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Seven copepod species considered as indicators of water-mass influence and changes: results from a Northumberland coastal station

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Zooplankton has been sampled monthly since 1969 at Station Z off the Northumberland coast. Seven copepod species were chosen as potential indicators of specific water masses. Data have been analysed to provide information about seasonal and interannual changes in the zooplankton community with special reference to the indicator taxa and to the possible role of hydrographic and climate drivers, including variations in the position of the Gulf Stream North Wall position and the North Atlantic Oscillation. Results show that, at this Northumberland coastal station, some copepod species are likely to be good indicators of water-mass influence and changes.

Keywords: copepods, long-term series, North Sea, water-mass indicators.

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Introduction

Many of the recent zooplankton long-time-series studies are based on data collected by the Continuous Plankton Recorder (CPR) in the Atlantic or in the North Sea (Fromentin and Planque, 1996; Planque, 1996; Beaugrand *et al.*, 2000b, 2001, 2002; Edwards *et al.*, 2002). Attempts have been made in these studies to explain or relate changes in zooplankton abundance and diversity with data on climatic trends and anomalies. For example, Fromentin and Planque (1996) showed that the abundances of both congeners *Calanus helgolandicus* and *Calanus finmarchicus* were strongly linked with the North Atlantic climatic index (North Atlantic Oscillation (NAO); Dickson and Turrell, 2000).

In the 1960s and 1970s, a few studies focused on indicator species to explain water-mass movements at specific sites (Colebrook *et al.*, 1961; Colebrook, 1964; Russell, 1973). Beaugrand *et al.* (2002) recently presented a large-scale study of the zooplankton of the North Atlantic and adjacent seas. Studying indicator species in a specific environment has to take into account that they can often be rare. Consequently, most of the time abundance is low and the risks of underestimation of abundance, or not observing such species, can be high.

In the North Sea, Fransz *et al.* (1991) listed zooplankton species in relation to the characteristics of their environment. Zooplankton are usually considered as a whole community (Colebrook, 1982; Roff *et al.*, 1988), yet copepods have been regarded as possibly being good markers of climatic trends or anomalies (Fromentin and Planque, 1996; Planque, 1996). Beaugrand *et al.* (2000b) recently published a map of the pelagic diversity of calanoid copepods for the North Atlantic and the North Sea using the data collected by the CPR. In Beaugrand *et al.* (2002), they proposed nine assemblages of indicators. The copepod species studied in the present work are, according to both Fransz *et al.* (1991) and Beaugrand *et al.* (2002), good water-mass indicators.

In the North Atlantic, the dominant atmospheric signal is the NAO. The impact of the variations in climate reflected in the NAO index, on biogeography and abundance of zooplankton have been demonstrated previously in the Northeast Atlantic (Fromentin and Planque, 1996; Planque, 1996). Although Edwards *et al.* (2002) considered that most of the pronounced shifts and extreme values in North Sea plankton community structure could not be explained by or related to the NAO index, they did identify two exceptional hydro-climatic events in the North Sea during the past four decades. They suggested that these events could have induced changes in the plankton biology. The first period, in the late 1970s, was associated with cold-boreal conditions, while the second period, in the late 1980s, was associated with a warm-temperate climate.

The purpose of this article is to study the abundance of selected rare copepod species, which are considered likely to be indicators of water masses in the Northumberland coast region, and to compare anomalies in their abundance to records of environmental changes.

Material and methods

A permanent plankton station, the Dove series, was established in 1968 at approximately 55°07′N 01°20′W, 5 nmi east of the port of Blyth, Northumberland, UK (Figure 1). The sampling station is located between two river mouths: the rivers Tyne and Blyth. Monthly zooplankton species abundance data were used from 1969 to the present. For technical reasons, no sampling occurred in 1989. This area is considered to experience slight stratification of the water column in summer (Harding and Nichols, 1987) and the site has an average depth of 54 m.

Sea surface temperatures (SST) were from the International Council for the Exploration of the Sea for the central-western North Sea (54.5–56°N, and 0–1°W). The Gulf Stream and NAO data were downloaded from http://www.pml.ac.uk/gulfstream/inedat.htm and http://www.cru.uea.ac.uk/cru/data/nao.htm web sites, respectively.

