Ecological status report

2005/2006

Results from the North Atlantic CPR survey

Monitoring the health of the oceans using planktonic indicators

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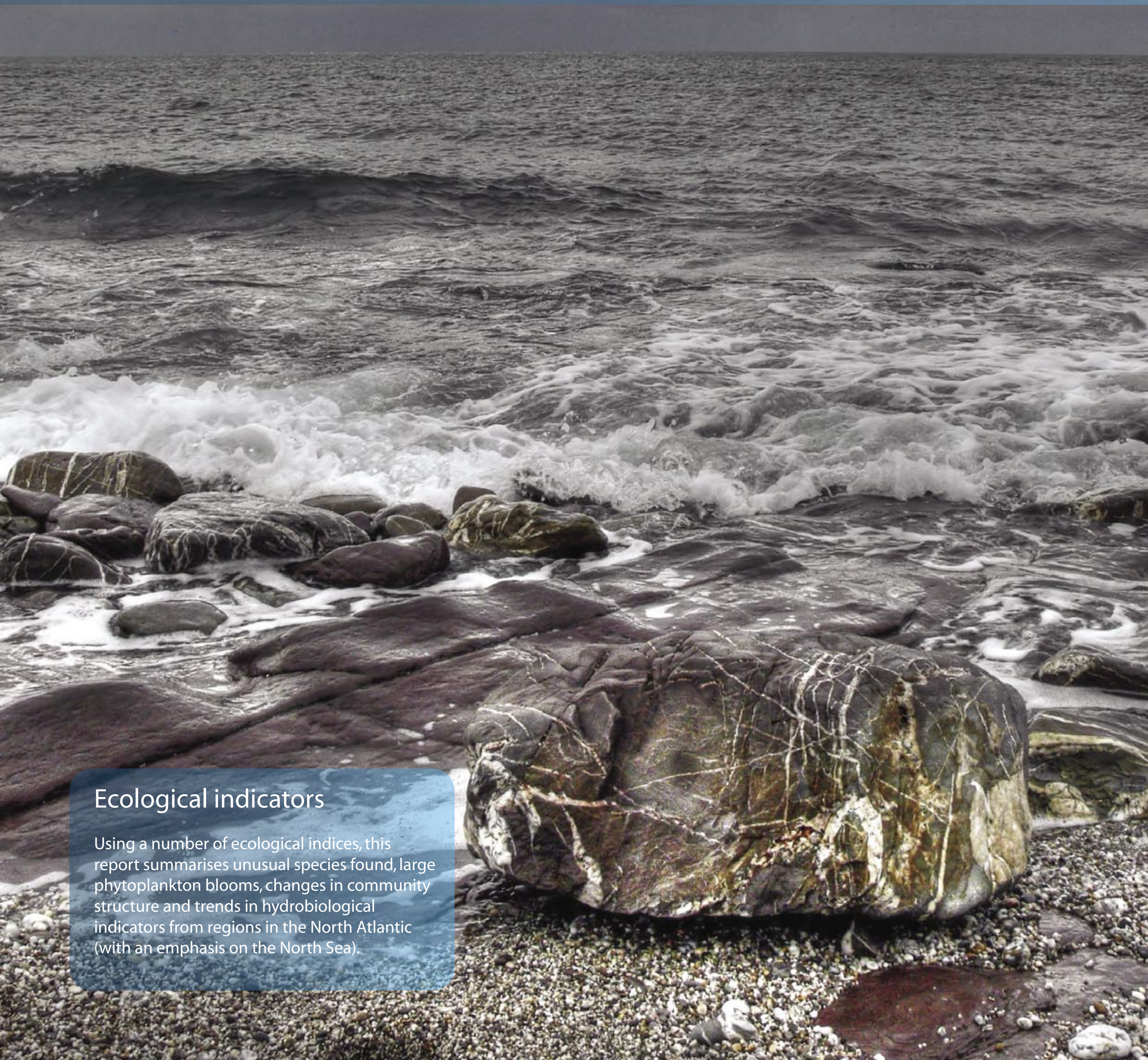
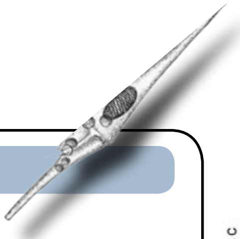


Ecological indicators

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).

Large-scale decadal trends in the North Atlantic



Key Summary

North Atlantic changes

Generally, SST in all areas of the North Atlantic were above the long-term mean in 2005, with areas in the Gulf Stream to the north and east of Newfoundland particularly high. 2005 showed that in most areas the phytoplankton colour was also generally above the base-line mean (1946-2005). The zooplankton biomass anomaly showed that most regions in the North Atlantic were below the long-term average (excluding some more northern regions and the Scotian Shelf). Particularly low values were recorded in the southern North Sea.

