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THE STATUS OF PLANKTON POPULATIONS IN THE NORTHWEST EUROPEAN SHELF SEAS AND THE NORTHWEST ATLANTIC AS DETERMINED BY THE CONTINUOUS PLANKTON RECORDER SURVEY

by

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Abstract

Despite a crisis in support in 1988, the Continuous Plankton Recorder (CPR) Survey of the upper mixed layer mesoscale plankton of the north Atlantic Ocean continues to operate. The trends of the last decade in the abundance of zooplankton and phytoplankton in the North Sea and the NE Atlantic around the British Isles were largely maintained in 1991 and 1992 although there are indications that the increasing trend in zooplankton of the North Sea is now diminishing. Data are presented on the resumption of sampling in the NW Atlantic and it appears that the abundance of the commoner taxa have not altered from previously observed levels. Data are also presented on the status of phytoplankon in the North Sea. New attempts are being made to characterise the true meaning of the CPR phytoplankton colour index and to measure and monitor the sampling performance of the Recorders. The latter information is essential for a more accurate estimation of the true biomass of the plankton populations sampled by the CPR.

Introduction

During the 60 years of its existence the Continuous Plankton Recorder (CPR) Survey has provided unique data on the spatial and temporal patterns of distribution and population structure of the upper mixed layer mesoscale plankton in the shelf seas around the British Isles and also across the North Atlantic. Despite this achievement, the Survey almost closed down in 1988 when the major source of funding was withdrawn and only survived through an international effort in which ICES played a major supportive role. However, for continued survival it is obvious that the Survey must widen its relevance and, in particular, must be able to provide quantitative data which can be of direct use in multidisciplinary oceanographic research programmes such as JGOFS and GLOBEC for which the CPR data can provide an unparalleled spatial and temporal perspective.

Unlike the other two spatio-temporal plankton surveys, CalCOFI (Chelton *et al*, 1982, McGowan, 1990) and MARMAP (Sherman, 1980, Meise-Munns *et al*, 1990), the CPR Survey does not operate on a regularly sampled grid system but samples plankton using a specially designed instrument towed behind commercial ships (Hardy, 1939, Glover, 1967). While this sampling strategy made it realistically possible to establish a basin-wide survey across the North Atlantic; the data obtained is necessarily limited in its scope, in particular being confined to a single depth and restricted to robust organisms caught on a relatively wide mesh (nominally 270µm) screen. These problems were recognised from the onset by Hardy (1935) and subsequent workers (Rae, 1952, Colebrook, 1960, 1975) and an analytical strategy was developed which concentrated on maintaining consistency at all stages throughout the entire operational process.

The purpose of this paper is therefore twofold; firstly to provide an update on the status of the plankton populations as determined in the traditional manner by the Survey and secondly, to outline some of the questions which we are now addressing about the methods used and the true meaning and accuracy of the data obtained. The update will consist of the most recent incrementation of the time series in the NE Atlantic and the North Sea, some of the latest data from the re-instated routes in the NW Atlantic and a discussion of the regional changes in the phytoplankton populations in the North Sea. Our questions will relate to aspects of the performance of the CPR and to an evaluation of the meaning of the colour index used to estimate the overall abundance of phytoplankton.

Long-term trends in the North Sea and NE Atlantic.

The first principal component of the fluctuations in abundance of plankton populations has traditionally been used as an analogue of the overall plankton abundance measured by the CPR. Despite reservations about the current usefulness of the use of principal components analysis to summarise the long term population trends in plankton (CPR Survey Team, 1992), it still remains instructive to use this standard technique developed by Colebrook (1978). The overall trend in the populations of most of the planktonic entities sampled by the CPR since the re-establishment of the Survey in the late 1940s was a steady decline for the first 30 or so years (Colebrook, 1982, 1985). However

Colebrook *et al*, (1984) presented the first evidence of a reversal in the 35 year decline but stated that more data was required before the upward trend could be confirmed. This was substantiated in subsequent publications (Dickson *et al*, 1988, Aebischer *et al*, 1992, CPR Survey team, 1992) where parallels were drawn between the long term trends in the abundance of zooplankton and phytoplankton and several hydrographic and climatic indices. The inferences made from these comparisons, in concert with the work of Taylor *et al*, 1992, were that the plankton populations of the NE Northern Atlantic and the North Sea were responding to changes in meteorological and climatic events although the mechanisms involved have not been resolved.

The increasing trend in the abundance of the zooplankton and phytoplankton was maintained throughout the 1980s in the North Atlantic but it is apparent that, when subdivided into North Sea and NE Atlantic regions (i.e. the shelf area to the N, W and SW of the British Isles), the increase in the trend is most evident in the North Sea zooplankton and, to a lesser extent, in the phytoplankton of both regions (Fig 1). The Atlantic zooplankton merely maintained the same rate of decline since the slight reduction which occurred around 1970. No obvious changes have occurred in both phytoplankton and the Atlantic zooplankton trends in recent years but the North Sea zooplankton was considerably more variable. The value in 1989 attained the highest level in the entire 40+ year series at over 2 standard deviations (sd) greater than the long term mean however, in the following year the decline of >2sd was the largest ever recorded in the entire time series. The 1992 data somewhat redressed the situation.