Two nets of different mesh sizes were used to collect the zooplankton. Fishing the WP2 net (200 μm mesh, mouth area 0.25 m^2) involved hauling it vertically four times on 50 m of wire and combining the four samples. Thus a nominal volume of close to 50 m^3 of water was filtered, which is the minimum volume recommended for comparison of plankton samples by UNESCO (1968). The WP3 net (1-mm mesh, mouth area 1 m^2) was towed horizontally at 4 knots at a depth of approximately 30 m for 10 min. Both nets were fitted with a flowmeter to derive the volume filtered. The catch from each haul was preserved immediately in 4% buffered formaldehyde in sea water.

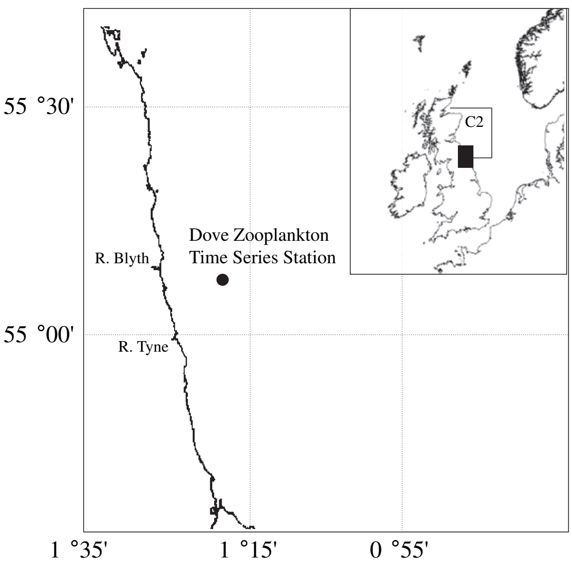

Figure 1. The zooplankton sampling station in relation to the Northumberland coast and CPR area C2.

The samples from the WP3 and WP2 nets are counted separately. A Stempel pipette is used to subsample the WP2 sample, while the larger organisms collected by the WP3 net require a slightly different technique. Samples up to 1988 were subsampled using the Huntsman technique (Van Guelpen *et al.*, 1982), while a Folsom splitter was used to subsample from 1990 onwards. Identification of the organisms was to the taxonomic levels established at the start of the time-series (Evans and Edwards, 1993). From these analyses, several copepod species were chosen as indicators of specific water masses. *Calanus finmarchicus* is adapted to subarctic water, *Metridia lucens*, *Candacia armata*, *Corycaeus anglicus*, and *Rhincalanus nasutus* were chosen as indicators of Atlantic Water inflow into the North Sea and *Anomalocera patersoni* and *Centropages typicus* are possible indicators of temperate oceanic waters (Fransz *et al.*, 1991; Beaugrand *et al.*, 2002). For *C. finmarchicus*, we used only female abundance data because it is difficult to distinguish between males of *C. finmarchicus* and *C. helgolandicus* without a dissection of the P5.

CPR records of the phytoplankton index for area C2 (see Figure 1) were used for the 1969–2000 study period (data courtesy of The Sir Alister Hardy Foundation for Ocean Science). The phytoplankton colour index is a visual assessment of the green colour of the silk mesh into one of four categories by reference to a standard chart. It is assumed that the green colouration gives an index of the chlorophyll *a* concentration and this index has been used widely to describe the seasonal and long-term patterns of phytoplankton abundance (Reid, 1975, 1977).

ICES salinity data covering the period 1969 to 1996, for the central-western North Sea (54.5–56°N and 0–1°W), from just south of the Tees to the Firth of Forth were examined. The trend in these data was examined using a Mann–Kendall test.

There is no simple statistical test for the significance of fluctuations in variability in the abundance of species found. The Cumulative Sum (CUSUM) technique was used to detect small but persistent changes in the mean of the time-series (Woodward and Goldsmith, 1964; Ibañez *et al.*, 1993; Beaugrand *et al.*, 2000a; Beaugrand and Reid, 2003), by standardizing the data to a zero mean and unit standard deviation and pooling the residuals progressively. This cumulative function is sensitive to changes in the local mean values along the series (Ibañez *et al.*, 1993). Break points were determined using a method known as the Decision Interval Control Scheme (DICS) (see Woodward and Goldsmith, 1964; Van Dobben de Bruyn, 1968 for details of the technique).

