

Ecological status report

2006/2007

The ecological status of the North Atlantic environment based on observations from the Continuous Plankton Recorder survey

Monitoring the health of the oceans since 1931

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Plankton indicators

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.

Climate change impact indicators

1. Biogeographical and northward shifts

Over the last five decades 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 and a decline of colder-water species. This trend seems to be accelerating over the last five years. The mass biogeographical movements are related to changes in sea surface temperature. A particularly interesting feature over the last five years is the decline in subarctic species to the south-east of Iceland and their movement more to the north and west (Figure 1).

A useful indicator of the warming trend in the North Sea (a northward shift indicator) is the percent ratio of the cold-temperate *Calanus finmarchicus* and the warm-temperate *Calanus helgolandicus* 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 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.

Figure 2 shows a simple percentage ratio between *C. helgolandicus* and *C. finmarchicus*. 2006 was again dominated by *C. helgolandicus*, a trend that has been evidently accelerating over the last decade. While *C. helgolandicus* is becoming more abundant in the North Sea the overall *Calanus* biomass has considerably declined. 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.

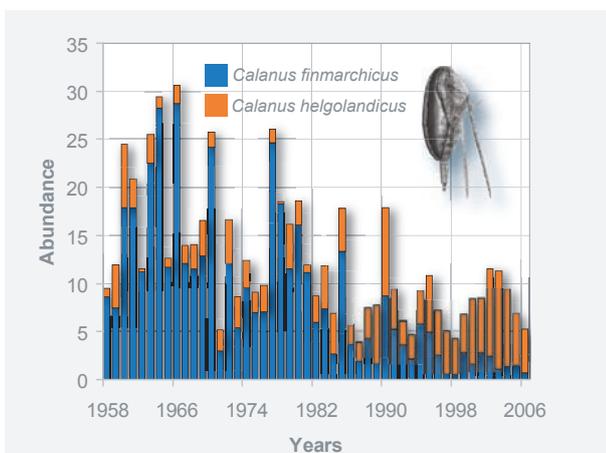
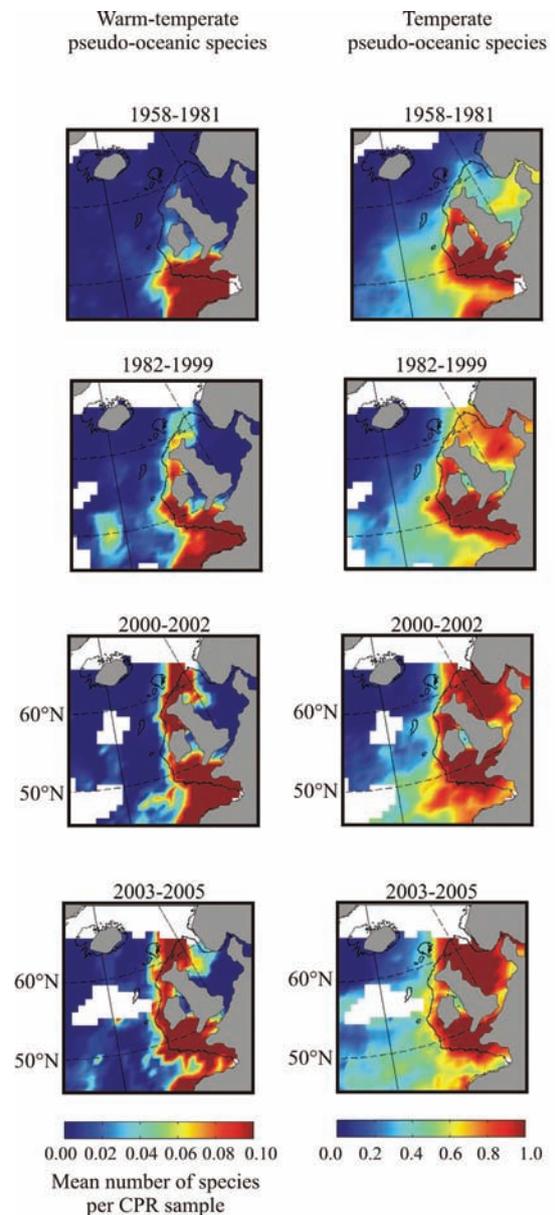
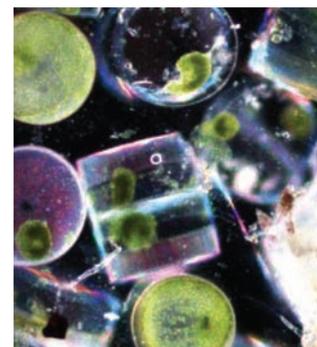