The cause of the decline in North Sea zooplankton in 1991 is as yet unexplained, although the high levels in the late 1980s could be associated with the circumstance and consequences of the increase in dinoflagellates in the northern North Sea (Dickson *et al*, 1988). The dinoflagellates, (several *Ceratium* species), have returned to normal levels (Fig 2) as have the numbers of the copepod *Metridia lucens*, although the population levels of the less abundant copepod, *Corycaeus* spp still appear to be fluctuating above average levels.

Northwest Atlantic.

One of the main questions which arises when sampling is resumed after a lapse is to whether any significant changes have taken place in the intervening period. For the purposes of this initial examination, three taxa were singled out, two, *Thalassiosira* spp and *Calanus finmarchicus* CV and CVI as they are distributed most evenly over the length of the transect and are the most widespread and abundant of the CPR-sampled phyto- and zooplankton, and the other, *Ceratium arcticum*, as it is an indicator of cold water associated with the Labrador Current (Edinburgh Oceanographic Laboratory, 1973).

Standardised annual mean abundances for these taxa are shown in Figure 3b where the data along the length of the transect have been subdivided into five latitudinally differentiated areas. (Fig 3a). The plots in Fig 2 have been arranged in order with the lowest latitude at the bottom and the highest at the top. The *Thalassiosira* and *C. finmarchicus* population abundances in 1991 and 1992 do not appear to be any different from the populations previous sampled with the exception of the *C. finmarchicus* in Area 4, which includes the Scotian Shelf, where the abundance in 1992 was the lowest measured, almost 2sd lower than the standardised mean. The major feature of the *C. finmarchicus* however was the coherent decline in numbers between 1991-1992 in each area along the transect. This was not shown by *Thalassiosira*.

The focal point of the populations of the dinoflagellate *Ceratium arcticum* is in area 3 which encompasses Newfoundland and includes the Grand Banks. The 1991-92 abundances from this area are very close to the long-term mean but there were considerable increases in 1991 in the two most northerly areas in the eastern Irminger Basin and the most southerly region which includes Georges Bank. On many occasions in the past *C. arcticum* was not recorded in these regions at all, and indeed it returned to very low levels to the east of the Irminger Basin in 1992, implying that, in 1991 there was an incursion of cold Labrador Current water displacing the warmer North Atlantic Current to the east. This situation was not sustained in 1992.

North Sea Phytoplankton

Although the majority of phytoplankton cells pass through the 270μm mesh of the CPR filter, sufficient phytoplankton material is retained to colour the silk mesh superficially which provides a convenient relative index (Robinson and Hiby, 1980, Robinson, 1983) of phytoplankton concentration. The monthly fluctuations in the phytoplankton colour index for the six CPR subdivisions of the North Sea (see Reid *et al*, 1990) illustrated in Fig 4 show clear differences particularly when comparing the samples from the northern areas with those in the south below 55°N. The disparity in the length of the growing season, (March to end of September in the NW region B2, compared with February to end of November in the SE region D1), and the clearer bimodal seasonality in the northern and central regions are the most striking differences.

However, the most significant changes apparent from the contour presentations are the increased concentrations and extended growing seasons in most recent years and in the eastern Central North Sea area (C1) in particular. It appears in this region that, in 1988, there was abundant phytoplankton in January and February thus implying that production continued throughout the year. Comparisons were made therefore between the average seasonal distributions of the diatoms and dinoflagellates captured by the CPR in the 5-year periods from 1965-70 and 1985-90.

There is no evidence of any increase in the abundance of diatoms (Fig 5), indeed it would appear that in some regions such as the south-western area D2, the diatom concentrations are at an overall lower level (the values in area B1 should be treated cautiously as the sampling in this area was much reduced in 1985-90 compared with 1965-70). In contrast, there are clear differences between the abundance of dinoflagellates (Fig 6) with greater concentrations occurring recently compared with 20 years previously in both northern and central areas. This clearly relates to the outbreak of dinoflagellates in the northern North Sea attributed by Dickson *et al*, (1993) to an efflux of low salinity water over the region from the Baltic. While these differences in dinoflagellate abundance probably do explain the increased concentrations of phytoplankton colour in July - September in the northern and central areas, there is no evident explanation of the extension of the growth season. It is possible, however, that this could be due to the increased prevalence of microplankton which would remain unrecognised as intact cells on the CPR sampling silks.

Questions about the Survey

There are many aspects of the CPR Survey which need to be addressed and evaluated as they relate to assumptions made about the integrity and internal consistency of the entire operation One of the more controversial measurements is the phytoplankton colour index discussed above and in particular the correlation between the colour index and chlorophyll. This has been examined by Hays and Lindley (submitted) who showed that a significant correlation could only be obtained in the absence of large phytoplankton cells recorded on the CPR silks. It appears that the high intensity green colouration is due either to high ambient levels and/or high numbers of large phytoplankton cells (independent of the high chlorophyll levels in the latter case) retained on the CPR silk. While the CPR colour index remains an internally consistent measurement (depending on the consistency of the visual recorders), interpretation of absolute levels of phytoplankton standing stock from this index must be regarded with a significant degree of circumspection.

