Plankton Report for
Strategic Environment Assessment Area 3
(Addendum to SEA 2 Plankton report)

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1. Introduction

1.1 This report is to be read as an addendum to the earlier SEA 2 document on plankton ecology in the North Sea, concentrating more specifically on the SEA 3 area and topics of interest specified at the Expert Workshop (Aberdeen, July 2002). To highlight similarities and differences between the SEA 3 area and the North Sea, the plankton of the SEA 3 area are compared with that of the North Sea as a whole (60°N to 52°N, 9°E to 3°W).

1.2 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 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.*, In press). 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.

1.3 Topics covered in this report are as the following sections:

2. Phytoplankton (Colour index and community structure, long term changes and seasonality).
3. Echinoderm larvae (long term changes and seasonality).
4. Non–indigenous plankton species (examples of and possible problems).
5. Concluding remarks.
6. References.

2. Phytoplankton

2.1 Phytoplankton colour is a visual index of chlorophyll, based on the ‘greenness’ of the CPR filtering silk, and is assigned a numerical value (one of four categories) (Reid *et al.*, 1998). As such, it gives an estimation of chlorophyll *a* values, and thus an indication of phytoplankton biomass.

2.2 Figure 1 shows phytoplankton colour values in the North Sea and in the SEA 3 area. Since the mid 1980s, there has been a steady increase in values. This increase, with a peak in 1989 corresponded with anomalous warm sea surface temperatures (SST) (Edwards *et al.*, 2001).

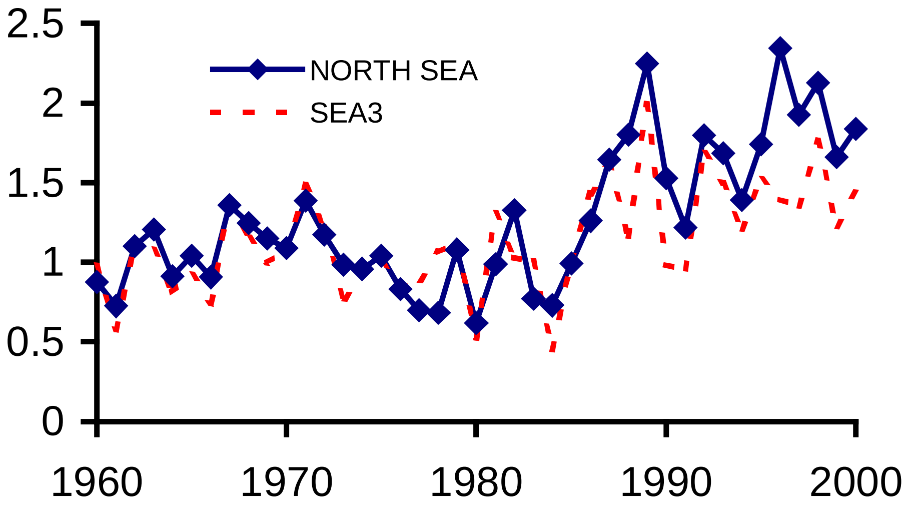


Figure 1. Phytoplankton colour values in SEA 3 and the North Sea.

The two indices show very similar trends, with the SEA 3 area having marginally lower values in the 1990s. The most likely explanation is that there has been a warming in SSTs over the last decade, as a response to hydro-climatic forcing mechanisms (such as the North Atlantic Oscillation, NAO). The NAO, a large-scale alternation of atmospheric mass with centres near the Icelandic Low and the Azores High (Stein 2000), is one of the main driving forces of the North Atlantic climate. During the 1990s the NAO has seen its most prolonged positive phase since records began (1864), and the intensity appears to be ‘amplifying’ with time (Dickson and Turrell, 2000). This positive phase of the NAO has seen pronounced changes in the northeastern Atlantic, with identified biological responses in the plankton community due to this (Planque and Fromentin, 1996, Edwards *et al.*, 1999).

2.3 From the comparison between areas in Fig 1, it is apparent that the SEA 3 area is not substantially different in chlorophyll *a* values to the rest of the North Sea. However, the colour index does indicate high phytoplankton biomass in the area, especially when compared with other shelf seas surrounding the British Isles (Edwards 2001).

