

Ecological status

2004/2005

Results from the North Atlantic CPR survey



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Monitoring the health of the oceans using *planktonic indicators*



Diatoms



Dinoflagellate



Copepod



Crab larvae

Phytoplankton

Zooplankton

The free floating plant life of the sea (phytoplankton), at the base of the marine food web, provides food for the animal plankton (zooplankton) which in turn provide food for many other marine organisms. The carrying capacity of marine ecosystems in terms of the size of fish resources and recruitment to individual stocks as well as the abundance of marine wildlife (e.g. seabirds and marine mammals) is highly dependent on variations in the abundance, timing and composition of the plankton.

These organisms also play a crucial role in climate change through the export of the important greenhouse gas CO₂ to the deep ocean by carbon sequestration in what is known as the 'biological pump'. Without this process concentrations of CO₂ would be much higher in the atmosphere and the climate of the world would be much warmer.

Apart from playing a fundamental role in the earth's climate system and in marine food-webs, plankton are also highly sensitive indicators of environmental change and provide essential information on the 'ecological health' of our seas. The following report provides indicators for the status of the North Atlantic Ocean and supplies information for important marine management issues such as climate warming impacts, biodiversity, pollution and fisheries.

Ecological indicators

Using a number of ecological indices, this report summarises unusual species found, large phytoplankton blooms, changes in community structure and trends in hydrobiological indicators from regions in the North Atlantic (with an emphasis on the North Sea). In the majority of cases, the term 'unusual' or 'large' in referring to phytoplankton blooms refers to

population increases greater than four standard deviations above the

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species recorded baseline mean (baseline mean: 1980-2003). Notable blooms that are geographically large refer to patch sizes greater than 100 km in diameter. The primary regional assessment area used to monitor changes in community structure, biomass and phenological changes is the central North Sea, an area that has been consistently sampled on a monthly basis over the last six decades. Most data analysis has been performed to highlight the year 2004 in relation to the long-term dataset. 2005 sample data is presented here as preliminary and has not yet undergone quality checks.

Annual abundance estimates were

calculated for each CPR box for years when eight or more months were sampled (Fig. 1). For years when fewer than eight months were sampled, no annual estimate of abundance was calculated. Sea surface temperature (SST) was used as an indicator of ocean climate and climate change, as organisms respond physiologically to temperature. Monthly sea surface temperature (SST) data on a 1° by 1° grid for the period 1946-2004 were obtained from the Hadley Centre, UK Met Office. This dataset is a gridded product combining in situ sea surface observations and satellite derived estimates. For each of the 41 regions, SST values were averaged per year to provide unbroken 58-year time series of annual/spring SST in each CPR box.

Pan-North Atlantic indicators



Phytoplankton biomass

Figure 1 shows the long-term inter-annual values of phytoplankton colour (an index of total phytoplankton biomass) for standard CPR areas in the North Atlantic from 1946 to 2004. It is obvious from this figure that there has been a large increase in phytoplankton biomass since the late 1980s in most regional areas (particularly the north-east Atlantic and the Newfoundland shelf). From the late 1940s to the late 1980s, the majority of biomass was restricted to the spring and autumn bloom periods, i.e. diatoms dominated the phytoplankton assemblage. Since the late 1980s, biomass has increased throughout the seasonal cycle. 2004 showed a drop in phytoplankton colour but generally the index was still higher than the base-line mean (1946-2004). In other parts of the North Atlantic, high increases in phytoplankton biomass were seen off the Newfoundland Shelf (with an increase in winter blooms), the Scotian Shelf and the Labrador Sea.

In the northern North Atlantic and in the sub-polar gyre, phytoplankton biomass has been generally declining over the last two decades but has shown an increase post 1998.

Zooplankton abundance

Figure 1 shows the time series of total zooplankton copepod abundance (numbers.sample⁻¹) from 1946-2004 in CPR standard areas in the North Atlantic. This method excludes years in which data from fewer than eight months were available. The dashed line represents the long-term mean in each standard area. The most obvious feature of the time series is a general long-term decline in total copepod abundance east of Iceland, although some areas shown no trend (e.g. northern North Sea areas B1 and B2). 2004 is much lower than the long-term average and is one of the lowest values recorded in some regional areas.

