Plankton Report for Strategic Environment Assessment Area 4

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Contents

1. Introduction

1.1 The aim of this report is to provide information on the planktonic community of the SEA 4 area, covering approximately 58.5°N to 64°N and 7°W to 2°E, see Figure 1. The area is influenced by a number of currents, flowing through the Faroe – Shetland Channel, notably the Shelf Edge Current, which transports warm oceanic water northwards, a proportion of which enters into the North Sea (Turrell, 1992, Holliday and Reid, 2001). Data for this report will be provided by the Continuous Plankton Recorder Survey, as well as sourced from outside organisations. Any existing gaps in knowledge will be highlighted.

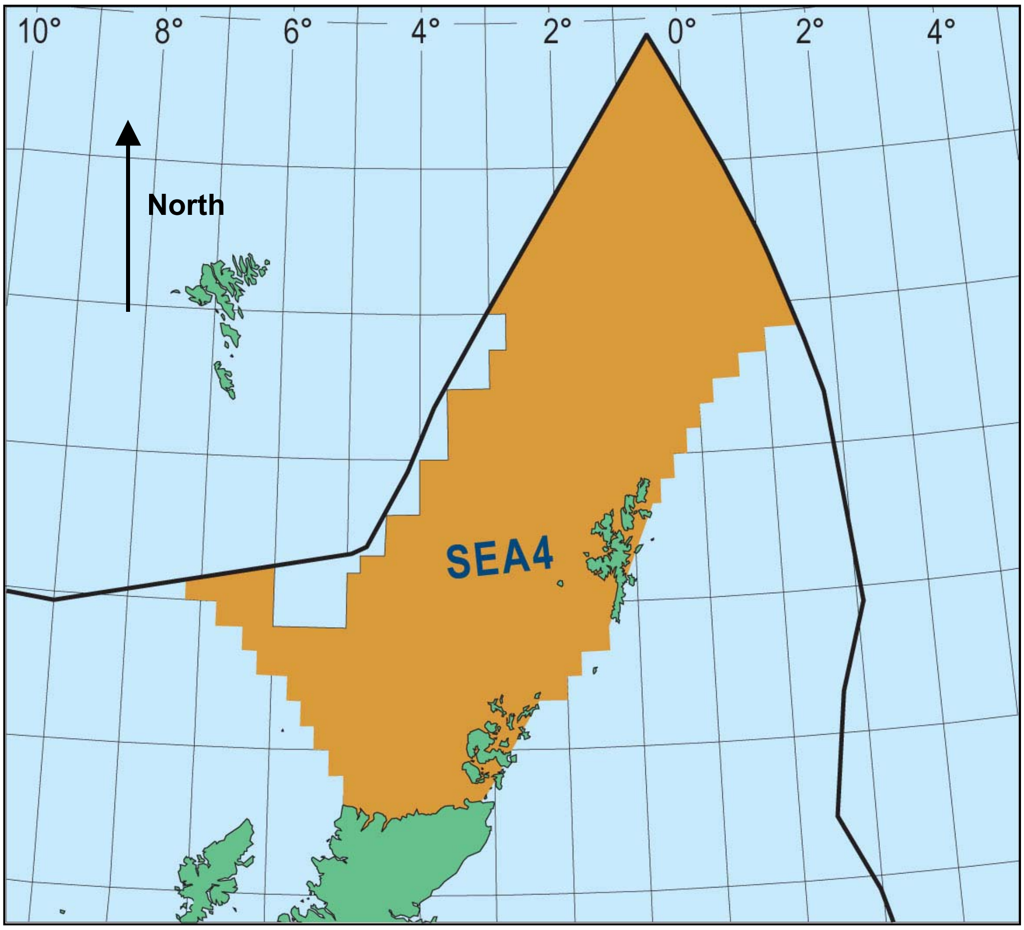


Figure 1. Map showing position of SEA 4 area, north of Scotland.

1.2 The report will address the following issues:

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

1.3 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., 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.

1.4 It is assumed the readers are familiar with basic plankton 'details', but if further information is required see the SEA 2 report section on plankton. In addition, due to the complex nature of the locale's hydrography, which is outside the remit of this report, see Holliday and Reid (2001) for more information.

2. Phytoplankton and zooplankton community composition

2.1 In the SEA 4 study area, the CPR survey has over 4600 samples, each containing both phytoplankton and zooplankton taxa (presence / absence or abundance), spanning over 40 years. Tables 1 and 2 list phytoplankton and zooplankton taxa respectively that occurred on over 5% of samples (% occurrence in samples is given). Species that occurred below 5% were deemed rare and disregarded for the later community analysis.

Phytoplankton taxa	% samples
Ceratium fusus	28.48
Thalassiosira spp	22.53
Chaetoceros (*Hyalochaete*) spp	20.84
Ceratium furca	19.63
Chaetoceros (*Phaeoceros*) spp	19.04
Rhizosolenia alata alata	15.20
Ceratium tripos	13.40
Thalassionema nitzschioides	12.08
Rhizosolenia styliformis	10.67
Nitzschia delicatissima	10.24
Nitzschia seriata	9.50
Ceratium lineatum	9.43
Ceratium horridum	8.33
Protoperidinium spp	6.51
Dactyliosolen mediterraneus	6.14
Rhizosolenia imbricata shrubsolei	5.99
Ceratium macroceros	5.88
Rhizosolenia hebetata semispina	5.29
Thalassiothrix longissima	5.23

Table 1

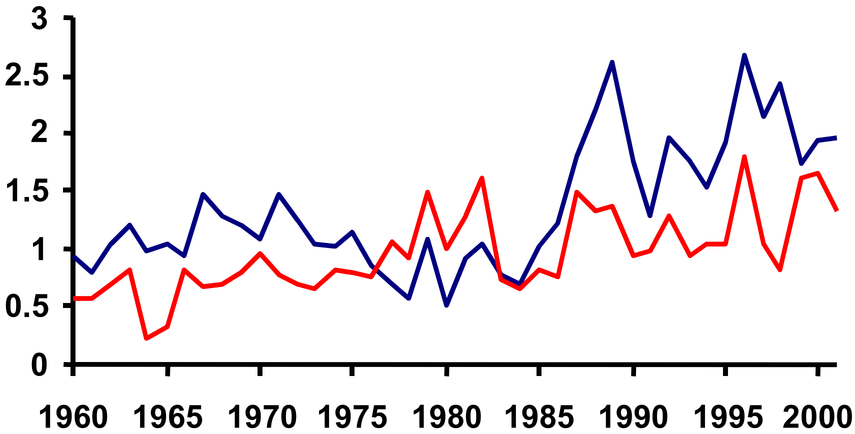
Zooplankton taxa

Table 2

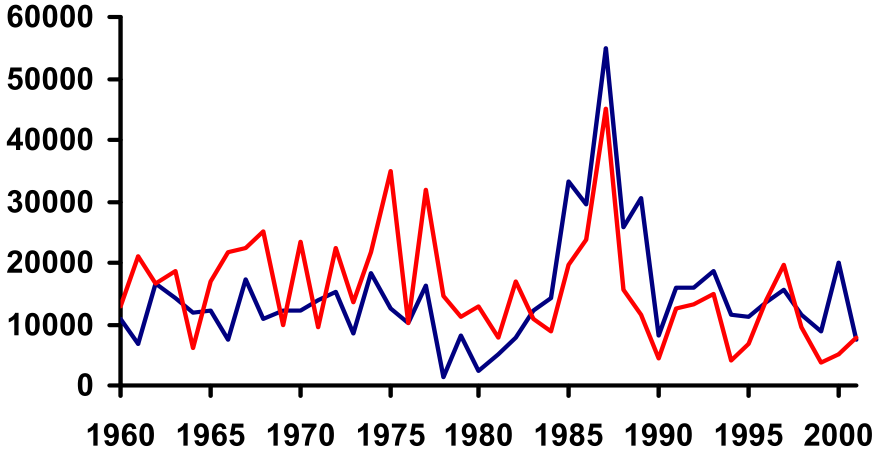
Table 1. Phytoplankton taxa recorded on >5% of samples in the SEA 4 area.
Table 2. Zooplankton taxa recorded on >5% of samples in the SEA 4 area.