CPR standard areas in the North Atlantic

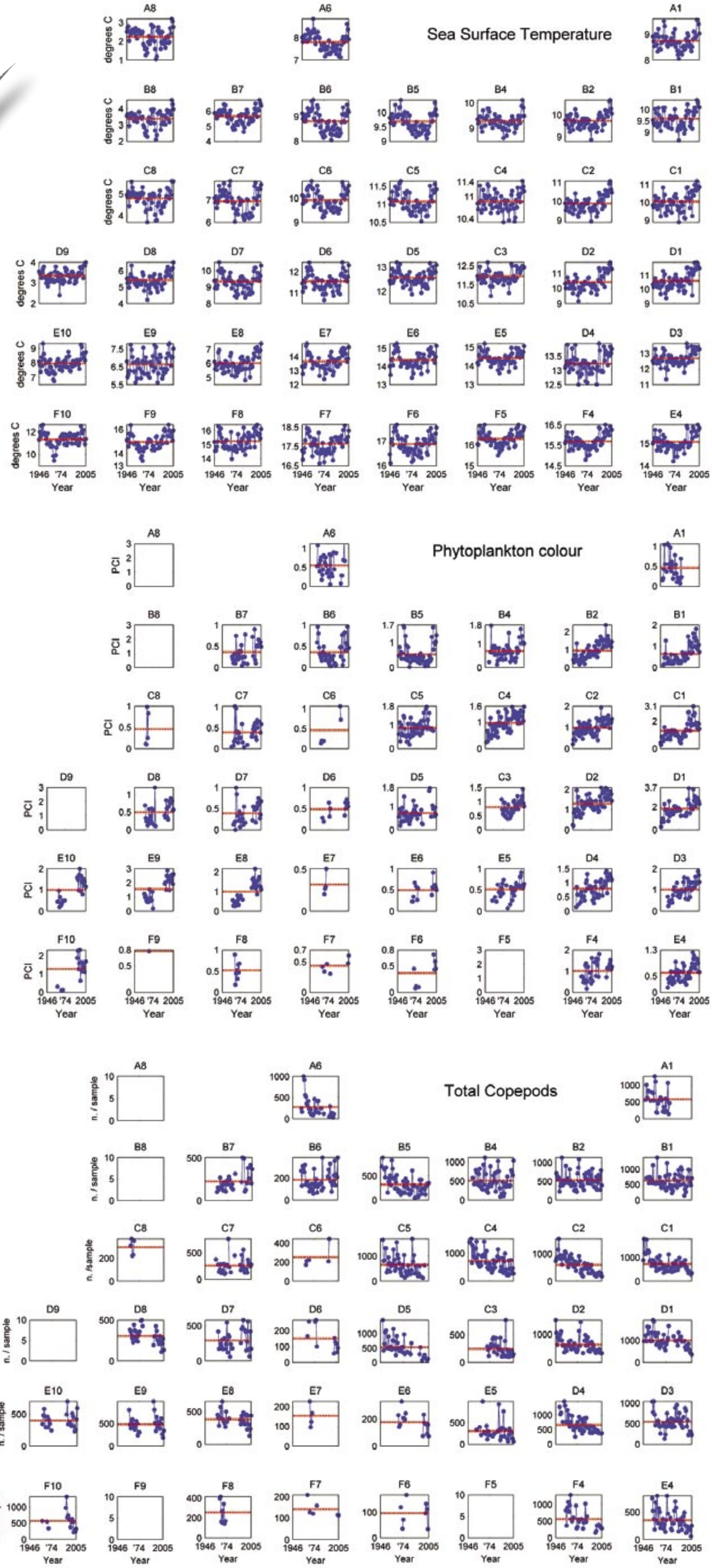
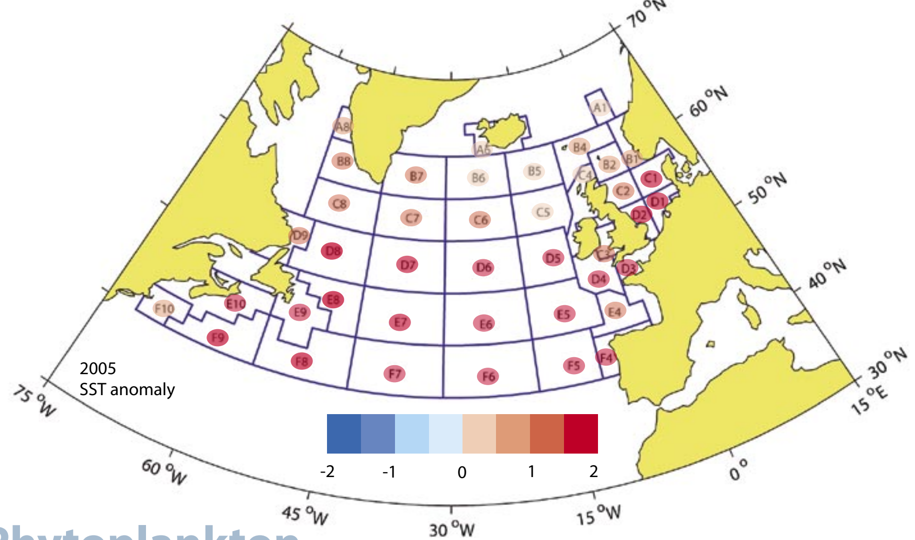