Regional assessment

a regional scale indicator overview of the North Sea



Assessment icons

1. Trend



2. Stability 3. Confidence



Statistical confidence at the 5% level

4. Prognosis



○ Climate change
○ Contaminants
○ Fisheries
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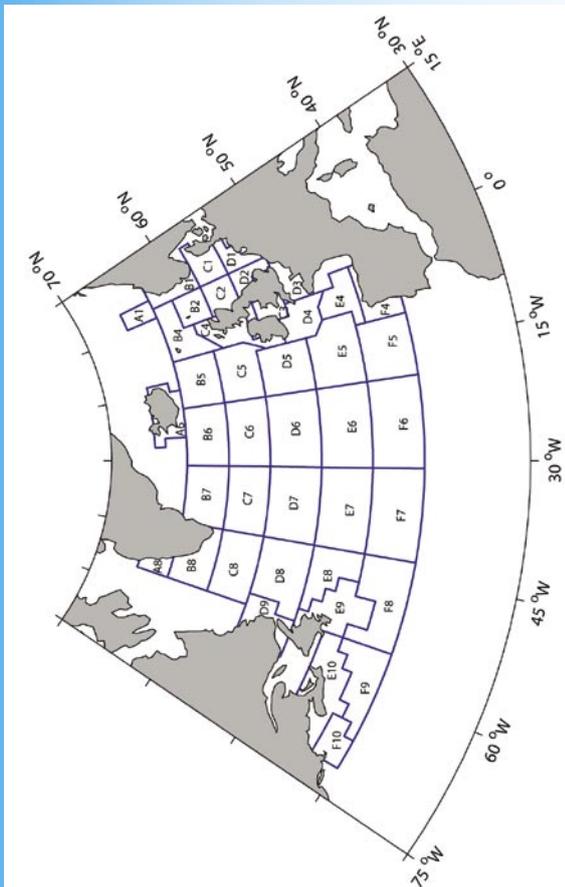
While the CPR is operated on an ocean-basin scale and the ecological status report reflects this we have particularly focused on the North Sea for regional assessment purposes as an aid to policy makers. For each indicator used in the report we have provided a visual summary in the form of icons specific for the North Sea regional ecosystem. The icons summarise the trend in the index (i.e. its behaviour) and whether this trend is statistically significant. The icons also summarise whether the trend is following a degree of stability/predictability (i.e. do we have a significant amount of understanding to provide information on why a trend is behaving in such a way) or is its behaviour unpredictable/unstable.

Prognosis

Outer circle: is the trend affected by climate change?
 Middle circle: is the trend affected by contaminants (e.g. pollution, eutrophication)?
 Inner circle: does the trend have a consequence for fisheries?
 The colours of the circles reflect to the best of our understanding our current scientific knowledge of the affect of these changes on the North Sea ecosystem. For example, an outer circle in red indicates that the index is affected by climate change and the impact is negative/detrimental to the ecosystem as a whole.