The second aspect of the Survey being examined at present relates to the performance of the CPR itself. It has become commonplace to accept that the sampler operates at a depth of 10m which is maintained irrespective of the speed of the towing vessels. Secondly there is a need to provide accurate information on the biomass of plankton sampled by the CPR which, in turn, requires detailed information on the sampling characteristics of the sampler. In recent years instrumentation packages have been developed for CPRs (Williams and Aiken, 1990) which, among other information, provide data on the depth of sampling Using data provided by R. Williams of the Plymouth Marine Laboratory (*pers comm.*) on CPR tows in the North Sea, Hays and Warner (in press) have demonstrated that CPRs fitted with box section tail assemblies (introduced on the Survey from the late 1970s) but without the forward hydroplane, sampled at a depth of around 7m. Furthermore, sampling depth was shown to be independent of towing speeds ranging between 8 and 16 knots (Fig 7) although it is noticeable that there was considerable variation in the depth range from 2 to 14 metres.

The abundance of just under 400 phyto- and zooplanktonic taxonomic entities are estimated in the routine CPR analysis. However these vary greatly in size and invariably are retained with wide ranging efficiency by the 270µm of the CPR. Further, we need to know whether the CPR has the predictable functioning characteristics of a 270µm mesh sampler or whether there are features associated with the unique construction of the CPR. In a recent study Hays (submitted) placed a fine(140µm) nylon mesh behind the usual CPR filtering silk to catch organisms passing through the CPR. These experiments have revealed that the CPR catches plankton, in this case copepods, in the manner predicted for 270µm nylon mesh (Nichols and Thompson 1991). The relationship obtained (Fig 8) can be used to predict the proportions of different sized organisms retained by the CPR and should thus be used in the estimation of the population biomass sampled.

Such filtering characteristics assume that the plankton mesh is filtering with 100% efficiency and that the retention of the plankton is solely dependent upon the geometry of the mesh. However we know from experience that, in the spring and summer periods in particular, the mesh of the CPR must become clogged by high concentrations of organisms despite the constant movement of the mesh across the flow path. While nothing can be done within the constraints of the CPR operation to circumvent clogging of the filter meshes it is possible to monitor the flow rate through the filter and thus estimate true sample volumes. Indeed in some recent trials we have measured the flow volume over known towing distances and have recorded values of about 50% of the value predicted from the dimensions of the mouth of the CPR. We are therefore beginning to suspect that the oft cited $3m^3$ sample per 10 mile sampling unit is an over-estimation.

Conclusion

The Continuous Plankton Recorder Survey, with support from several countries and international organisations, continues to increment its long term database on the distribution and abundance of plankton in the North Atlantic. Recent data would suggest that the increasing trend in the fluctuations of abundance in plankton in the North Sea have been checked although more years of data are required to see whether there is actually to be a persistent downturn. The Survey routes in the Northwest Atlantic were recommenced in 1991 and, although it is too early to make definitive comparisons with the earlier time series, the recent abundance of the commoner species do not appear to differ from the earlier records. An exception may have been the cold water dinoflagellate, *Ceratium arcticum,* which seemed to have an extended distribution in 1991.

Many assumptions have been made about the CPR data and the nature of its collection. It is recognised that these must be systematically addressed if the Survey is to become of more direct use to other ongoing programmes. At present we are concentrating on understanding the sampling characteristics of the CPR itself. The outcome of this will be to take measures to monitor sampling performance, such as flow metering and depth recording, routinely in the future.

