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CONTINUOUS PLANKTON RECORDS: LARGE-SCALE CHANGES IN THE ABUNDANCE OF PHYTOPLANKTON IN THE NORTH SEA FROM 1958 TO 1973

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INTRODUCTION

Continuous Plankton Recorders (CPRs) sample regularly in the North Sea at a depth of approximately 10 m (Hardy, 1939; Glover, 1967). The plankton is collected on a continuously moving band of silk, which is later cut into samples representing 10 miles of tow. The sampling gear is primarily aimed at zooplankton; its mesh size of 270 μm is not adequate for retaining all size categories of phytoplankton in a quantitative manner. However, for many areas of the North Sea the survey provides the only available information on the distribution and long-term variability of the phytoplankton. Previous surveys in the the North Sea using water-bottle samples (for example, Gran, 1915; Grøntved, 1952; Braarud et al., 1953) were limited in their geographical coverage and to one or a few months of the year. This paper describes the results of a study of the phytoplankton in more than 15000 CPR samples taken in almost every month from 1958 to 1973 in six standard areas of the North Sea (Fig. 298).

METHODS

CPR samples are analysed for phytoplankton in two stages. Firstly, phytoplankton colour is assessed into three categories of greenness against standard colour charts; numerical values are given to the colour categories, based on acetone extracts (Robinson, 1970). These assessments of colour give gross estimates of phytoplankton standing crop which are comparable within the CPR survey. Secondly, species of diatoms and dinoflagellates are counted, using a method introduced in 1958 (Colebrook, 1960). Twenty fields with diameters of 0·3 mm are examined in two diagonals across the filtering silk. The number of fields in which each species is observed is used to calculate the number of that species in the sample. To reduce bias and errors introduced by the category system, a logarithmic transformation is applied to all counts.

Monthly means for phytoplankton colour and phytoplankton species counts were calculated for samples in rectangles (2° longitude × 1° latitude) and then averaged to give monthly means for the larger standard areas (Fig. 298). Summed average monthly numbers of the eighteen most common diatoms and seven species of *Ceratium* (Table 163) were then calculated for each standard area and contoured month/year arrays (with interpolated missing months) constructed for phytoplankton colour, diatoms, and *Ceratium* spp. (Figs. 299a, b, c). These arrays are limited to the period, starting in 1958, when the method of counting was standardized.

RESULTS

Since 1958, there have been major changes in the abundance of certain components of North Sea phytoplankton in all six standard areas. In general, phytoplankton colour (a standing crop index of all phytoplankton components) has increased, whereas the numbers of diatoms have declined drastically, while *Ceratium* spp. have only undergone minor changes in numbers. It is not known how these changes have affected the production of North Sea phytoplankton.

Phytoplankton colour showed the same pattern of changing abundance in standard areas D1, D2, C2, and B2 (Figs. 299a, b, c); in all these areas there was a general increase in season length and colour intensity, particularly in the summer months since 1965 or 1967. In standard area C1 (Fig. 299b) there was little change, except for a slight increase in season length after 1965 and a considerable decline in the intensity of the spring bloom in the last three years. The intensity of both the spring and autumn blooms varied in area B1 (Fig. 299c).