CPR standard areas in the North Atlantic



Decadal Pan-North Atlantic plankton indicators

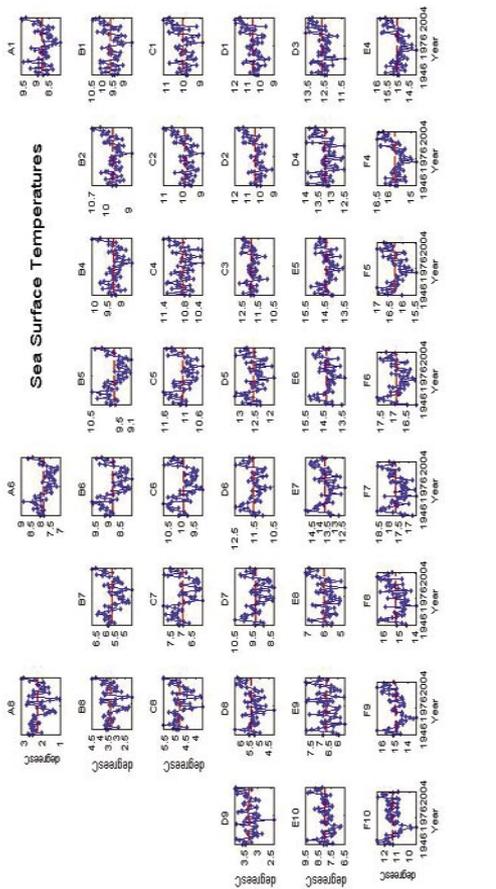
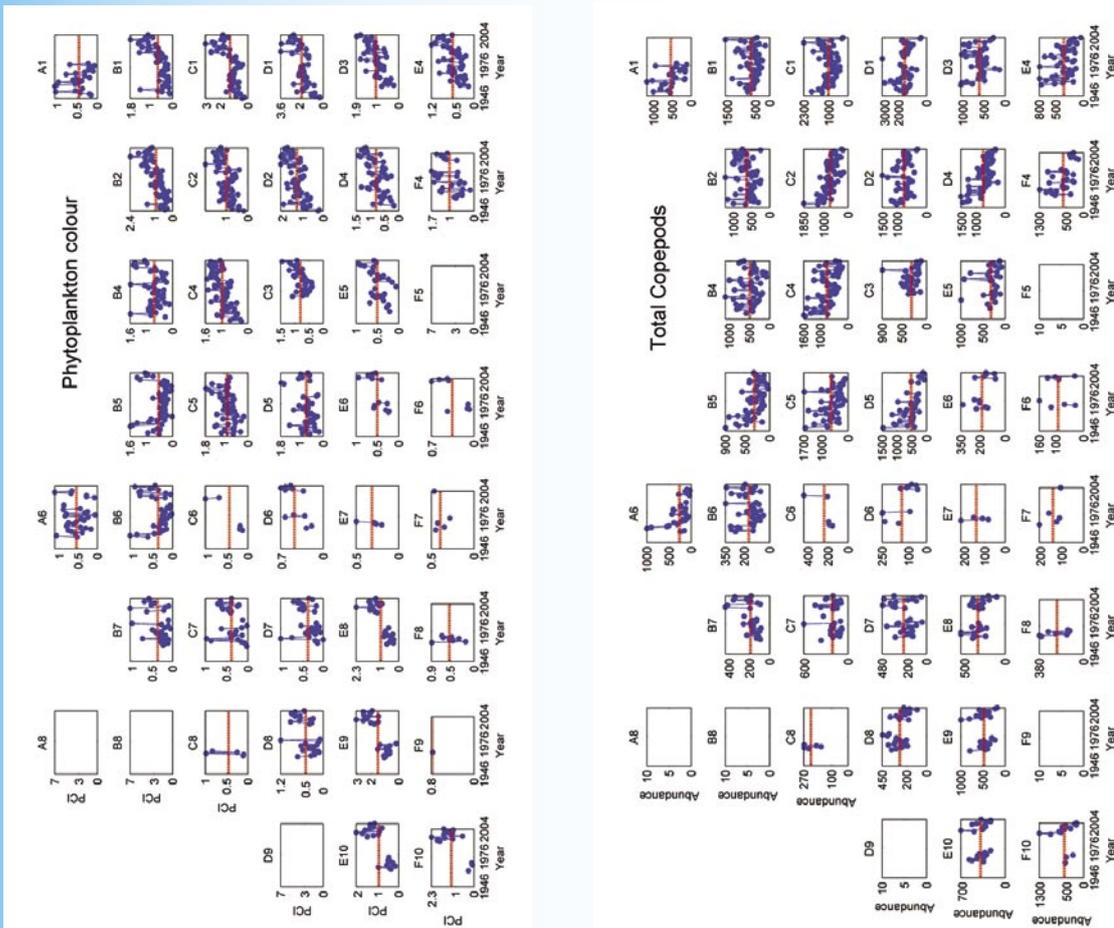


Fig. 1. Standard CPR boxes used to examine spatial variability in the North Atlantic and annual Sea Surface Temperatures, phytoplankton colour and total copepods for each CPR box from 1946-2004. Annual values were only calculated for each CPR box when eight or more months were sampled in any given year.



Indicators of climate change

Biogeographical changes and northward shifts

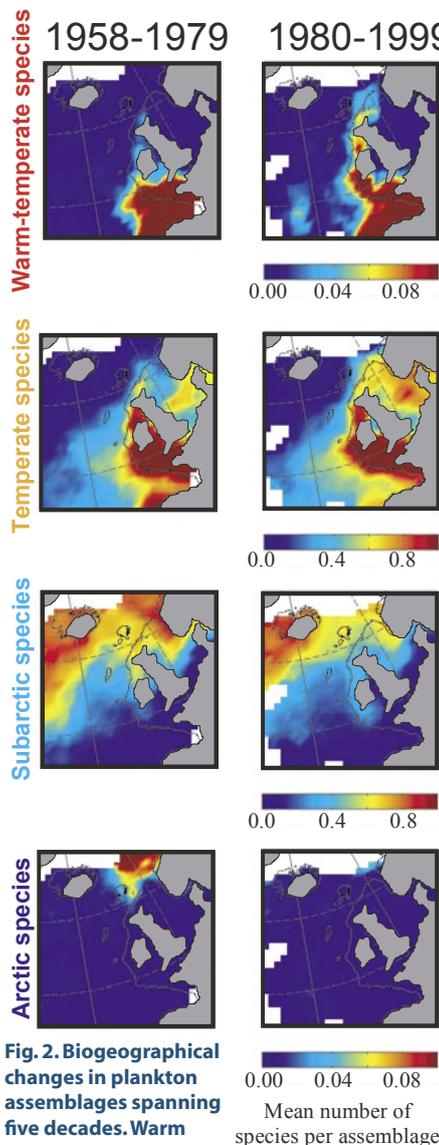


Fig. 2. Biogeographical changes in plankton assemblages spanning five decades. Warm water plankton are moving north and cold water plankton are moving out of the North Sea. Based on Beaugrand et al. 2002.