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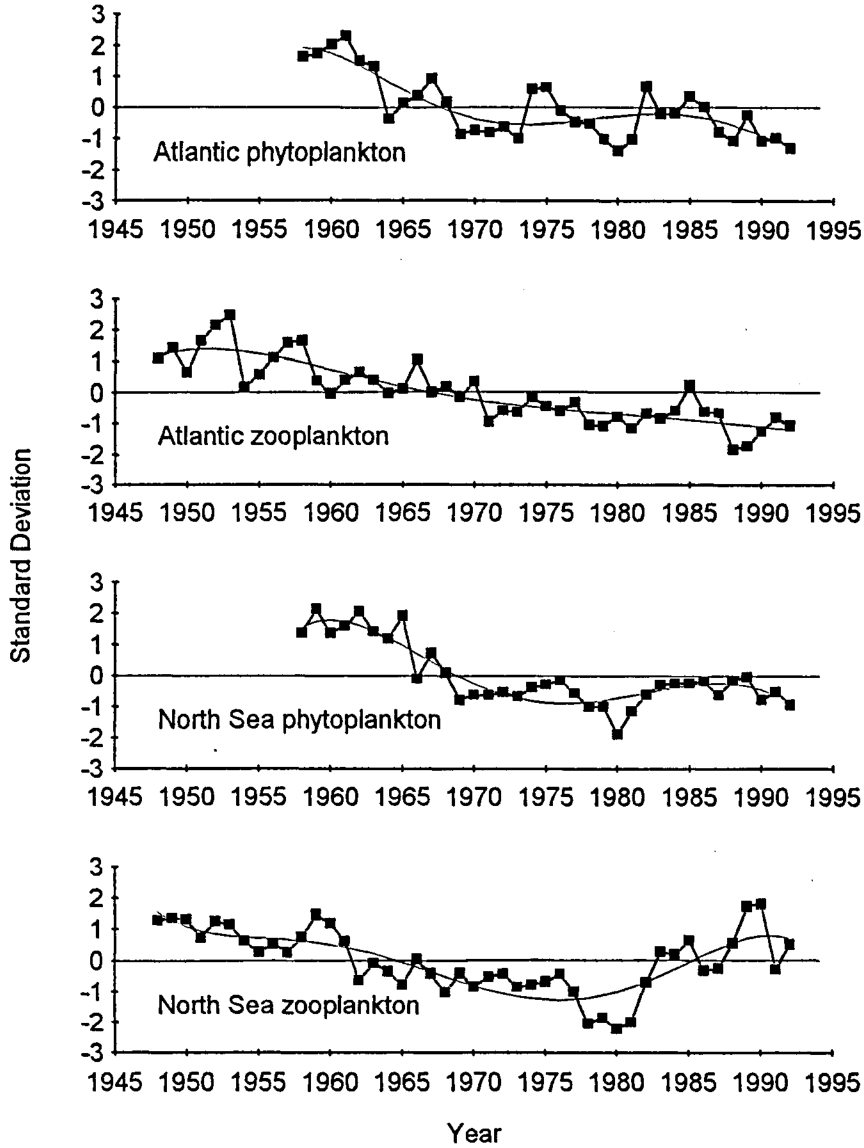


Figure 1. First principal component of the fluctuations in abundance (standardised to zero mean and unit variance) of phytoplankton and zooplankton in the northeast Atlantic around the British Isles and the North Sea. Fifth order polynomial fitted to data.