2.2. Long term abundance of the 5 most frequently recorded phytoplankton taxa, in addition to Phytoplankton Colour, is shown in Figures 2 (a-f). Graphs show comparison between SEA4 area and the rest of the North Sea. X axis represents years, Y-axis represents annual average abundance per sample (except phytoplankton colour where y-axis represents average phytoplankton colour value).

Phytoplankton colour **a)**



Ceratium fusus **b)**



Thalassiosira spp. **c)**

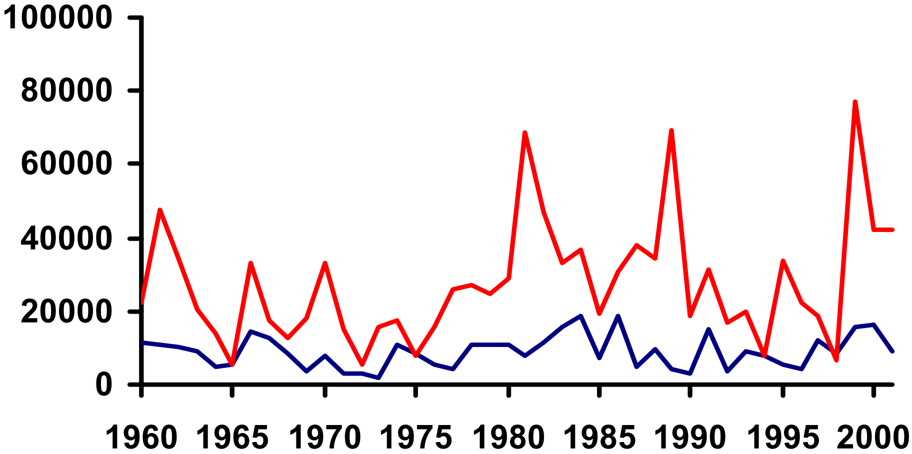


Figure 2 (a-c) Long-term taxa abundance in the SEA 4 area (red line), in comparison with the rest of the North Sea (Blue line)

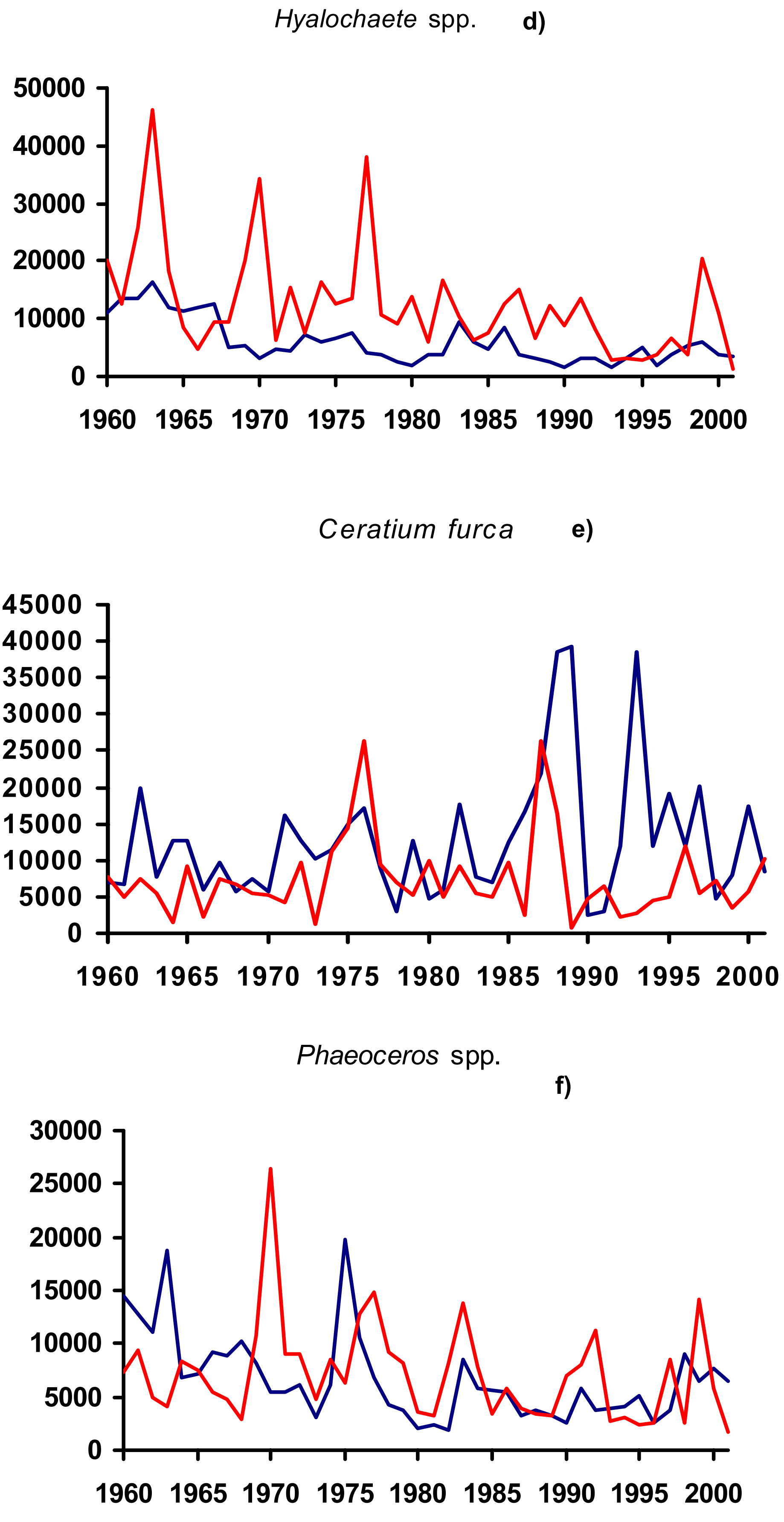


Figure 2 (d-f) Long-term taxa abundance in the SEA 4 area (red line), in comparison with the rest of North Sea (Blue line)

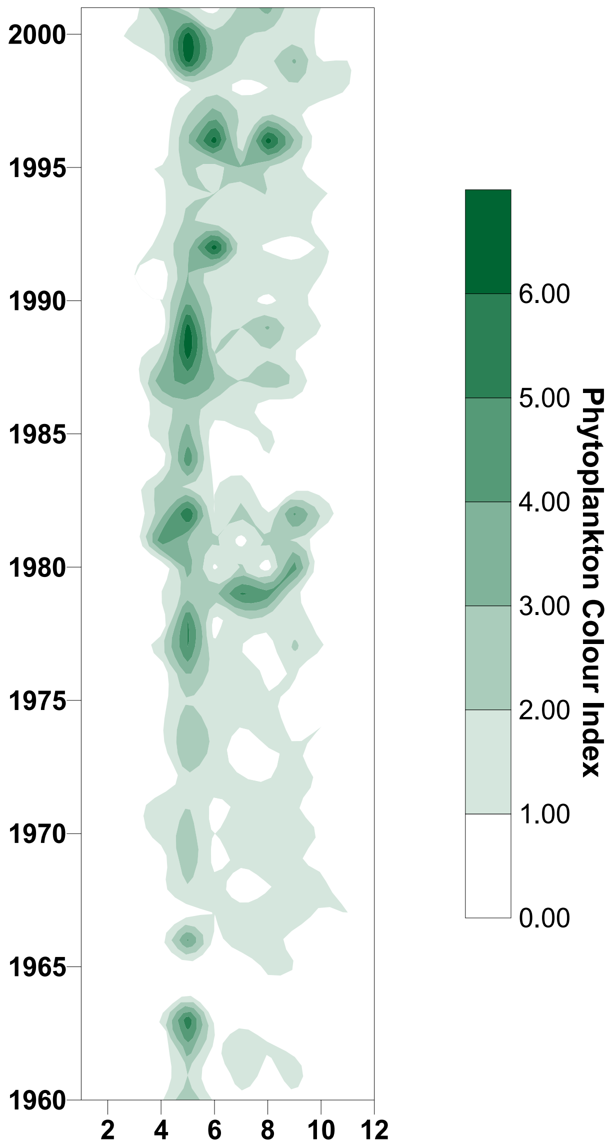


Figure 3. Long term seasonality of Phytoplankton Colour in the SEA 4 area.