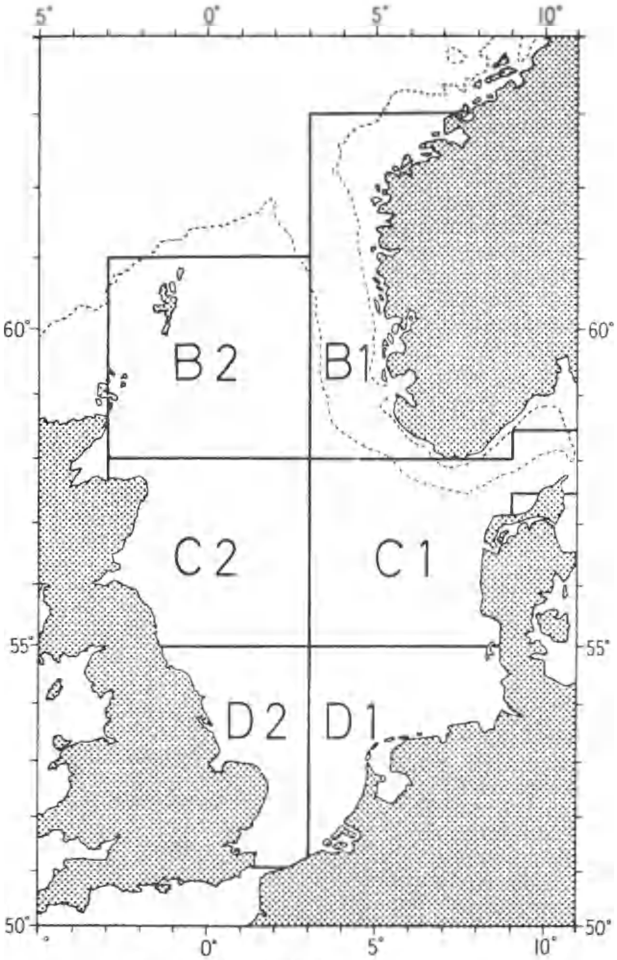

Figure 298. North Sea standard areas.

Table 163. Standard Area Species List

	D2	D1	C2	C1	B2	B1
Paralia sulcata (Ehrenb.) Cleve	×	×	×	×	–	–
Skeletonema costatum (Grev.) Cleve	×	×	×	×	×	×
Thalassiosira spp.	×	×	×	×	×	×
Dactyliosolen mediterraneus Perag.	–	–	×	×	×	×
Rhizosolenia imbricata forma *shrubsolei* (Cleve) Schröder	×	×	×	×	×	×
Rhizosolenia styliformis Brightw.	×	×	×	×	×	–
Rhizosolenia hebetata forma *semispina* (Hensen) Gran	×	×	×	×	×	–
Rhizosolenia alata forma *indica* (Perag.) Gran	–	–	×	–	–	–
Rhizosolenia alata forma *alata* Brightw.	×	×	×	×	×	×
Rhizosolenia alata forma *inermis* Castr.	–	–	–	–	×	–
Hyalochaeta spp.	×	×	×	×	×	×
Phaeoceros spp.	×	×	×	×	×	×
Biddulphia sinensis Grev.	×	×	–	×	–	–
Asterionella glacialis Castr.	×	×	×	×	×	–
Thalassiothrix longissima Cleve & Gran	×	×	×	×	×	×
Thalassionema nitzschioides Hust.	×	×	×	×	×	×
Nitzschia seriata Cleve	×	×	×	×	×	×
Nitzschia delicatissima Cleve	×	×	×	×	×	×
Ceratium fusus (Ehrenb.) Dujardin	×	×	×	×	×	×
Ceratium furca (Ehrenb.) Clap. & Lachm.	×	×	×	×	×	×
Ceratium lineatum (Ehrenb.) Cleve	×	×	×	×	×	–
Ceratium tripos (Müller) Nitzch	×	×	×	×	×	×
Ceratium macroceros (Ehrenb.) Vanhöffen	×	×	×	×	×	×
Ceratium horridum (Cleve) Gran	×	×	×	×	×	×
Ceratium longipes (Bailey) Gran	×	×	×	×	×	×

Includes common species selected to give diatom abundance and *Ceratium* spp. abundance.

× = included in calculations.

The numbers of diatoms showed the same general trend in all six areas; diatoms have declined greatly in abundance since approximately 1965 and, by 1968, had almost disappeared from CPR samples in late summer, autumn, and winter. Spring diatoms underwent a less dramatic decline in abundance after 1968. These trends are seen as a much reduced season length, especially after 1968.

There were considerable year-to-year fluctuations in the abundance and timing of *Ceratium* spp. but no common overall trend during the period studied (Figs. 299a, b, c), although there were signs of an earlier start to the season during the last two or three years in three areas (D2, D1, and C1).