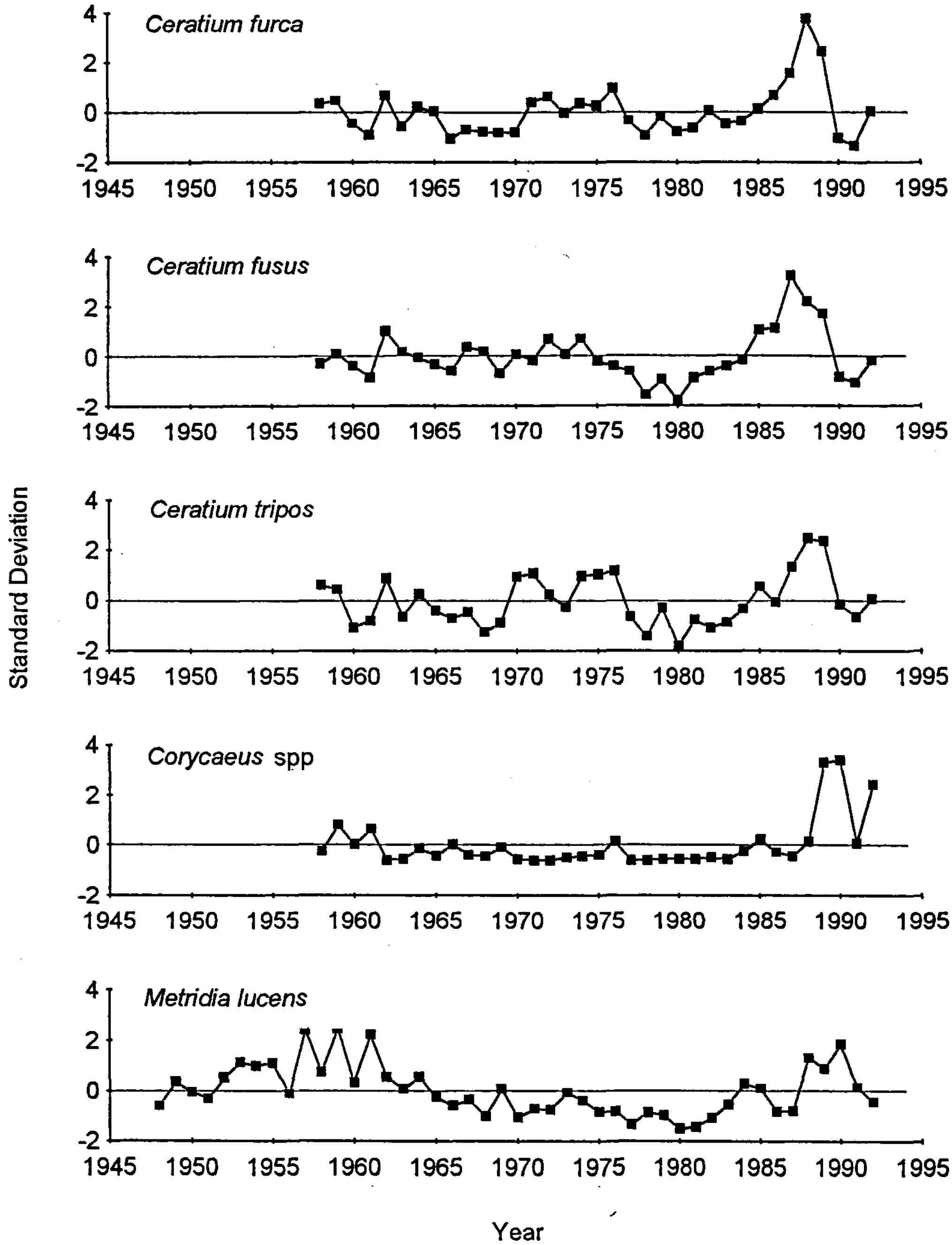


Figure 2 Standardised annual mean abundance of three *Ceratium* spp and two copepod taxa in the North Sea.

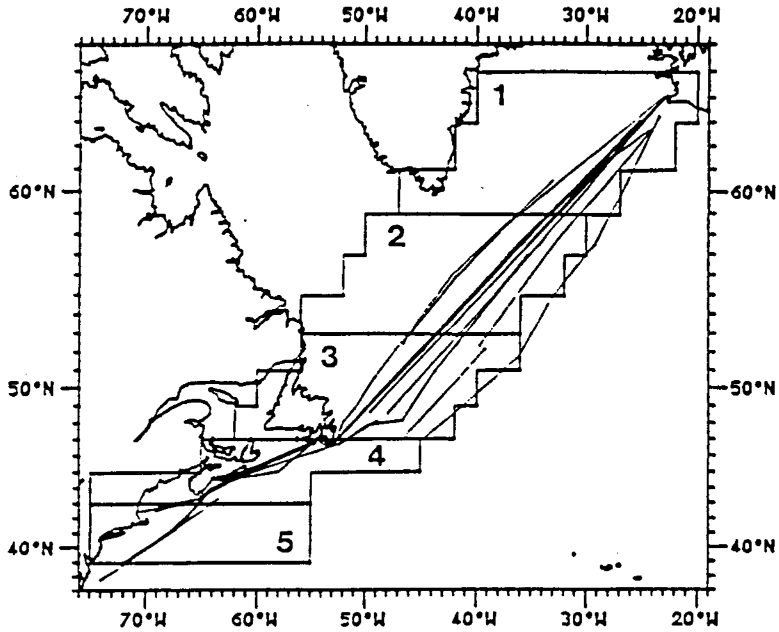


Figure 3(a) Subdivisions of the area transected by the CPR tow routes in the NW Atlantic. Route tracks from March 1991 to February 1992 are indicated.