Over the last decade there has been a progressive increase in the presence of warm-water/sub-tropical species into the more temperate areas of the north-east Atlantic, with 2004 continuing with this trend. Sea Surface Temperature (SST) was very high in the North Sea during 2004 and showed a continued increase throughout most areas of the North Atlantic (Fig. 1).

The plankton community in 2004 had unusually high numbers of warm-water/sub-tropical species as well as oceanic species including Doliolids. The sub-tropical cladoceran *Penilia avirostris* has increased considerably in abundance in the North Sea in recent years. In 2003 and 2004 high numbers were present in the eastern North Sea west of Denmark in September, and in the south-eastern North Sea and off the Dutch coast in October. Of other note was the presence of the warmer water *Ceratium* species *C. hexacanthum* which was unusually found in high numbers in the northern North Sea (Moray Firth) during August and September of 2004.

A useful indicator of the warming trend in the North Sea (a biogeographical/northward shift indicator) is the percent ratio of the warm-temperate *Calanus helgolandicus* and the cold-temperate *Calanus finmarchicus* copepod species. Although these species are very similar they do occupy distinct thermal niches. The thermal boundary for the arctic-boreal distributed copepod *Calanus finmarchicus* in the northeast Atlantic lies between ~10-11°C isotherm and is a useful indicator of major biogeographical provinces. *Calanus helgolandicus* usually has a northern distributional boundary of 14°C and has a population optimum lying between 10-20°C, these two species can therefore overlap in their distributions. When these two

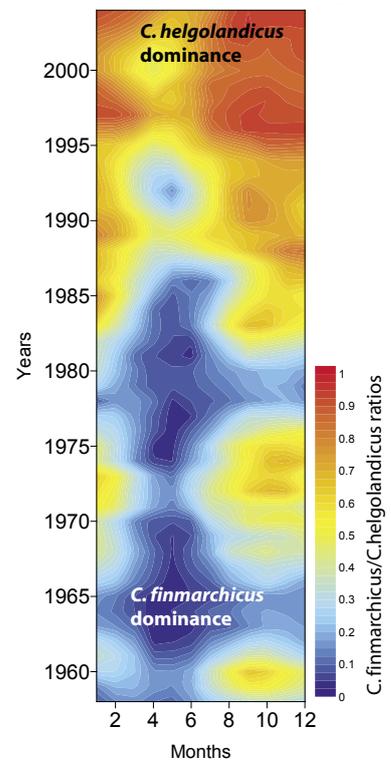


Fig.3. A simple ratio between a warm-water species (*Calanus helgolandicus*) and a cold-water species (*Calanus finmarchicus*) per month from 1958-2004. Red values indicate a dominance of the warm-water species and blue values the dominance of the cold-water species. (0= total *C. finmarchicus* dominance, 1=total *C. helgolandicus* dominance)

species co-occur there is a tendency for high abundances of *C. finmarchicus* earlier in the year and *C. helgolandicus* later in the year. There is clear evidence of thermal niche differentiation between these two species as well as successional partitioning in the North Sea, probably related to cooler temperatures earlier in the year and warmer temperatures later in the year.

North Sea

Northward shifts

The warmer water species are currently increasing in the North Sea due to regional climate warming and the NAO. Currently considered detrimental because the warmer water species are not replacing the colder water species in similar abundances and hence detrimental to other trophic levels including fish larvae (i.e. the overall biomass has significantly decreased).