2.4. Figure 2 shows the long-term seasonality of phytoplankton colour values in the SEA 3 area. From 1960 to the mid 1980s, the plot highlights the typical spring and autumn blooms of the North Sea, with reduced production during the winter months. Since the late 1980s, there has been a shift to predominately all-year round production, with higher values being recorded in the winter than previously. Edwards (2001) notes that winter phytoplankton biomass has increased by 97% during the 1990s in the North Sea. Note also 1978-1980, when there was a lack of a distinct spring bloom (although there was a definite, strong autumnal bloom). This period corresponds with the Great Salinity Anomaly (GSA), which was an ocean climate anomaly of fresher water and colder winter air temperatures (Dickson *et al.*, 1988). The effect of the GSA was more persistent, lasting a number of years with the phytoplankton community affected after temperature and salinity values had returned to normal.

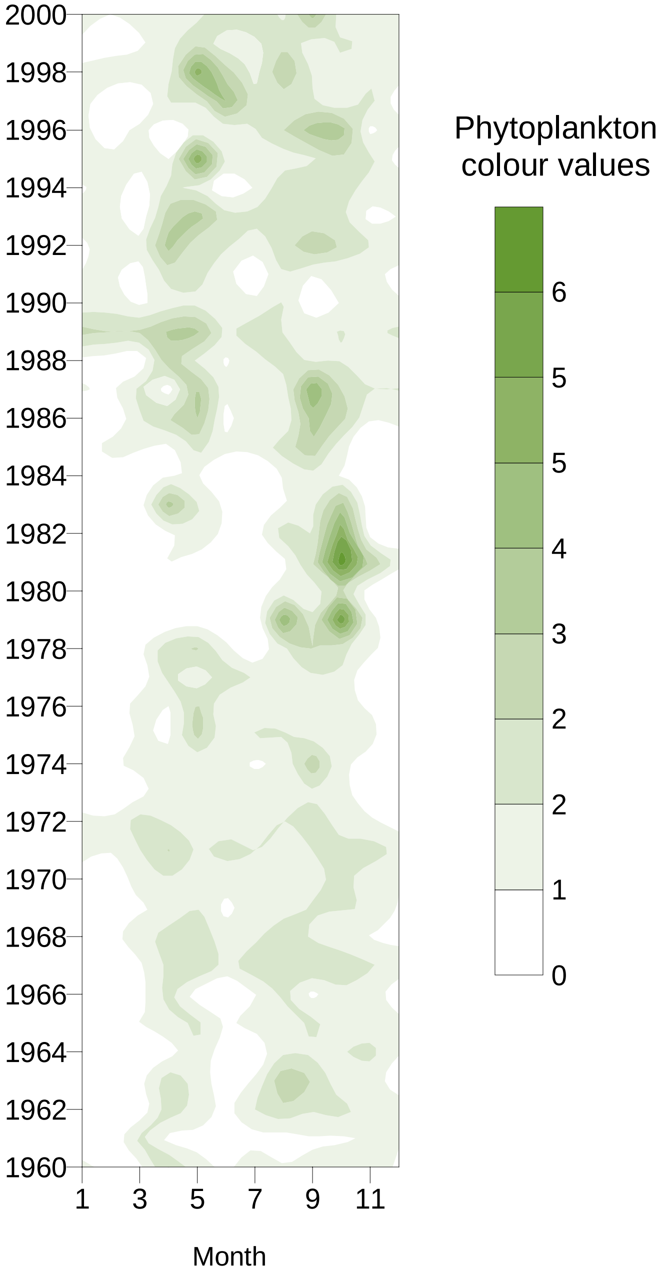


Figure 2. Contour plot of long term seasonality of phytoplankton colour values in the SEA 3 area.

2.5 Table 1 shows the ten most frequent phytoplankton taxa from both the SEA 3 area, and the North Sea. ‘Frequency’ is the percentage of times that the entity has been recorded in the specified area. ‘Contribution’ is the percentage of the total phytoplankton community abundance that the entity contributes. Both areas have nine common species, with the seven most frequent species being identical.