Results

Figure 2 shows the long-term trends in climatic and hydrographic parameters (GNSW, NAO, SST) and for biological components, CPR colour as an index of phytoplankton abundance and zooplankton abundance, from the Dove time-series. Similar trends can be seen for the GSNW, the NAO, and the phytoplankton index in area C2, with generally low values through the early 1980s, then increasing values which then decreased into the late 1990s. SST has increased steadily since the early 1980s. Zooplankton biomass at the Dove station was relatively constant during the 1970s and 1980s before declining in the early 1990s, subsequently rising again. Salinity (Figure 3) decreased slightly over the 1968−1995 period, but a Mann−Kendall test shows that the trend was not significant ($S = 610$, $p = 0.23$).

The mean zooplankton abundance shows a large degree of interannual variability (Figure 4a). Annual mean densities ranged from a maximum of 10 552 indivduals m^{-3} in 1978 to a minimum of 1203 individuals m^{-3} in 1990. Although there was a slight downward trend in the year-to-year

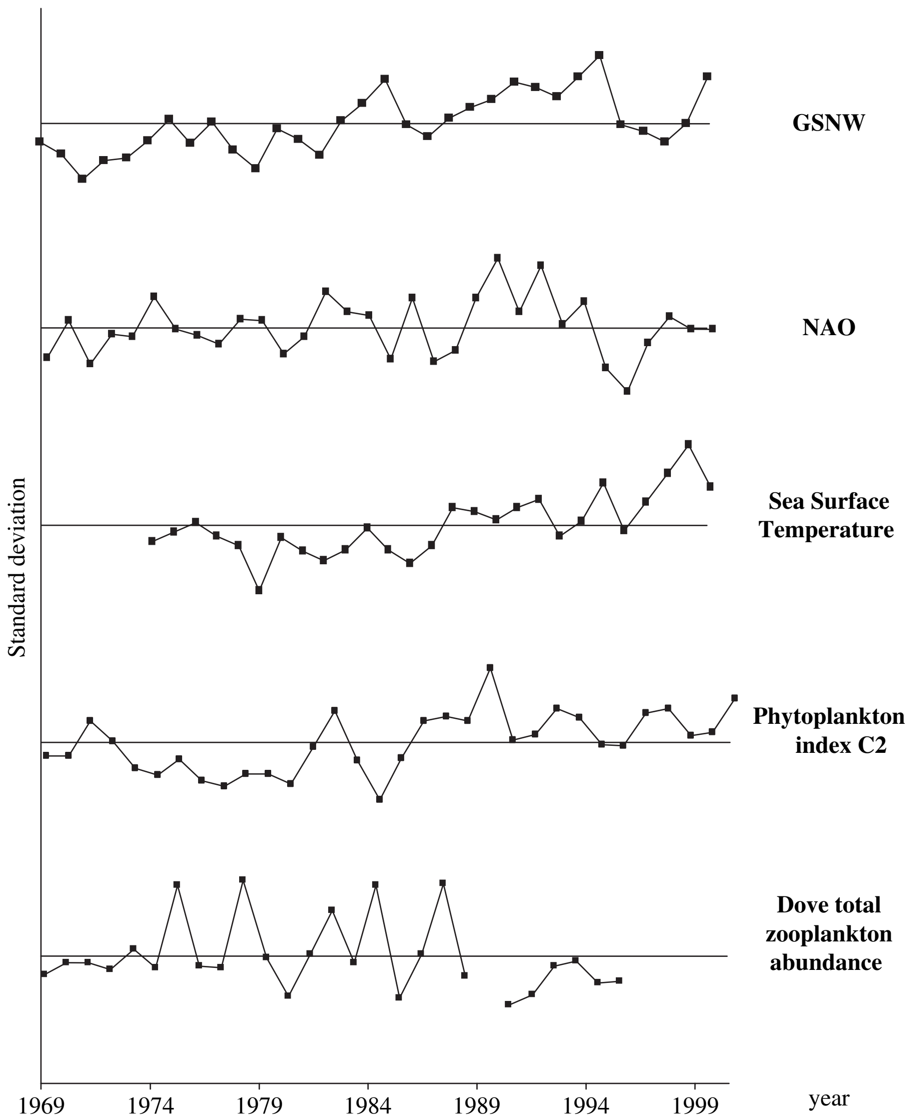

Figure 2. Long-term trends for Gulf Stream North Wall (GSNW) position annual mean, North Atlantic Oscillation (NAO), sea surface temperature, phytoplankton index, and Dove total zooplankton abundance between 1969 and 2000 (only 1969−1996 for total zooplankton). Data are standardized to zero mean (horizontal line) and unit variance.