2.2 Continued. Most of the above graphs (Fig 2) show similar trends and values between the two areas, although *Thalassiosira* spp. are significantly more abundant in the SEA 4 area than the North Sea as a whole.

Figure 3 shows the long-term seasonality of Phytoplankton Colour in the SEA 4 area, with the spring bloom clearly visible. The trend of the contour plot follows that of more oceanic areas of the North East Atlantic, rather than the North Sea (Edwards et al. 2001b), with a gradual increase in Phytoplankton Colour over the past 40 years.

2.3 The zooplankton community of the SEA 4 area, as shown in Table 2, can be seen to include the calanoid copepods *Calanus helgolandicus* and *C. finmarchicus*, which are discussed in Section 4. The remaining group is composed of small copepods and Crustacea, as well as a number of meroplanktonic organisms (Decapoda larvae and Echinodermata larvae), that are discussed in Section 5. The community as a whole can be examined using Bray-Curtis similarity index dendrograms, as well as using a multi-dimensional scaling (MDS) approach. This is shown in Figure 4 (a+b). Using the cut-off of 70% similarity (dashed line on Fig 4 a), two groups can be seen (also shown in the MDS plot 4 b). The small outlying group are generally in years of low North Atlantic Oscillation (NAO) index values, although the community as a whole does not appear to follow any distinct trend.

2.4 The position of the SEA 4 area, in that it contains the Faroe – Shetland Channel, means that the zooplankton (and phytoplankton) communities are greatly influenced by the inflow of Atlantic Oceanic water through the Channel into the North Sea. This inflow is thought to be linked to the North Atlantic Oscillation Index (Reid et al. 2001), the dominant atmospheric mode in the North Atlantic. The oceanic water that travels through the Faroe-Shetland Channel often introduces warm/temperate oceanic species of plankton, such as the copepods *Euchaeta hebes*, *Rhincalanus nasutus* and *Eucalanus elongatus*, as well as the doliolids (Thaliacea) *Doliolum nationalis* and *Dolioletta gegenbauri* (Edwards et al. 1999). It also 'seeds' the North Sea with other species (such as the copepods of the genera *Metridia* and *Candacia*, and warm water euphausiids such as *Nyctiphanes couchi*). Such inflow events, thought to be 'exceptional', have in fact increased in frequency, and are thought to have had a massive impact on the North Sea plankton ecosystem.

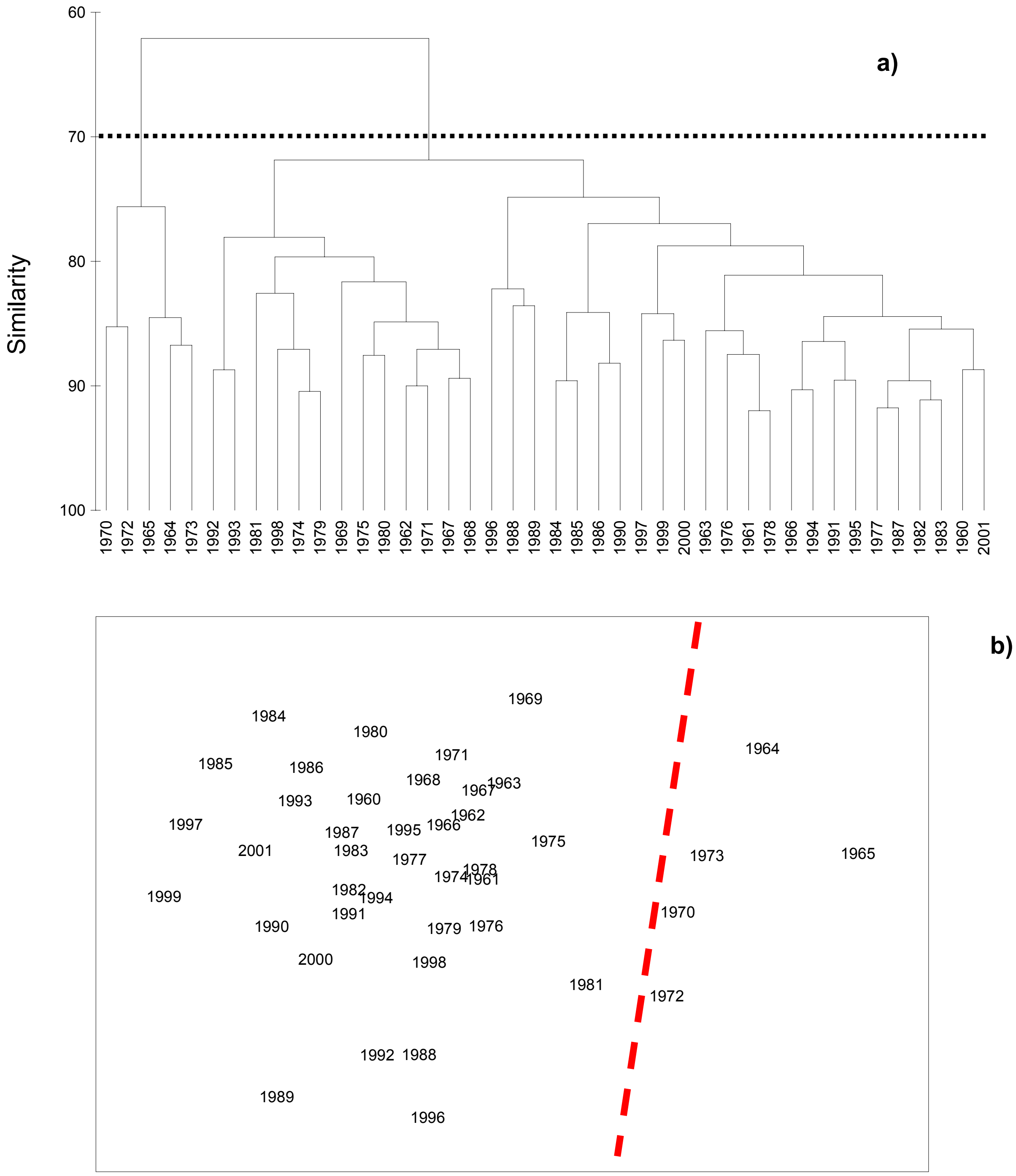


Figure 4 a) Dendrogram using Bray- Curtis similarity indices of log transformed abundance of SEA 4 zooplankton (>5% of samples), b) MDS ordination of the same zooplankton community (stress value=0.2). Dashed lines represent similarity cut-off point

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). This section deals with exceptional phytoplankton blooms (transient, un-sustained growth, often monospecific) and Harmful Algal Blooms (HAB's), as opposed to the more typical annual bloom scenario that occurs in the North Atlantic of spring diatom bloom followed by autumnal dinoflagellate blooms (Edwards and John 1996). 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). In the SEA 4 area, the case of HAB's takes on further significance, with the large number of fish and shellfish farms in the location (for further information see www.sepa.org.uk/aquaculture/projects/index.htm). Occasions of fisheries closure in the area due to Amnesic Shellfish Poisoning (as well as other forms) are not uncommon (Ayres et al. 1982, Gidney and Hermse, 1999, Tett and Edwards, 2002).

3.2 Analysis of the long-term data provided by the CPR survey indicates that phytoplankton biomass, and some species and communities, could possibly be responding to the anomalous atmosphere and climate conditions seen over the last decadal period. During the 1990s, phytoplankton biomass (Phytoplankton Colour) in the North Sea has increased in winter months by over 90% compared to the long-term mean, showing the most pronounced seasonal change and possibly reflecting the milder winter conditions seen throughout the last decade. Phenological changes are also evident in the CPR data, with some species (e.g. a number of dinoflagellates) reaching their seasonal peak up to two months earlier in the 1990s compared to the long-term seasonal mean (unpublished data). Recent research on calanoid copepod diversity have revealed a strong biogeographical shift in all copepod assemblages, with a northward extension of more than 10° in latitude of warm-water species associated with a decrease in the number of colder-water species (Beaugrand, et al. 2002). These biogeographical shifts in plankton diversity are correlated with Northern Hemisphere temperature, suggesting that climate warming is causally involved. Biogeographical shifts in phytoplankton species have not yet been investigated.