SEA 3			**NORTH SEA**		
Species	**Frequency (%)**	**Contribution (%)**	**Species**	**Frequency (%)**	**Contribution (%)**
Ceratium fusus	27.95	13.23	***Ceratium fusus***	27.03	13.92
Ceratium furca	22.51	11.24	*Ceratium furca*	23.02	10.64
Phaeoceros spp.	17.82	6.83	*Phaeoceros* spp.	20.68	5.45
Hyalochaete spp.	17.44	6.56	*Hyalochaete* spp.	18.96	6.12
Thalassiosira spp.	17.16	7.83	*Thalassiosira* spp.	16.37	10.73
Ceratium tripos	16.18	4.63	*Ceratium tripos*	14.99	5.34
Ceratium macroceros	10.69	8.64	*Ceratium lineatum*	13.32	3.76
Rhizosolenia alata alata	10.29	5.09	*Rhizosolenia alata alata*	11.60	4.06
Ceratium horridum	9.88	1.88	*Protoperidinium* spp	9.49	2.32
Protoperidinium spp.	9.35	2.55	*Ceratium macroceros*	9.28	1.76

Table 1. Most frequent phytoplankton taxa in the SEA 3 area and the entire North Sea.

2.6 The most abundant phytoplankton taxa in the SEA 3 area are dinoflagellates of the genus *Ceratium*, which include the species *C. fusus, C. furca, C. tripos, C. lineatum, C. macroceros* and *C. horridum.* Comparisons between area SEA 3 and the North Sea are shown in Figure 3. The results for *Ceratium* species are similar between the two areas, but with the following trends identifiable: *C. lineatum* has greater abundance in the SEA 3 area than the rest of the North Sea, but a lower frequency, *C. tripos* is generally less abundant in the SEA 3 area than the rest of the North Sea and *C. macroceros* has been in decline in both areas since the mid-1970s. The decline of *C. macroceros* is most likely a response to ocean climate anomalies (Edwards *et al.,* in press), although it was never as abundant as other *Ceratium* species (1960-2000).

2.7 Comparisons between the diatom members of the plankton community, *Rhizosolenia alata alata*, *Phaeoceros* spp., *Hyalochaete* spp., *Thalassiosira* spp. and the dinolagellate *Protoperidinium* spp. can be seen in Figure 4. Again, the two areas indicate similar long-term trends, although there appears to be more variability in the SEA 3 area. *Thalassiosira* spp. abundance in SEA 3 in the early 1980s, compared with the rest of the North Sea, does show a marked difference, with numbers being much lower. This is likely due to a stronger response to an ocean climate anomaly (such as the aforementioned Great Salinity Anomaly), as *Thalassiosira* are typically spring blooming diatoms (which can be seen to have been affected, see section 2).

2.8 The *Chaetoceros* groups of *Phaeoceros* sp. and *Hyalochaete* sp. both suggest a decline (particularly the former), with the SEA 3 and North Sea showing similar trends.

