Plankton Report for Strategic Environment Assessment Area 5

Contract for the Department of Trade and Industry

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Contents

1. Introduction

1.1 The remit of this report is to provide data on the plankton community in the Strategic Environment Assessment area 5, as shown below in Fig. 1.1. Data for this report will be provided by the Continuous Plankton Recorder Survey, as well as sourced from outside organisations. Any gaps in existing knowledge will be highlighted.

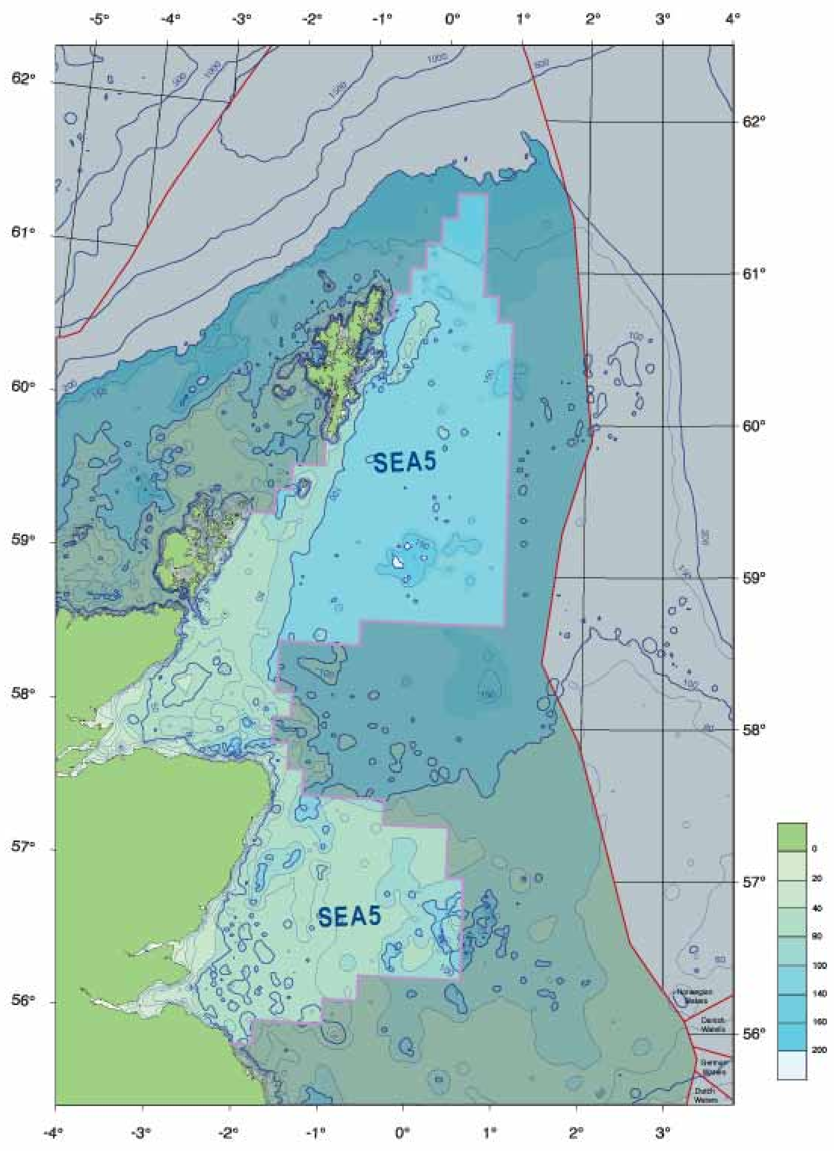


Figure 1.1 Map of the SEA 5 area (sourced from DTI). Colour scale shows depth contours.

1.1 The SEA 5 area is influenced by the Shelf Edge Current, which breaks off its main route in the form of the Fair Isle Current, the Dooley Current and the East Shetland Inflow (Holliday and Reid 2001). Oceanic water flows into the North Sea in this area, causing periodic incursions of associated planktonic organisms.

1.2 Aims: The report will address the following issues:

- Phytoplankton and zooplankton community composition
- Phytoplankton blooms
- Abundance of the copepod *Calanus*
- Mero-, pico- and megaplankton
- Phytodetritus and vertical fluxes
- Resting stages of phytoplankton

1.3 Methodology: The Continuous Plankton Recorder (CPR) survey provides a unique long-term dataset of plankton abundance in the North Atlantic and North Sea, using 'ships of

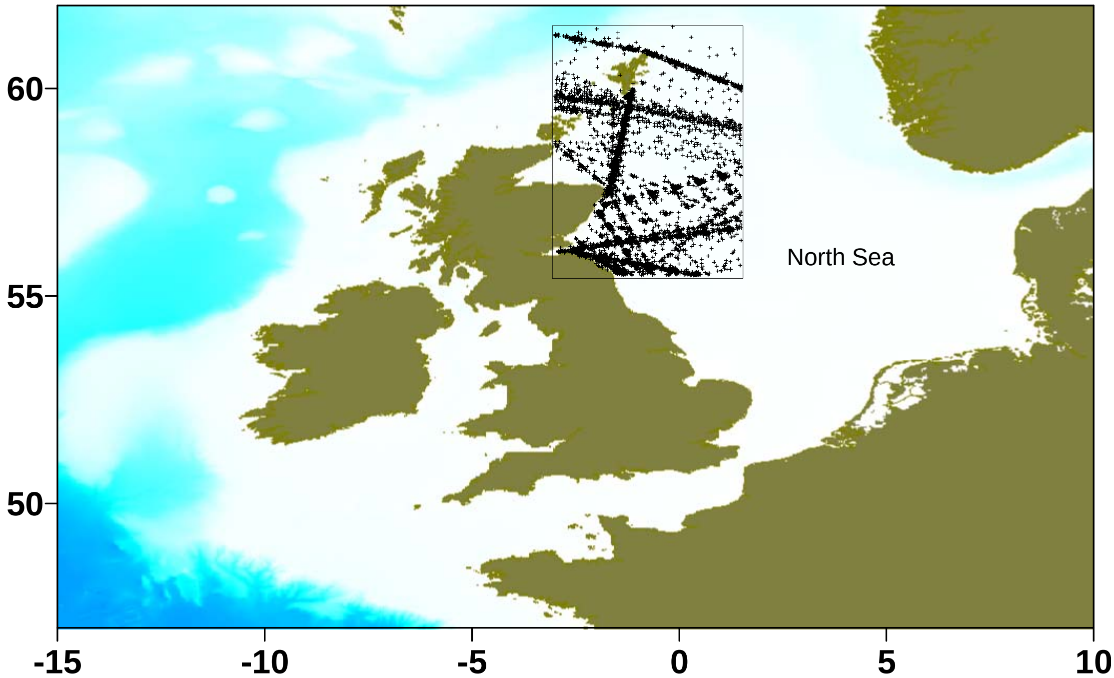


Figure 1.2 Map of the north east Atlantic showing CPR samples used for data analysis in the SEA 5 area

opportunity' to tow the CPR on regular routes, sampling at a depth of approximately 10m (methodology described in full in Warner and Hays 1994). Each sample represents 18km of tow and approximately 3m^3 of filtered seawater (John et al. 2002). The survey records over 400 taxa of plankton, composed of phytoplankton (plants) and zooplankton (animals) entities, many of which are recorded to species level. It is the only biological survey that can monitor long term changes over broad areas, such as the North Atlantic. The survey began in the North Sea in 1931, with computerised records from 1948 (for this report data were extracted from 1960). Data collected from the survey allows long term changes, as well as seasonal cycles, in the plankton community to be identified. In addition to the examination of specific planktonic entities, phytoplankton colour, an index of estimation of chlorophyll *a* values (Hays and Lindley 1994), can be seen to represent changes in primary production.

For this study, an area encompassing SEA 5 (shown in Fig. 1.2) was chosen, containing over 11000 samples from 1960 to 2002.

2.Phytoplankton and zooplankton community composition

2.1 For this report data were extracted from 55.5 ^{o}N to 61.5 ^{o}N, 3 ^{o}W to 1.5 ^{o}E, from 1960 to 2002 giving a total of over 11000 samples. Planktonic entities that occurred on over 1% of samples that were used for the community analysis are shown in Table 2.1.

Phytoplankton	Zooplankton
Paralia sulcata	*Calanus* I-IV
Skeletonema costatum	*Pseudocalanus elongatus* Adult
Thalassiosira spp	*Para-pseudocalanus* spp
Dactyliosolen mediterraneus	*Temora longicornis*
Rhizosolenia imbrica shrubsolei	*Acartia* spp
Rhizosolenia styliformis	*Centropages typicus*
Rhizosolenia hebetata semispina	*Centropages hamatus*
Rhizosolenia alata alata	*Oithona* spp
Rhizosolenia alata inermis	*Podon* spp
Chaetoceros (*Hyalochaete*) spp	*Evadne* spp
Chaetoceros (*Phaeoceros*) spp	*Limacina retroversa*
Asterionella glacialis	Lamellibranchia larvae
Thalassionema nitzschioides	Cyphonautes larvae
Nitzschia seriata	Echinoderm larvae
Nitzschia delicatissima	Larvacea
Ceratium fusus	*Calanus fin finmarchicus*
Ceratium furca	*Calanus helgolandicus*
Ceratium lineatum	*Euchaeta hebes*
Ceratium tripos	*Metridia lucens*
Ceratium macroceros	*Candacia armata*
Ceratium horridum	*Tomopteris* spp
Ceratium longipes	Hyperiidea
Unidentified *Coscinodiscus* spp	Decapoda larvae
Ditylum brightwellii	*Clione limacina*
Navicula spp	Euphausiacea
Cylindrotheca closterium	Chaetognatha Eyecount
Dinophysis spp	Fish larvae
Exuviaella spp	Harpacticoida
Prorocentrum spp	Copepod nauplii
Scrippsiella spp	Cirripede larvae
	Caligoida
	Polychaeta larvae

Table 2.1 Table showing planktonic entities occurring on over 1% of samples that were used in the community analysis.