Fig.2. A simple percentage ratio between a warm-water species (*Calanus helgolandicus*) and a cold-water species (*Calanus finmarchicus*) annually from 1958-2006 and total annual *Calanus* abundance. Note: while the warm species is replacing the cold water species the actual total *Calanus* abundance is decreasing.

‘Plankton are continuing to move northward and plankton seasonal cycles are occurring earlier’



2. Phenology and the marine growing season

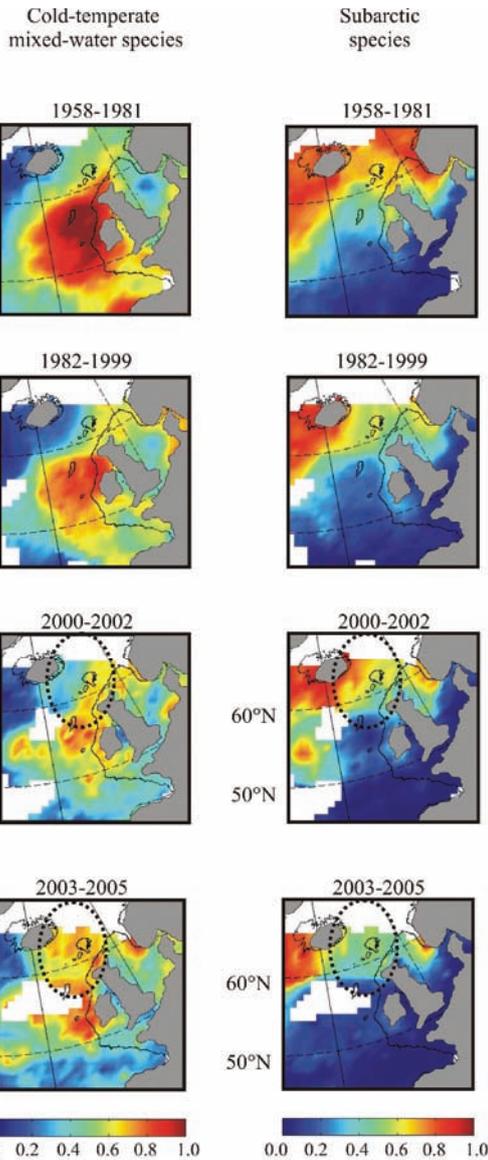
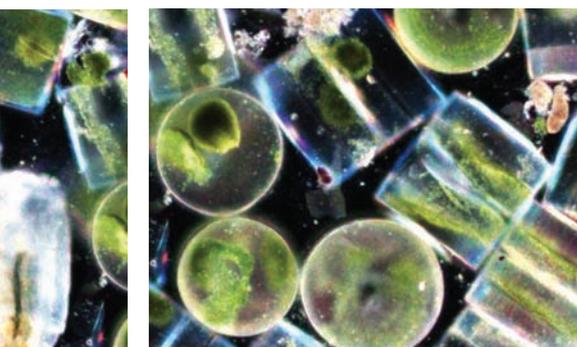


Fig. 1. Biogeographical changes in plankton assemblages spanning five decades. Warm water plankton are moving north and cold water plankton are moving out of the North Sea.



Phenology is the study of the timing of recurring natural phenomena (e.g. seasonal events). Due to the sensitivity of the physiological development of meroplankton to temperature, we have chosen echinoderm larvae as a representative of phenological changes in shelf sea environments. Figure 3 shows the annual peak seasonal abundance 'centre of gravity index' of echinoderm larvae from 1959–2006 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 echinoderm larvae has occurred much earlier than the long-