3.3 Due to the spatially and temporally extensive nature of the CPR survey, the data has already been used as a general reference point to deviations from ecological 'normal' conditions and 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 & 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). Bloom events recorded by the CPR survey also show strong similarities between other phytoplankton surveys (Kat, 1982, Zevenboom et al. 1990).

3.4 Species that have been identified as harmful that are recorded in the CPR survey can be seen in Table 3. The nature of their potential hazard is also listed. Of the above mentioned species, the long term abundance of *C. furca* has already been examined in section 2. Note this species is not in itself thought to be toxic, but by means of its large bloom-forming abilities can cause anoxic conditions, leading to localised die-offs of higher trophic levels. Figure 5 shows the long-term abundance of the most frequently recorded other potentially harmful taxa. Note that these taxa have low values, although all the examined phytoplankton taxa can be seen to periodically peak. In the SEA4 area *C. furca* is the predominant species likely to be instigated in HAB's.

Table 3: Example of known harmful and detrimental phytoplankton taxa recorded by the CPR survey in the North 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-

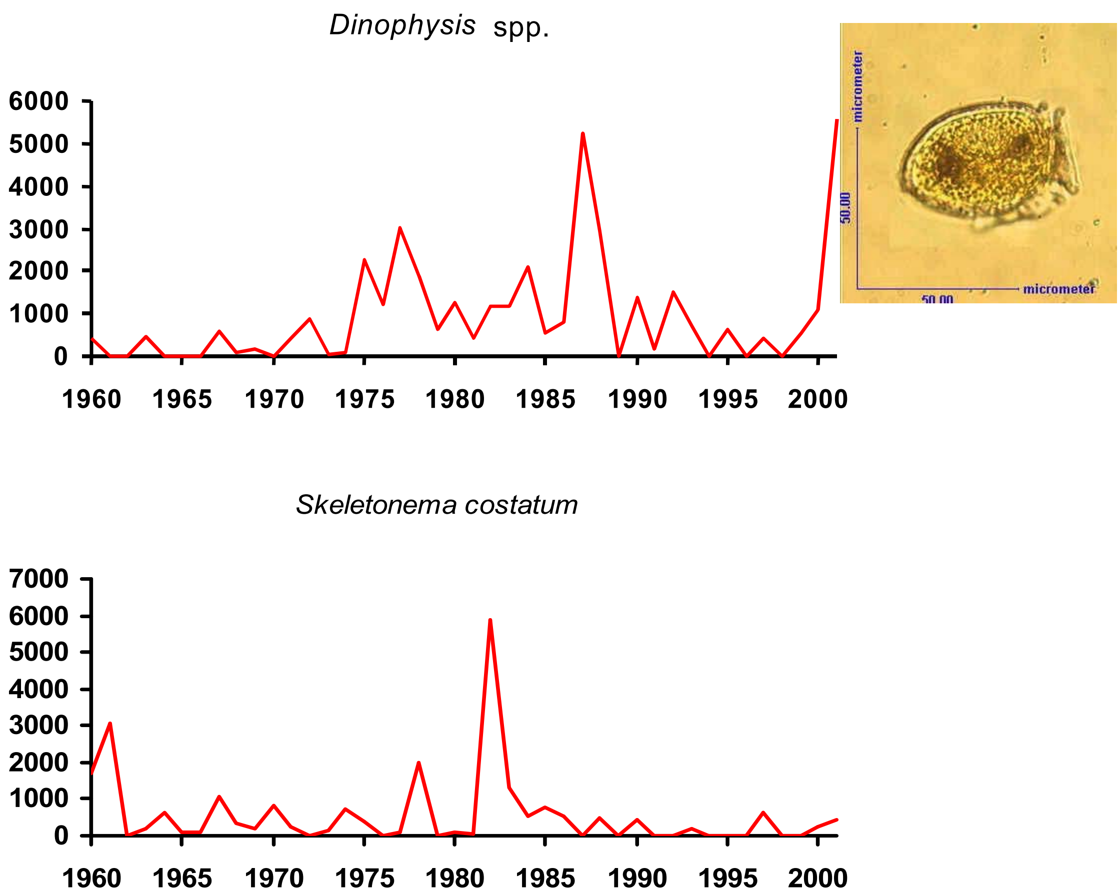


Figure 5. Two frequently recorded potential HAB taxa from the SEA 4 area. Graph shows long term abundance, photograph shows *Dinophysis acuminata*.

4. Abundance of the copepod *Calanus*.

4.1 The dominant copepod genus in the North Atlantic is *Calanus*, which represents a major resource to the higher trophic levels (Planque, 1997). In the SEA 4 area, both common species of *Calanus*, *helgolandicus* and *finmarchicus* are endemic. *C. finmarchicus* was first identified in 1770 by Gunnerus, but was not separated from *C. helgolandicus* as a different species until 1958. Figure 6 shows the long-term abundance of both *Calanus finmarchicus* and *C. helgolandicus* in the SEA 4 area. *C. finmarchicus* has declined significantly since the 1960s, as also noted by Beare and McKenzie (1999), likely due to a rise in Northern Atlantic sea surface temperatures.

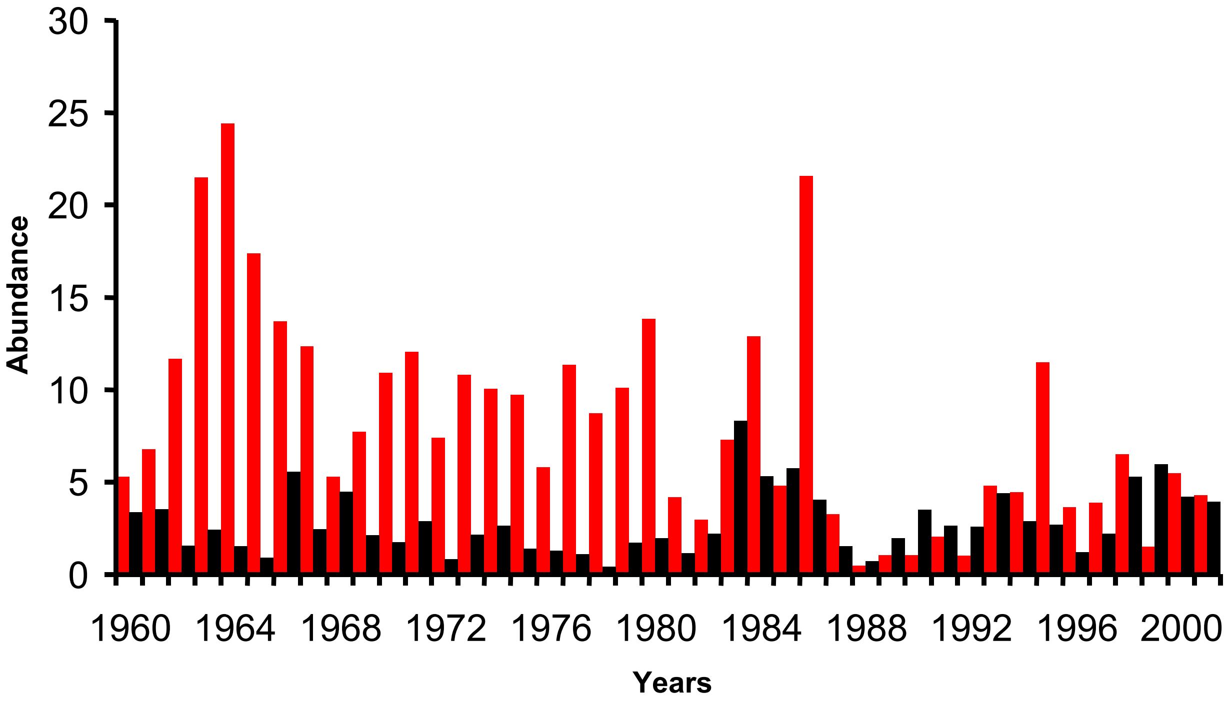
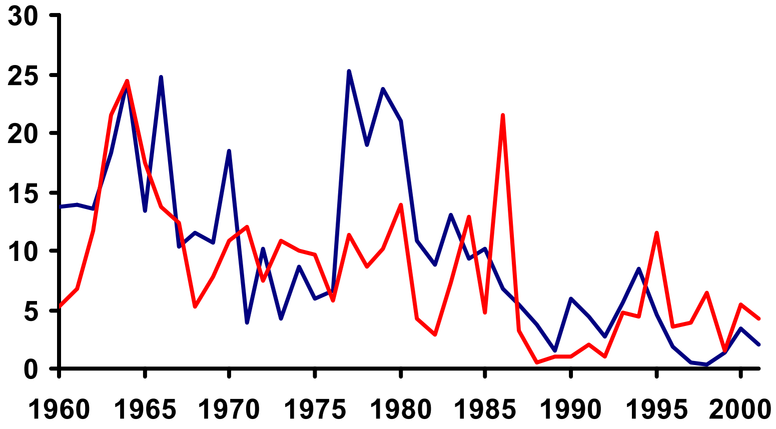