2.2 A community analysis was carried out on both the phytoplankton and zooplankton components of the community. Figure 2.1 is the North Atlantic Oscillation (NAO) Index for reference. Figure 2.2 shows both a MDS and a dendrogram of the phytoplankton component, the high NAO periods are apparent in both (with the exception of 1996 in the dendrogram high NAO group, as 1996 was the greatest dip in the NAO index on record).

In Figure 2.3, the results of the zooplankton community analysis can be seen, with a period of low NAO apparent in both MDS and the dendrogram, and the high NAO apparent in the MDS. In addition to this group, another section is clearly separate (1970,1978,1980 and 1981), the reason for this is that it could be related to below average SSTs in the area in the late 1970s (data not shown, Bundesamt für Seeschifffahrt und Hydrographie, Germany, Edwards et al. 2002).

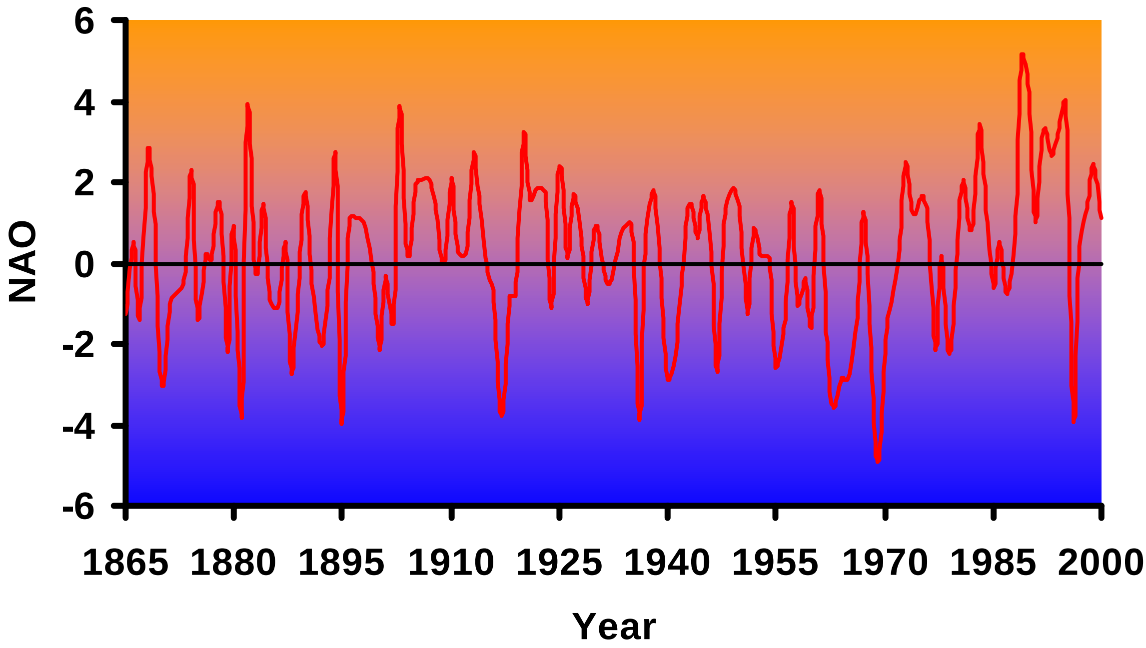


Figure 2.1 The NAO Index

2.3 Figure 2.4 shows the ten most frequently recorded phytoplankton taxa in the SEA 5 area, in order of prevalence. All taxa show a high degree of variability, with a number of peaks apparent across the taxa in the late 1980s, this is in line with earlier work by Edwards et al. (2001). It is interesting to note that the two most frequently recorded taxa are both dinoflagellates (*Ceratium*), and this is in line with the rest of the North Sea, where there is an increasing trend of dinoflagellate dominance.

2.4 Figure 2.5 shows the ten most frequently recorded zooplankton taxa, and includes both organisms recorded in traverse and eyecount (see methodology). In studying the graphs, the most (continued page 12).

