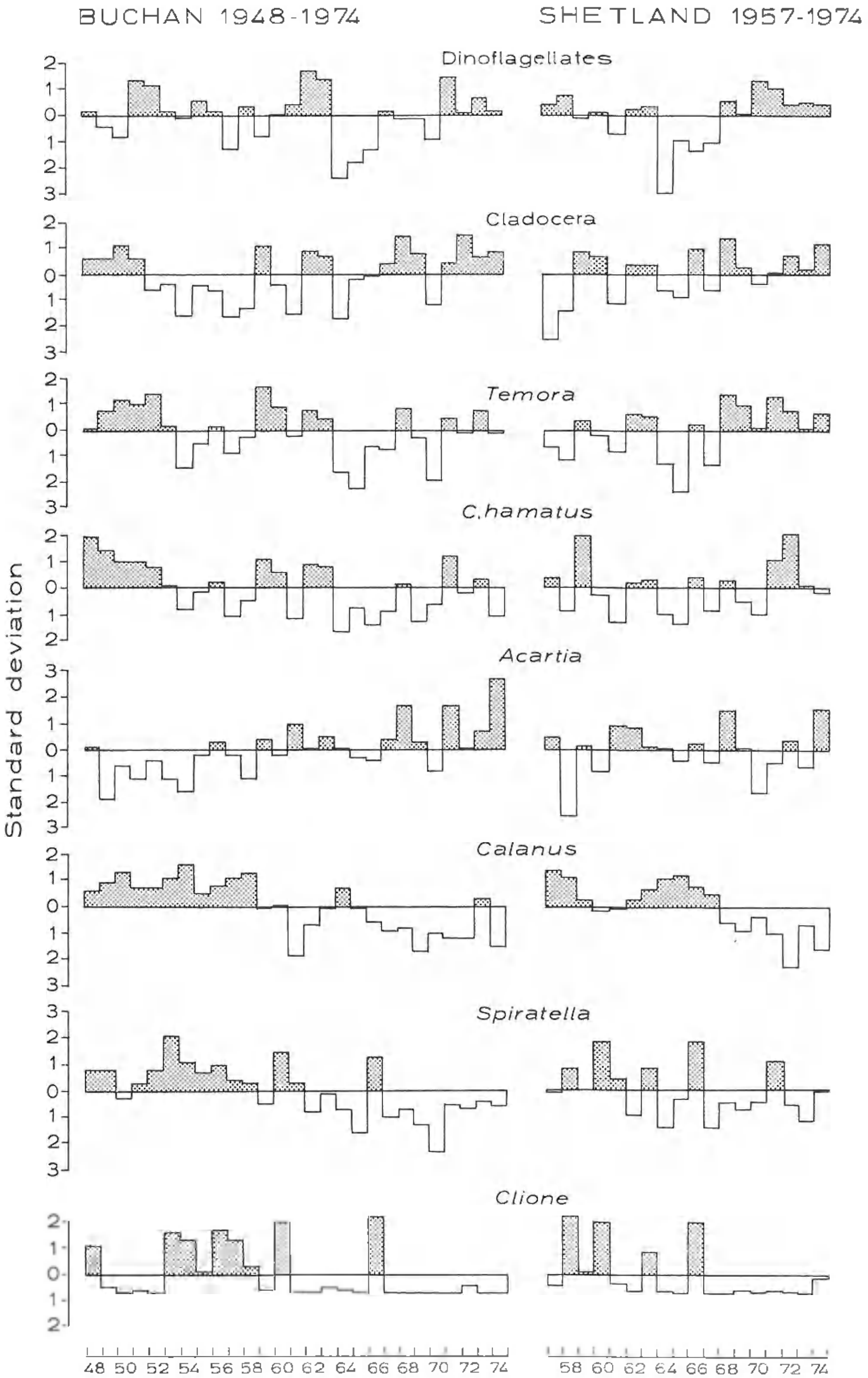

Figure 311. Annual fluctuations in the summer plankton of the Buchan and Shetland areas. Data are 12-week averages for organisms standardized to zero mean and unit variance.