Thus, by combining the results of analysis for a number of the dominant species, major patterns of variability in the abundance of the phytoplankton have been emphasized. Changes which have occurred in the three entities, phytoplankton colour, diatoms, and *Ceratium* spp., can be detected to a greater or lesser degree in all areas of the North Sea (Figs. 299a, b, c); in particular, three sequences of years can be distinguished:

1) 1958–1965 was characterized by the occurrence of large spring and autumn diatom blooms in all six areas.
2) From 1966 to 1973, autumn diatoms declined drastically in all six areas, but "season length" of

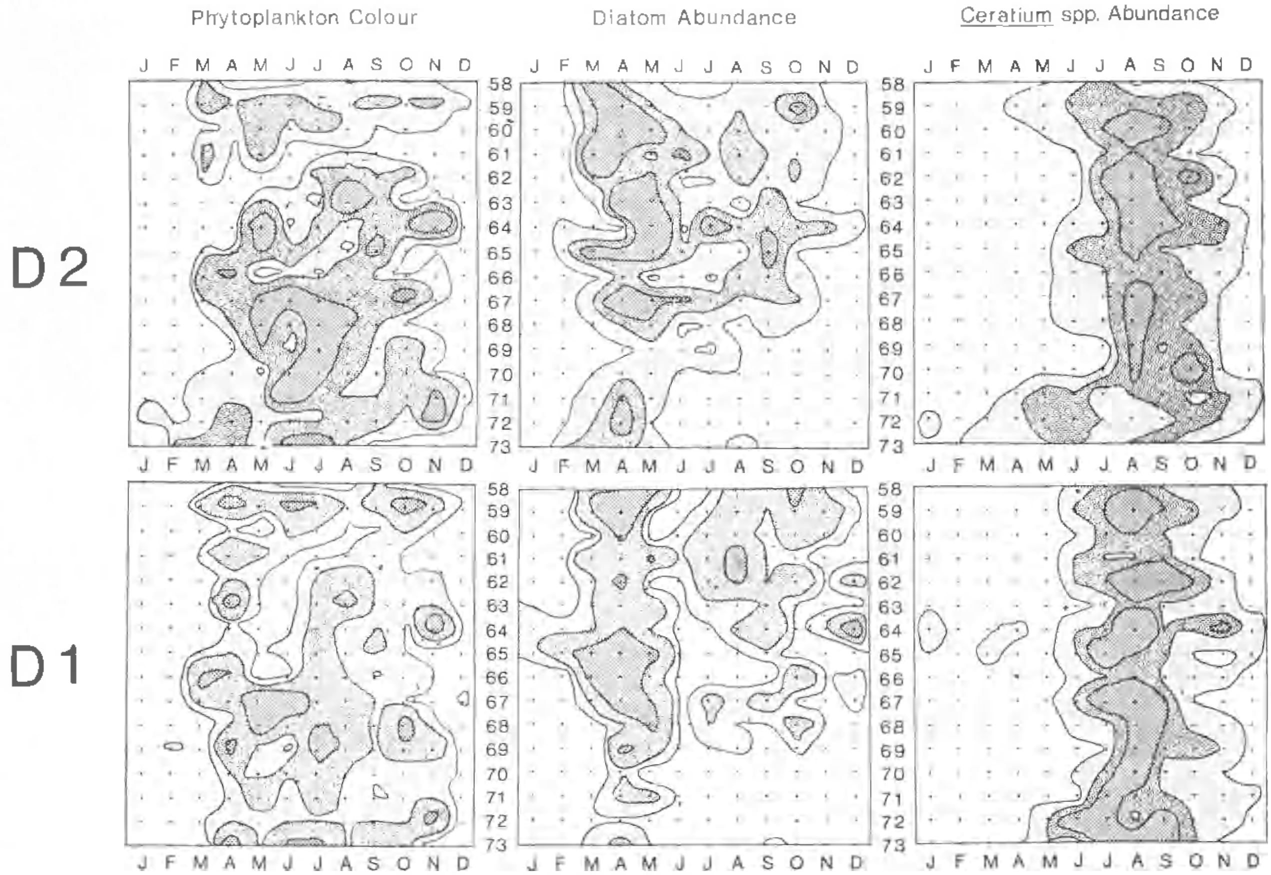

Figure 299a. Phytoplankton from 1958 to 1973 in standard areas D2 and D1.

Contour levels:

	Phytoplankton colour			Diatom abundance			*Ceratium* spp. abundance		
D2	110	150	230	183	366	585	183	640	1353
D1	130	200	330	183	274	530	128	823	1207

phytoplankton colour increased in all except B1 and C1.