Fig 6. *Calanus finmarchicus* (red) and *C. helgolandicus* (black) abundance in the SEA 4 area.

4.2 Figure 7 a and b shows a comparison between *C. helgolandicus* and *finmarchicus* in the SEA 4 area (red line) and the rest of the North Sea (blue line) respectively. Note the similar decline in *C. finmarchicus* in both areas, although in 1995 in the SEA 4 area there was an increase of *C. finmarchicus* (also noted by Gaard and Reinert 2002). *C. helgolandicus* appears to be increasing, albeit slightly, in both areas. This increase in the more temperate species of *Calanus* is in line with other findings in the northeast Atlantic (Corten 2001, Beaugrand et al. 2002), which indicate warmer conditions are resulting in a northwards shift (of more than 10^{o} latitude) of copepod assemblages.

4.3 For further comparison of the two areas, a phenological indicator method was used (Colebrook and Robinson 1965). Figure 8 a shows such a comparison for *C. finmarchicus* in the SEA 4 area and the rest of the North Sea. It is interesting to note that in the North Sea as a whole, there is a trend for the centre of gravity of *C. finmarchicus* to occur earlier in the year, with a close match with an increase in the North Atlantic Oscillation. In the SEA 4 area, there appears to be no such trend, possibly because of its more northerly location and colder sea surface Temperatures. The same phenological method was used to examine the two communities of *C. helgolandicus*, results of which can be seen in Figure 8 b. In this case there appears to be a slight tendency for the centre of gravity index to occur earlier in the year, although there is no appreciable difference between the North Sea as a whole and the SEA 4 area.

Calanus fin.finmarchicus **a)**



Calanus helgolandicus **b)**

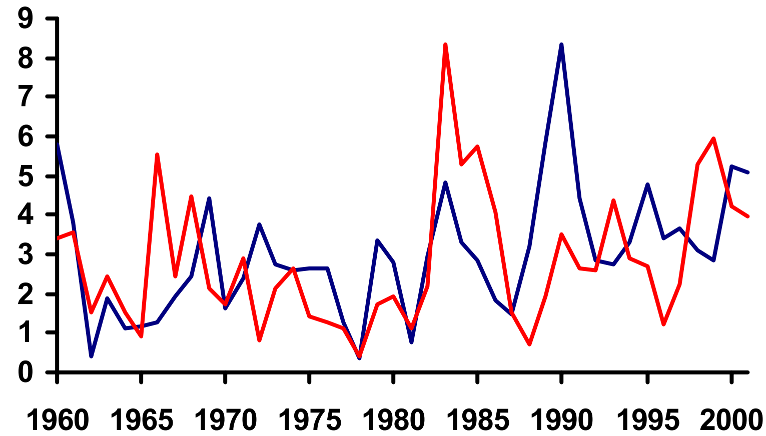
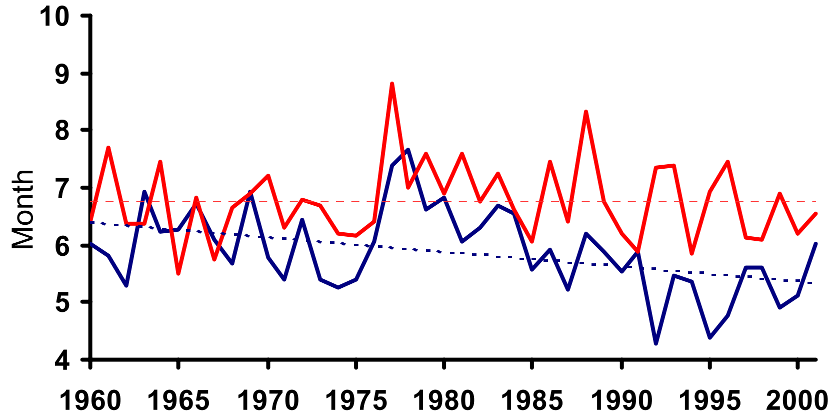


Figure 7. a+b Comparison between SEA 4 area (red line) and the rest of the North Sea (blue line) for *Calanus finmarchicus* and *C. helgolandicus* respectively.

Calanus finmarchicus **a)**



Calanus helgolandicus **b)**

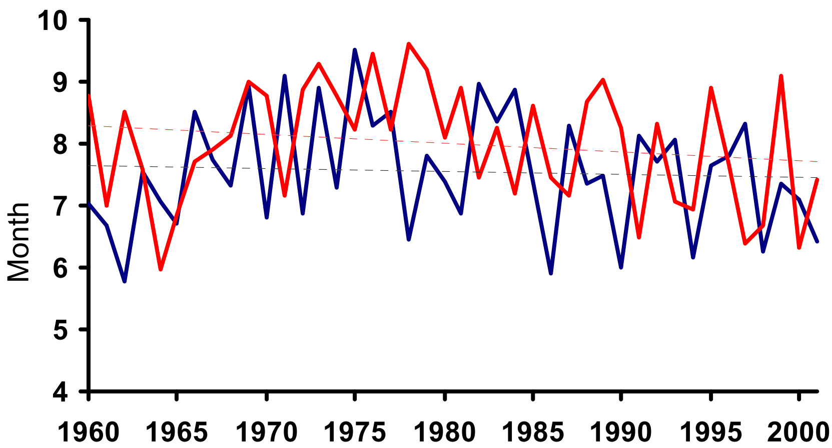


Figure 8 a+b. Phenological index comparisons between SEA 4 (red line) and the rest of the North Sea (blue line) for *Calanus finmarchicus* and *C. helgolandicus* respectively.

4.4. In summary, populations of both species of *Calanus* in the SEA 4 area are comparable with those in the North Sea as a whole: both areas exhibit similar signals. The well documented decline of *C. finmarchicus* in the North Sea is equally apparent in the SEA 4 area, likely due to warmer conditions in the north east Atlantic. The SEA 4 area is important for *C. finmarchicus*, as it is thought that the Faroe – Shetland Channel contains the majority (at times approx. 50000 m^{-2}) of the overwintering population (at a depth of approx. 1000m), which 'invades' the northern North Sea shelf in the spring (Harms et al. 2000, Heath et al. 2000a + b, Gallego et al. 1999, Hainbucher and Backhaus 1999).

The population of *Calanus helgolandicus* is increasing slightly, with little change in its centre of gravity. The SEA 4 area is probably at the more northerly extent of the species' range, indicated by the relatively low values of abundance.

5. Mero-, pico- and 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. In the CPR survey, Decapoda larvae and Echinodermata larvae are the main constituents of the meroplankton community. Recent research (Lindley and Batten 2001) have indicated that during the past number of years, meroplankton abundance in the North Sea has risen, this is evident from Figure 9, which shows Echinodermata larvae long term abundance in the SEA 4 area, compared to the North Sea as a whole.