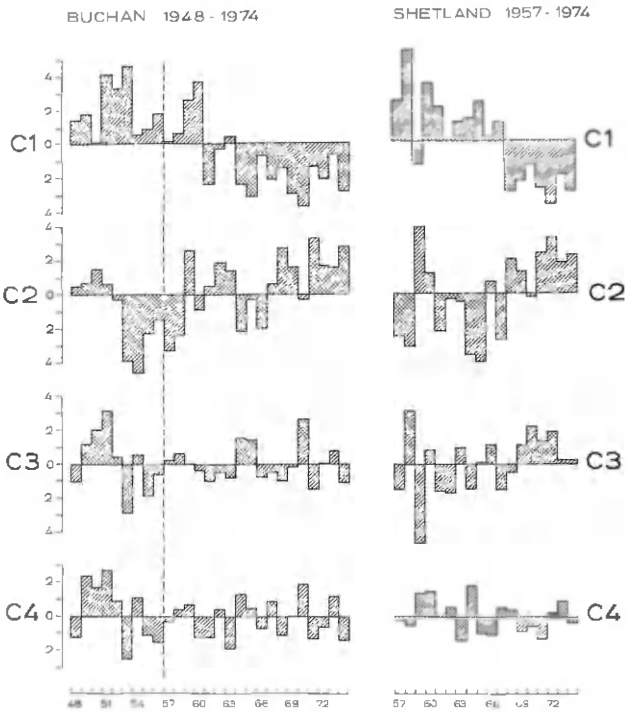

Figure 312. The first four components of the plankton data for the Buchan and Shetland areas.

and 1957–1974 in the Shetland area. The first four components in the Buchan area accounted for 24·8%, 19·3%, 10·2%, and 8·7% of the variance respectively and, off Shetland, 28·0%, 23·2%, 14·1%, and 8·3%. Each component has a value for each year and a mean of zero over the period (27 years at Buchan, 18 years at Shetland). Figure 312 shows the annual values; the first and second components show striking evidence of long-term trends.

To discover whether there were groups of species with similar fluctuation patterns, the first two vectors were plotted against each other. In the Buchan area, three groups could be distinguished. These were labelled *neritic*, *southern intermediate*, and *northern intermediate*, following the classification of Colebrook (1964). The first, Group A, consisted of *Temora*, Dinoflagellata, *Centropages hamatus*, *Centropages typicus*, and the combined genera *Paracalanus* and *Pseudocalanus*. This is basically the *neritic* group of earlier workers (Williamson, 1961, and Bainbridge and Forsyth, 1972) but with the addition of *Centropages typicus* and *Para/Pseudocalanus*, both of which were previously considered to be *southern intermediate* species. In this area the groups Cladocera and Larvacea do not appear to be as highly correlated with the other *neritic* entities as was previously thought. Group C, consisting of *Calanus*, *Spiratella*, *Clione*, and euphausiids, is a fairly compact group of *northern intermediate* forms and this group very closely resembles a similar group found by the earlier workers. The third, Group B, consisting of *Sagitta*, *Candacia*, *Tomopteris*, and *Oithona*, can be said to be a *southern intermediate* group but does not agree closely with the groupings found previously.

In the Shetland area, the groups are more easily identified. Group D, the *neritic* group, contains *Temora*, *Centropages hamatus*, *Centropages typicus*, Larvacea, and the Cladocera. This is a compact group and contains all the elements of both Williamson's (1961) and Bainbridge and Forsyth's (1972) *neritic* groups with the addition of *Centropages typicus*. Group E, however, which at Buchan (B) was considered *southern intermediate*, now includes the molluscs *Spiratella* and *Clione*. Group F is similar to Buchan Group C but without *Spiratella* and *Clione*.