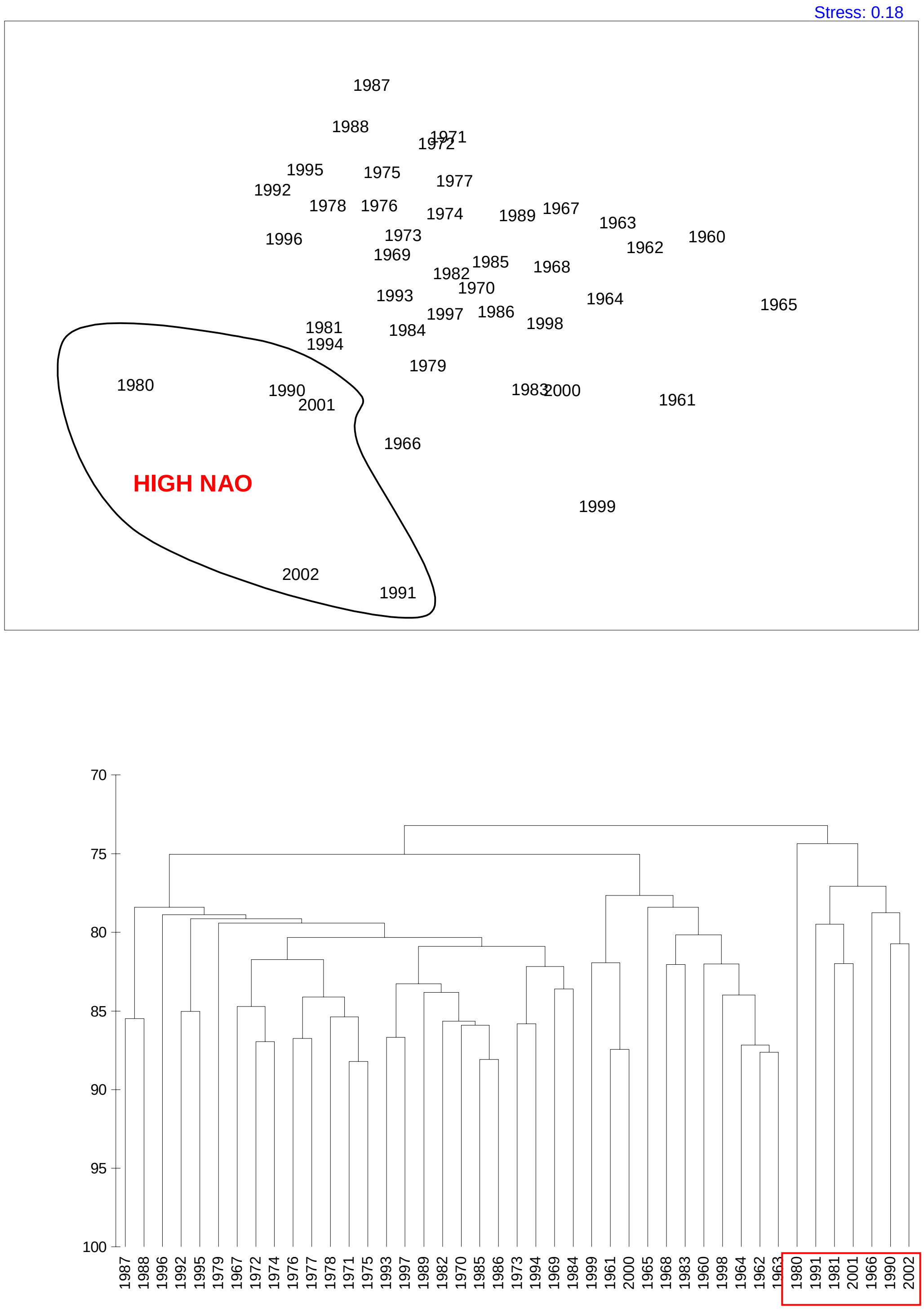


Figure 2.2 Phytoplankton community MDS and dendrogram

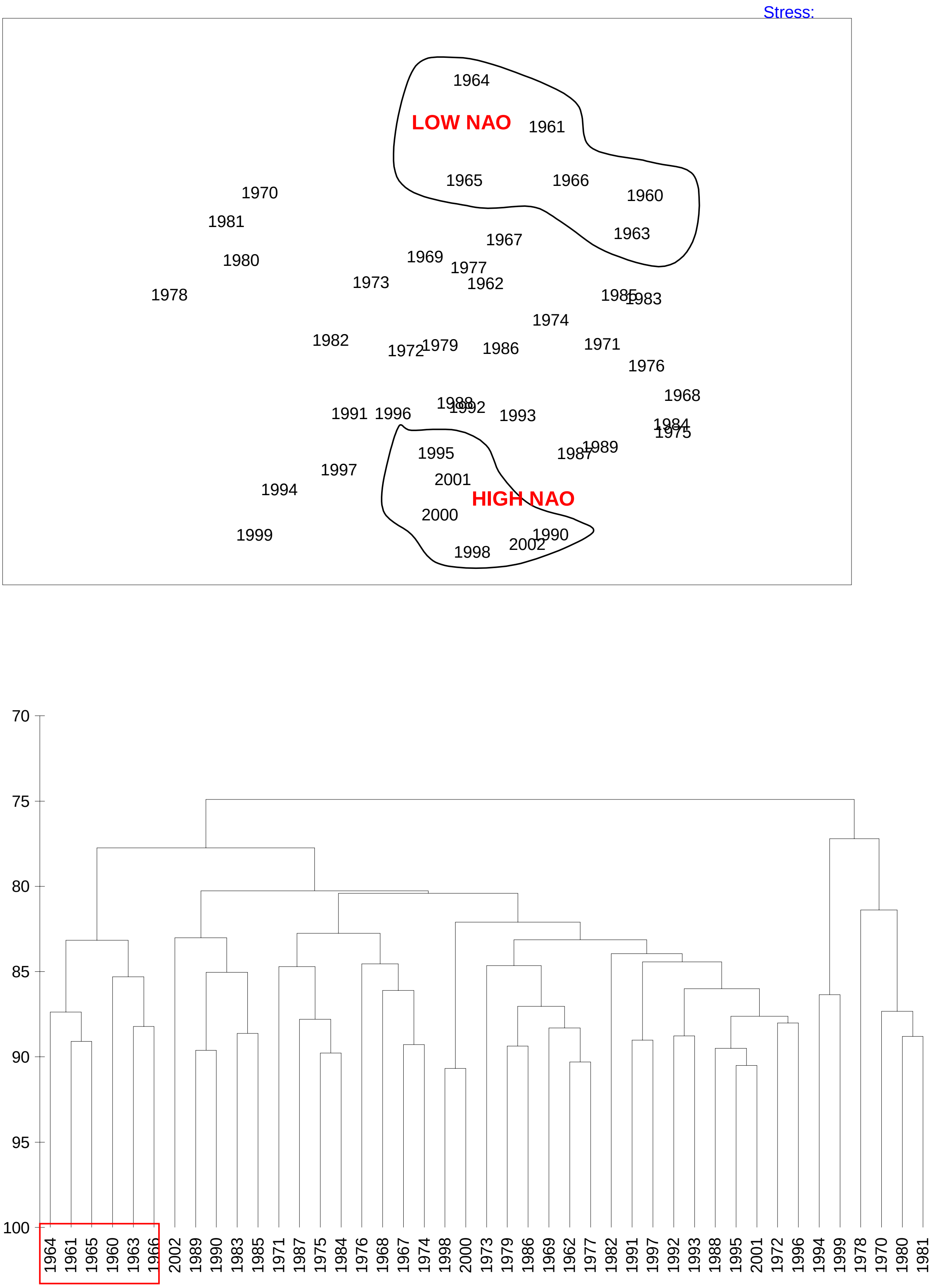
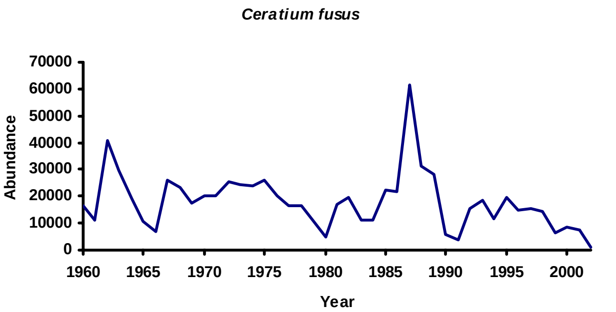
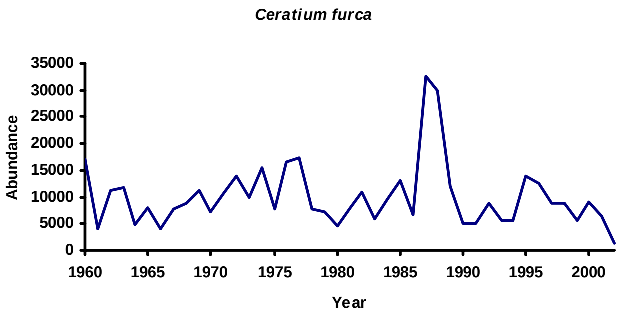
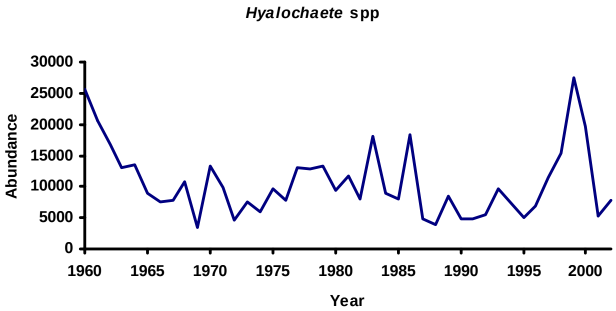
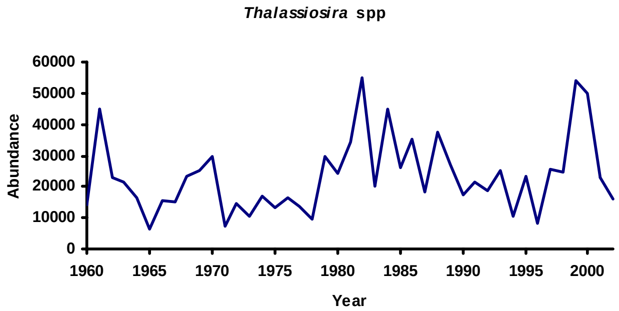


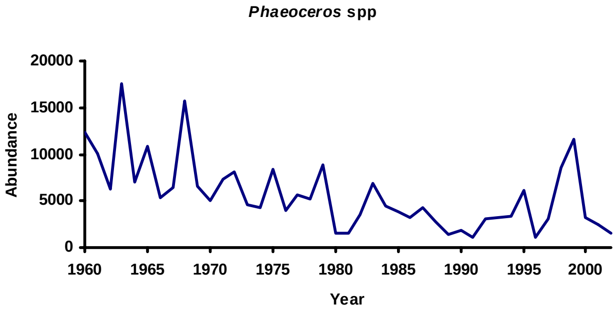
Figure 2.3 Zooplankton community MDS and dendrogram

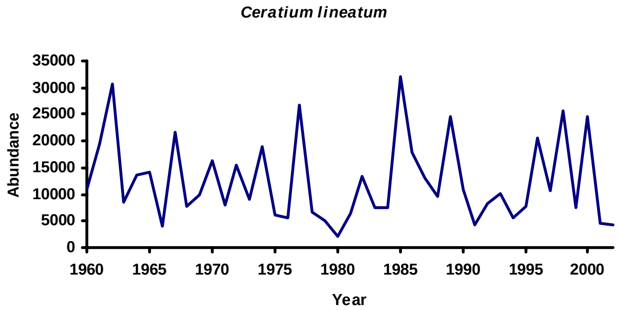

Ceratium fusus
Abundance
70000
60000
50000
40000
30000
20000
10000
0
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

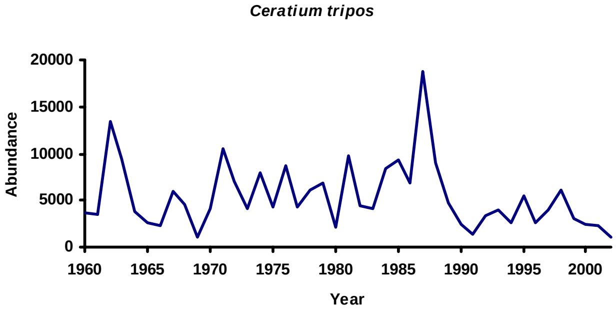

Ceratium furca
Abundance
35000
30000
25000
20000
15000
10000
5000
0
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

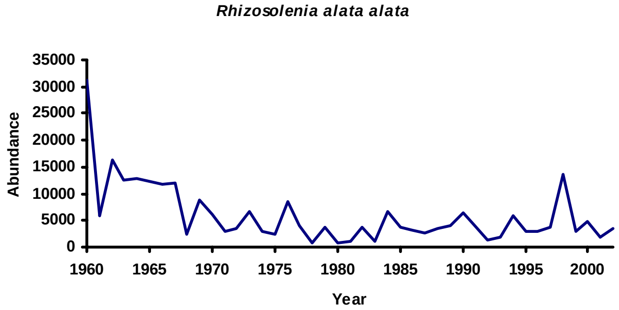

Hyalochaete spp
Abundance
30000
25000
20000
15000
10000
5000
0
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

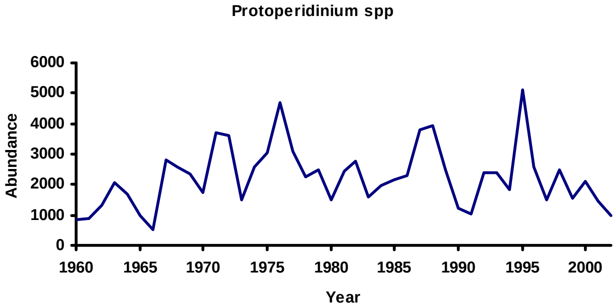

Thalassiosira spp
Abundance
60000
50000
40000
30000
20000
10000
0
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