3) 1971–1973 in areas C1, D2, and D1 was distinguished particularly by a greatly increased season length of *Ceratium* spp.

The increase in phytoplankton colour in the last decade cannot be explained by the patterns of abundance shown by *Ceratium* spp. and the diatoms. As phytoplankton colour has increased, the abundance of *Ceratium* spp. has remained constant or declined, and diatom abundance has greatly declined. Neither can the increasing colour be explained by the occurrence of *Phaeocystis*, which showed a decline similar to that of the diatoms after 1965, nor Silicoflagellates or Coccolithophores which occurred in only small numbers. Associated with this increase in phytoplankton colour are anomalies between peaks of colour and of abundance of phytoplankton. Such anomalies occurred in nearly all areas but are particularly evident in the summer months of the southern North Sea (areas D2, D1). It would appear, therefore, that an unidentified component of the phytoplankton is increasing as diatoms are declining.

DISCUSSION

A major change appears to have taken place in the composition and abundance of North Sea phytoplankton within the last decade. How these changes may have affected phytoplankton productivity is impossible to assess, since there are no time series of

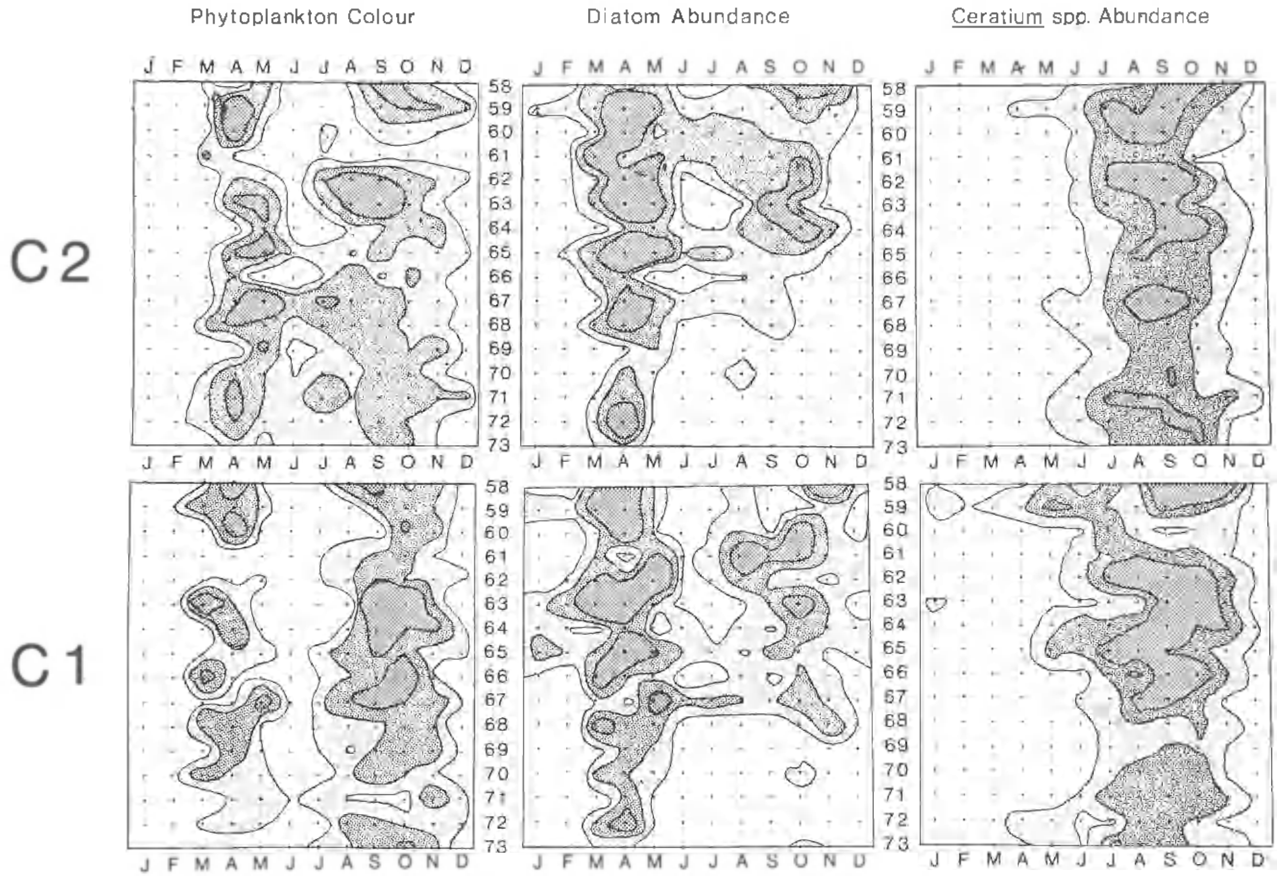

Figure 299b. Phytoplankton from 1958 to 1973 in standard areas C2 and C1.

Contour levels:

	Phytoplankton colour			Diatom abundance			*Ceratium* spp. abundance		
C2	80	120	170	220	366	585	274	878	1902
C1	90	130	210	183	329	530	420	1079	1993