70 % decline in total *Calanus* biomass in the North Sea

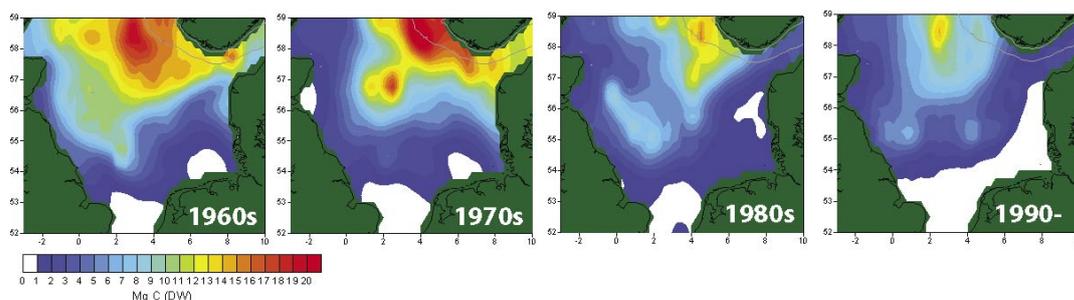


Fig. 4. Total *Calanus* biomass in the North Sea in the 1960s, 1970s, 1980s and from 1990 to the present. *Calanus* biomass is considered very important to other marine organisms that feed on them (e.g. cod larvae). It is clear that total *Calanus* biomass has shown a major decline through time, this has been related to regional climate change.

Figure 3 shows a simple ratio between *C. helgolandicus* and *C. finmarchicus* (0 = total *C. finmarchicus* dominance, 1 = total *C. helgolandicus* dominance). 2004 was dominated by *C. helgolandicus*, a trend that has been evidently accelerating over the last decade. Since the late 1980s, *C. helgolandicus* has dominated in the North Sea but is more abundant in the late summer/autumn period while *C. finmarchicus* was more abundant in the spring. While *C. helgolandicus* is coming more abundant in the North Sea the overall *Calanus* biomass has

considerably declined (see figure above on 'total *Calanus* biomass in the North Sea'). Between the 1960s and the post 1990s, total *Calanus* biomass has declined by 70%. This huge reduction in biomass has had important consequences for other marine wildlife in the North Sea including fish larvae (e.g. cod larvae). For more information on the relationship between the decline in zooplankton and cod larvae see Beaugrand et al. 2004.

Phenology and the marine growing season

Phenology is the study of the timing of recurring natural phenomena (e.g. seasonal events). Interannual changes in seasonal/successional timing is considered to be a good indicator of climate change. For example, interannual changes in the timing of species associated with the spring bloom, or the earlier appearance of dinoflagellates, associated with summer stratified conditions, may indicate hydroclimatic changes. Due to the sensitivity of the physiological development of



meroplankton to temperature, we have chosen decapod larvae as a representative of phenological changes in shelf sea environments. Figure 5 shows the annual peak seasonal abundance 'centre of gravity index' of decapod larvae from 1959–2004 in the central North Sea (i.e. the peak in seasonal appearance). It is clearly visible that there is a major trend towards an earlier seasonal peak. In particular, since 1988, with the exception of 1996 (a negative NAO year), the seasonal development of decapod larvae has occurred much earlier than the long-term average (baseline mean: 1958–2004). For example, the seasonal cycle has been up to 4–5 weeks earlier in the 1990s than the long-term mean. This trend towards an earlier seasonal appearance of meroplanktonic larvae during the last decade is highly correlated to Sea Surface Temperature (see Edwards & Richardson, 2004). 2004 continued with this trend with the early seasonal appearances of decapod larvae.

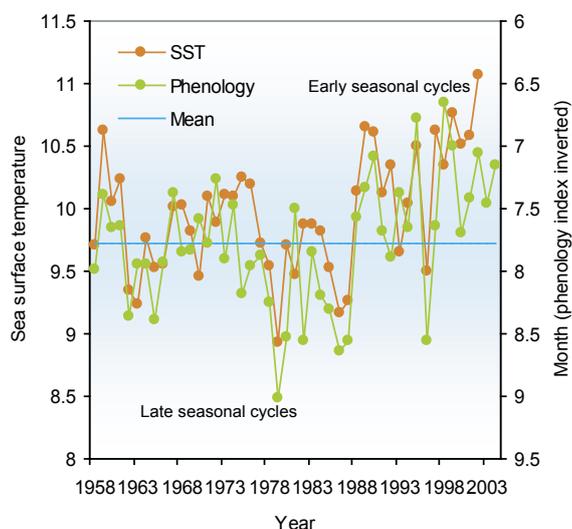


Fig. 5. Inter-annual variability in the peak seasonal development of decapod larvae (an indicator of plankton phenology) in the North Sea and its relationship with sea surface temperature. Warmer temperatures = earlier seasonal appearance, colder temperatures = late seasonal appearance.

North Sea

Seasonal shifts



Seasonal timing and phenology is occurring earlier in the North Sea and is related to regional climate warming. However, not all trophic levels are responding in the same level, therefore, currently considered detrimental because the potential of mis-timing of peak occurrences with other trophic levels including fish larvae. Future adaptations are likely to take place in response to climate warming.