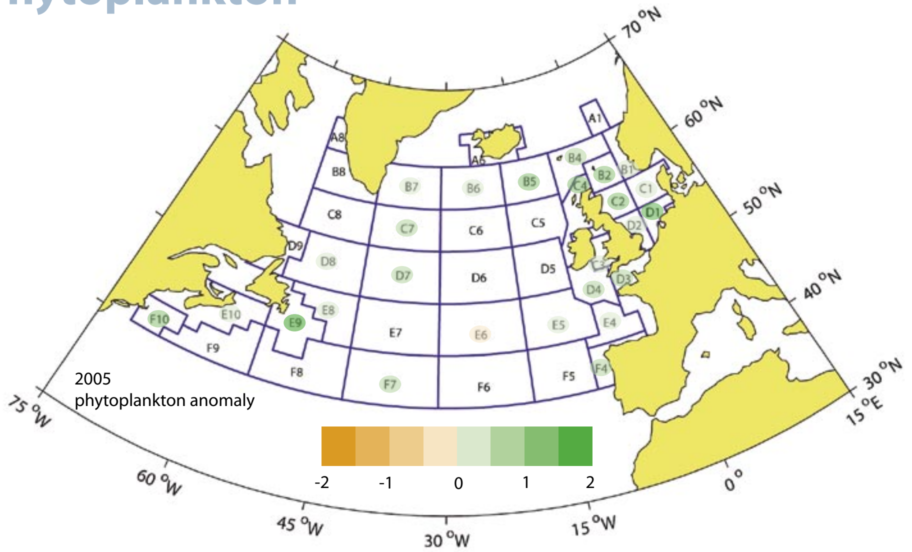
Fig. 1. Standard CPR boxes used to examine spatial variability in the North Atlantic and annual Sea Surface Temperatures, phytoplankton colour and total copepods for each CPR box from 1946-2005. Annual values were only calculated for each CPR box when eight or more months were sampled in any given year. SST data is derived from the Hadley Centre, UK Met Office.