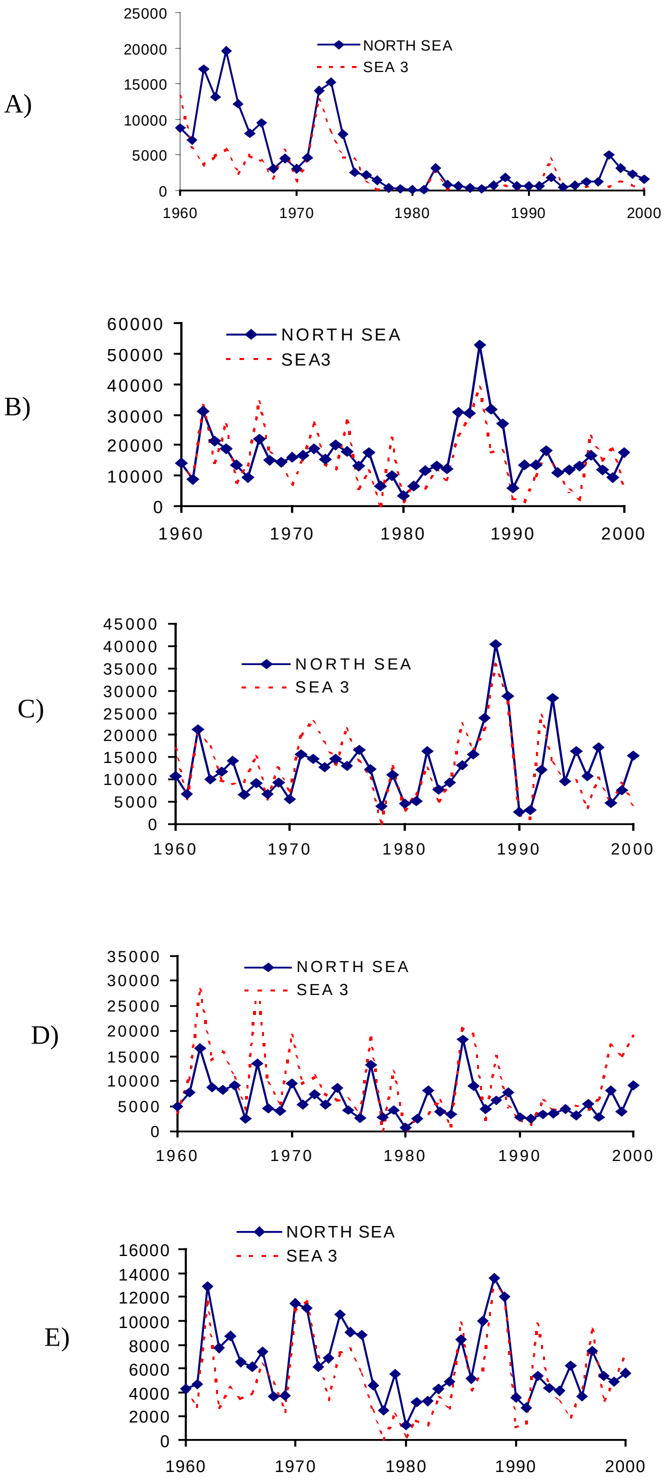


Figure 3. Long term abundance of *Ceratium* species in SEA 3 and North Sea areas: A) *C. macroceros* B) *C.fusus* C) *C.furca* D) *C.lineatum* E) *C. tripos*. Abundance is average number of individuals per month.

