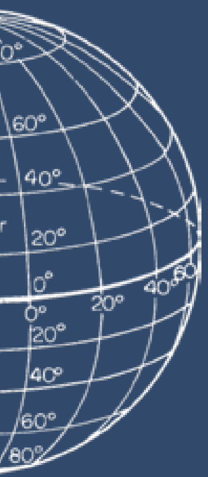
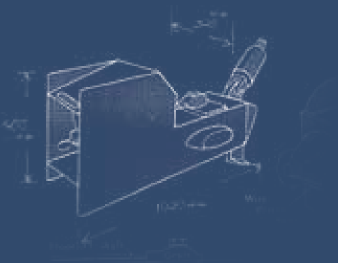


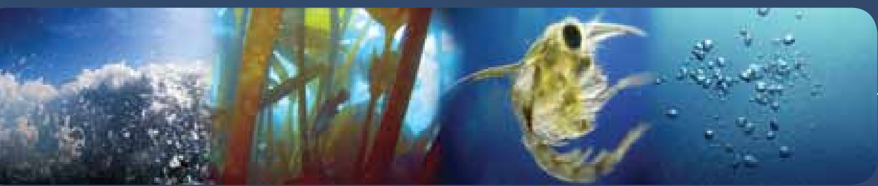
Ecological Status Report

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

2009



Monitoring the health of the oceans since 1931

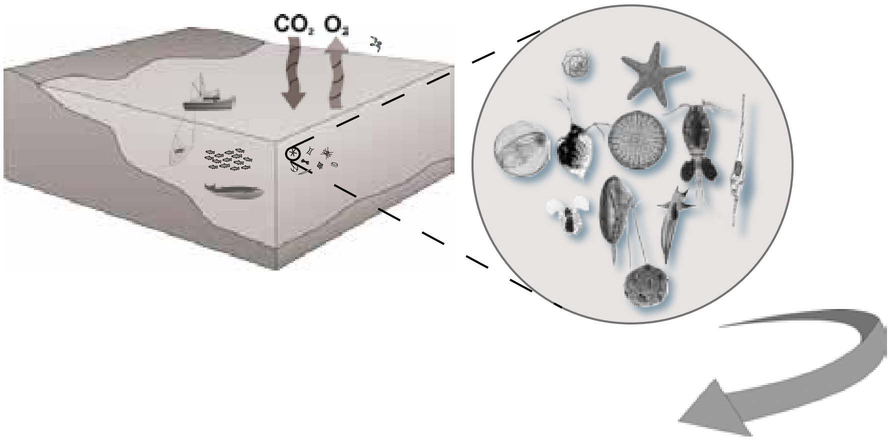


Citation: Edwards, M., Beaugrand, G., Johns, D.G., Licandro, P., McQuatters-Gollop, A. & Wootton, M. 2010. Ecological Status Report: results from the CPR survey 2009. *SAHFOS Technical Report*, 7: 1-8. Plymouth, U.K. ISSN 1744-0750

Plankton as indicators of the health of the oceans

At the base of the marine foodweb, the free floating plant life of the sea (phytoplankton) provide 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 CO_2 to the deep ocean by carbon sequestration in what is known as the 'biological pump'. Without this process concentrations of CO_2 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 foodwebs, 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.

Status report summary

Marine climate change impacts: Northward shifts

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 which may negatively impact 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.

Marine climate change impacts: Changes in seasonality and phenology

Seasonal timing, or 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 cycles by 4-5 weeks. However, not all trophic levels are responding to the same extent; 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.

Marine biodiversity and invasive species

Oceanic plankton biodiversity is increasing in the North Atlantic associated with temperature increases. There is a strong relationship between biodiversity and size-structure in pelagic communities. Increasing biodiversity is associated with a decreasing size-structure of the community. This in turn may have implications for marine ecosystem services such as smaller-sized fish communities and reduced carbon drawdown.

Marine ecosystem health and water quality

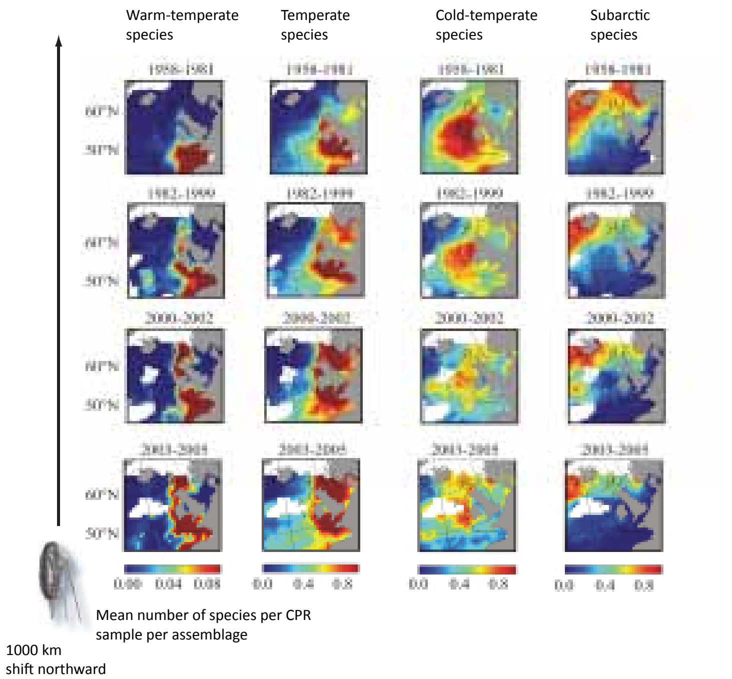
At the regional scale, it has been found that most phytoplankton trends are related to hydro-climatic variability as opposed to anthropogenic input (e.g. nutrient input leading to eutrophication). This means that the North-East Atlantic as a whole is generally considered to be fairly healthy. This is 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 regions. It has also been found that the number of microplastics collected on CPR samples is increasing and the frequency of occurrence and bloom timing of some Harmful Algal Bloom species are related to regional climate warming.