Pan-North Atlantic 2005 anomalies

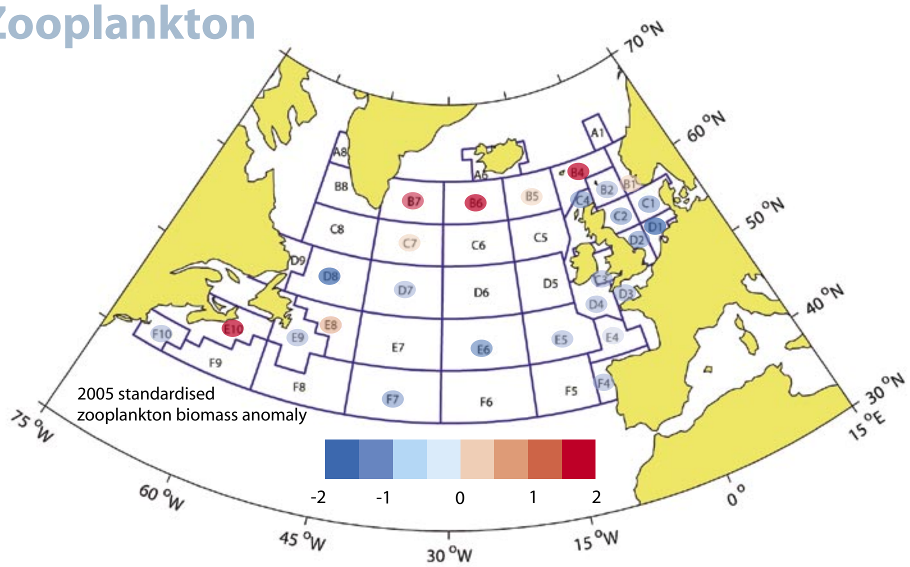
Temperature



Phytoplankton



Zooplankton



2005 North Atlantic anomalies

Figure 1 shows the long-term trends in the North Atlantic for Sea Surface Temperature (SST), phytoplankton biomass and zooplankton abundance from 1946-2005 and Figure 2 shows the anomalies of these variables in 2005. Generally, the SST in all areas of the North Atlantic were above the long-term mean in 2005, 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. 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 2005. It is clear 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. 2005 showed that in most areas the phytoplankton colour was generally above the base-line mean (1946-2005). The zooplankton biomass anomaly showed that most regions in the North Atlantic were below the long-term average (excluding some more northern regions and the Scotian Shelf). Particularly low values were recorded in the southern North Sea and to the north of Newfoundland.

Fig. 2. Standard CPR boxes used to examine 2005 anomalies in the North Atlantic of annual Sea Surface Temperature, phytoplankton colour and total copepods. Anomalies relate to the difference between 2005 and the long-term mean (1958-2004). SST data is derived from the Hadley Centre, UK Met Office

Indicators of climate change

Biogeographical changes and northward shifts

Key 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.

***More information**: Beaugrand, G., Reid, P.C., Ibanez. F., Lindley, J.A., Edwards, M. 2002. Reorganization of North Atlantic Marine Copepod Biodiversity and Climate. Science, 296:1692-1694*

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 2005 continuing with this trend. Sea Surface Temperature (SST) continued to rise in the North Sea during 2005 and showed a continued increase throughout most areas of the North Atlantic (Fig. 1).

The plankton community in 2005 had high numbers of warm-water/sub-tropical species, as well as oceanic species including Doliolids. The warm-water cladoceran *Penilia avirostris* has increased considerably in abundance in the North Sea in recent years.

A useful indicator of the warming trend in the North Sea (a biogeographical/ 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 ~10-11ºC isotherm and is a useful indicator of major biogeographical provinces. *Calanus helgolandicus* usually has a northern distributional boundary of 14ºC and has a population optimum lying between 10-20ºC. 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.

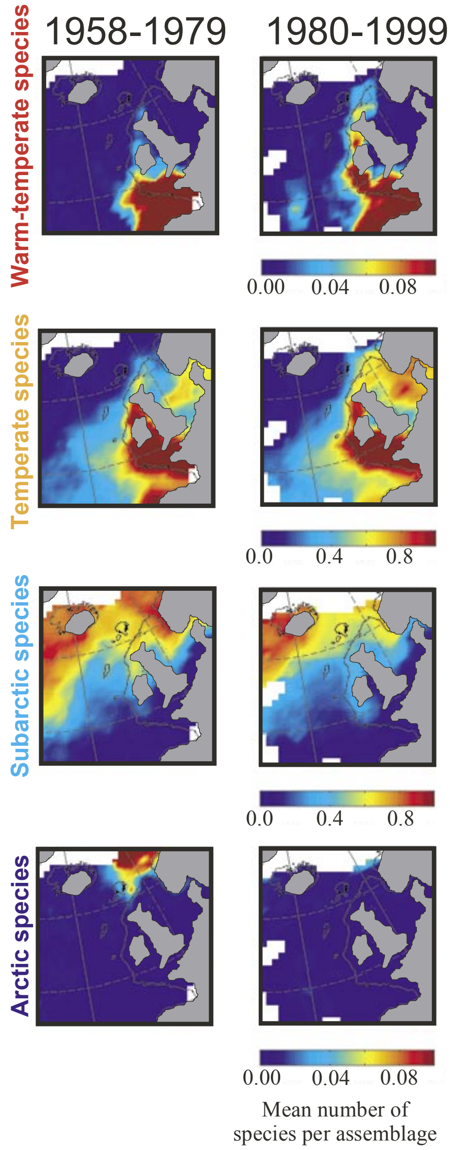


Fig. 3. Biogeographical changes in plankton assemblages spanning five decades. Warm water plankton are moving north and cold water plankton are moving out of the North Sea. Based on Beaugrand et al. 2002.

Figure 4 shows a simple ratio between *C. helgolandicus* and *C. finmarchicus* (0= total *C. finmarchicus* dominance, 1=total *C. helgolandicus* dominance). 2005 was again 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. Although *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 (e.g. cod larvae).