Indicators of water quality

Exceptional and Harmful Algal Blooms

As well as providing an index of phytoplankton biomass (phytoplankton colour), the CPR survey identifies approximately 170 phytoplankton taxa. Apart from diatom species (which bloom in spring), by far the most common bloom forming taxon recorded by the CPR survey in 2004 was *Coccolithaceae* and the *Ceratium* genus in particular the ubiquitous species *C. fusus* and *C. furca* (particularly off Norwegian coastal waters) and *C. arcticum* in more arctic-boreal waters. Large blooms of *Coccolithaceae* occurred throughout June-August particularly in the waters between the U.K. and Iceland and north of the Azores in May. The warmer water ceratium species *C. hexacanthum* were unusually found in high numbers in the northern North Sea (Moray Firth) during October and in September in the western approaches of the English Channel. Apart from geographically extensive blooms, of particular note are the occurrences of Harmful Algal Blooms (HABs) in European waters. Figure 6 shows the geographical distribution of four common HAB taxa in European waters. It is evident from the figure that these HAB taxa are most numerous along the Dutch

coast and in the western approaches of the English Channel. In particular the red-tide forming species *Noctiluca scintillans* naturally forms extensive blooms during the summer period in these areas. Unusually the species also occurred in bloom proportions in the German Bight in January of 2004.

Plastic debris

Microscopic plastic fragments collected by the CPR appear to be increasing in the NE Atlantic. The incidence of monofilament netting snagged by the CPR towed body also seems to be increasing particularly in the southern North Sea.

A distinguishing feature of 2004 in terms of HABs was the infrequency of *Dinophysis* spp. blooms compared to the long-term mean and a higher frequency of *Pseudo-nitzschia* spp blooms particularly in the southern North Sea. Large blooms of the non-indigenous diatom *Coscinodiscus wailesii* occurred in October off the Dutch coast. The seasonal development and frequency of *Phaeocystis* was similar in 2004 to the long-term baseline mean. For more information on climate and HABs in the NE Atlantic see Edwards et al. (2006).

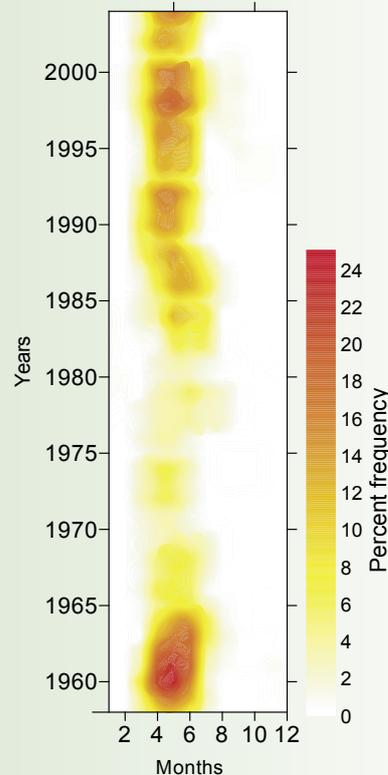


Fig. 7. Monthly means of the percentage frequency of *Phaeocystis* spp. recorded on CPR samples in the central North Sea from 1960-2004.

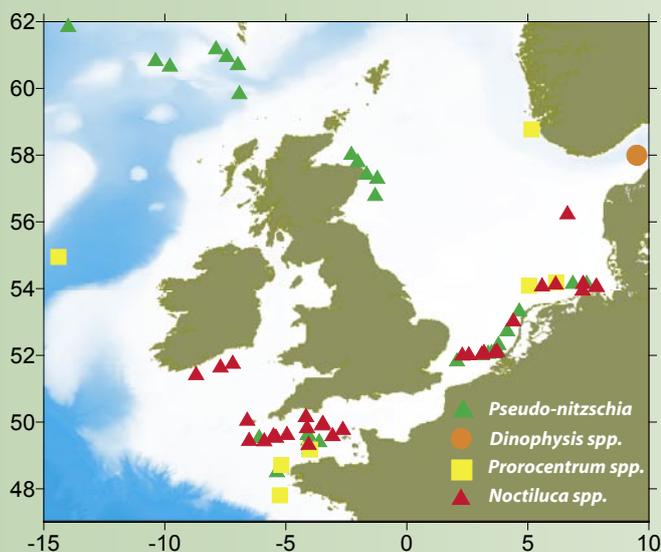


Fig. 6. Spatial distribution of 4 HAB taxa in Northern European waters during 2004. Only occurrences of the taxa above 4 standard deviations above its baseline mean (1960-2004) are shown, i.e. exceptional blooms.