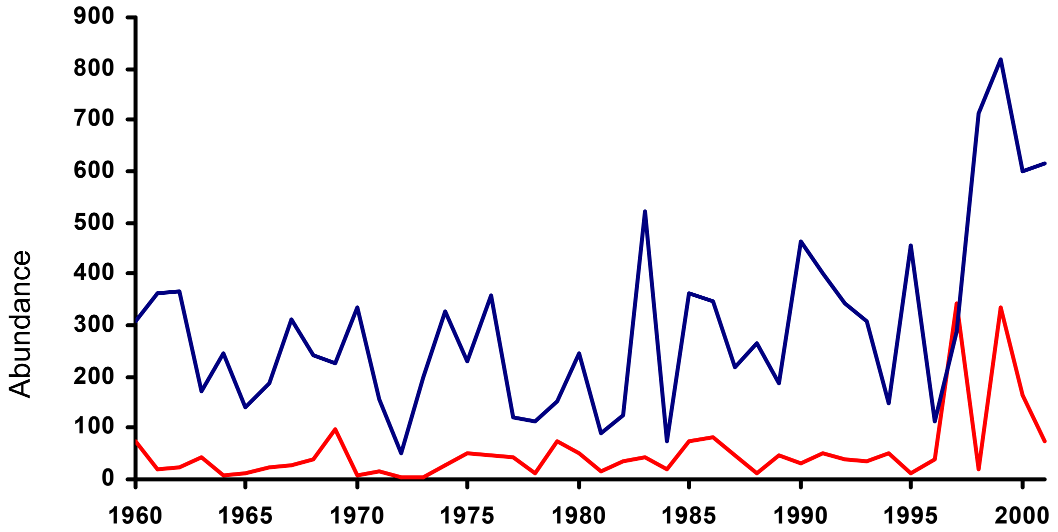


Figure 9. Echinodermata larvae long term abundance in the SEA 4 area (red), compared with the North Sea as a whole (blue).

5.2. As mentioned in previous SEA Plankton Reports, the spiny nature of Echinodermata larvae, in addition to the tendency to reproduce in large numbers over a short period, has historically

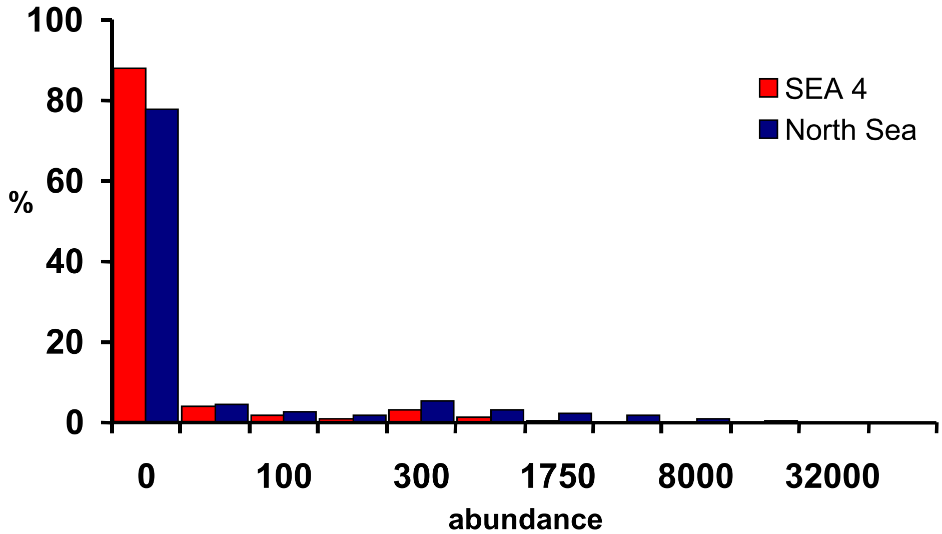


Figure 10. Frequency of abundance of Echinodermata larvae in the SEA 4 area and North Sea.

posed problems to water intake systems in the North Sea. Reid and Hunt (1986) state that in such a case in the North Sea, concentrations reached over 2000 individuals per sample. It is apparent from Fig 10 that this number of individuals does not occur often in the SEA area (in fact 11 times out of 4611 samples).

5.3. The term picoplankton refers 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 4 area. The picoplankton community in the SEA 4 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/

5.4. Megaplankton in the CPR survey consists of euphausiids ('prawn-like' organisms, not routinely speciated within the CPR survey), Thaliacea (salps and doliolids) and siphonophores. Larger organisms, such as Coelenterata (i.e. jellyfish) and ctenophores are poorly sampled in the CPR survey due to the fragile gelatinous nature of their bodies.

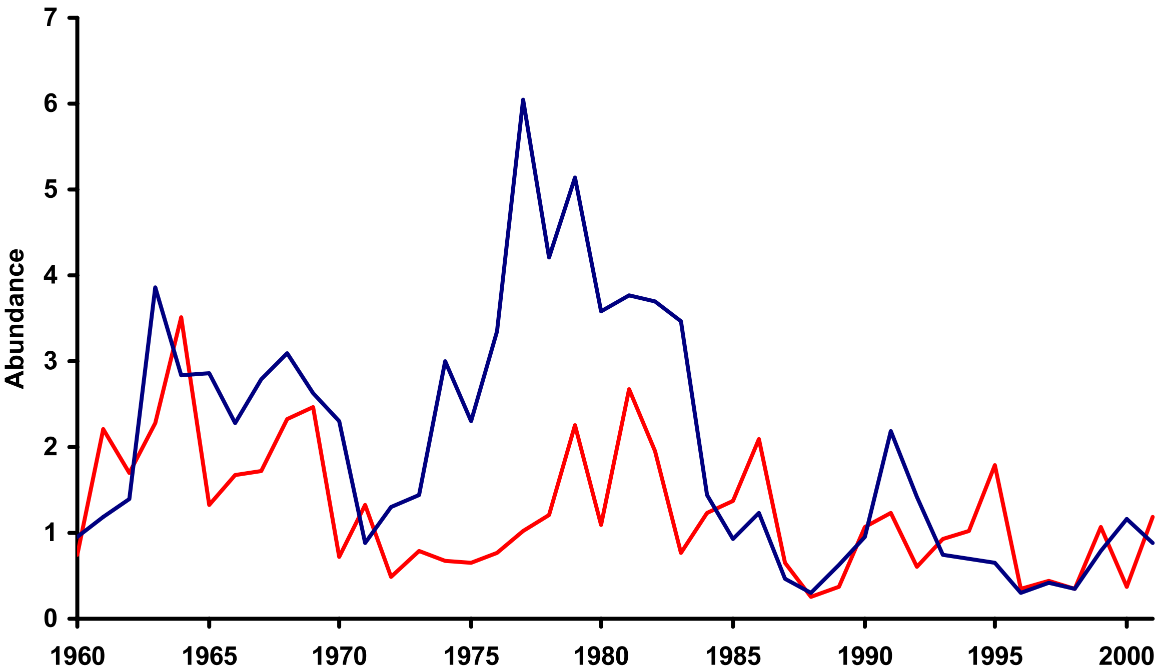


Figure 11. Euphausiid long term abundance in the SEA 4 area (red) and the rest of the North Sea (blue).

Euphausiid long term abundance is shown in Figure 11. Note that in the SEA 4 area, and the North Sea as a whole, the taxa is decreasing steadily. The exact reason for this is unclear, with some species (such as *Nyctiphanes couchi*, a dominant CPR euphausiid identified on retrospective analysis by Lindley (1977 and 1982)) being positively correlated with the NAO in the North Sea and negatively correlated to the south west of Britain (Reid and Planque, 2000). This is an area that would benefit from further research.