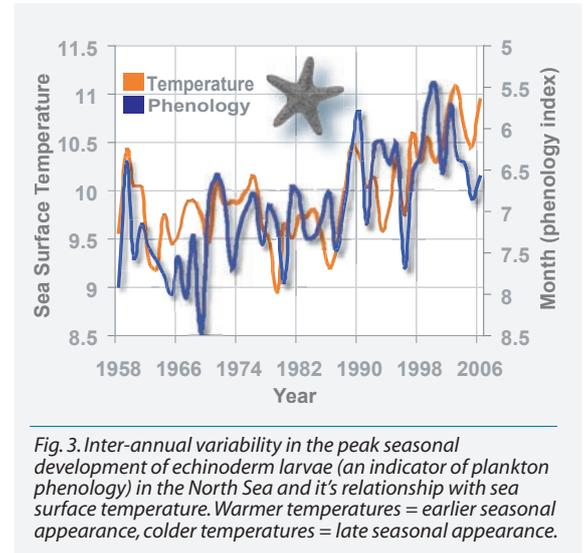


Fig. 3. Inter-annual variability in the peak seasonal development of echinoderm larvae (an indicator of plankton phenology) in the North Sea and its relationship with sea surface temperature. Warmer temperatures = earlier seasonal appearance, colder temperatures = late seasonal appearance.

term average. 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 with Sea Surface Temperature. 2006 continued with this trend with the early seasonal appearances of echinoderm larvae.

Key summary

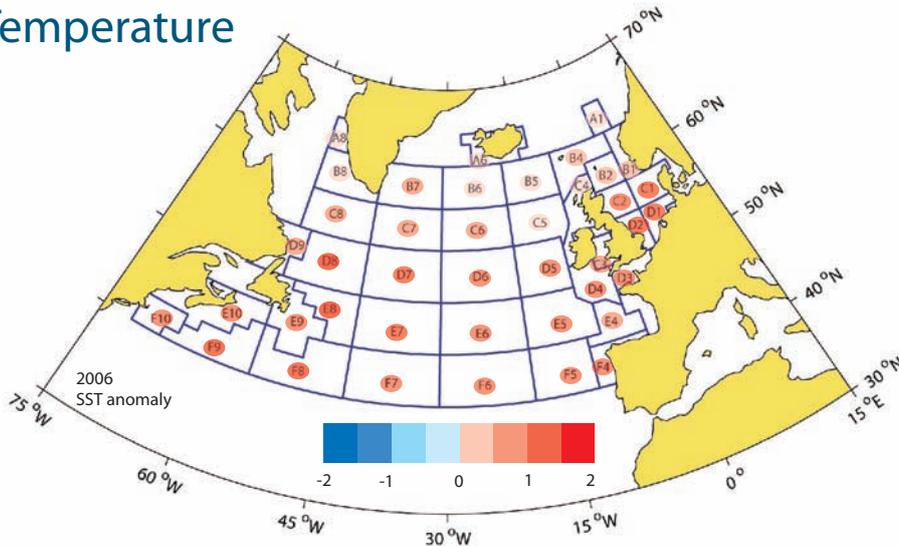
The warmer water species are currently increasing in the North Sea due to regional climate warming and the NAO. In terms of a productive environment this change is currently considered detrimental because the warmer water species are not replacing the colder water species in similar abundances and this is detrimental to other trophic levels* including fish larvae.

Seasonal timing and phenology* is occurring earlier in the North Sea and is related to regional climate warming. For example, some species have moved forward in their seasonal cycle by 4-5 weeks. However, not all trophic levels* are responding in the same level, therefore in terms of a productive environment, this change is currently considered detrimental because of the potential of mis-timing (mismatch*) of peak occurrences of plankton with other trophic levels including fish larvae. There is a high confidence that these trends are related to regional climate warming.