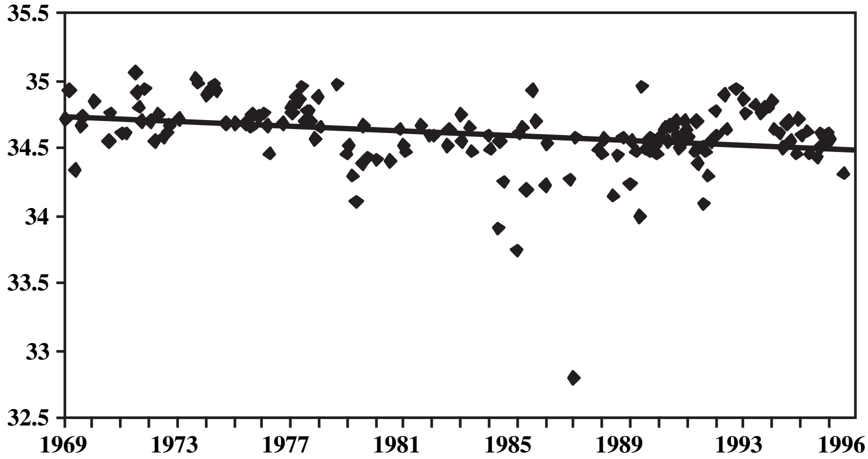

Figure 3. Salinity in the area C2 from 1969 to 1996 (ICES data).

abundances, a Mann−Kendall test indicates that there was no significant trend (S = −49, p = 0.24). Visual examination of the year-to-year fluctuations and calculation of the CUSUM breakpoints indicate three different phases in the zooplankton time-series. The first phase from 1969 to August 1975, with relatively low and steady mean densities, the second phase from September 1975 to June 1987, with high intra-annual variability and the third phase between July 1987 and 1996, which shows a return to relative stability and a low mean abundance.

Abundance of seven copepod indicator species throughout the whole time-series is presented in Figure 5. They each have distinct years of greatest abundance appearing almost successively from the beginning of the 1980s to the late 1990s. The cold-water species, *C. finmarchicus* is abundant in 1983 and 1984. The temperate species *M. lucens*, *C. armata*, *C. anglicus*, and *R. nasutus* show abundance peaks in 1984 and 1991, whereas *C. typicus* and *A. patersoni* were relatively abundant in the years 1990−1993. A variation in *C. typicus* abundance can be seen at the beginning of the 1980s. A high peak of *A. patersoni* in 1998 and two peaks of *C. finmarchicus* females in 1997 and 2000 can also be observed.

Discussion

Edwards *et al.* (2002) described the period of the late 1970s to early 1980s in the North Sea as anomalous, because temperature and salinity were lower, coinciding with a reduced inflow of warmer Atlantic Water into the North Sea. They associated a major hydro-climatic event with a warm-temperate climate in the late 1980s. These events were not observed in the temperature and salinity records at Dove, although there was a rising trend in SST during the 1980s and 1990s (Figures 2 and 3). Local variability may have concealed the salinity signal because of the location of the sampling station between two river mouths. Edwards *et al.* (2001) have suggested that this is a likely phenomenon in coastal areas.

At Station Z, the zooplankton community abundance data do not show any obvious trends corresponding to these two major climatic events in the North Sea. Nevertheless, the two break points calculated from the CUSUM do coincide with the periods of the turning points for biota changes in the North Sea (Edwards *et al.*, 2002).

In the late 1970s, changes in biological communities of the North Sea have been noticed with high abundance of arctic boreal species (Evans and Edwards, 1993; Kröncke *et al.*, 2001). In this study, the high abundance of *C. finmarchicus* in 1983, a subarctic species, supports this view, and Planque and Fromentin (1996) have suggested that a high abundance of *C. finmarchicus* in the northeast North Sea is indicative of the influence of boreal water.

The seven indicator species appear successively at Station Z, correlating well with the timing of hydro-climatic events described by Edwards *et al.* (2002). The presence of *C. finmarchicus* could be attributed to the GSA influence with a pulse of cold, low salinity water from the east Greenland Sea resulting in a lagged increase in the influx of arctic boreal water and indicator species into the North Sea from the North. Much reduced variation in *C. typicus* abundance can be noticed at the beginning of the 1980s. This could be associated with pulses of cold low salinity water coming into the North Sea at this time. In contrast, the late 1980s was a period associated with temperate and warm species, such as *M. lucens*, *C. armata*, *C. anglicus*, *R. nasutus*, and *A. patersoni*. A lag should be expected between the dates at which the climatic event is observed and any subsequent impact on the biological communities on the Northumberland coast. The presence of *C. finmarchicus* in the coastal waters off Northumberland is a result of water transport from the North. However, Taylor *et al.* (1992) note that the water masses in currents of the