Phenology and the marine growing season

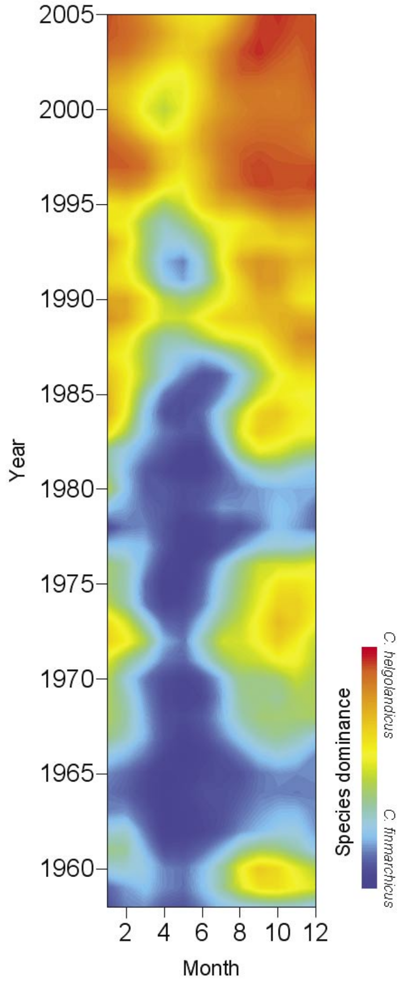


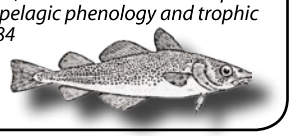
Fig.4. A simple ratio between a warm-water species (*Calanus helgolandicus*) and a cold-water species (*Calanus finmarchicus*) per month from 1958-2005. Red values indicate a dominance of the warm-water species and blue values the dominance of the cold-water species. (0= total *C. finmarchicus* dominance, 1=total *C. helgolandicus* dominance). Data from North Sea.

Key Summary

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.

***More information**: Edwards M, Richardson AJ. 2004. Impact of climate change on marine pelagic phenology and trophic mismatch. Nature, 430:881-884*



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 1958–2005 in the central North Sea (i.e the peak in seasonal appearance). It is clear 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). 2005 continued with this trend with the early seasonal appearances of decapod larvae.

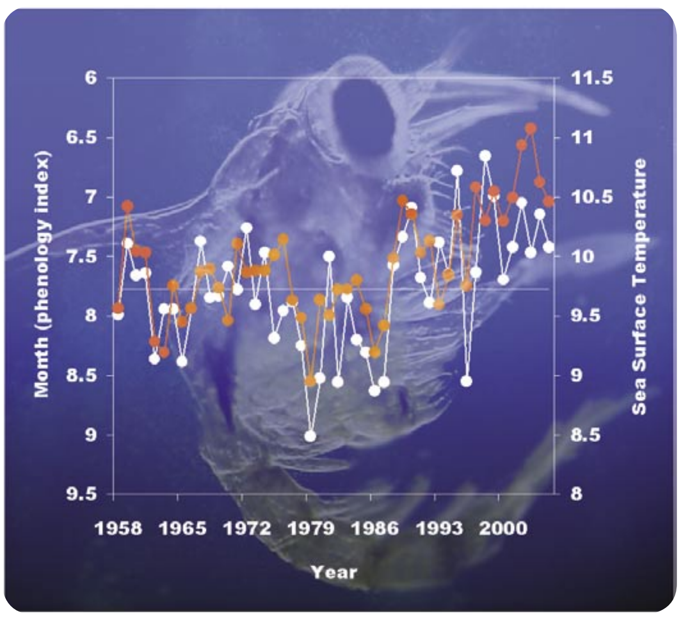


Fig. 5. Inter-annual variability in the peak seasonal development of decapod larvae (an indicator of plankton phenology) in the North Sea and its relationship with sea surface temperature. Warmer temperatures = earlier seasonal appearance, colder temperatures = late seasonal appearance.

Indicators of water quality

Key summary

Water Quality

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.