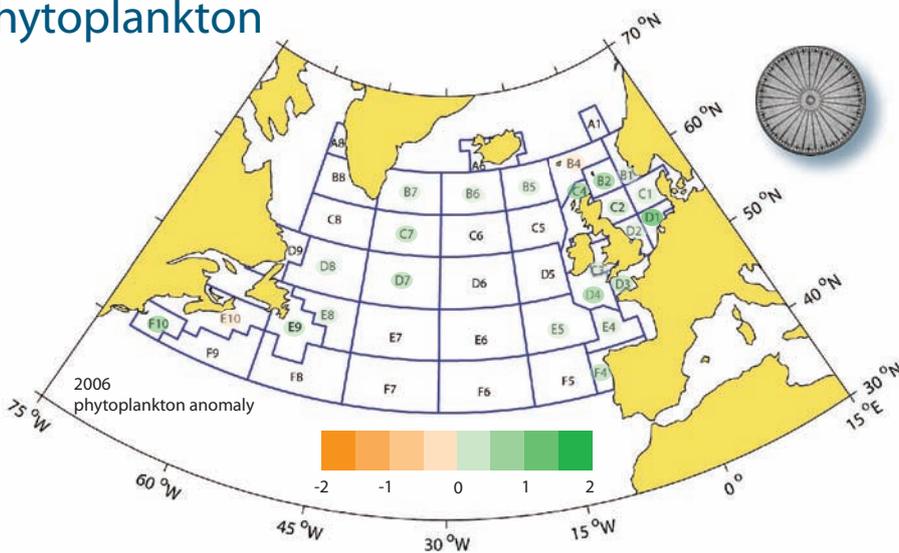
More information: *Science* (2002) 296: 1692-1694; *Nature* (2004) 430:881-884

3. Pan-North Atlantic biological indicators

Temperature



Phytoplankton



Zooplankton

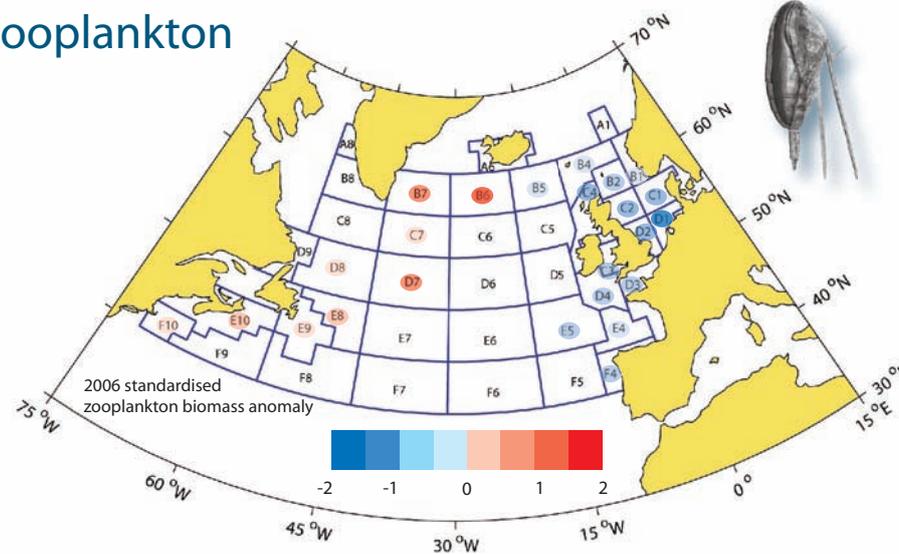


Figure 4 shows 2006 anomalies for the North Atlantic for Sea Surface Temperature (SST), phytoplankton biomass and zooplankton abundance based on the long-term trends in these variables from 1958-2006. Generally, the SST in all areas of the North Atlantic were above the long-term mean in 2006, with areas in the Gulf Stream and in areas to the north and east of Newfoundland particularly high. The difference in the degree of warming between the southern and northern North Sea is also evident, with the southern North Sea warming faster. For phytoplankton biomass there has been a large increase since the late 1980s in most regional areas (particularly the north-east Atlantic and the Newfoundland shelf). 2006 showed that in most areas the phytoplankton colour was generally above the baseline mean (1958-2006), apart from the Scotian Shelf and to the north of the British Isles. The zooplankton biomass anomaly showed that in the eastern North Atlantic most regions were below the long-term average (particularly low values were recorded in the southern North Sea), while the western North Atlantic values were higher than average. It is not yet clear why this inverse pattern is evident, although the see-saw behaviour of the North Atlantic Oscillation is thought to play an important part.



Fig. 4. Standard CPR boxes used to examine 2006 anomalies in the North Atlantic of annual Sea Surface Temperature, phytoplankton biomass and zooplankton biomass. Anomalies relate to the difference between 2006 and the long-term mean (1958-2005). SST data is derived from the Hadley Centre, UK Met Office.