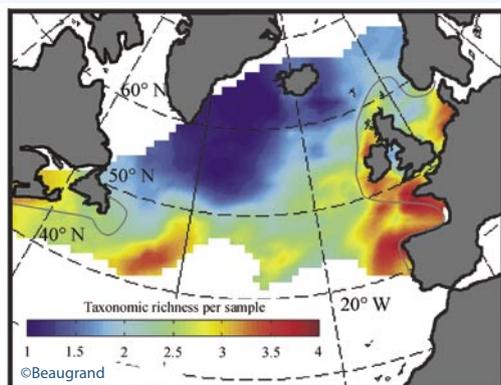
North Sea

Water quality

Currently considered of 'unknown consequences/non-detrimental' as most trends at the regional scale are related to hydro-climatic processes as opposed to anthropogenic input. However, the number of micro-plastics collected on CPR samples is increasing and the frequency and blooms of some HAB species are related to regional climate warming.

Indicators of ecosystem health

Biodiversity in the North Atlantic



Biodiversity and community structure

Figure 8 shows a multi-dimensional scaling plot of the annual plankton community in the central North Sea. The decadal changes in the community are characterised by the colder-water community in the 1960s and the warmer-water community in the 1990s. The two most distinguishable shifts are those that occurred in the late 1970s and late 1980s. Both these community shifts are associated with ocean climate anomalies (see Edwards et al. 2002). Since the 1990s, when a notable regime

shift occurred, the planktonic community has remained in a warm-water state. One of the main reasons why the 1990s community is so distinctive compared to the 'normal' community is that the plankton community has more warmer/sub-tropical species present in the 1990s assemblage (e.g. *Penilia avirostris*). The planktonic community in 2004 has remained in a position of post regime shift characteristic of a warm-

temperate plankton community with increasing diversity. However, there also appears to be another regime shift in 2000 (according to the community structure) mainly driven by the increasing prevalence of the copepod *Euchaeta hebes*. Using the five-year community averages emphasises the temporal shifts in plankton community since the 1960s and shows how the community is continuing to evolve (i.e. the community does not behave in a stable way but is constantly changing as the environment continues to change).

Regime Shifts

Since the CPR has been in operation in the North Sea the most prominent ecological shifts have occurred in the late 1970s and in the late 1980s. The late 1970s shift seems to have been an extreme event whereas the late 1980s shift has been classed as a regime shift proper. A significant regime shift has also been detected in 2000 with the zooplankton community.

Unusual taxonomic records and exotic species

Bacterosira bathyomphala (previously *Bacterosira fragilis*) occurred on 511ZC block 23 (April 2005). This was in the same area as the two previous CPR records, both found off Newfoundland. *Blepharocysta paulsenii*, a dinoflagellate, occurred in May off Scotland (696V 5); there are only 5 previous records. The sub-tropical diatom *Planktoniella sol* was present north of Newfoundland on the ZB route in August (514ZB

35), unusually far north. *Calanus hyperboreus* is normally thought of as an Arctic cold water species. An extraordinary record of an adult female *C. hyperboreus* found over deep water south-west of Ireland at 48°18'N 18°07'W (411BB 25) in May 2005. A similar extra-limital record of *C. hyperboreus* was of one found in May 1986 at 530 m depth at 51°01'N 12°56'W in a Longhurst-Hardy Plankton Recorder sample. There is only one previous similar CPR record at 50°N 26°W.

The pontellid copepod *Labidocera acutifrons* is normally rare in CPR samples. Exceptional numbers were present over Georges Bank on the September and October 2005 EB routes, being found on six samples in September and two in October. Two Poecilostomatoid copepods have been recorded recently off the Dutch coast. A male *Giardella callianassae* was