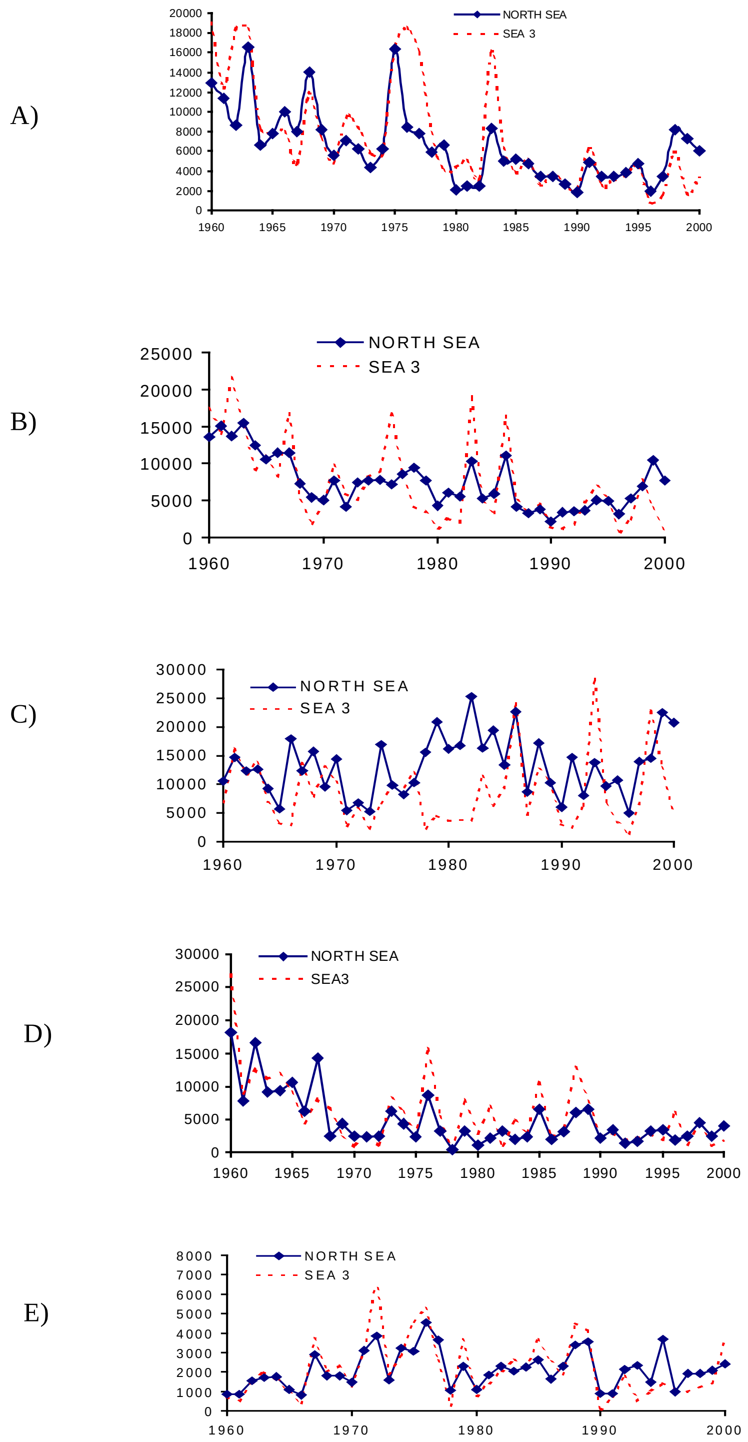


Figure 4. Phytoplankton long term abundance in the SEA 3 and North Sea areas: A) *Phaeoceros* spp. B) *Hyalochaete* spp. C) *Thalassiosira* spp. D) *Rhizosolenia alata alata* E) *Protoperidinium* spp. Abundance is the average number of individuals per month.

3. Echinoderm larvae

3.1 Echinoderm larvae are meroplanktonic, organisms that spend only part of their life within the plankton community. Sea urchins and starfish belong to the Echinodermata, and are recorded in the CPR survey (although they are not generally speciated). The ‘spiny’ nature of this taxa, and the tendency to reproduce in very large numbers, can lead to the blockage of water inflow units (Reid and Hunt, 1986).

3.2 Figure 5 (a + b) represents the long term seasonality, and long term abundance of echinoderm larvae in the CPR survey respectively, within the SEA 3 area. There appears to be a gradual increase in abundance throughout the time period, which has been noted by Lindley *et al*. (1995), and Lindley and Batten (2001), in keeping with an increase in production from the benthos. Peak periods of abundance are in the summer months.