Biodiversity and invasive species

Geographical and long-term trends

The mean overall geographical pattern of species diversity in the North Atlantic is shown in Figure 5. From our current knowledge based on zooplankton diversity, the overall pelagic biodiversity of the NE Atlantic is increasing and moving northward. This trend is related to regional climate warming leading to perhaps a more diverse environment. However, in terms of an economically productive environment this could be considered a detrimental situation as diversity/productivity are considered inversely related with this possibly having a negative affect on overall carrying capacity of regional systems.

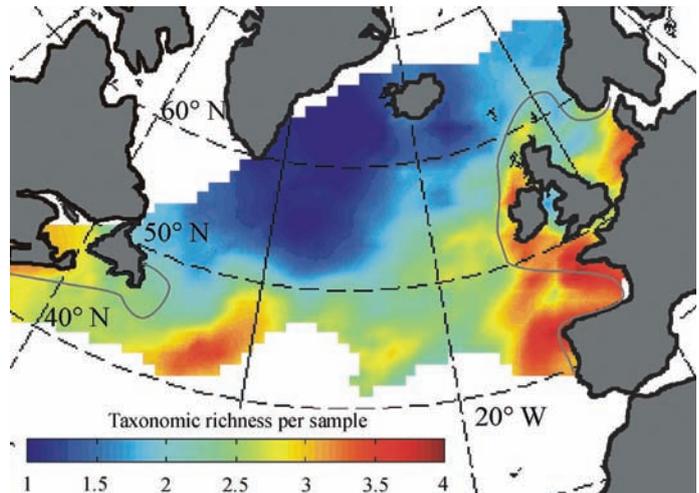


Fig. 5. The mean geographical pattern of species diversity for the North Atlantic ocean based on over 200,000 CPR samples taken over five decades. A clear boundary is seen between the North Atlantic current and the Subpolar Gyre where biodiversity is at its minimum.

Unusual biodiversity records in 2006/2007

An unusual example of the warm water dinoflagellate *Ceratium platycorne* with divided antapical horns was seen southwest of Ireland in October (on 460 W). The Arctic diatom *Bacterosira bathyomphala* was recorded in the northwest Pacific off the Kuril Islands in May 2007 (131 VJ 15) (see also the 2004/5 Ecological Status Report). The cold water copepod *Calanus hyperboreus* was found over deep water southwest of Ireland in May (on 433 BB 7, at 46°54'N 14°02'W); it is very unusual this far south. There have been three previous records of *C. hyperboreus* on CPR samples in this area (since 1946!), two of them in May. Two copepods were recorded for the first time in the CPR survey. The calanoid copepod *Gaetanus simplex* was found in the Gulf of Alaska in March (on 119 VJ 39, at 57°56'N 142°21'W). The benthic cyclopoid copepod *Cyclopinoides longicornis* occurred in the southern North Sea in May (on 516 R 5, at 52°04'N 3°03'E). Some rare

or unusual copepods noted northwest of the Azores in 2007 included *Scaphocalanus echinatus* in March (on 431 BD 31, at 41°47'N 38°41'W – the 17th record) and *Euaetideus giesbrechti* in November (on 440 BD 23, at 43°16'N 36°42'W – 13th record). The mesopelagic copepod *Haloptilus spiniceps* was present north of the Azores in November (on 440 BC 9 - 46°05'N 27°45'W), only the third time this species has been found in the CPR survey.

Preliminary results from CPR analysis indicate that 2007 has again been a year in which high numbers of snake pipefish *Entelurus aequoreus* have been found on CPR samples taken in the Western Approaches (on the BA route) and to the southwest of Ireland in the Celtic Sea (W route). Although they were found during most months of the year, the highest numbers were recorded in the summer/autumn months (July-October) and these were concentrated around the shelf-break. Much lower numbers of pipefish (as yet to be identified to species) were found in the North Sea, primarily on the A route off the east coast of Scotland. Sandeels (*Ammodytes* spp.) were again found in good numbers in late spring, on the A route (east coast of Scotland) and particularly on the LR route (along the east coast of England).

Trans-Arctic invasion?