phytoplankton production measurements in the North Sea. The difficulties of interpreting such changes in the plankton in relation to environmental variables were recently discussed in a series of papers by Glover et al. (1972, 1973, 1974). Many causes of biological variability are now known from laboratory experiments, but it is difficult to extrapolate to the natural environment because time-series data for physical and chemical variables are inadequate. Consequently it is only possible to speculate about causal relationships. They can be discussed under five main headings: pollution, climatic change, biological succession, phytoplankton composition, and sampling artifacts.

Moore and Harriss (1974) have shown that the components of a natural phytoplankton community are differentially sensitive to PCBs. Such a selective toxicity to pollutants could clearly result in changes in community structure. The considerable increase in nutrients which has taken place in the southern North Sea in recent years (Folkard and Jones, 1974) could also, conceivably, affect the productivity and community composition in areas D1 and D2. However, pollution seems an unlikely cause of the changes described here, because a recent survey (ICES, 1974) reports that the North Sea is relatively unpolluted.

Changes observed in both the phytoplankton and zooplankton of the North Sea are part of a pattern which is typical of a large area of the North Atlantic (Colebrook, 1972; Glover et al., 1974). These results tend to suggest that major northern hemisphere hydrometeorological trends as described by Dickson and Lee (1972) are likely to be the main causative factor