***More information**: Edwards, M., Johns, D.G., Leterme, S.C., Svendsen, E. & Richardson, A.J. 2006. Regional climate change and harmful algal blooms in the northeast Atlantic. Limnol. Oceangr., 51: 820-829. Thompson, R.C., Olsen, Y., Mitchell, R.P., Davies, A., Rowland, S.J., John, A.W.G. 2004. Lost at sea: where is all the plastic? Science, 308:834*

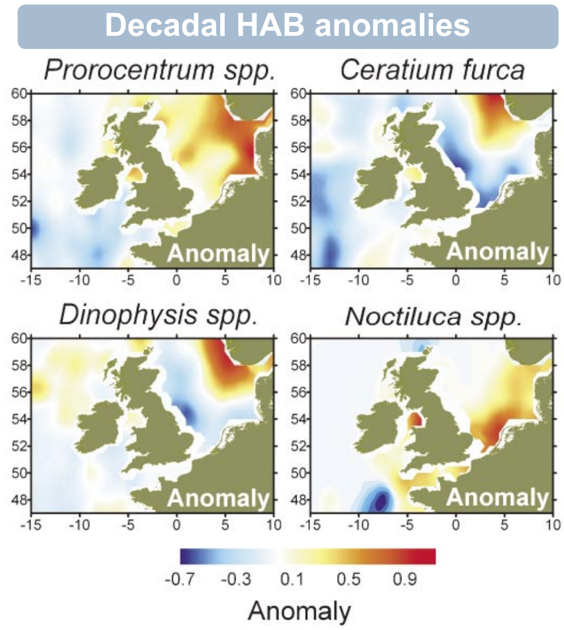


Fig. 7. Decadal anomaly maps of four common HAB taxa. Anomaly is the difference between the long-term mean (1960-1989) and post 1990s (1990 - 2002).

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 peak in April in the North Sea), by far the most common bloom forming taxon recorded by the CPR survey in 2005 was *Coccolithaceae* and silicoflagellates. The first species to reach bloom proportions in the North Atlantic was *C. 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 large blooms of *Coccolithaceae* occurred throughout June-August, particularly in the waters west of the British Isles. Large blooms were also recorded in the English Channel, off the coast of Portugal, Georges Bank, the Scotian shelf and the Celtic Sea. Number of blooms of the genus *Ceratium* were unusually low in the North Sea in 2005. *Ceratium furca* recorded its lowest ever abundance in 2005 for the last 50 years.

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 exceptional blooms of four common HAB taxa in European waters. The term 'exceptional blooms' refers to phytoplankton blooms greater than four standard deviations above the species recorded baseline mean (baseline mean: 1980-2005). It is evident from the figure that these HAB taxa are 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. A distinguishing feature of 2005 in terms of HABs was the larger frequency of *Prorocentrum* spp. blooms off the coast of Denmark compared to the long-term mean.

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.

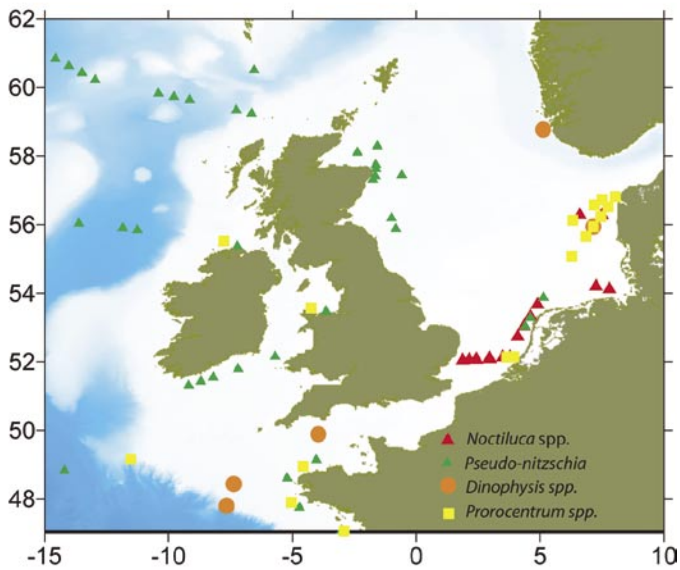
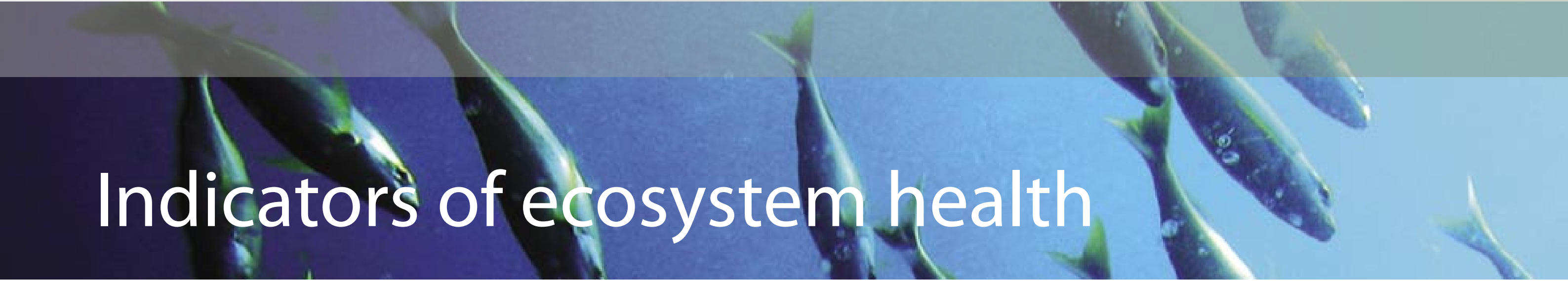