It has recently been highlighted that Arctic ice is reducing faster than previous modelled estimates. As a consequence of this the biological boundaries between the North Atlantic Ocean and Pacific may become increasingly blurred with an increase of trans-Arctic migrations becoming a reality. The CPR survey has already documented the presence of a Pacific diatom in the Labrador Sea since the late 1990s which has since spread southwards and eastwards. The diatom species itself has been absent from the North Atlantic for over 800,000 years and could be the first evidence of a trans-Arctic migration in modern times and be the harbinger of a potential inundation of new organisms to the North Atlantic. The consequences of such a change to the function and biodiversity of Arctic systems is at present unknown.

More information: *Global Change Biology*(2007) 13: 1910-1921



Marine ecosystem health indicators

1. Ecosystem stability

Figure 6 shows a 50 species meta analysis of the plankton community in the central North Sea from 1958-2006. 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. 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 2006 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 warm-water copepod species. Using the community similarity between 2006 and the preceding years the major community shifts occur in 1988 and 2000. The 1960s community now differs from the 2006 community by 27%.

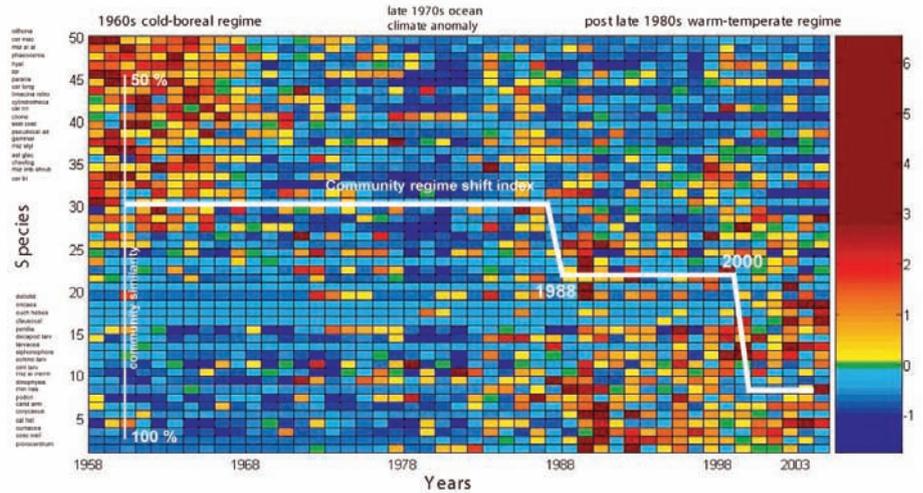
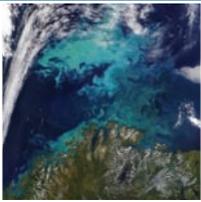


Fig. 6. 50 species meta analysis of plankton in the central North Sea ordered by first principal component (standardised abundance). Community regime shift index calculated by the percent similarity between 2006 and preceding years (2006 = 100 % community similarity) using a displacement sequential regime detection (minimum regime shift = 10 years).

Acidification



Ocean acidification is the term applied to the ongoing increase in acidification of the world's oceans as a consequence of their uptake of anthropogenic carbon dioxide. Over the last 250 years the ocean has absorbed a large amount of the increased carbon dioxide emissions due to the burning of fossil fuels thereby reducing the amount remaining in the atmosphere. Plankton organisms play a fundamental part in the natural absorption of CO₂ and have thus helped mitigate the climate effects of anthropogenic CO₂. However, it is thought that increasing pH may in the future have a negative affect on certain planktonic organisms and thus lead to a reduction in the amount of CO₂ absorbed by the world's oceans and accelerating global warming. The organisms that are particularly vulnerable to acidification are the calcifying organisms such as coccolithophores and foraminifera. The CPR survey is proving a critical baseline and is currently keeping a close eye on these vulnerable organisms in case in the future these organisms start to show any negative effects due to acidification.

2. Abrupt ecosystem 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 anomalous hydro-climatic event (lasting only a few years), whereas the late 1980s shift has been classed as a regime shift proper. There is now growing evidence that a prominent ecosystem shift occurred throughout the oceanic waters of the North Atlantic from approximately 1997 onwards. The shift is related to Northern Hemisphere Temperature changes and large-scale changes in important oceanographic features and circulation patterns.