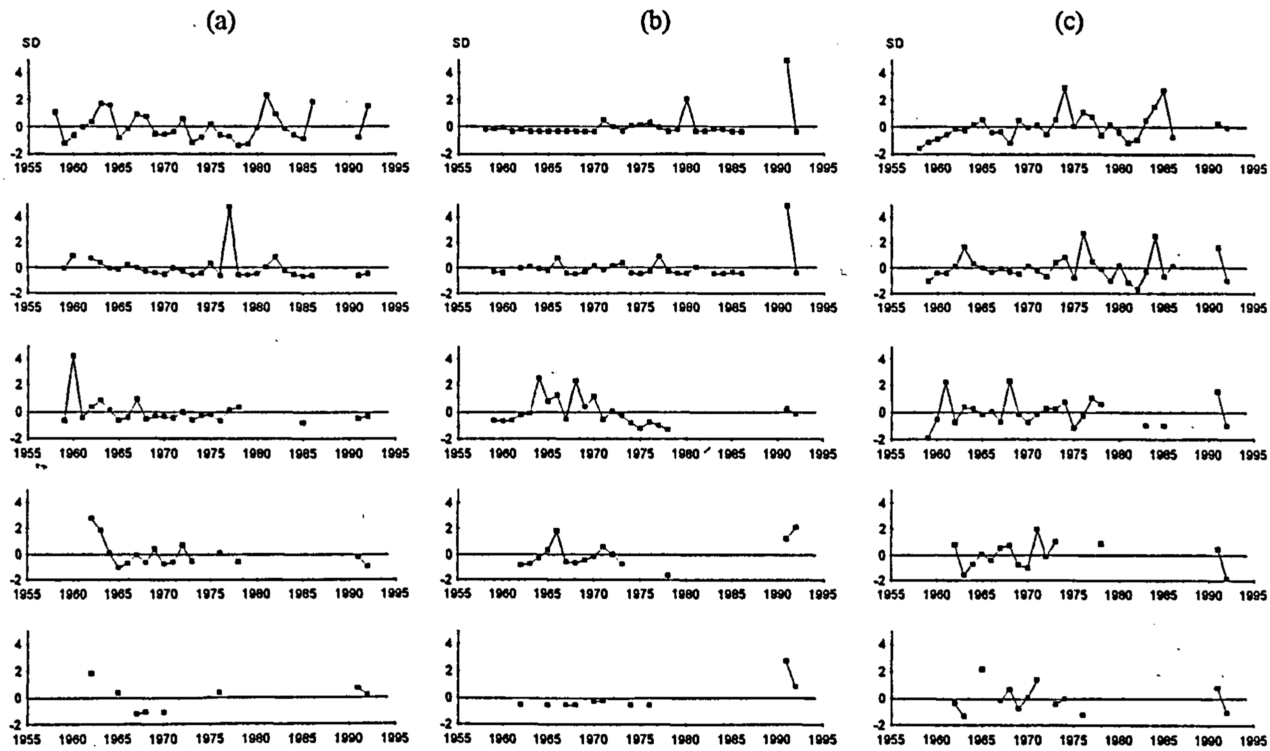
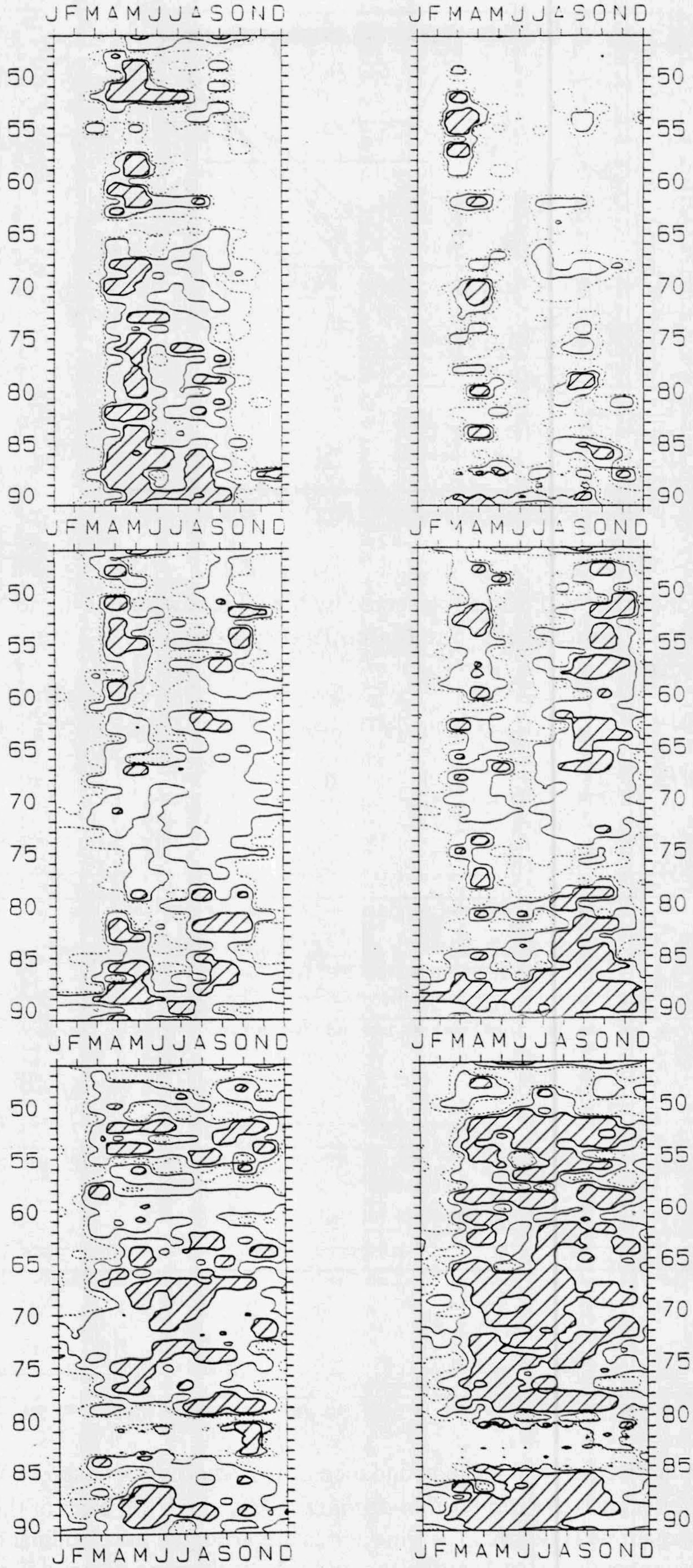


Figure 3b Standardised annual mean abundance of (a) *Thalassiosira* spp, (b) *Ceratium arcticum* and (c) *Calanus finmarchicus* CV and CVI in each of the regions shown above (Fig 3a). The time series are arranged in latitudinal order with the most northerly, Area 1, at the top and the southernmost, Area 5, at the base. SD - Standard Deviation.



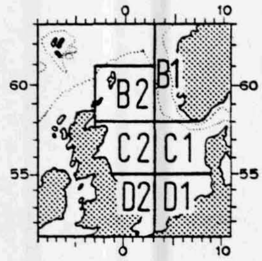


Figure 4. Seasonal and inter-annual changes in the phytoplankton colour index for six North Sea areas (arranged as inset above) from 1946 to 1991. Contour levels; 0.5, 1.0 and 2.0.