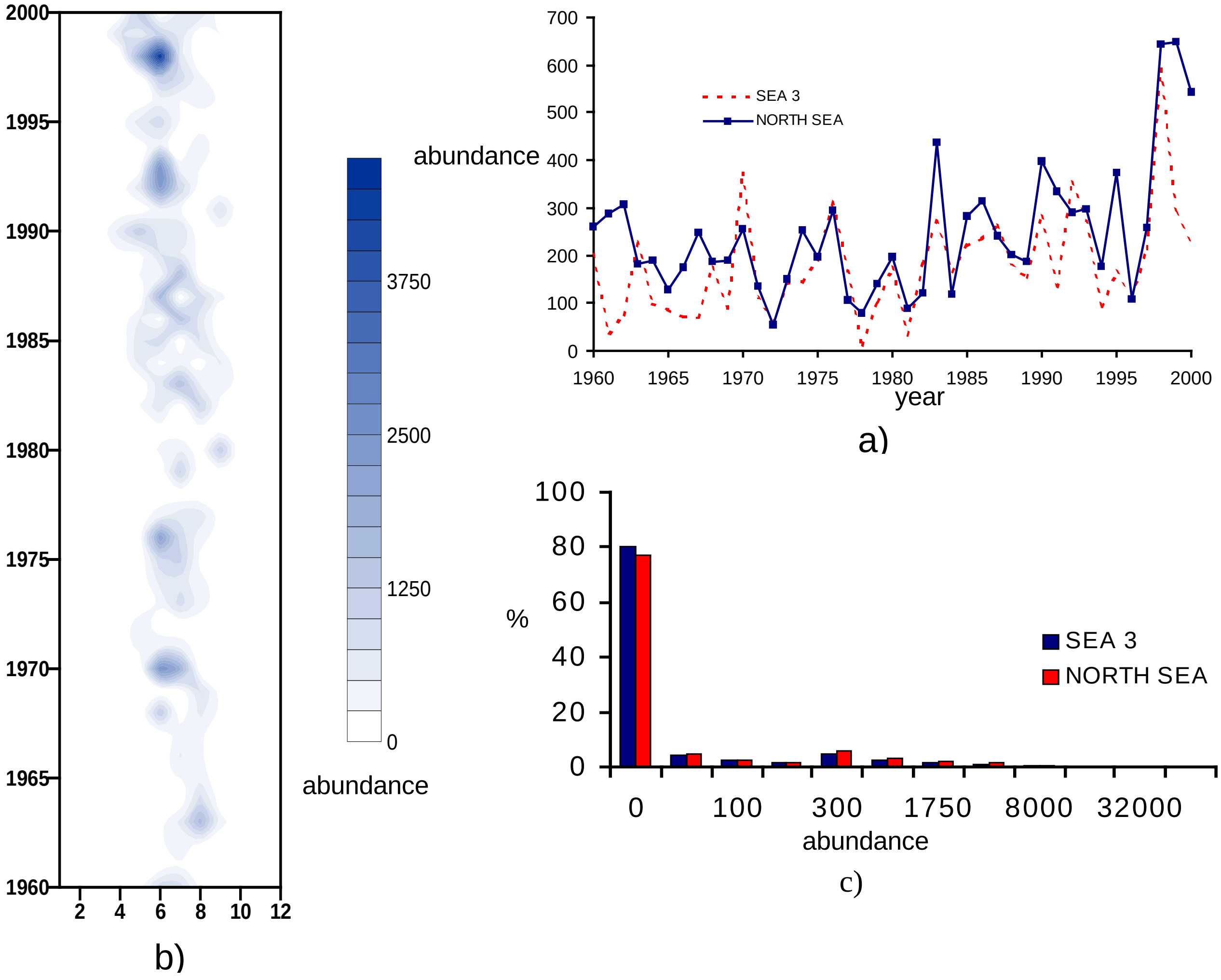


Figure 5. a) Long term abundance of echinoderm larvae in SEA 3 area and North Sea.
b) Long term seasonality of echinoderm larvae in SEA 3 area.
c) Frequency of abundance of echinoderm larvae in SEA 3 area and North Sea.

3.3 Figure 5 (c) shows the frequency of abundance of echinoderm larvae from the SEA 3 and North Sea areas. It can be seen that the majority of samples have zero echinoderm larvae recorded, with the second most frequent abundance being in the 300 to 849 group. Reid and Hunt (1986) state that in the case of the filter blockage of equipment on the Leman Bank area (June 1986), echinoderm larvae reached concentrations of over 2000 per sample. In the SEA 3 area this occurs on 3.26% of the samples from 1960, whereas in the North Sea as a whole it is 4.6% of the samples. Unusual occurrences can occur, and the trend of the graph in Fig. 5 (a) is rising, so monitoring of establishments during the summer months could be beneficial.

4. Non–indigenous plankton species

4.1 The plankton report for SEA 2 contains a section (pages 26-28) on non-indigenous (previously named ‘invasive’) plankton species, their vectors and possible outcomes of introduction. Of particular interest were the species *Odontella sinensis* (Ostenfeld, 1908) and *Coscinodiscus wailesii* (Edwards *et al.*, 2001).

4.2 These species, although well established in other parts of the North Sea, are less common in the SEA 3 area (although *C. wailesii* occurs more frequently in the southern part of the SEA 3 area). Figure 6 shows both species long-term abundance. Note that *C. wailesii* (Fig. 6 (b) did not occur until 1978, the 1989 peak (mentioned in 2.2) is evident. Also of interest is that the species was not recorded from 1995 on any sample in the SEA 3 area (but *O. sinensis* , Fig. 6 (a),reached its highest abundance in the SEA 3 area in the same year).