3. Harmful Algal Blooms and water quality

As well as providing an index of phytoplankton biomass (phytoplankton colour), the CPR survey identifies approximately 170 phytoplankton taxa. Apart from diatom species (which peak in April in the North Sea), by far the most common bloom forming taxon recorded by the CPR survey in 2006 was Coccolithaceae. The first species to reach bloom proportions in the North Atlantic was *Ceratium arcticum* in more arctic-boreal waters of the Northwest Atlantic. Unusually compared to most phytoplankton species *C. arcticum* can reach bloom proportions in December and January in this region, possibly due to strong haline stratification. Geographically extensive blooms of Coccolithaceae occurred throughout June-August particularly in sub-polar gyre and in oceanic waters to the south-west of Iceland. Number of blooms of the genus *Ceratium* were unusually low in the North Sea in 2006. *Ceratium lineatum*, for example, recorded its lowest ever abundance in 2006 for the last 50 years.

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.

Apart from geographically extensive blooms, of particular note are the occurrences of Harmful Algal Blooms (HABs) in European waters. HAB taxa are generally most numerous along the Dutch coast and off the Danish coast. In particular the red-tide forming species *Noctiluca scintillans* naturally forms extensive blooms during the summer period in these areas. Large blooms of *Dinophysis* spp. occurred in the Skagerrak during July and *Prorocentrum* spp in the English Channel and off the Iberian Peninsula.

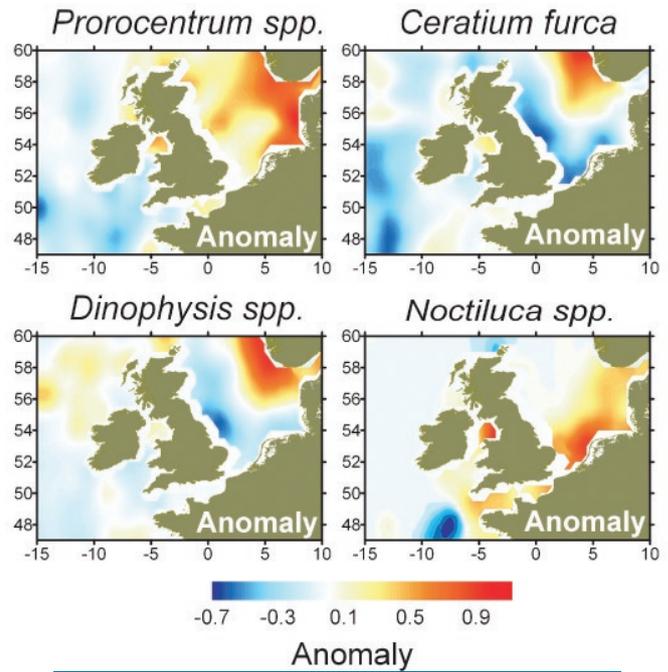
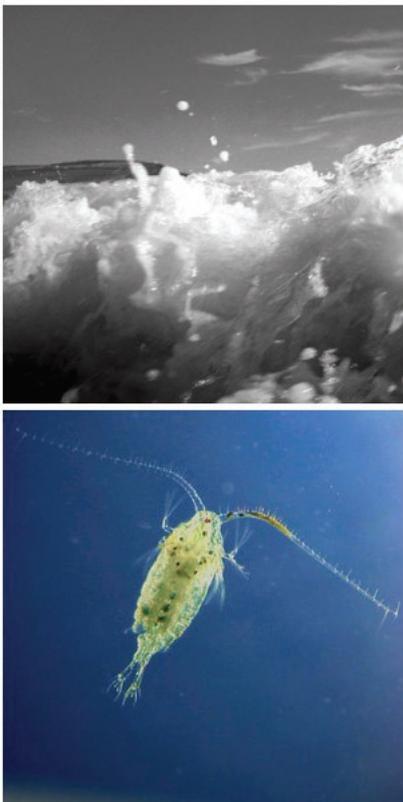


Fig. 7. Decadal anomaly maps of four common HAB taxa in the NE Atlantic. Anomaly is the difference between the long-term mean (1960-1989) and post 1990s (1990-2002). Note the increases along the Norwegian Coastal Current and the southern North Sea.