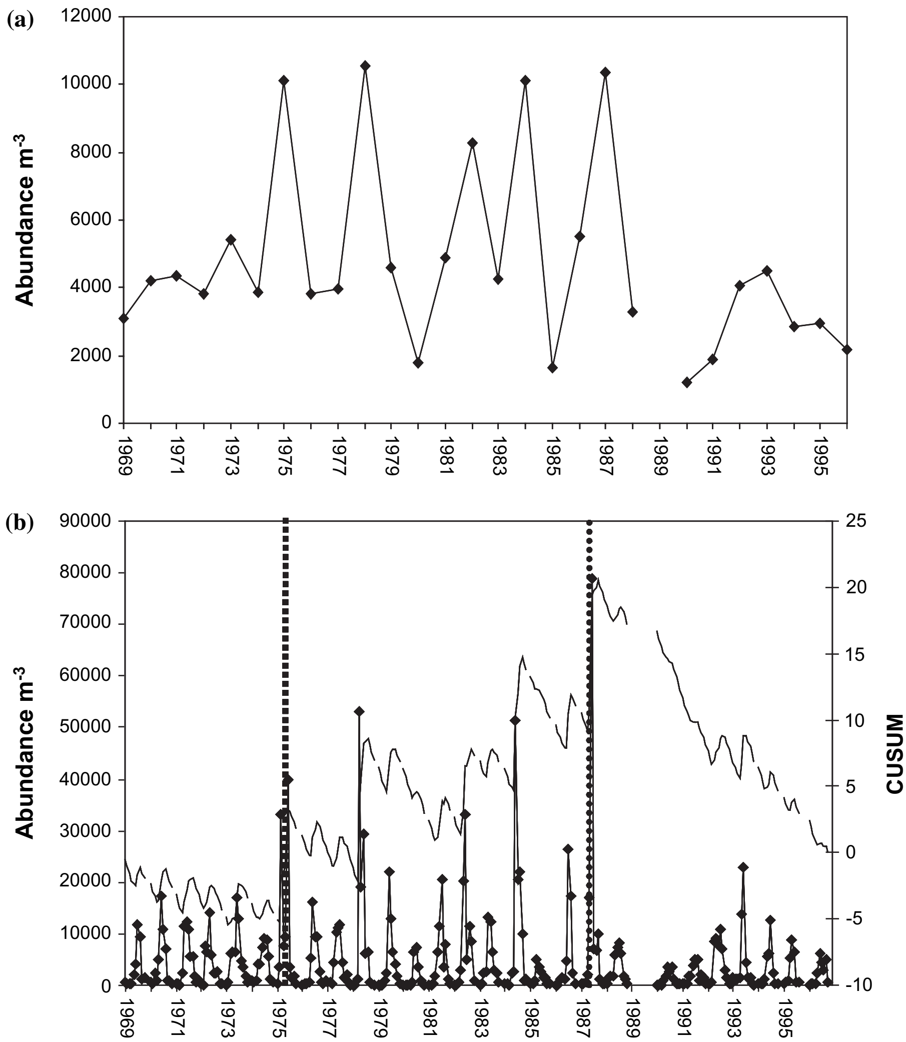

Figure 4. (a) Annual mean total zooplankton abundance (per m^3) covering 1969–1988 and 1990–1996. (b) Monthly zooplankton abundance (per m^3) (♦) in the Dove Time-Series, with cumulative sums (---) calculated from standardized data and showing CUSUM break points (···).

North Atlantic require several months to cross the ocean. Thus these are less likely to explain variations in zooplankton abundance and diversity than atmospheric circulation processes. For example, Clark and Frid (2001) observed a strong relationship between the phytoplankton index in CPR Box C2 and the local weather in this area, suggesting that forcing of primary production is predominantly related to climatic influences. Peak years in zooplankton species abundances may in turn be caused by high secondary production in the local area reflecting such food variability.

Frid and Huliselan (1996) concluded that the Dove zooplankton data showed a negative correlation with the GSNW, representing an indirect response to coastal nutrient fluxes influenced by climatic variation. They suggested that, contrary to previous observations of Evans and Edwards (1993) or Austen *et al.* (1991), biotic factors were more important than physical factors in controlling the long-term zooplankton dynamics in coastal regions of the west-central North Sea. The indirect impact of hydrographic events on biota (via variations in local climate, nutrient fluxes, and primary production) is therefore more likely to explain the time-lags we observed for zooplankton.