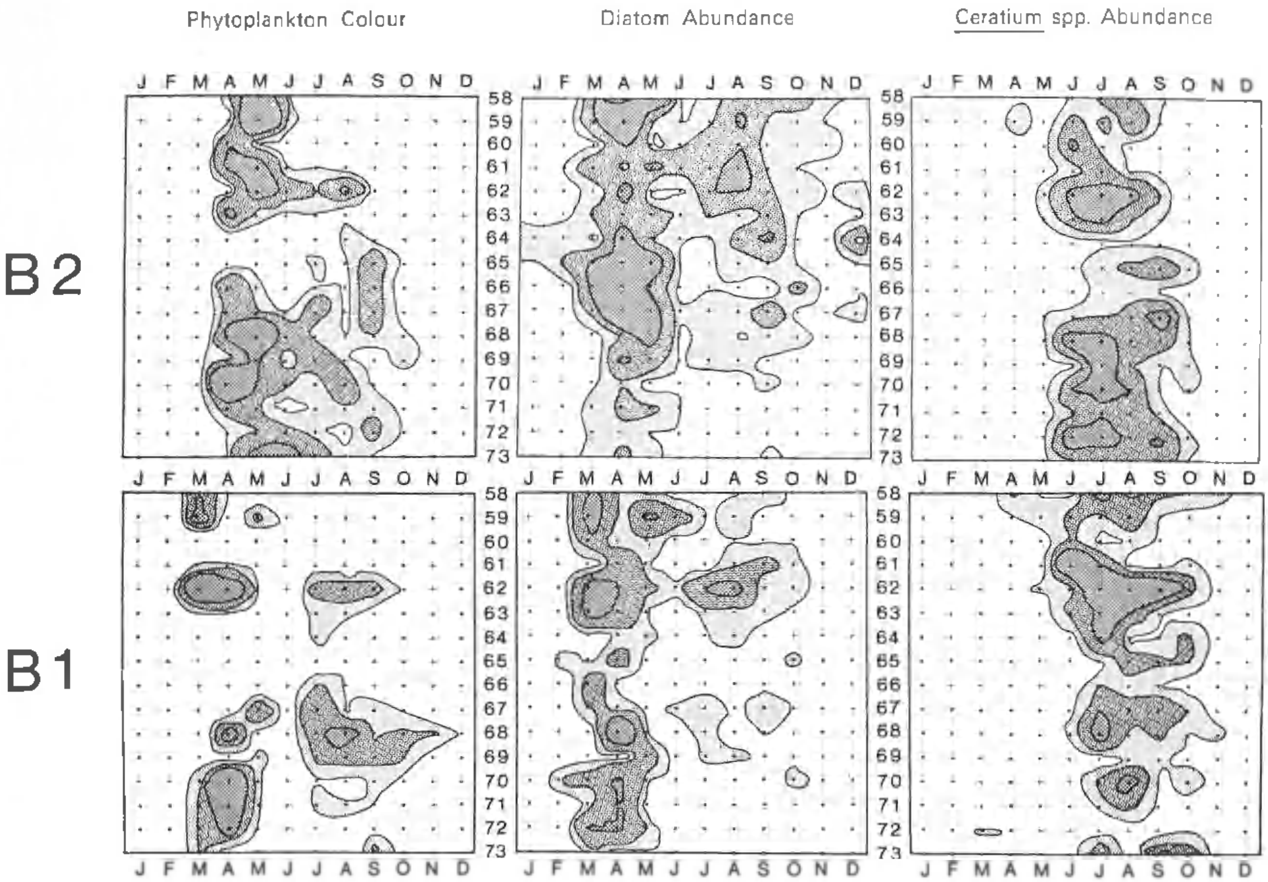

Figure 299c. Phytoplankton from 1958 to 1973 in standard areas B2 and B1.

Contour levels:

	Phytoplankton colour			Diatom abundance			*Ceratium* spp. abundance		
B2	70	110	235	128	274	530	274	640	1150
B1	50	87	150	128	274	750	220	530	1134

behind the variability of North Sea phytoplankton. These climatic trends appear to be related to an unexplained decline in available solar energy (Dickson and Lee, op. cit.) which has led to a change in pressure belts and a southerly advance of arctic ice. These in turn have led to lower temperatures and changes in the water movements of the North Atlantic. A possible reversal of these trends from 1971 to 1974 is mentioned by Miles (1975) in a recent review of the causes of climatic change.

The large-scale changes which have taken place in the North Sea in the last decade may be part of a long-term phytoplankton succession, as distinct from the annual succession discussed by Braarud et al. (1953). The causes of phytoplankton succession are poorly understood. In particular, little is known regarding inhibition by other components of the phytoplankton or about the feedback effects of a change in the grazing pressure of higher trophic levels. Such a mechanism becomes especially feasible considering the man-made changes in North Sea fish stocks and the complicated life cycles, incorporating resting stages, of many phytoplankton groups.

An increase in the abundance of microflagellates could explain the general increase of phytoplankton colour in the last decade. Microflagellates would not be identifiable in the CPR samples, as they disintegrate in formalin, but their chloroplasts would survive to add to the coloration of the silks. A seasonal succession of large numbers of flagellates in the North Sea after a rapid increase in diatom numbers was observed by Grøntved (1952) in 1947.

An alternative possibility is that the changes observed in the phytoplankton could be an artifact due to the sampling characteristics of the CPR. CPRs are towed at an approximately constant depth of 10 m, but the effect of waves, and the turbulence caused by the ship's screw, mean that a representative sample of, perhaps, the top 20 m is obtained. It is, however, unlikely that the changes reported here could be caused by the phytoplankton sinking below the sampled depth, especially as large areas of the North Sea are unstratified throughout the year.

SUMMARY

Patterns of changes in phytoplankton colour and phytoplankton species counts, sampled by the Continuous Plankton Recorder (CPR) in the past sixteen years, appear to be widespread in the North Sea. Unexplained anomalies between phytoplankton colour and the species counts might possibly be caused by an increase in microflagellates. The extensive nature of these changes implies that they are unlikely to be related to pollution but are probably related to major climatic events that have taken place over the same period. A programme to examine changes in community structure and to extend the record back to 1931 by utilizing prewar CPR data is currently under way.

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