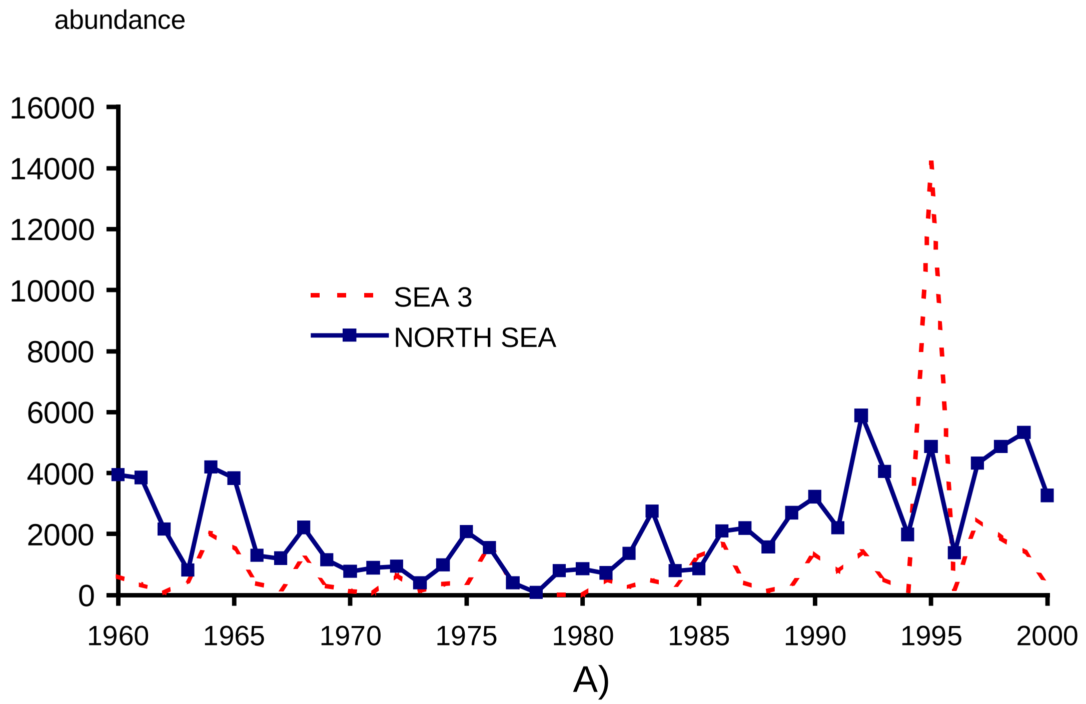
4.3 The reason these species have not established themselves in the majority of the SEA 3 area is likely due to the seasonal stratification that occurs. As spring progresses, surface waters warm and form a more permanent thermocline. Colder, nutrient rich waters remain below this layer, with little mixing, hence stratification occurs. The SEA 3 area, with its strong seasonal stratification (Pingree and Griffiths, 1978), is not a favourable environment for the two above-mentioned species, which (as diatoms) prefer well mixed / transitional waters (Edwards *et al.*, 2001).

4.4 Possible non–indigenous phytoplankton that could thrive in the SEA 3 area would be dinoflagellates, which depend upon seasonal stratification and limited nutrients (Williams and Lindley, 1980). A further factor to consider, if precipitation increases due to climate change (IPCC, 2001), that is the climate becomes warmer and wetter, is the possible effect of winter dinoflagellate blooms. Winter blooms have been identified as a response to halostratification occurring as a result of freshwater run-off (Labry *et al.*, 2001), and could pose problems, as many dinoflagellate species are known to be toxic (GEOHAB, 2001). An increase in winter phytoplankton colour values has already been observed, this is probably a response by the phytoplankton to large scale hydro-climatic variations.

4.5 Non-indigenous zooplankton species could be introduced via ballast water into the SEA 3 area, although this is more unlikely than phytoplankton species (as many phytoplankton form resilient ‘resting cysts’, and are thus more robust in transit). As mentioned in the SEA 2 plankton report, a number of non-indigenous zooplankton species have been identified in the North Sea, although none appear to have been introduced anthropogenically. The most likely reason for this is increased warm water in the North Atlantic, as a response to the North Atlantic Oscillation. Beaugrand *et al.* (2002) has commented on a 10^{o} northward shift of calanoid copepods as a similar response to hydro-climatic processes.

4.6 Non-indigenous zooplankton appear to have advected to the area with warmer waters (Beaugrand et al., 2002), along with larger species such as mantis shrimp and triggerfish. Ballast water introductions would appear to be very uncommon, with the one possibility being *Penilia avirostris* (a cladoceran, or water flea). This species has occurred in the North Sea since 1999, possibly after being introduced in a resting egg stage. It is impossible to tell if this is a case of an anthropogenic introduction, as the species could as likely shifted northwards as other species mentioned above. It does occur in large numbers when favourable conditions occur (although not in the SEA 3 area), but is not a significant part of the zooplankton community, nor altered the community structure, such as the introduced cladocera *Cercopagis* sp. in the Baltic Sea (Gorokhova *et al*., 2000).

4.7 According to the Expert Workshop on the SEA 3 area (Aberdeen, July 2002), this area is more likely to contain gas than oil, and destined for the UK market, rather than exported. This will restrict the possibility of vessels from foreign waters entering the area, and therefore lower the risk of ballast water dumping, and the introduction of non-indigenous species.