Key summary

Ecosystem health

At the regional scale, it has been found that most phytoplankton trends are related to hydro-climatic variability as opposed to anthropogenic* input (e.g. nutrient input leading to eutrophication*). This means that the NE Atlantic taken as a whole is generally considered to be fairly healthy. This is not to say, however, that certain coastal areas and the southern North Sea are not vulnerable to eutrophication and climate change may also exacerbate these negative effects in these vulnerable areas. It has also been found that the number of micro-plastics* collected on CPR samples is increasing and the frequency and blooms of some Harmful Algal Bloom* species are related to regional climate warming.

The plankton community is continuing to evolve in time with large changes occurring in the late 1980s and in 2000 (regime shifts*) in response to regional climate warming. The ecosystem is therefore not temporally stable. Similarly, higher trophic levels* (e.g. fish, seabirds) are also changing.

More information: *Limnology and Oceanography* (2006) 51:820-829; *Science* (2004) 308:834

Indicator summary



Northward shifts

The warmer water species are currently increasing in the North Sea due to regional climate warming and the NAO. In terms of a productive environment this change is currently considered detrimental because the warmer water species are not replacing the colder water species in similar abundances and this is detrimental to other trophic levels* including fish larvae (For example, an important zooplankton species has declined by 70 % in the North Sea). There is a high confidence that these trends are related to regional climate warming.



Changes in seasonality

Seasonal timing and phenology* is occurring earlier in the North Sea and is related to regional climate warming. For example, some species have moved forward in their seasonal cycle by 4-5 weeks. However, not all trophic levels* are responding in the same level, therefore in terms of a productive environment, this change is currently considered detrimental because of the potential of mis-timing (mismatch*) of peak occurrences of plankton with other trophic levels including fish larvae. There is a high confidence that these changes are associated with regional climate warming.



Biodiversity and invasive species

From our knowledge of copepods (zooplankton) we believe the overall pelagic biodiversity* of the North Sea is increasing. The CPR survey has already documented the presence of a Pacific diatom in the Labrador Sea since the late 1990s which has since spread southwards and eastwards. The diatom species itself has been absent from the North Atlantic for over 800,000 years and could be the first evidence of a trans-Arctic migration in modern times.



Ecosystem health and water quality

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Acidification

Organisms that could be particularly vulnerable to acidification are the calcifying organisms such as coccolithophores and foraminifera. The CPR survey is proving a critical baseline and is currently keeping a close eye on these vulnerable organisms in case in the future these organisms start to show any negative effects due to acidification.

Glossary

Anthropogenic: Effects, processes, objects, or materials that are derived from human activities, as opposed to those occurring naturally. **Biodiversity:** The variation of life at all levels of biological organisation, i.e. from genes, species to ecosystems. Biodiversity is sometimes used to measure the health of biological systems. In CPR terminology, biodiversity usually refers to species diversity. For example, an ecoregion that has a large number of species is considered diverse. **Eutrophication:** The enrichment of waters with nutrients (e.g. nitrate, phosphate) usually from human activities which may lead to an enhancement in phytoplankton growth. This in turn may lead to detrimental effects on an ecosystem. **Harmful Algal Blooms:** Blooms of phytoplankton that can have detrimental effects on the environment either by the bloom producing toxins or/and causing deoxygenation of the water-column. **Match-Mismatch:** An ecological theory that due to fluctuating annual environmental conditions the seasonal timing of fish larvae and their prey (zooplankton) maybe closely timed (match) or out of time (mismatch). The close seasonal timing of fish larvae with their prey is considered beneficial to fish larvae. **Micro-plastics:** Microscopic fragments of plastic as opposed to large plastic detritus such as bottles and packaging. The number of micro-plastics has been increasing in CPR samples over the last 40 years. **Phenology:** The study of annually recurring life cycle events such as the timing of migrations and flowering of plants. It is an important indicator of climate change impacts on biological populations. **Regime shift:** A step-wise change in the mean of a variable that is persistent in time. In CPR terminology a regime shift refers to an abrupt ecosystem shift (i.e. the shift is evident in many ecological variables and trophic levels) that lasts for a least a decade in time. Shorter shifts are referred to as ocean-climate anomalies. **Trophic level:** Level in a food chain at which an organism takes its food, where phytoplankton are considered at trophic level 1. Higher trophic levels usually refer to organisms further up a food-chain (e.g. fish, seabirds, sea mammals).

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