Control of the copepod annual cycle is complex. Populations may be limited by food supply (predominantly phytoplankton) and by their reproductive rate, which has optima and adaptive temperature limits that differ among species. The population production achieved may also be controlled by predator pressure (Roff *et al.*, 1988). Open ocean currents have been clearly shown to play an important role in the regulation of pelagic zoogeography and biodiversity at

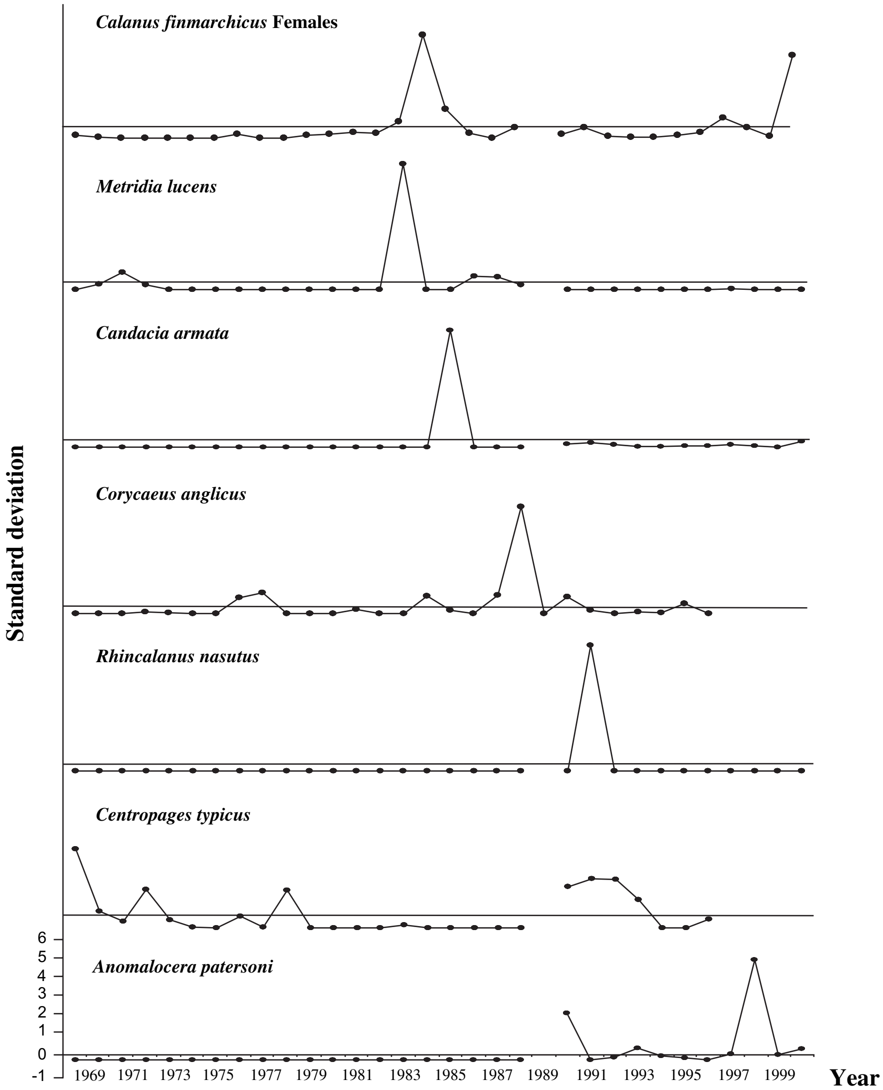

Figure 5. Abundance of seven copepod indicator species in the North Sea. Data are standardized to zero mean (horizontal line) and unit variance.

both meso- and macroscales (Beaugrand *et al.*, 2002). Nevertheless, in many coastal areas, the signals of large hydrographic events are less clear. There are effects from local fresh water inputs, anthropogenic impacts, local climatic events, and variable population dynamics which may have a strong influence on the interannual dynamics and spatial distribution of zooplankton communities. Nevertheless, simple monitoring of coastal plankton does provide information to relate to wider-scale processes and to help interpret their effects in the highly productive shelf sea regions. It should be possible to combine information from a range of coastal monitoring sites to extend and enhance the effectiveness of such information and analyses.

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