Fig. 6. Spatial distribution of 4 HAB taxa in Northern European waters during 2005. Only occurrences of the taxa above 4 standard deviations above its baseline mean (1960-2005) are shown, i.e. exceptional blooms.



Indicators of ecosystem health

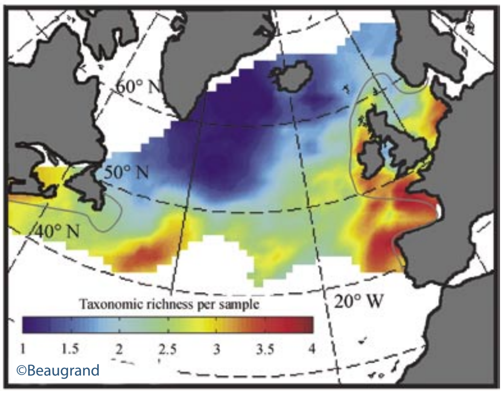
Key summary

Ecosystem health

From our knowledge of copepods (zooplankton) we believe the overall pelagic biodiversity* of the North Sea is increasing. This trend is related to regional climate warming leading to perhaps a more diverse environment. However, in terms of a 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 fish stocks. 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: *Beaugrand G, Ibanez F, Lindley JA, Reid PC. 2002. Diversity of calanoid copepods in the North Atlantic and adjacent seas: species associations and biogeography. Marine Ecology-Progress Series, 232:179-195*
Edwards M, Beaugrand G, Reid PC, Rowden AA, Jones MB. 2002. Ocean climate anomalies and the ecology of the North Sea. Marine Ecology-Progress Series, 239:1-10

Biodiversity in the North Atlantic



Biodiversity and community stability

Figure 8 shows a 50 species meta-analysis of the plankton community in the central North Sea from 1958-2005. 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 2005 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 2005 and the preceeding years, the major community shifts occur in 1988 and 2000. The 1960s

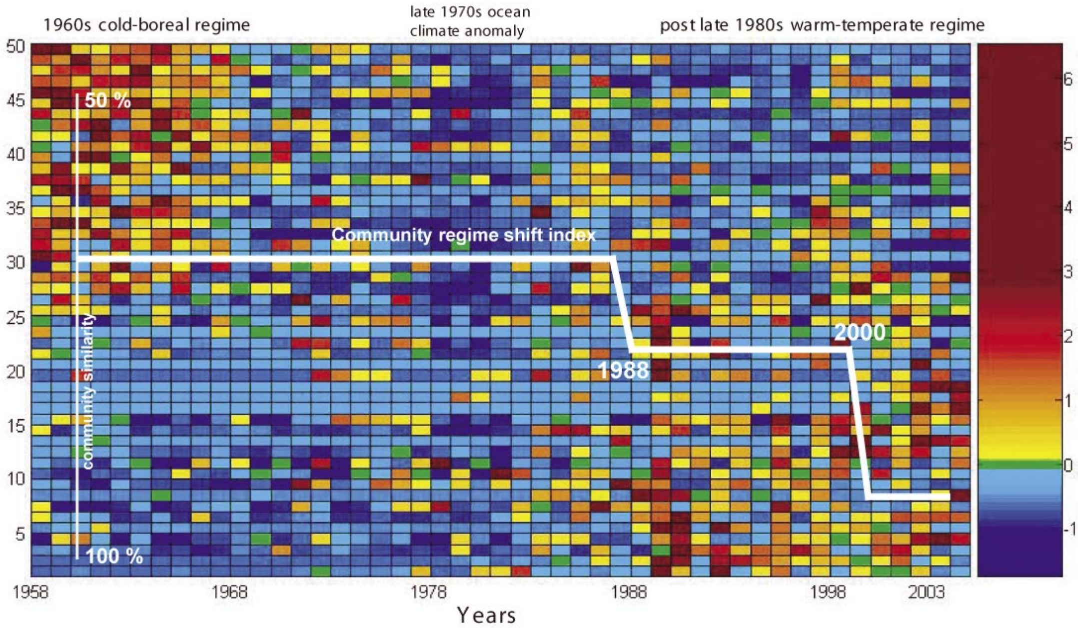
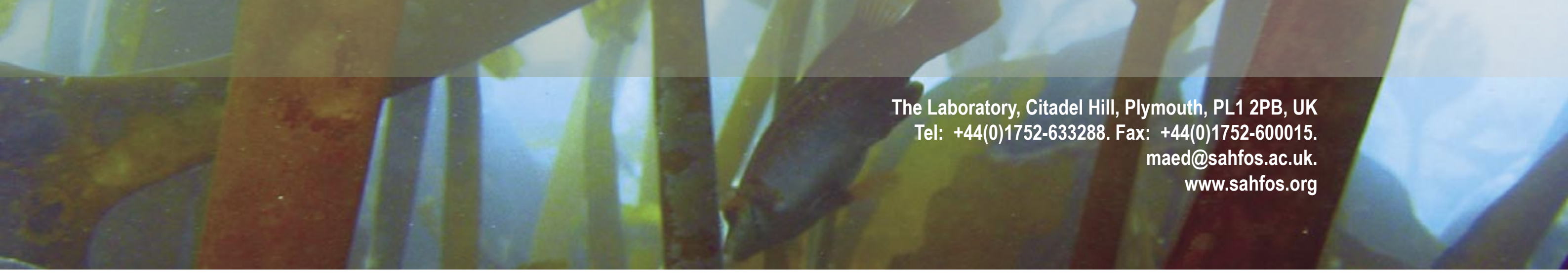