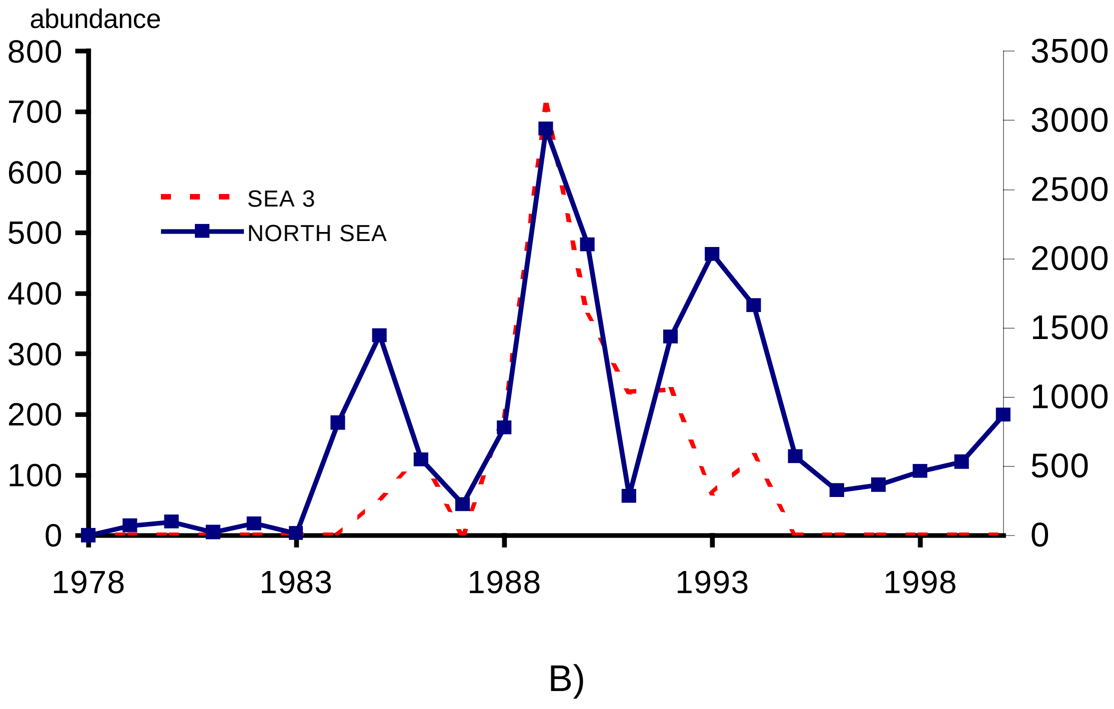


Figure 6. a) *Odontella sinensis* long term abundance in the SEA 3 area and North Sea.
b) *Coscinodiscus wailesii* long-term abundance in the SEA 3 (1st axis) and North Sea (2nd axis).

5. Summary

It is apparent from recent research (Reid and Edwards, 2001, Beaugrand *et al.*, 2002) that the plankton community in the North Sea has undergone a marked change since the late 1980s. Phytoplankton colour values have increased in all areas of the North Sea, but also west of the British Isles in oceanic waters (Edwards *et al.*, 2001), as well as in the North west Atlantic (Johns, unpublished), suggesting a large scale response, such as climate forcing, and not as a response to eutrophication.

Non-indigenous phytoplankton species that have been introduced into the North Sea area have not reached large concentrations in the SEA 3 area, most likely due to the strong seasonal stratification that occurs. Although *C. wailesii* can be very abundant in parts of the North Sea, it is not a toxic species and has not reached nuisance levels, and has not been recorded since in the SEA 3 area since 1995. As yet, no introduced potentially hazardous phytoplankton have been identified. The hydrography of the area would probably favour dinoflagellates, which could be introduced via ballast water, in a resting cyst stage. But, the likelihood of mainly gas for the United Kingdom market being produced in SEA 3, would mean that foreign vessels, with their associated ballast water flora / fauna, are unlikely to be greatly utilised.

Long term changes of the phytoplankton species in SEA 3 area do not appear substantially different to the rest of the North Sea, although slightly more variable. The community composition is very similar, although with marginally lower chlorophyll *a* levels. Hydro-climatic events are responded to in a similar way to the whole of the North Sea.

The abundance of echinoderm larvae is not particularly high, although there is an increasing trend. Large occurrences of echinoderm larvae (over 2000 individuals per sample) can occur (on approx. 3% of samples since 1960), and these can present potential problems to filtration equipment. It is impossible to predict these events, although analyses of long term seasonality can highlight potential ‘danger’ times to some extent.

In conclusion, the SEA 3 area is as variable as the rest of the North Sea, showing similar trends. Current research indicates that the changes in the plankton ecosystem in the North Sea over the last 20 years are likely due to hydro-climatic forcing (which may be anthropogenically forced itself), rather than the more obvious anthropogenic impacts such as eutrophication and ballast water dumping.

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