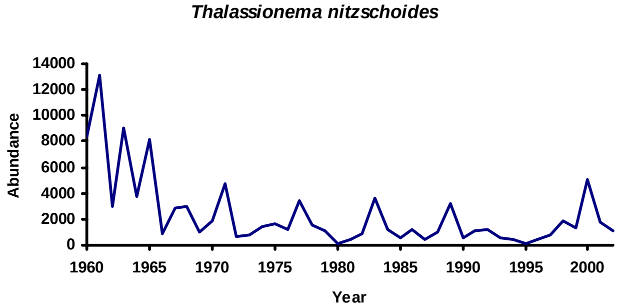

Phaeoceros spp
Abundance
20000
15000
10000
5000
0
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

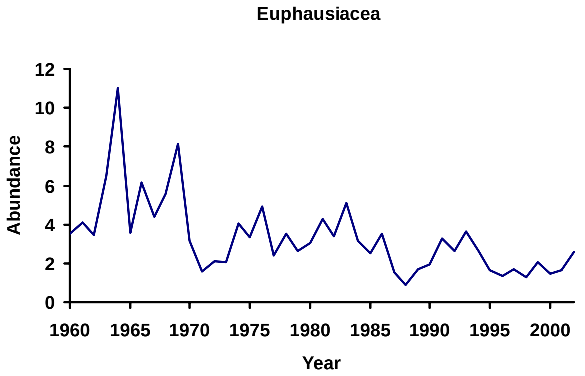

Ceratium lineatum
Abundance
35000
30000
25000
20000
15000
10000
5000
0
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

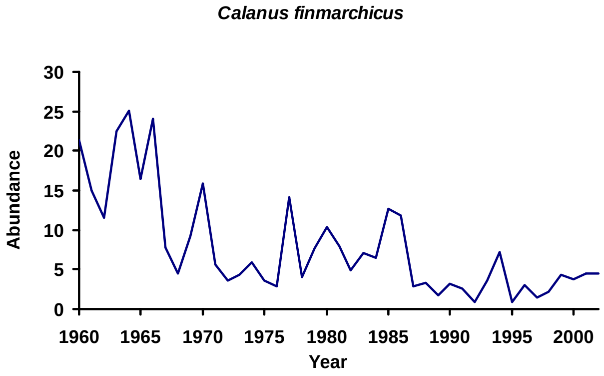

Ceratium tripos
Abundance
20000
15000
10000
5000
0
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

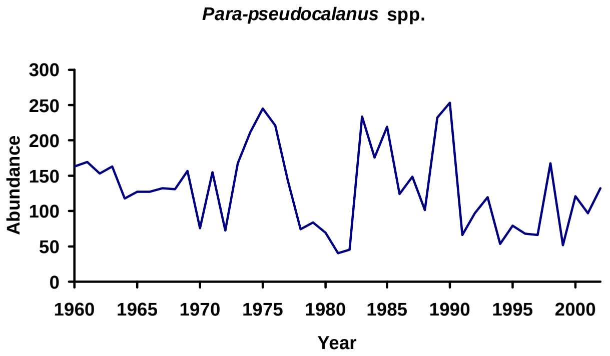

Rhizosolenia alata alata
Abundance
35000
30000
25000
20000
15000
10000
5000
0
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

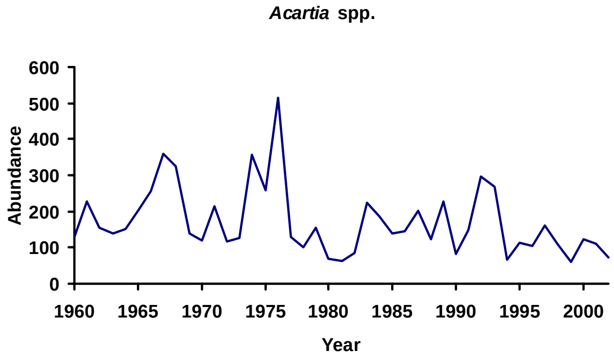

Protoperidinium spp
Abundance
6000
5000
4000
3000
2000
1000
0
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

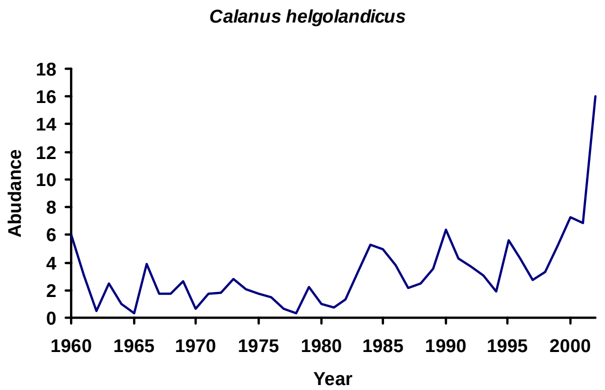

Thalassionema nitzschoides
Abundance
14000
12000
10000
8000
6000
4000
2000
0
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

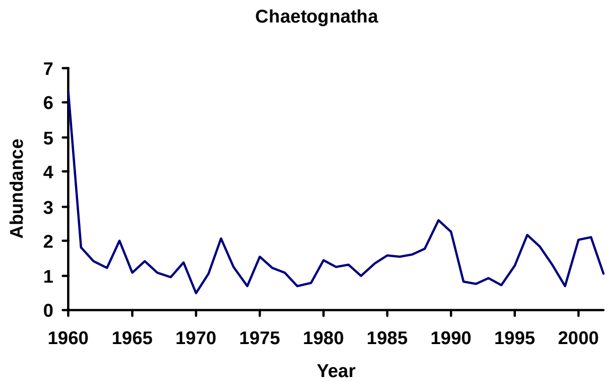

Euphausiacea
Abundance
0
2
4
6
8
10
12
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

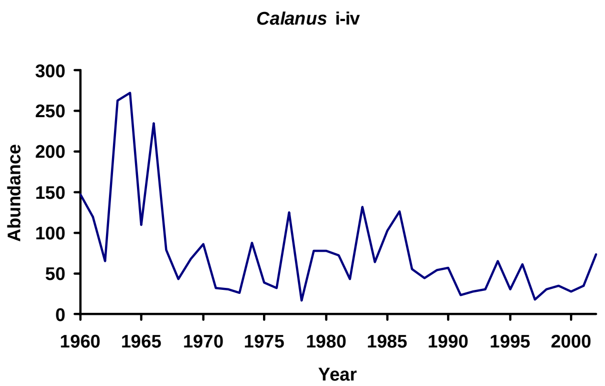

Calanus finmarchicus
Abundance
0
5
10
15
20
25
30
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

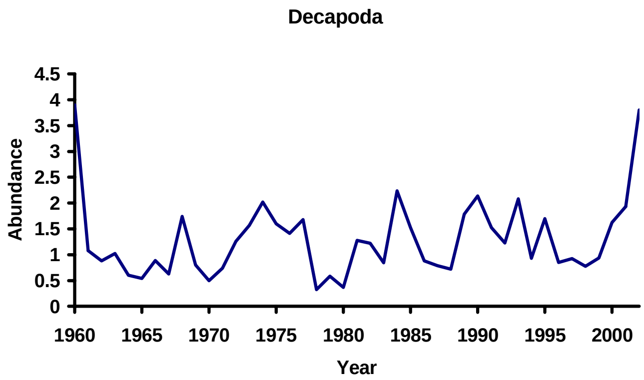

Para-pseudocalanus spp.
Abundance
0
50
100
150
200
250
300
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year


Acartia spp.
Abundance
0
100
200
300
400
500
600
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year


Calanus helgolandicus
Abundance
0
2
4
6
8
10
12
14
16
18
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year


Chaetognatha
Abundance
0
1
2
3
4
5
6
7
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year


Calanus i-iv
Abundance
0
50
100
150
200
250
300
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year


Decapoda
Abundance
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
1960 1965 1970 1975 1980 1985 1990 1995 2000
Year

2.4 (continued) apparent change in the graphs is between *Calanus finmarchicus* and *C. helgolandicus*, this is discussed further in Chapter 4. There have also been significant changes in Decapoda larvae, with large increases after 2000, and an apparent decline in the numbers of Euphausiacea (this is in keeping with results from other SEA areas, and could be a response to the NAO, as suggested by Reid and Planque, 2000. It is an area that requires further work). Other taxa that are shown in Figure 2.5 include the small copepods *Acartia* spp., *Para-pseudocalanus* spp. and the juvenile stages of *Calanus*. These are quite variable, although there does appear to have been a decrease in the number of juvenile *Calanus* recorded. The last taxa to mention is the Chaetognatha, which occurs in low numbers but is quite consistent over the study period.

3 Phytoplankton blooms

3.1 A phytoplankton bloom can be thought of as a period of enhanced growth of diatoms, dinoflagellates, cillates etc, where the population increases drastically, taking advantage of current conditions (such as enhanced silicate levels) (Bruno et al. 1989). A phytoplankton bloom can be thought of as a natural annual event, in the North Atlantic this is a spring diatom bloom followed by autumnal dinoflagellate blooms (Edwards and John 1996). In addition to this, there are exceptional phytoplankton blooms (transient, un-sustained growth, often monospecific) and Harmful Algal Blooms (HAB's). The issue of HAB's has become more topical of late, with an attempt to separate anthropogenically forced increases (through eutrophication), from more widespread 'natural' changes (such as global warming, which may or may not be anthropogenically forced), and this has lead to the UNESCO initiative GEOHAB (http://ioc.unesco.org/hab/GEOHAB.htm for further information).