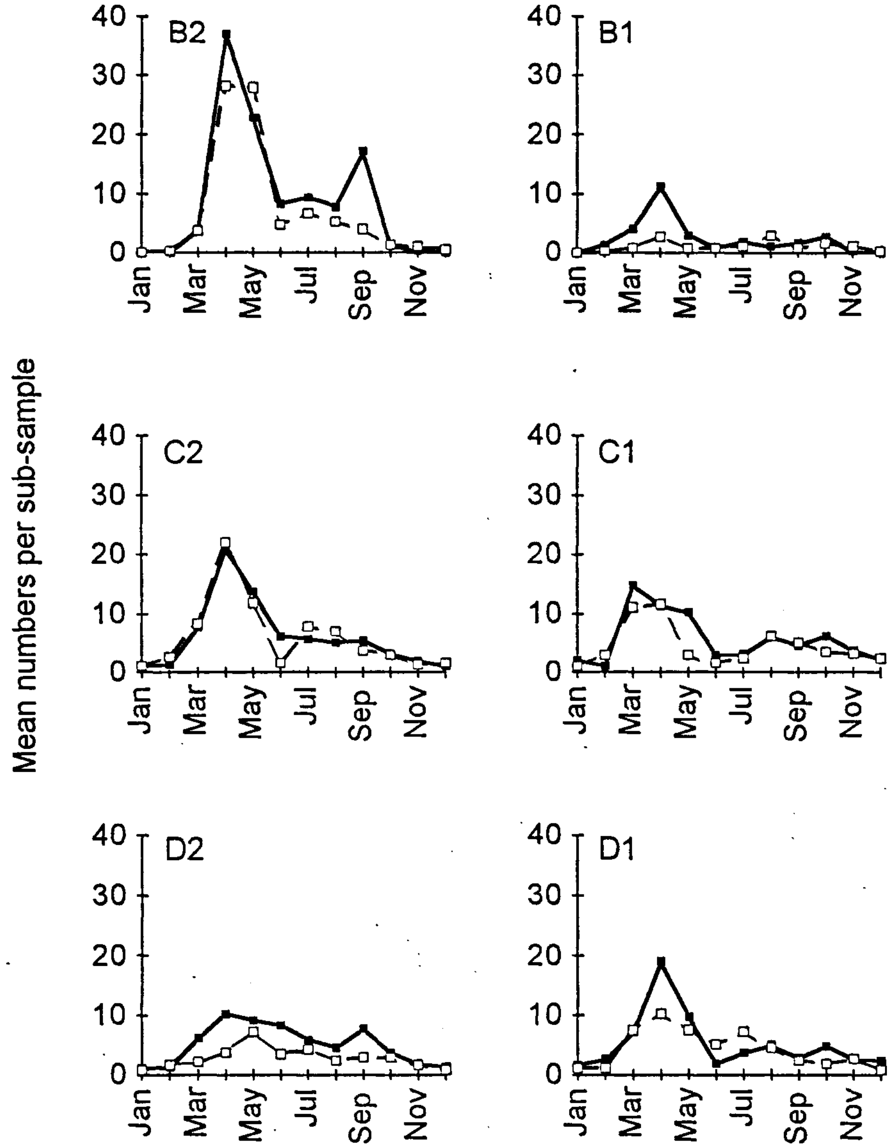


Figure 5 Long-term monthly means of diatoms in the North Sea CPR "Standard Areas", (see Figure 3a); comparison between 1965-70 (solid lines) and 1985-90 (broken lines).