By plotting V_1 against V_2 the closely allied groups of species can be identified, but this does not show how closely they are correlated. Using the data from both the Buchan and Shetland areas, correlation coefficients between the annual fluctuations in abundance of all possible pairs of entities were calculated using standardized 12-week averages and are presented as matrices in Figure 313. The affinities between the entities as demonstrated by the vector plots are clearly shown, especially in the matrix of the Shetland data.

Having identified groups of species with similar annual fluctuations, the mean abundance of these species was then calculated and correlated with the components. These, together with their significance levels, are shown in Table 165.

IDENTIFICATION OF COMPONENTS WITH ENVIRONMENTAL VARIABLES

The first four principal components were tested for correlation with a few selected physical properties of the environment.

Monthly mean values of surface temperature and salinity in the northeastern Atlantic and North Sea are available for standard rectangles of 2° longitude by 1° latitude. From these were calculated averages for the defined areas of the northwestern North Sea as illustrated in Figure 308. Monthly anomalies of surface temperature and salinity for the Buchan area were calculated as the deviations of the monthly means from the long-term mean for that month over the years 1948–1974. At Shetland, however, there were too many gaps in the salinity data to allow for interpolation. Sums of these anomalies for different sets of consecutive months during the spring and summer were then used for comparison with the

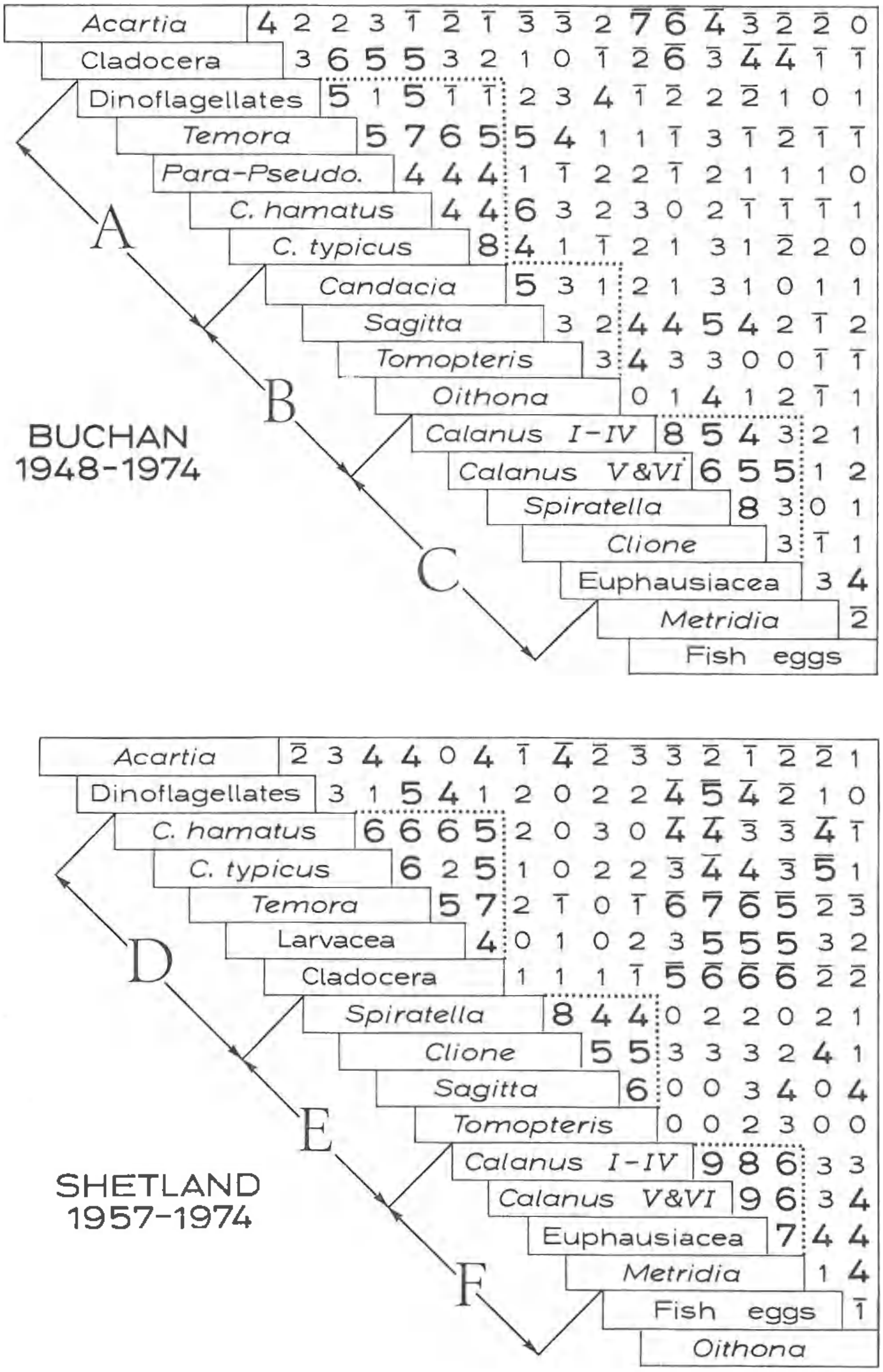

Figure 313. Matrices of the product moment correlation coefficients between the annual fluctuations in the average a of plankton entities during a 12-week period from June to mid-August, in the Buchan and Shetland areas. The correl multiplied by 10 and negative correlations are indicated by a bar.