3.2 Due to the spatially and temporally extensive nature of the CPR survey, in this study there are over 11000 samples covering over 40 years of study, the data can been used as a general reference point to deviations from ecological 'normal' conditions and therefore in the assessment of the overall health of an ecosystem. By using CPR data it has been concluded that the affects of eutrophication on European regional seas cannot be assessed without taking into account the wider Atlantic influences on phytoplankton populations, helping to distinguish between eutrophication and climate signals (Edwards and Reid 2001). For example, some of the most exceptional phytoplankton blooms recorded by the CPR survey have been associated with ocean climate anomalies and oceanic incursions into the North Sea (Edwards et al*.* 2002). Inflow events can be detected in the SEA 5 area, see Chapter 4.

3.3 Figure 3.1 shows Phytoplankton Colour Index (PCI) in the SEA 5 area, as compared to the North Sea as a whole. The SEA 5 area appears to be less productive, although it does follow a similar trend to the rest of the North Sea. The seasonality of PCI in the SEA 5 area can be seen in Figure 3.2, with an obvious increase in productivity and a increased 'greenness' throughout the year in recent years.

3.4 Returning to the issue of HABs, mentioned in 3.1, species that have been identified as harmful that are recorded in the CPR survey can be seen in Table 3.1. The nature of their potential hazard is also listed. Of the mentioned species, the long term abundance of *C. furca* and Chaetoceros (*Hyalochaete* and *Phaeoceros* in the CPR survey) has already been examined in section 2. Note these species are not in themselves thought to be toxic, but by means of their large bloom-forming abilities can cause anoxic conditions, leading to localised die-offs of higher trophic levels, and clog the gills of fish in the case of Chaetoceros (due to there spines). Figure 3.3 shows the long-term abundance of the most frequently recorded other potentially harmful taxa, *Dinophysis* spp., which is recorded on just over 7% of samples in the SEA 5 area.

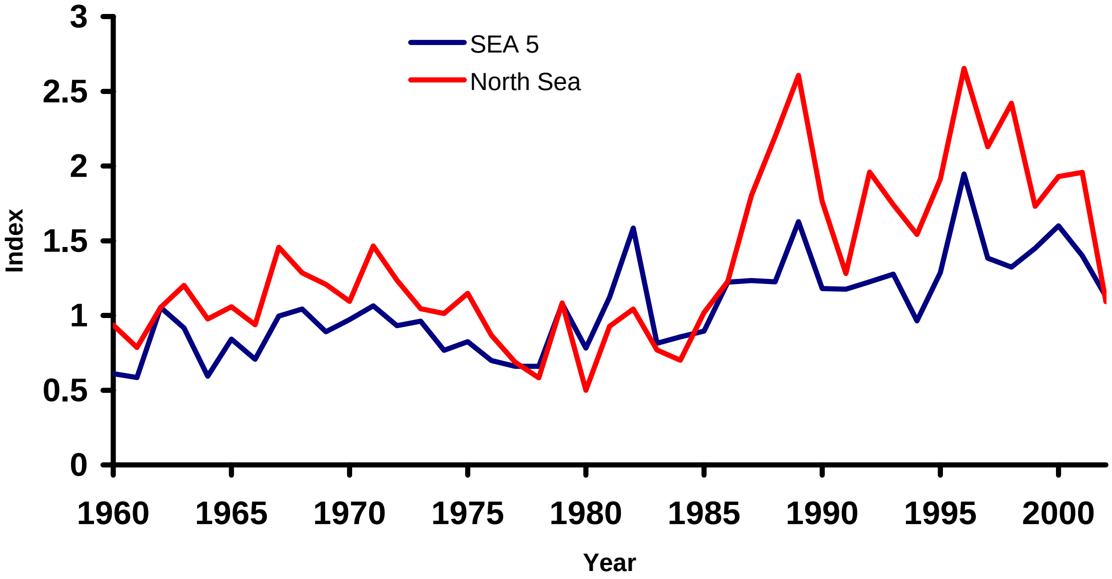


Fig 3.1 Phytoplankton Colour values in the SEA 5 area and a comparison with the North Sea as a whole.

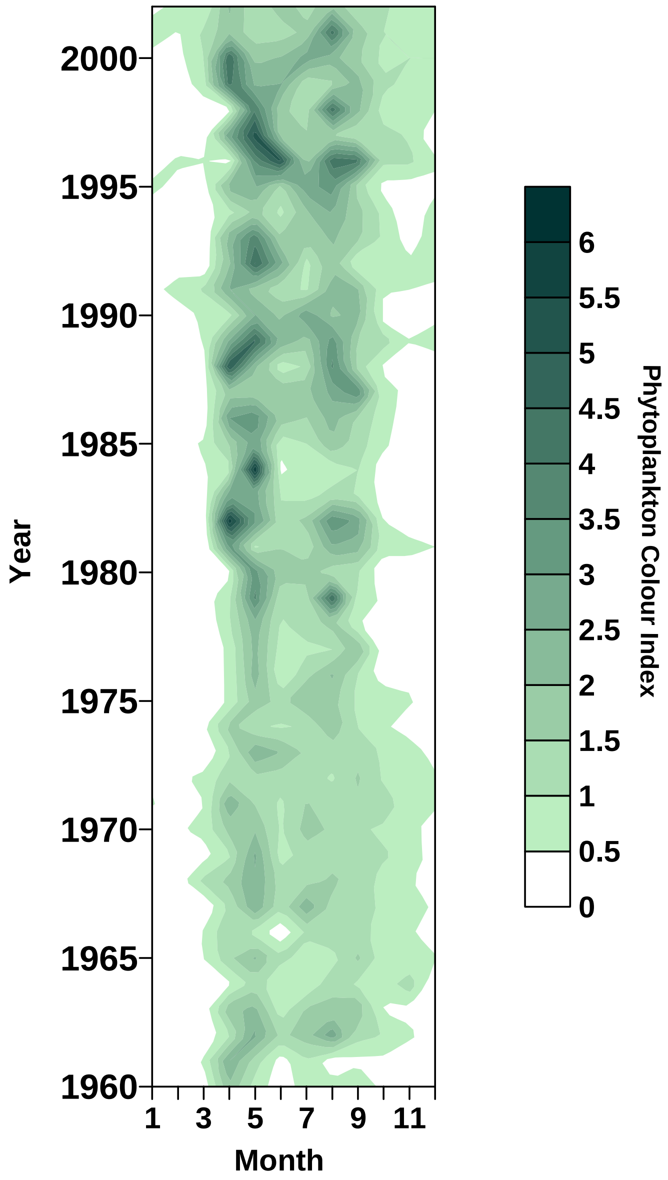


Figure 3.2. Seasonal contour plot of Phytoplankton Colour Index in the SEA 5 area

Table 3.1: Example of known harmful and detrimental phytoplankton taxa recorded by the CPR survey in the Atlantic and North Sea

Species/genus	Associated harmful/detrimental effects	Time-series
Ceratium furca	Hypoxia/anoxia	1948-
Coscinodiscus wailesii	Production of mucilage.	First recorded in 1977 (invasive)
Dinophysis spp	Diarrhetic shellfish poisoning (DSP).	1948-
Gonyaulax spp	Unspecified toxicity.	1965-
Noctiluca scintillans	Discolouration and hypoxia/anoxia.	1981-
Phaeocystis spp	Production of foam and mucilage. Hypoxia/anoxia.	1948- (presence/absence)
Prorocentrum micans	Diarrhectic shellfish poisoning (DSP.) Discolouration and hypoxia/anoxia	1948-
Pseudo-nitzschia spp	Amnesic shellfish poisoning (ASP)	1948-
Nitzschia closterium	Production of foam and mucilage.	1948-
Chaetoceros spp	Gill clogging	1948-
Skeletonema costatum	Gill clogging	1948-

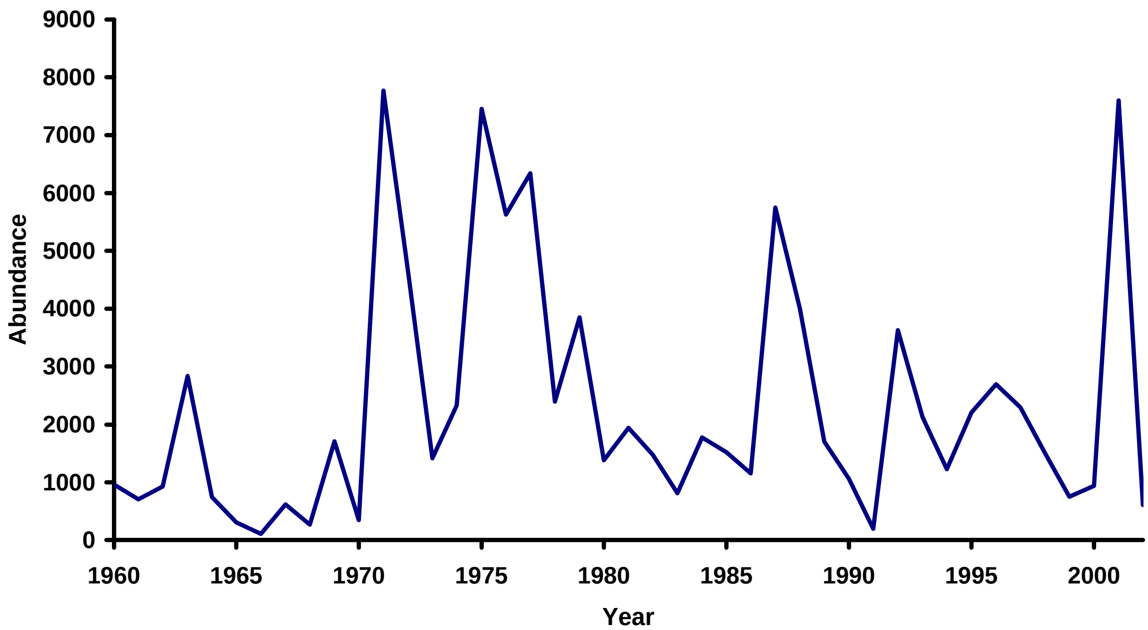


Figure 3.3. The abundance of *Dinophysis* spp. in the SEA 5 area

4. Abundance of the copepod *Calanus*

4.1 Copepods, such as *Calanus*, constitute a major food resource for many commercial fish species, such as cod and herring (Brander 1992). Changes in their populations are therefore of considerable importance, be it natural or anthropogenically forced. The dominant copepod genus in the North Atlantic is *Calanus*, which represents a major resource to the higher trophic levels, and is itself a strong grazer on phytoplankton (Planque 1996). In the North Sea, the dominant species are *Calanus finmarchicus* and *Calanus helgolandicus*, and these species have been extensively studied for many years. *C. finmarchicus* was first identified in 1770 by Gunnerus, but was not separated from *C. helgolandicus* as a different species until 1958.