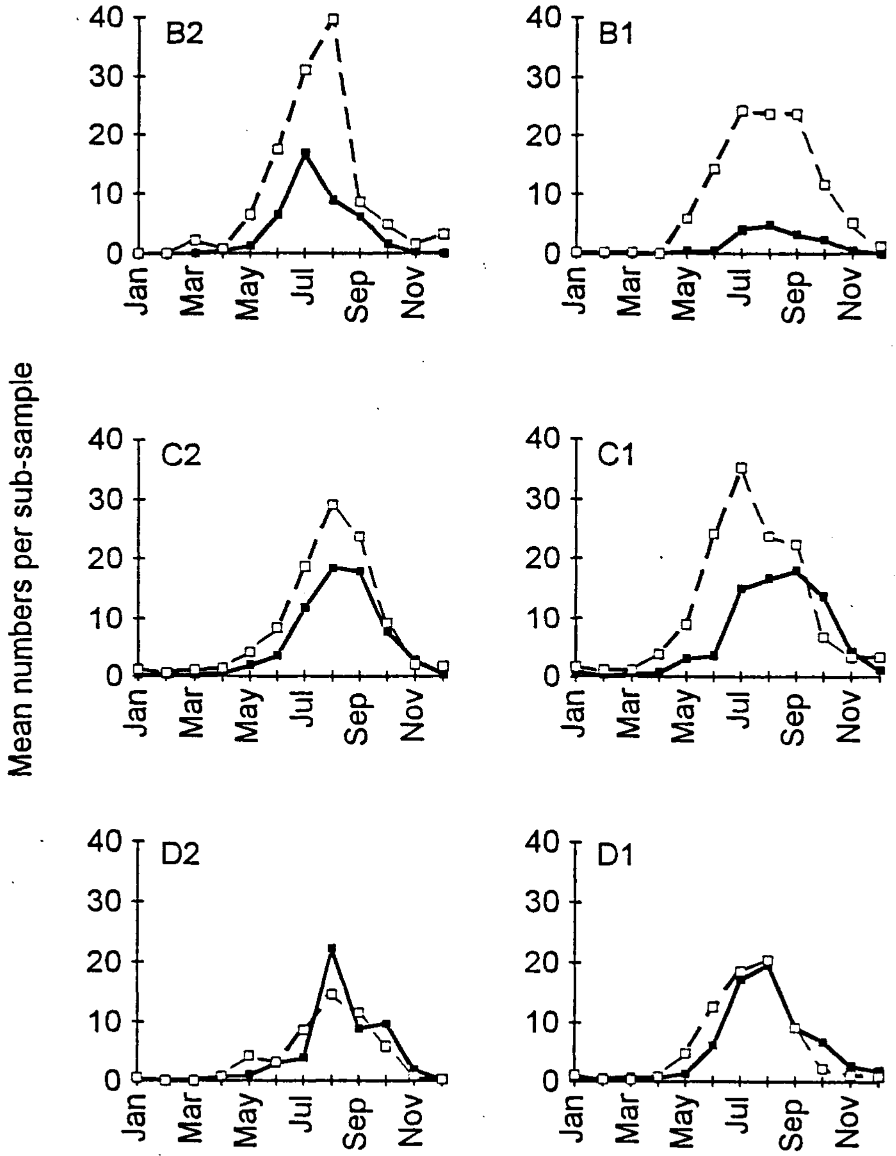


Figure 6 Long-term monthly means of dinoflagellates in the North Sea CPR "Standard Areas", (see Figure 3a); comparison between 1965-70 (solid lines) and 1985-90 (broken lines).

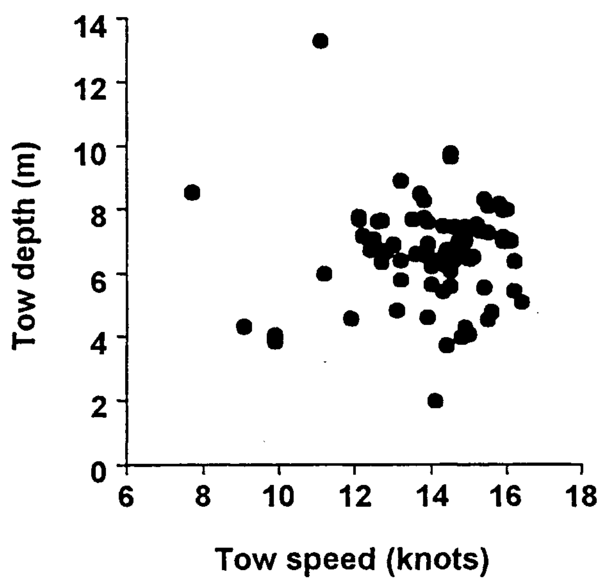


Figure 7 The mean tow depth recorded on 77 CPR tows plotted against the mean speed of each of those tows. Mean tow depth was 6.7 m and was independent of tow speed (from Hays and Warner, in press).

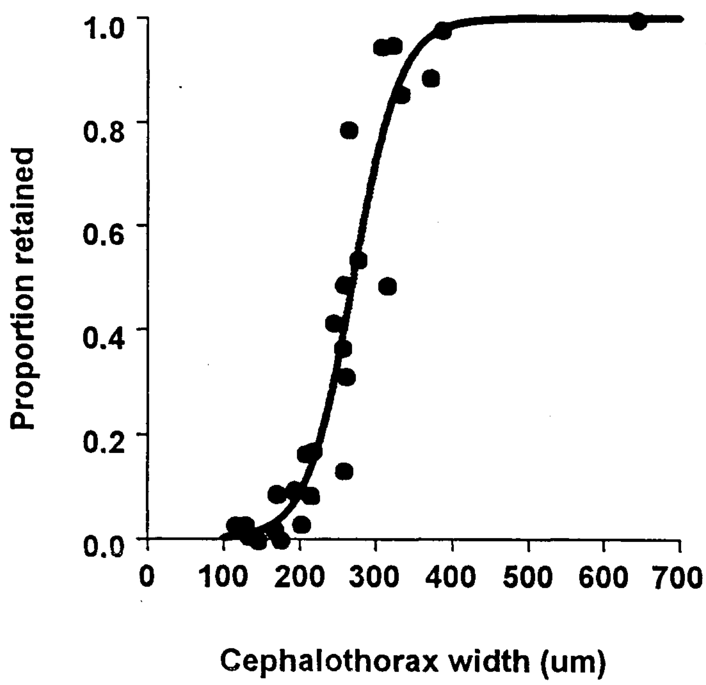


Figure 8 The proportion of copepods retained on the CPR silk in relation to copepod width. The line represents the retention predicted for a 270µm nylon mesh (from Hays, submitted).