Table 165

Group	Buchan C_1	C_2	C_3	C_4	Group	Shetland C_1	C_2	C_3	C_4
A.	0·62***	0·47	−0·27	−0·12	D.	−0·76***	0·96***	−0·06	0·04
B.	0·89***	−0·13	−0·10	0·14	E.	0·55*	0·09	0·22	0·14
C.	0·75***	−0·78***	−0·19	−0·20	F.	0·89***	−0·78***	−0·31	0·12

*** $p < 0{\cdot}001$ ** $p < 0{\cdot}01$ * $p < 0{\cdot}02$

principal components of the plankton from the two areas.

As a measure of the effects of vertical mixing, Craig (1960) used the rate of increase of surface temperature during the early summer (TI), measured by the function ("Craig's difference"): $TI = (A_{My} + A_{Jn} + A_{Jy})/3 - A_M$ where A_{My}, A_{Jn}, A_{Jy} and A_M are the temperature anomalies for May, June, July, and March respectively.

Various functions of temperature, salinity and sunlight are compared with the first four components of the plankton at Buchan and Shetland in Table 166.

For the Buchan area, component 1, accounting for the largest part of the variance, was most highly correlated ($p < 0{\cdot}05$) with Craig's difference (TI). This may be interpreted as meaning that, when TI values were high, there was early stabilization of the water column and consequently an early spring increase in the phytoplankton cycle. This led to high average abundance of zooplankton within the 12-week period. Conversely, when stabilization was late (low TI values) then zooplankton numbers were low within the 12-week season.

No correlation was found between the other chosen functions of temperature and salinity although Bainbridge and Forsyth (1972), in their previous review of these data (up to 1966) did find a significant correlation ($p < 0{\cdot}01$) between the summer temperature anomalies at Buchan and C_1.

At Shetland, the only significant correlation found was between the summer temperature anomaly and C_2. In years of high surface temperatures, the *neritic* group of plankton entities tended to be more abundant as this group at Shetland was also significantly correlated with C_2.