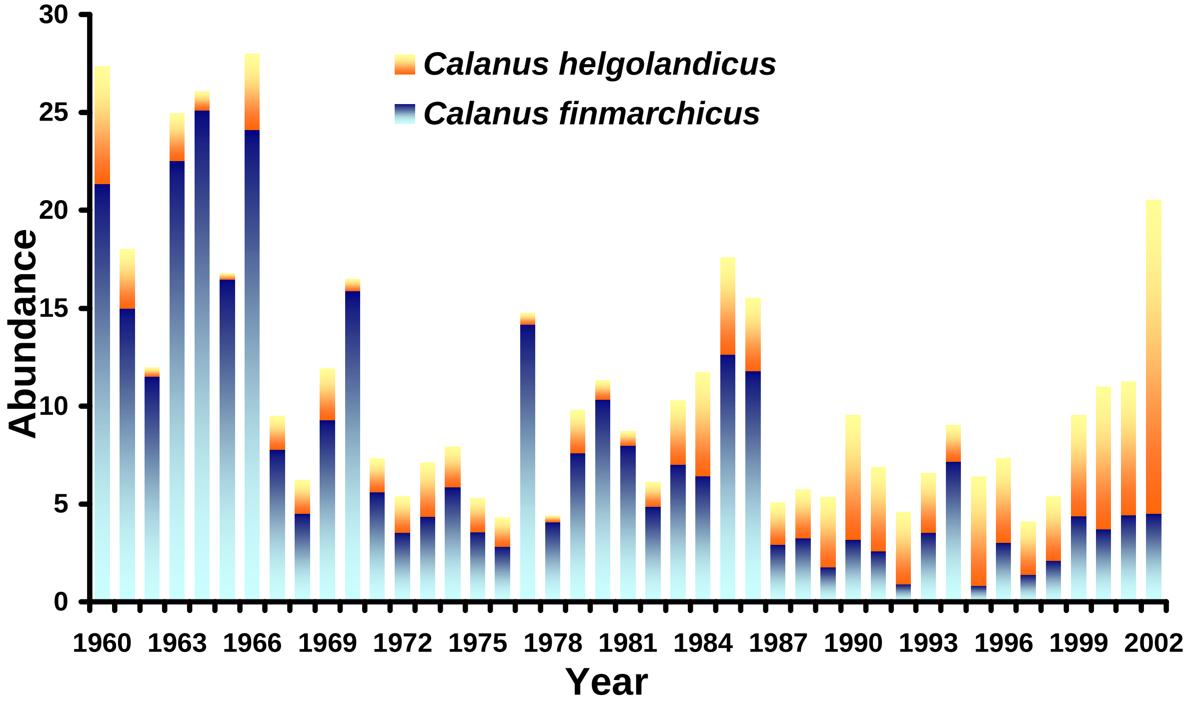


Figure 4.1 *Calanus finmarchicus* and *helgolandicus* abundance in the SEA 5 area.

4.2 Figure 4.1 shows the abundance of both *Calanus finmarchicus* and *C. helgolandicus* in the SEA 5 area. It is apparent from the Figure 4.1 that *Calanus finmarchicus* has declined significantly in the North Sea during the late 1990s, whereas *Calanus helgolandicus* has increased in the North Sea (it has moved northwards as SST has increased, Beaugrand et al. 2002). A number of hypotheses have been proposed to explain the switch in the relative abundances of the two *Calanus* species in the North Sea. For example, changes in sea temperature, food availability, inter-species competition, the transport of overwintering populations onto the shelf, and the flow and temperature of the Shelf Edge current (Reid and Beaugrand 2002). Another important aspect is the volume of the overwintering habitat in Norwegian Sea deep water, which has reduced, (Østerhus and Gammelsrød 1999), because in the high NAO state convection is halted in the Greenland Sea, leading to a reduction of Norwegian Sea deep water. It is also interesting to note that in Chapter 2, Figure 2.5, juvenile stages of *Calanus* (i-iv) have also declined and seem to follow a similar pattern to *Calanus finmarchicus,* which could suggest that Calanus juveniles in this area could be predominately *C. finmarchicus*, and *C. helgolandicus* move into the area as adults.

4.3 The SEA 5 area can be influenced by inflow events, i.e. oceanic waters are known to enter the North Sea via the Shelf Edge current (Holliday and Reid 2001, Edwards et al. 1999). This can be seen in the presence of the calanoid *Euchaeta hebes*, an oceanic species that is indicative of warm oceanic water penetrating the North Sea. Figure 4.2 shows the long term abundance of the species in the North Sea, with two periods of inflow events clearly apparent. The increase after 2000 could be attributable to increased inflow, but just as likely is a northward advancement of the species due to increased SSTs, as noted in other species by Beaugrand et al. 2002.

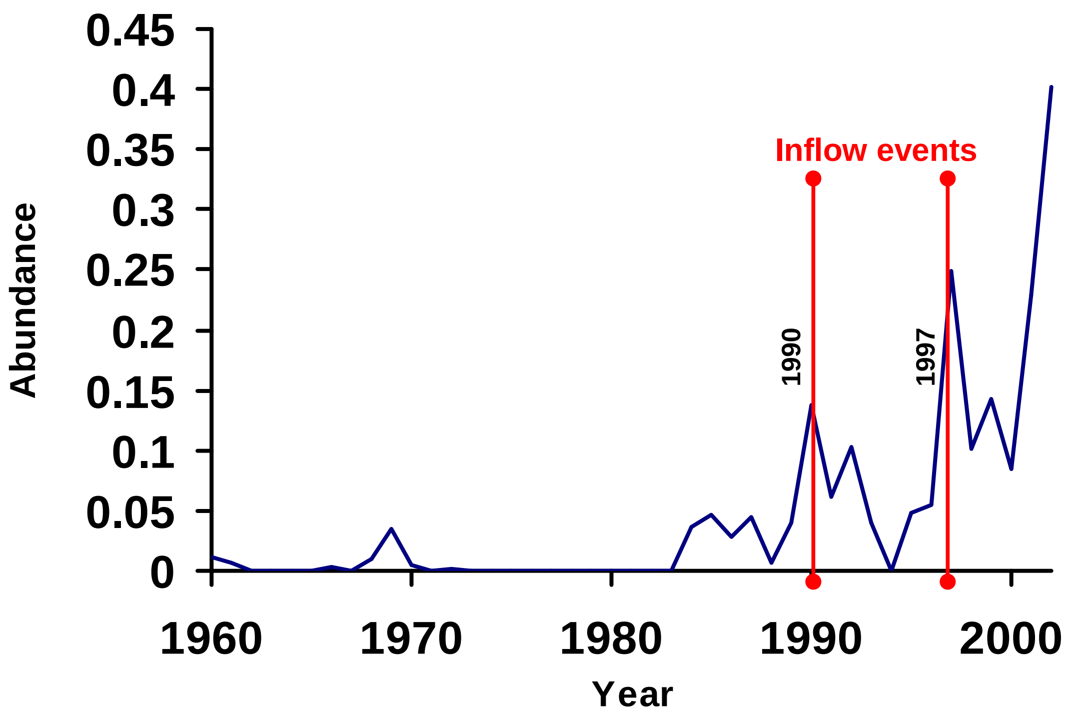


Figure 4.2 Abundance of the copepod *Euchaeta hebes*, an indicator of oceanic inflow, in the SEA 5 area.

5 Mero-, pico-, megaplankton

5.1 Meroplanktonic organisms are those that spend a part of their life cycle in the pelagos, followed by a settling to the benthos at a later (adult) stage, meroplankton in the CPR survey include Echinodermata larvae, Decapoda larvae, Euphausiids and Coelenterate (jellyfish) tissue.

5.2 Echinodermata larvae, as mentioned in earlier SEA reports, have a relevance to the oil industry due to the fact that they can clog water intake filters, due to their spiny nature and the large concentrations that can occur rapidly (Reid and Hunt 1986). Figure 5.1a shows the long term abundance of Echinodermata larvae in the SEA 5 area, compared with the North Sea. Numbers can be seen to be lower, but the general increasing trend in the North Sea is apparent but not so great. Figure 5.1b shows the percentage occurrence of different abundance categories, again comparing the SEA 5 area and the North Sea. Work by Reid and Hunt (1986) on blockages of water filters on oil rigs noted that potential problems could occur when abundances were greater than 2000 individuals per sample. In the SEA 5 area this has happened on less than 1% of samples, compared with over 3% of samples in the North Sea as a whole.