Fig. 8. 50 species meta analysis of plankton in the central North Sea ordered by first principal component (standardised abundance). Community regime shift index calculated by the percent similarity between 2005 and preceeding years (2005 =100 % community similarity) using a displacement sequential regime detection (minimum regime shift = 10 years).



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community now differs from the 2005 community by 25%.

Unusual taxonomic records and exotic species

Unusual phytoplankton. The dinoflagellate *Prorocentrum rostratum* was abundant off Portugal in October and November (on the SB route); this taxon will be counted in routine analysis from January 2007. The sub-tropical dinoflagellate *Ceratocorys horrida* was recorded unusually far north in the Bay of Biscay from September to November (on the SA route), the furthest north being 46°01'N. *Ceratium limulus*, which is rare in CPR records, was recorded in November (on 538 SB).

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 anomalous hydro-climatic event (lasting only a few years) whereas the late 1980s shift has been classed as a regime shift proper. Regime shift detection software has also identified another regime shift in 2000 based on plankton community structure.

Zooplankton. 'Arachnactis' larvae (Anthozoa: Ceriantharia), which are larvae of anemone-like Anthozoa, occurred in October on a number of samples west of the Rockall Plateau (on 361 DA). According to the Plymouth Marine Fauna (1957), these larvae are common in Plymouth Sound and outside in spring and summer. The cladoceran *Penilia avirostris* was once again very abundant in the southern North Sea and the German Bight from August to October (on the HE, LG and R routes). On the September LG tow it was abundant along the entire tow from the Dutch coast to the Skagerrak. Unusual numbers of the benthopelagic isopod *Eurydice truncata* were recorded in September 2006 on samples SW of the Isles of Scilly (on both the 426 BA and 239 IB routes). This sand-burrowing isopod migrates from the benthos up to the neuston layer during the night to feed on neustonic animals.

Diaixis hibernica, a hyperbenthic calanoid copepod rarely found in the plankton, was recorded north of Aberdeen in November 2006 (on 695 A). This is only the third record in the survey. However, this species is recorded regularly in near-bottom townettings from the same area (J. Fraser, pers comm). A Poecilostomatoid copepod, a male *Giardella thompsoni*, was found in March off the Dutch coast (on 243 HE); this species is associated with callianassid decapods (burrowing mud-shrimps). Doliolids, which are normally rare in the southern North Sea, were recorded in Sepember and October on the LG and HE routes, with high numbers on some samples. Several brachiopod larvae were recorded, in May southwest of Georges Bank (on 312 EB) and in December off the Dutch coast (on 272 LG). These are rarely observed in CPR samples. Holothurian 'wheel ossicles', which are found on the auricularia larvae of Holothuria, were recorded on a number of samples taken southwest of Britain in May (e.g. on 424 BA). These have occurred in previous years, usually in April or May and in oceanic waters west and southwest of Britain.

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).