DISCUSSION

Glover (1957) considered the period 1947 to 1955, Williamson (1961) used data from 1949 to 1959, and Bainbridge and Forsyth (1972) were able to incorporate data from 1948 to 1966. Consideration of the results, after adding the intervening years up to and including 1974, confirms broadly the findings of the earlier workers. For Buchan, the plankton associations they found are similar to those described in this paper. They had concluded that the annual fluctuations in abundance and distribution of the plankton in the Buchan area were related to the degree of vertical mixing of the water column in the spring and to the measure of Atlantic inflow during the summer. The latitudinal distribution of the herring stock was also related to the strength of Atlantic influence in the northwestern North Sea, which might be indicated by the salinity anomaly in May–August. At Shetland there are different groups of species, and only Group D, the *neritic* group, bears much similarity to the *neritic* Group A of the Buchan area. Of the principal components of the Shetland plankton, only C_1 and C_2 could be shown to have any correlation with the

Table 166

	Buchan C_1	C_2	C_3	C_4		Shetland C_1	C_2	C_3	C_4
Craig's difference	0·39*	−0·18	−0·10	−0·16	Craig's difference	0·11	0·10	0·44	−0·18
Temp. anomaly Mar–May	0	0·15	−0·16	−0·09	Temp. anomaly Mar–May	−0·29	0·39	−0·32	−0·01
Temp. anomaly May–Aug.	0·14	0·16	−0·30	−0·24	Temp. anomaly May–Aug.	−0·31	0·57**	0·21	−0·14
Salinity anomaly May–Aug.	−0·14	−0·12	−0·07	−0·12	Hours sunshine Lerwick Apr–Jun	−0·24	0·29	−0·12	−0·14

* $p < 0{\cdot}05$ ** $p < 0{\cdot}02$

plankton groups, and even these components showed little or no correlation with the various parameters of the physical environment considered in this study.

In their paper, Bainbridge and Forsyth (1972) concluded that there was little doubt that one of the factors governing the distribution of the herring was the distribution of *Calanus finmarchicus* and *Spiratella retroversa*, the chief food organisms of the herring. Together they form the bulk of the biomass of plankton in the areas under review. In all the years since 1966, both these organisms have been less abundant than the long-term mean in both areas, and during this period there has been no evidence of the return of the now "extinct" Buchan fishery and there has been a steady decline in the yield of the Shetland fishery apart from a slight resurgence in 1972.

ACKNOWLEDGEMENTS

The authors would like to thank their colleagues at the Oceanographic Laboratory, Mr. Collins for helping with the analysis and data processing, and Mr. Hunt for valuable help and advice on statistical techniques.

This work forms part of the research programme of the Institute for Marine Environmental Research, a component body of the Natural Environm search Council.

REFERENCES

Bainbridge, V. & Forsyth, D. C. T. 1972. An ecologi of a Scottish herring fishery. Part V: The plankt north-western North Sea in relation to the physica ment and the distribution of herring. Bull. mar. Ecol.,

Colebrook, J. M. 1964. Continuous Plankton Records: pal component analysis of the geographical distributi plankton. Bull. mar. Ecol., 6: 78–100.

Craig, R. W. 1960. A note on the dependence of c temperature and wind in the Buchan pre-spawnin fishery. J. Cons. perm. int. Explor. Mer, 25: 185–190

Glover, R. S. 1953. The Hardy Plankton Indicator and A description of the various models in use. Bull. n 4: 7–20.

Glover, R. S. 1957. An ecological survey of the drift-n fishery off the north-east coast of Scotland. Part II: T tonic environment of the herring. Bull. mar. Ecol.,

Harden Jones, F. R. 1968. Fish migration. Edward Ar London. 325 pp.

Saville, A. 1967. The Scottish herring fishery and explo in the northern North Sea in 1966 and 1967. ICES H: 29, 8 pp. (mimeo).

Williamson, M. H. 1961. An ecological survey of a Sco ring fishery. Part IV: Changes in the plankton d period 1949–1959. Appendix: A method for studying tion of plankton variations to hydrography. Bull. n 5: 207–229.

Printed in Denmark by Bianco Luno A/S