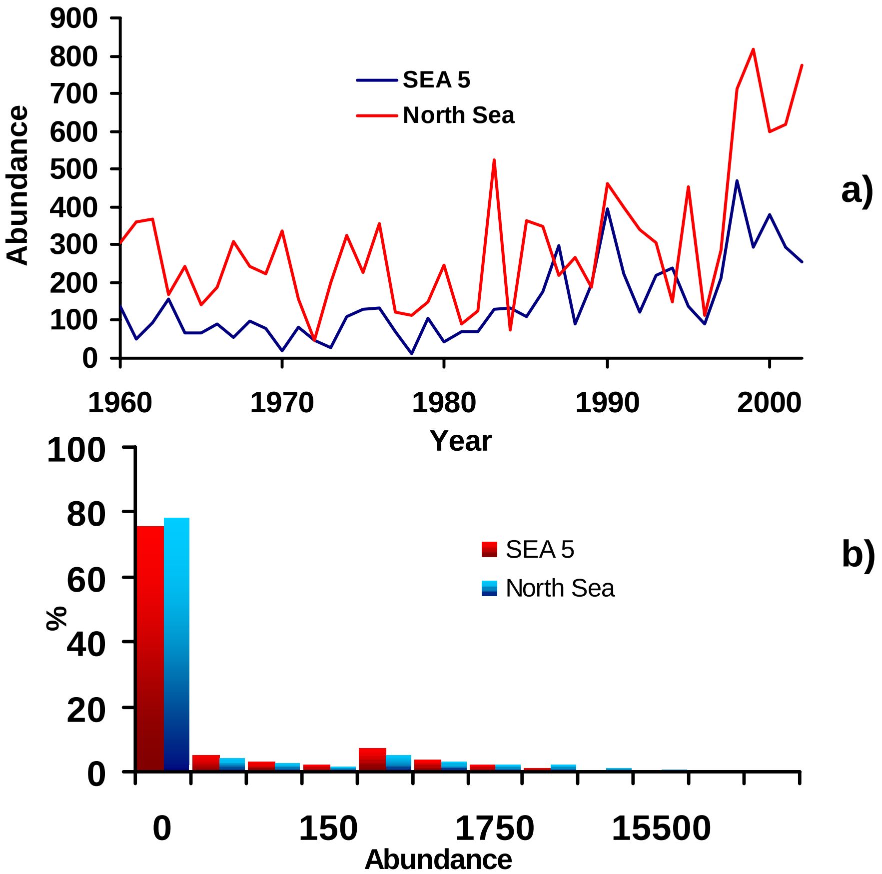


Figure 5.1a) Long term abundance of Echinodermata larvae in the SEA 5 and North Sea area, b) percentage occurrence of abundance categories of Echinodermata larvae

5.3 Figure 5.2 shows the long term abundance of Decapoda larvae in the SEA 5 area and the North Sea. Both areas exhibit an increase in abundance over the past few years, in keeping with work by Lindley and Batten (2001), which discusses a general increase in meroplanktonic organisms in the whole of the North Sea.

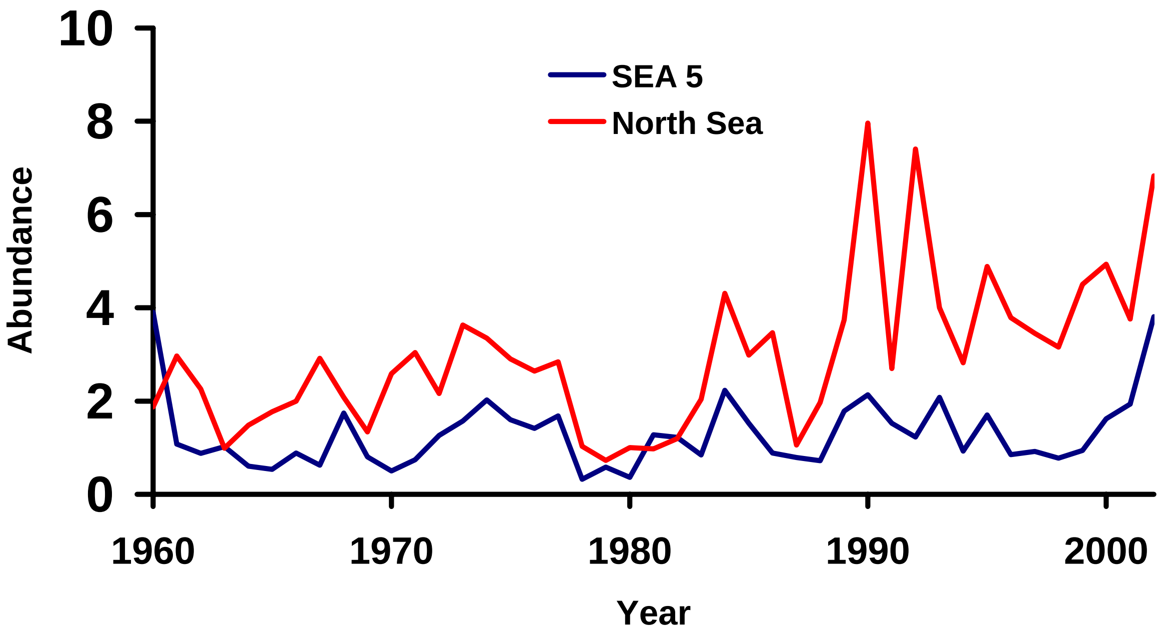


Figure 5.2 Long term abundance of Decapod larvae in the SEA 5 area and the North Sea

5.4 Picoplanktonic organisms refer to the very small plankton, between 0.2 and 2.0 microns in diameter (Carrick and Schelske 1997). As such it presents a challenge to sample, although it is thought that in the majority of the worlds oceans, the bulk of primary production is carried out by these organisms (Iriarte and Purdie 1993, Zeidner et al. 2003). Due to the limitations of sampling such small organisms by the CPR survey, it would be impossible to provide site-specific information for the SEA 5 area without using fluorescence excitation methods (Lutz et al. 2003). The picoplankton community in the SEA 5 area (and the North Sea as a whole) undoubtedly represents an important, understated part of the ecosystem, as well as a far more diverse one than previously imagined (Moon-van der Staay and Vaulot 2001). A recent Europe-wide research group, The European Picodiv project (*Exploring the picoplankton diversity*), has been set up to further investigate this community. For more information see http://www.sb-roscoff.fr/Phyto/PICODIV/

5.5 In the CPR survey, the term megaplankton refers to Euphausiids, Coelenterata (jellyfish tissue), Thaliacea (salps and doliolids) and siphonophores. For the purpose of this report, only the two former groups are examined, due to the rarity of the others (possibly due to their fragility, as they have soft gelatinous bodies that are not sampled well by the CPR survey. Euphausiids are prawn-like organisms, that can reach several centimetres in length, a number of species occur in the SEA5 area but they are not routinely speciated in the CPR survey. Figure 5.3 shows a comparison between the long term abundance of the taxa in the SEA 5 area and the North Sea. Abundance is higher in the SEA 5 area, although a distinct decline in numbers can be seen in both series. Beaugrand et al (2003) have hypothesized that this decline in Euphausiids has had a knock-on effect on cod recruitment, and the decline in Euphausiids is due to an increase in sea surface temperature in the North Sea.

5.6 In the CPR, Coelenterata are recorded as presence/absence. This is due to the fact that the soft nature of jellyfish means they disintegrate on impact with the CPR, and therefore only the presence of their tissue can be recorded. Obviously, speciation is impossible without genetic analysis, which is not routinely carried out on CPR samples. Figure 5.4 shows a long term graph of percentage occurrence on samples in the SEA 5 area and the North Sea. There appears to be a general increase in Coelenterata occurrence, which could be translated as an increase in abundance. This may be linked with anthropogenic impacts, either by overfishing (removal of finfish competitors, allowing jellyfish to exploit increased prey) or by alien species introductions (Mills 2001).

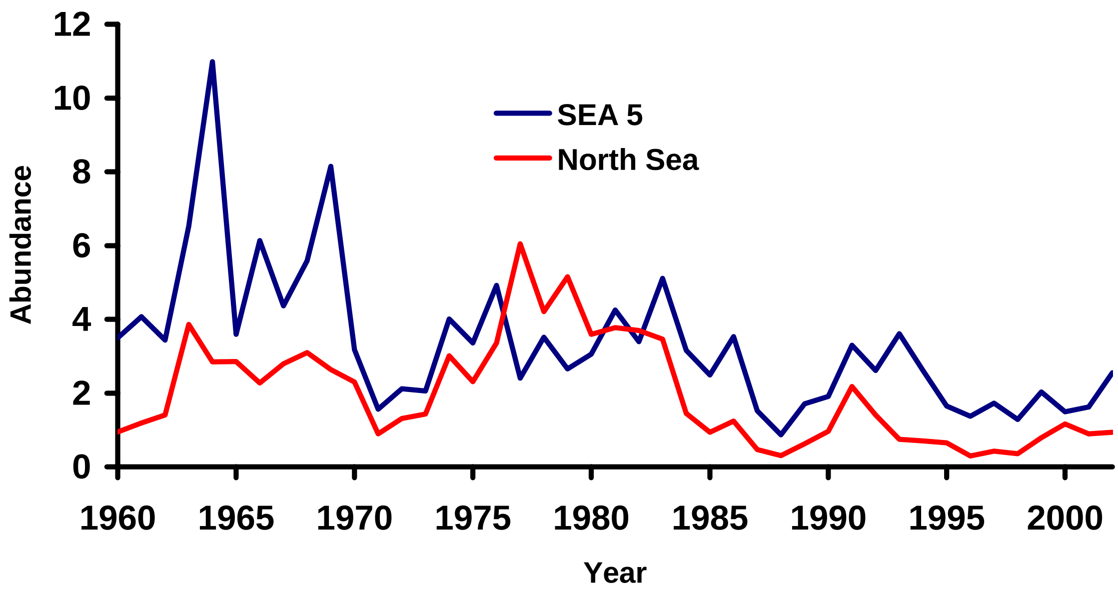


Figure 5.3 Long term abundance of Euphausiids in the SEA 5 area and the North Sea