5.5. Thaliacea in the CPR survey consists of doliolids and salps. These organisms are gelatinous, barrel-shaped creatures, that function like a simple pump, with water in one way and expelled out the other. One of the important features of these organisms is their ability to reproduce extremely rapidly under ideal conditions, forming enormous 'swarms' that can impact local primary production (by the ingestion of phytoplankton), and even pose a problem to water intake systems (Fraser 1982). The gelatinous nature of these organisms means that speciation in the CPR survey is not carried out on a regular basis, although in some cases it has been done, particularly as some species are indicative of oceanic water inflow to the North Sea (Edwards et al. 1999).

5.6. Occurrences of both salps and doliolids are rare: for the SEA 4 area, salps = 57 times and doliolids = 19 times, for the rest of the North Sea, salps = 6 times, doliolids = 30 times. In the case of the doliolids, the majority of recordings have been in 1989 and 1997, when the presence of such organisms was indicative of increased oceanic inflow into the North Sea (Lindley et al. 1990, Edwards et al. 1999). Salps on the other hand have been recorded very rarely in the North Sea as a whole, but more frequently in the SEA 4 area (most recordings are from the late 1980s – early 1990s). This is probably due to the oceanic nature of salps, which could not survive for long in the well-mixed sediment laden waters of the North Sea.

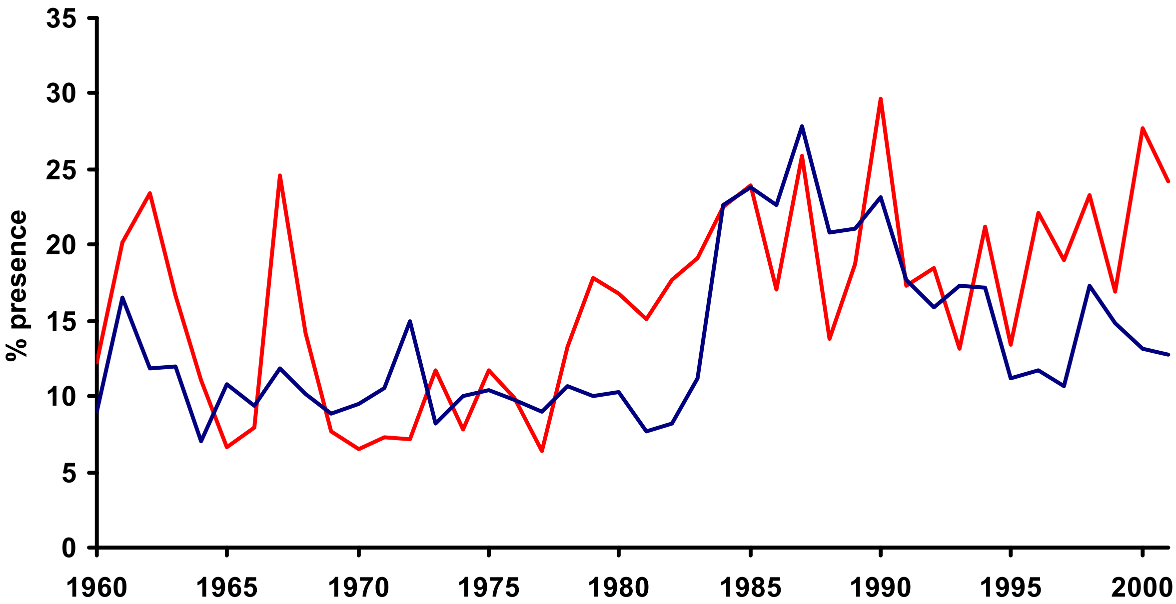


Figure 12. Graph showing percentage of blocks that have a recording of coelenterata tissue, SEA 4 area (red) and North Sea (blue).

5.7. Coelenterata (such as jellyfish) are recorded on a presence/absence basis in the CPR survey, due to their soft gelatinous bodies making positive species identification impossible. An indication of abundance would be to plot the percentage of blocks on which coelenterata tissue is recorded on, and this can be seen in Figure 12. It seems that the SEA 4 area has a higher percentage of recordings, and this seems to be on the increase. This is an area that is under-researched, as Coelenterata undoubtedly form a large part of the marine ecosystem, but are difficult to quantitatively study.

6. Sensitivity to contamination/disturbance.

6.1. The plankton community of the SEA 4 area is open to contamination from oil spills, as well as pollutants contained in freshwater run-off, much as any other shelf ecosystem. The SEA 4 site already contains a large port, Sullom Voe, built in the 1970s to handle the increase in petrochemicals brought about by the exploitation of North Sea oil fields. The area between the Orkney Islands and the Shetland Islands is also used as a short cut for oil tankers exiting the North Sea. In the time that the oil industry has been active in the area, there has only been 1 ‘major’ disaster, that of the Braer tanker in 1993, which deposited its cargo of 84 000 tonnes of oil in the Shetland area. Such an event has allowed detailed examination of trophic level response to oil contamination, for example on adult, juvenile and larval stages of lobsters (Laurenson and Wishart, 1996). But results on adults are inconclusive, with mortality due to oil exposure low, although behavioural changes took place on a short term in adult and juvenile stages. Planktonic larval stages and eggs were more susceptible, with higher mortalities, and an enhanced level of premature hatching. This effect on eggs was also apparent in Clark's (1997) study of the response of capelin (*Mallotus villosus*) to oil, and the response of sea urchin eggs to Ekofisk crude oil (Falk-Peterson, 1979). Conversely to this finding, the photosynthesis (and hence primary production) of phytoplankton is enhanced by low (<50ng g^{-1}) levels of petroleum hydrocarbons (Gin et al., 2001).

6.2. It is important to examine the effect on the whole plankton community, and not simply the dominant species, which may prove relatively insensitive to hydrocarbon pollution (Batten et al., 1998, Elmgren et al., 1980). In fact, according to Dale (1987) and Frithsen et al (1985), the addition of oil, in conjunction with high nutrient concentrations, can benefit certain ciliates, such as tintinnids. But such situations are liable to cause a monospecific bloom. Work by Batten et al (1998) on the after effects of the Sea Empress failed to find any significant effects on the plankton of the southern Irish Sea, suggesting that there were no changes to either the phytoplankton or zooplankton communities. But the scope of this work does not take into account ingested pollutants, and the possible accumulation and 'passing on' of these up the trophic levels. Mackie et al. (1978) and Gajbhiye et al. (1995) both found levels of aromatic hydrocarbons in zooplankton species near the site of an oil spill. Research carried out after oil spills has found that benthic species are particularly susceptible to hydrocarbon pollution, due to the trapping of substances in subtidal sediments (Frithsen et al., 1985, Poggiale and Dauvin 2001). The WWF International Report 1994 (van Beusekom and Diel-Christiansen, 1993) states how zooplankton communities are affected by oil both directly through the hydrocarbon content of their food and indirectly via a change in the ecosystem. Egg production and egg fecundity are lowered (possibly in a similar way to the aforementioned lobster study), as well as offspring mortality, and there is a strong suggestion that dispersant treated oil has a more pronounced effect.

6.3. Any possible long-term genetic changes, through the disruption of internal chemical signals, are effects that are hard to recognise, and likely to be subtle. Despite the detrimental effects that an oil spillage can cause, in less major spills bacteria can play an important role in removing the oil. Davis et al. (1979) and Gearing et al. (1980) both commented on the increase in bacteria after a spill, and estimated that between 80 and 90% of the oil held in sediments was affected by microbial biodegradation.

6.4. In addition to easily identifiable inputs of oil into the marine ecosystem (i.e. oil spills), industrial discharges and urban run-off of oil and other chemicals often amount to a greater volume. Pesticides for example can enter via runoff, and have a deleterious effect on phytoplankton communities (Rajendran and Venugopalan, 1983, DeLorenzo et al., 2002), particularly organochloride – based products, although there appears from some of the results to be a accumulation of toxins in the phytoplankton that are not necessarily passed up the trophic levels. Some pesticide chemicals disturb natural organic chemical communication in the plankton community (Hanazato, 1999), upsetting an ecosystem in a subtle way that is difficult to monitor.