Plankton community structure in the North Sea

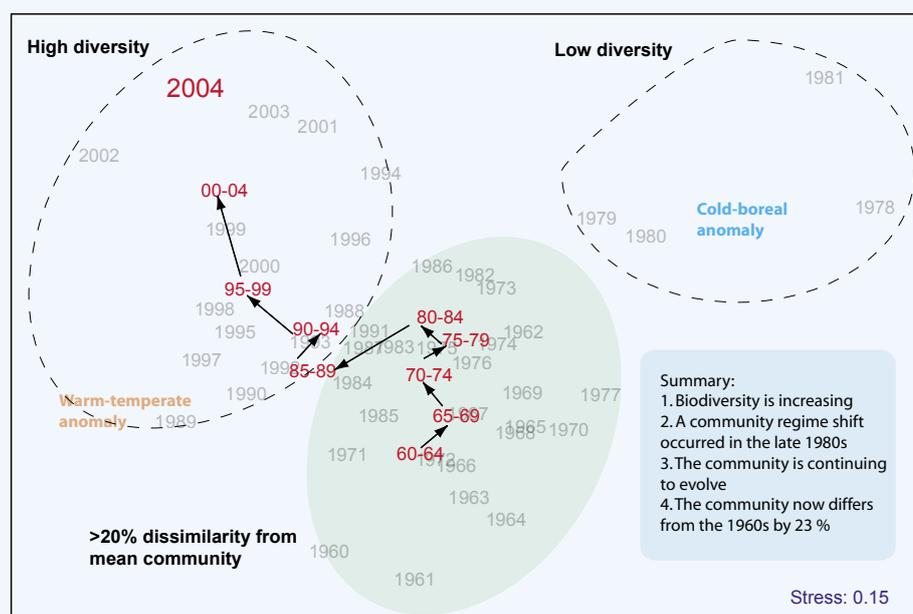


Fig. 8. Multi-dimensional scaling plot of the plankton community structure in the North Sea from 1960-2004 showing major structural shifts (late 1970s and late 1980s) and five-year community averages. Years close in space have a similar community structure (see summary).

North Sea

Biodiversity



Generally, pelagic biodiversity is increasing in the North Sea (based on copepod species). This trend is related to regional climate warming. However, in terms of production this could be considered a detrimental affect for fisheries as diversity/productivity are considered inversely related.



found on 250LG block 3 in February 2005 and in March 2005 a female *Hemicyclops aberdonensis* was present on 251LG block 13. The possible *Asterocheres* sp. found off Texel on the LG route in January 2004 (mentioned in the 2004 SAHFOS Annual Report) was re-identified by G.A. Boxshall as a *Giardella callianassae*. Both copepod species live in association with mud-burrowing shrimps, *G. callianassae* in the burrows of *Callianassa subterranea* and *H. aberdonensis* is associated with *Calocaris macandreae*.

The very distinctive larva of *Jaxea nocturna*, a thalassinid mud shrimp (related to *Callianassa*, *Upogebia*, etc.), was found off Lisbon in May 2005 (520SB 45) and off Cape Finisterre in July (522SB 13). A Monstrilloid copepod, *Monstrilla* sp., found on the southern (French) end of the January 2005 PR route (263PR 8) was very unusual. *Monstrilla longiremis* has been recorded once previously on the PR route in March 1977 when an adult male was recorded on 35PR block 6. The isopod *Heterophryxus appendiculatus*, parasitic

on euphausiids including *Euphausia krohni*, has been recorded on five occasions in 2004-2005. It was present north of the Azores on the B route in September (403BC) and December (406BD) 2004, in the southern North Sea in February 2005 (250LG) and on two samples over Georges Bank in December 2005 (307EB). These constituted the 26th – 30th records of this scarce parasite in the CPR survey.

On a sample taken west of Denmark on the September 2005 C route (628C), copepods including *Calanus*, *Centropages* and *Pseudocalanus* were heavily infected with parasitic cestodes. Some cestodes have fish as the final hosts in the parasite's life cycle. We take it for granted that all thecosomes found in CPR samples are *Limacina retroversa*/*L. helicina* (in the Atlantic) or *L. helicina* (in the Pacific). In April 2005 west of the Queen Charlotte Islands (23AT 47, 52°36'N 133°16'W) Alistair found an unusual thecosome with a reticulate pattern on the shell and identified it as *Peraclis*, possibly *P. apicifulva*. There are 16 previous CPR records of *Peraclis* spp., all in the North Atlantic. A further *Peraclis* was present on the northern (Plymouth) end of the PR route in August 2005. *Zoothamnium pelagicum* was found in the southern North Sea in December 2005 (240 HE 27, 54°6'N, 7°49'E). The species is rare in the North Sea.

Pipefish

Pipefish have been recorded with increasing frequency in CPR samples, particularly in the southwest approaches (on the BA and BB routes), since 2003. Previously they were rarely seen. Their identification has recently been confirmed by Richard Kirby as snake pipefish *Entelurus aequoreus*. Most pipefish species are coastal or inshore, but the snake pipefish is the only one described as an open sea or oceanic species.



Snake pipefish
© Mike Shaw

Further CPR reading

Climate impact on plankton (Richardson & Schoeman 2004: Science)
Climate change & trophic mismatch (Edwards & Richardson 2004: Nature)
Ocean climate and the ecology of the North Sea (Edwards et al. 2002: MEPS)
Increasing marine plastics (Thompson et al. 2004: Science)
Biogeography and climate (Beaugrand et al. 2002: Science)
Cod and climate change (Beaugrand et al. 2003: Nature)
Harmful Algal Blooms (Edwards et al. 2006: L&O)

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