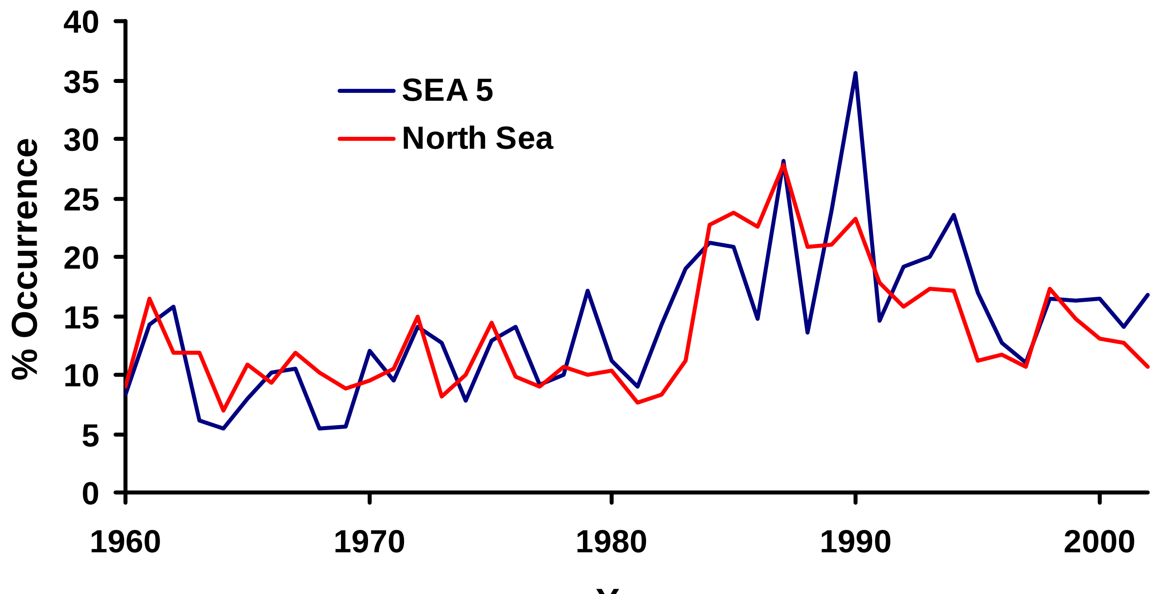


Figure 5.4 Percentage of samples with Coelenterate tissue present in the SEA 5 area and the North Sea

6. Phytodetritus and vertical fluxes

6.1 Detritus, or non-living particulate organic matter (POM), in the sea is estimated to exceed plankton mass by 10:1 (Verity et al. 2000). It is composed of a variety of organic substances, the major constituents being carbonate tests, opaline shells and other particulate organic matter (cellular and amorphous) (Honjo et al. 1982). The POM sinks through the vertical column, and the carbon contained within is often utilised for primary production in the sub-surface layers (Richardson et al. 2000). Faecal pellets constitute a major source of nitrogen removed from the upper layers, and pass through the water column, providing nitrogen flux (Hays et al. 1997). This export of biogenic material from the pelagic layers to the benthos in coastal and shelf areas can account for approximately 80% of the particle flux to the ocean floor (Varela et al. 2004).

6.2 Sediment (and re-suspension) rates of POM vary according to the dominant hydrodynamic characteristics of an area. In a shallow area of the North Sea the accumulation of sediment over a 14 day study period was estimated at 75g m^{-2} (Van Raaphorst et al. 1998). Sediment traps can be used to measure an estimate of vertical flux (Bale 1998). Using this method, Billen et al. (1990) estimated POM sedimentation of about 10 – 40 g C / m^2 yr. Sedimentation of POM is known to increase during bloom conditions (Riebesell et al. 1995, Vanderwall et al. 1995), due to the contribution from grazing species, via faecal pellet production.

7. Resting stages of phytoplankton

7.1 Certain species of both phytoplankton and zooplankton groups form resting cysts or eggs that sink to the bottom sediment until they are re-suspended or the right conditions return for them to re-emerge. In phytoplankton, these resting stages are small, typically between 40-80 microns in diameter, at times with appendages, and are preferentially concentrated in silt / mud sediment. They may be concentrated in faecal pellets and are found in high numbers in the floc that is found near the surface of sediments. The cysts often pass through the guts of deposit feeders before germination, and the ingestion process, far from being detrimental can in fact increase germination success (Kremp et al. 2003). The formation and germination of resting cysts represents a positive gain to a population through seeding, although there is a negative effect of sedimentation (Itakura et al. 1997). Excystment is commonly thought to be triggered by temperature, although light and oxygen levels to a lesser extent maybe involved (Paranjape 1980, Müller 2002).

7.2 Surveys of the distribution of dinoflagellate cysts around the British Isles in the late 1960s showed a change in species assemblages from one part of the coast to another that reflected hydrographic provinces, the positions of fronts and evidence for oceanic influence. These early observations are applied in Quaternary stratigraphy (Mudie and Harland 1996) and are known to reflect the changing climate of Europe. A recent re-examination of dinoflagellates in coastal sediments (Helen McCall, pers.comm.) indicates that the assemblages of the late 1990s are different to those found 30 years earlier.

7.3 Some of the most toxic dinoflagellates, causing for example PSP, form large numbers of resting cysts. They can easily be transported in fine bottom sediments at the bottom of ballast water tanks. Tropical species may also be carried in this way and could pose an invasive threat. Over the last few decades ballast water discharges have increased throughout the world in most of the major ports. The discharge volumes of ballast water can be considerable, and the probability of a successful establishment of a self-sustaining populations of exotic species is expected to increase with greater volumes of ballast water and reduced ship transit times (Rosenthal et al. 1998). Ships have been recognised as a major vector for the introduction of non-indigenous and harmful organisms (with their large volumes of ballast). Recent publications have advocated the use of ultraviolet radiation followed by a period of darkness to prevent photorepair (Sutherland et al. 2001, Wonham et al. 2001). The latter report states that over 50% of taxa and 98% of organisms did not survive a trans-Atlantic crossing, and this mortality was further enhanced by a mid-ocean exchange (the most common form of preventing invasion).

8. Conclusions

8.1 The effect of the most dominant driving force of the North Atlantic hydrodynamics, the North Atlantic Oscillation, is evident in both phyto- and zooplankton community structure, with periods of high NAO index and low NAO index apparent in the community structure. The phytoplankton community of the SEA 5 area is similar to the North Sea as a whole, with long term trends of abundance for taxa common to both areas responding similarly. In the case of zooplankton, the increase in the SEA 5 area of *Calanus helgolandicus* and the subsequent decrease in *C. finmarchicus*, due to changes in SSTs (higher SSTs favouring the more temperate *species C. helgolandicus*) is apparent. Periods of inflow of oceanic waters can also be detected in the SEA 5 area, notably by the presence of the calanoid copepod *Euchaeta hebes*, although the increase in abundance during the latter years is possibly due to the species' expansion northwards, again as a response to increased SSTs.

8.2 Phytoplankton Colour Index, a indicator of primary production, has increased in the SEA 5 area as it has throughout the majority of the North Sea. Spring and autumn blooms are evident in the examination of long term seasonality, as is a increase throughout the whole year after the mid-1990s, this is possibly due to an increase in the abundance of dinoflagellate species, commonly thought to bloom in the autumn period. Blooms of HAB forming species, such as *Dinophysis* spp. (not all species of this taxa are toxic, but routine identification of species did not start until January 2004 in the CPR survey) and *Ceratium furca* do occur, with the latter species very prevalent in the SEA 5 area.

8.3 Echinodermata larvae, which from past reports are known to be able, in very large blooms, to block water inflow systems, occur commonly in the SEA 5 area. When compared with the North Sea as a whole, the percentage of large blooms in the SEA 5 area is very small, possibly due to the influence of inflow from oceanic waters. Decapoda larvae have increased in the SEA 5 area, along with elsewhere in the North Sea, but Euphausiid abundance has fallen (although they are more abundant in the SEA 5 area than the North Sea, due to the generally lower SSTs). The occurrence of Coelenterata tissue has also increased, possibly as a response to the decrease in co-competitive fish species.

8.4 The picoplankton community of the SEA 5 area, although undoubtedly highly relevant, cannot be commented on due to the coarse nature of the CPR survey. This is an area that should be pursued further, as this part of the phytoplankton community can contribute greatly to primary production in the area.

8.5 Many of the above changes that have been noted are thought to be linked to hydro-climatic variations, such as the state of the NAO and increases in the North Sea SST. Separating these 'natural' responses from anthropogenically-forced changes, such as over-fishing, ballast water transport of invasive species, eutrophication etc. is near impossible to do. Undoubtedly all the above have a significant effect on the SEA 5 area, and the North Sea as a whole.

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