7. Phytodetritus and vertical fluxes.

7.1 Phytodetritus, commonly referred to as 'marine snow' (Alldredge and Gotschalk, 1990) or particulate organic matter (POM), is derived from various sources, such as by-products of primary production (cellular fragments, tests etc.), faecal matter and terrestrial run-off. The estimated amount of POM in the world's oceans is estimated to exceed the plankton community by 10:1 (Verity et al., 2000). POM contains a large source of carbon, which can be utilised in sub-surface primary production (Richardson et al., 2000). Settlement through the water column is dependent on the hydrographic characteristics of the area, with re-suspension likely in shallow areas and/or winter period. The re-suspension of POM via a breakdown in the stratification of the water column in the autumn period can allow a secondary diatom bloom in some areas of the North Sea, although this is uncommon in the SEA 4 area (for example, the dominant diatom taxa *Thalassiosira* spp. has exhibited secondary-bloomed less than 8 times in 41 years, data not shown).

7.2 Phytodetritus was not considered a major component of vertical flux until recently (Turner 2002). It was previously thought that zooplankton faecal pellets contributed the most to the vertical transference of nitrogenous products to the benthos, with up to a third of the primary production being passed this way (Riebesell et al., 1995, Vanderwall et al., 1995, Davies and Payne, 1984). It has been suggested that the increase in benthic production in the North Sea in recent years is due in part to an increase in primary production (notably diatom species, which are a major facilitator of organic carbon between trophic levels), with a consequential effect on the production of marine snow and the increase in vertical flux (Ragueneau et al. 2001). This phenomenon has been noted in the Porcupine Abyssal Plain, where the increase in surface primary production has been tentatively linked with a significant increase in benthic organisms (Billett et al., 2001).

8. Resting stages of phytoplankton

8.1 Members of both the zooplankton and phytoplankton community are known to produce non-motile or dormant egg/cyst stages (Nehring, 1995) that sink to the bottom sediment until they are re-suspended or the right conditions return for them to re-emerge. 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. Dinoflagellate cyst fossils (hystrichospheres) are often used in biostratigraphy (especially in oil exploration, Mudie and Harland, 1996).

8.2 For the zooplankton, the most common egg forming taxa are neritic copepods such as the genera *Acartia* and *Centropages*, as well as the cladocera *Evadne, Podon* and *Penilia*. In the case of *Penilia avirostris*, it is most likely its resting egg-forming ability that has allowed the species to successfully colonise the south eastern North Sea during the late 1990s, with subsequent outbreaks of the species appearing during favourable conditions (unpublished data). How a typically warm temporal species (Colton, 1985) appeared in the North Sea is open to debate, the most likely 'invasion' occurring through ballast water transport and/or warm water inflow.

8.3 Some of the most toxic dinoflagellates, causing HABs (as mentioned in section 3), form large numbers of resting cysts. The cyst-forming ability means that they can easily be transported in fine bottom sediments at the bottom of ballast water tanks and hence invade distant areas. 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 population 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). Ostenfeld (1908), who noticed the large diatom *Odontella sinensis* in the North Sea, a species previously known from the Pacific Ocean, initially suggested the idea of invasive species. Since then a number of planktonic organisms have been identified in the North Sea and Baltic Sea (Edwards et al., 2001a, Elbrachter 1999, Reisse et al. 1999, Nehring,1998).

9. Conclusions

9.1 The plankton community of the SEA 4 area is similar to the remainder of the North Sea, although some individual species are more / less abundant (notably the more abundant diatom *Thalassiosira* spp.). Trends that are apparent in the North Sea generally can be seen in both the SEA 4 phyto- and zooplankton community, for example the increase in Phytoplankton Colour and the mid 1980s peak in *Thalassiosira* spp. abundance.

9.2 The coastal area of the SEA 4 zone has been prone to outbreaks of Harmful Algal Blooms in recent years, not doubt more obvious due to the extensive fish farm industry in the area. From examination of CPR data (which is more offshore in its distribution), there are only a small number of potentially HAB forming species commonly recorded. One of the most frequently recorded phytoplankters, *Ceratium furca*, is known to cause hypoxic / anoxic conditions, due to its rapid bloom-forming tendencies. As for toxic algal organisms, such as *Dinophysis* spp., *Gonyaulax* spp. and *Pseudo – nitzschia* spp., these taxa occur in low numbers in CPR records, although on examining long term abundance, sporadic blooms have been observed in the past 40 years.

There is no clear evidence that HABs are increasing in frequency/intensity due to anthropogenic eutrophication, and current research is ongoing to investigate this. From CPR data, there is a strong link between algal blooms and hydro-climatic events, such as incursions of oceanic water via the Shelf Edge current.

9.3 The changes in *Calanus finmarchicus* and *helgolandicus* population are similar between the SEA 4 area and the North Sea as a whole, with a decline in the former and an increase in the latter, although the phenological changes that are occurring in the *C. finmarchicus* population in the North Sea are not evident in the SEA 4 area. The decrease/increase scenario is likely due to a change in SSTs in the northeast Atlantic, with the colder form *finmarchicus* responding adversely to the warming conditions of the North Sea as a whole. The SEA 4 area is, according to current research, especially important to *C. finmarchicus* stocks, as it is thought that a majority of the population over winters in the Faroe-Shetland Channel, which is the north-western boundary of the SEA 4 area. It is thought that *C. finmarchicus* spend the winter in diapause in the Channel, and then 'invade' the North Sea in the spring months. As *C. finmarchicus* represent such a valuable food resource to higher trophic levels, if the SEA 4 area really does represent a main over-wintering site for the species, it might be particularly sensitive to the risk of disturbance/contamination.

9.4 Meroplanktonic organisms in the CPR survey consist mainly of Decapoda larvae and Echinodermata larvae. Long term changes in both groups indicate an increase in abundance, as a consequence of increased productivity of the benthos of the North Sea during the 1990s. In the case of Echinodermata larvae, in the SEA 4 area there are very large peaks in abundance in the late 1990s. Occurrences of >2000 individuals per sample occur on 0.6% of records, but the majority of these have been noted in the last couple of years.

Coelenterata (megaplankton) are recorded as presence/absence. Long term studies of this would seem to indicate an increase in recordings of coelenterata in the SEA 4 area, with values higher than the neighbouring North Sea as a whole. This is most probably due to the influx of oceanic waters into the SEA 4 area. Other megaplanktonic organisms include euphausiids and Thaliacea. The former in the SEA 4 area are in decline, along with the rest of the North Sea population. The exact reason for this is currently unknown, further research would be needed to clarify this. Thaliacea in the SEA 4 area are rarely recorded, although salps are more frequently present in the area than the North Sea. This particular group of organisms are indicative of oceanic water inflow, and are therefore periodic in their distribution.

Due to the sampling method of the CPR, the picoplankton community cannot be examined. But, its potential importance should not be underestimated; the contribution of picoplankton to the overall plankton biomass has been estimated at between 15 and 33% (Klinkenberg and

Schumann, 1995) and between 6.6 to 57.5% of the total phytoplankton chlorophyll-a biomass (Iriarte and Purdie, 1993).

9.5. The response of the plankton community to disturbance or contamination is difficult to quantify, with conflicting results presented in scientific journals. The physical appearance of oil, and the addition of dispersants, is often more 'damaging' to the environment, than the actual oil itself is to planktonic organisms. Phytoplankton communities show a certain resilience to petro-chemical products, with species diversity often remaining unchanged but changes occurring in dominance. Higher trophic levels are often more affected than plankton, especially larval forms, although long term exposure to petro-chemicals is thought to be detrimental to planktonic life.

9.6. The extent that the phytoplankton community contributes to the vertical flux of biogenic products is not entirely known, although it seems apparent from current research that phytodetritus plays an important part in transference to the benthos. The SEA 4 area has had an increase in Echinodermata larvae in recent years, and a corresponding increase in Phytoplankton Colour (an indication of primary production), which is also evident in other studies in the North Sea.

9.7. Resting stages of plankton (zoo and phyto) offer a means of entry to the SEA 4 ecosystem via ballast water transport. Although there is a potential for invasive species this way, recent 'invaders' such as *Coscinodiscus wailesii* and *Penilia avirorostris* have not appeared in the SEA 4 area, although there have been short-lived incursions of oceanic species.

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