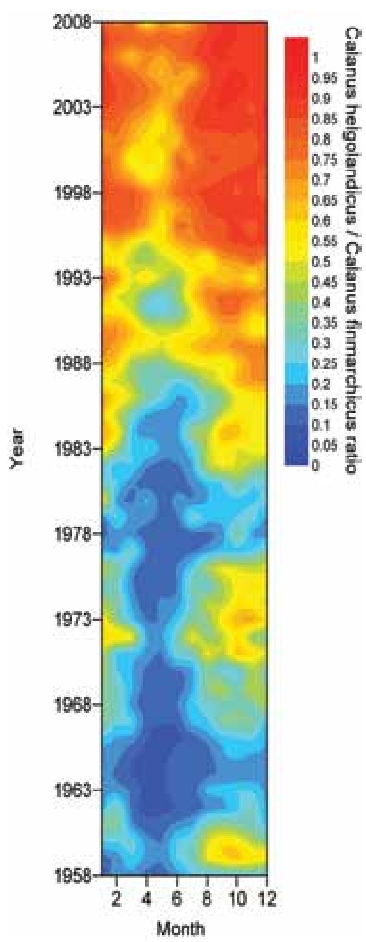
Ocean acidification

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

Marine climate change impacts

Northward shift indicators





Top: Biogeographical changes in plankton assemblages spanning five decades. Warm-water plankton (e.g. warm-temperate species) are moving north and cold-water plankton (e.g. subarctic species) are moving out of the North Sea. Based on *Science (2002) 296: 1692-1694.*

Bottom: A simple ratio between a warm-water copepod species (*Calanus helgolandicus*) and a cold-water species (*Calanus finmarchicus*) per month from 1958-2008. 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)

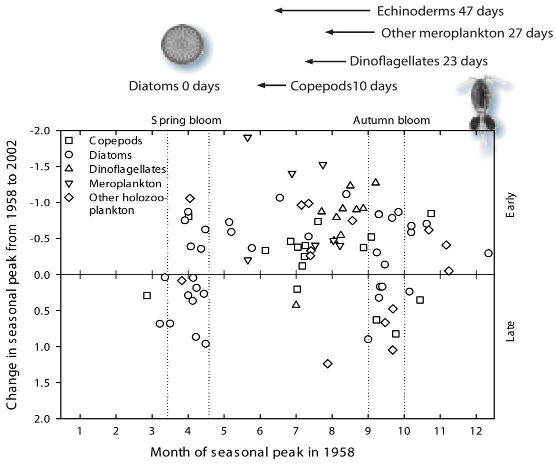
Northward shifts

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 to the north and west (see figure left).

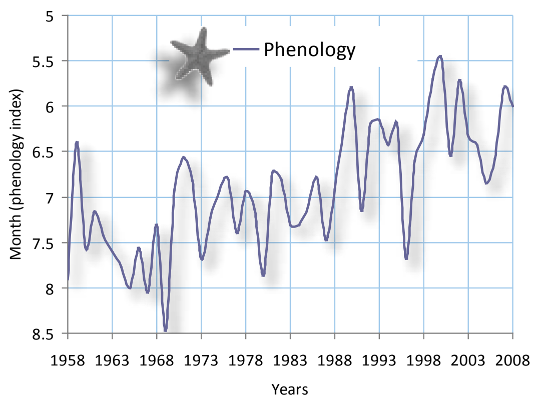
A useful indicator of the warming trend in the North Sea (a northward shift indicator) is the percent ratio of the cold-temperate *Calanus finmarchicus* and the warm-temperate *Calanus helgolandicus* copepod species. Although these species are very similar they do occupy distinct thermal niches. The thermal boundary for the arctic-boreal distributed copepod *Calanus finmarchicus* in the North-East Atlantic lies between the ~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.

The percentage ratio between *C. helgolandicus* and *C. finmarchicus in* 2008 was again dominated by *C. helgolandicus*, a trend that has evidently been accelerating over the last decade. While *C. helgolandicus* is becoming more abundant in the North Sea the overall *Calanus* biomass has declined by 70% since the 1960s. This huge reduction in biomass has had important consequences for other marine wildlife in the North Sea including fish larvae.

Phenology indicators



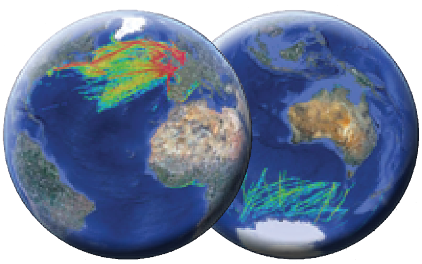
The change in the timing of the seasonal peaks (in months) for 66 plankton taxa over the 45-year period from 1958 to 2002 plotted against the timing of their seasonal peak in 1958. Based on *Nature (2004) 430: 881-884*.



Inter-annual variability in the peak seasonal development of echinoderm larvae (an indicator of plankton phenology) in the North Sea showing a movement from a July peak to presently a June peak. Warmer temperatures = earlier seasonal appearance, colder temperatures = late seasonal appearance.

Phenology

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 indicator of phenological changes in shelf sea environments. The figure above shows the annual peak seasonal abundance 'centre of gravity index' of echinoderm larvae from 1958–2008 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. Since 1988 in particular, with the exception of 1996 (a negative NAO year), the seasonal development of echinoderm larvae has occurred much earlier than the long-term average.



CPR samples in the Northern and Southern hemispheres. Courtesy of Google Earth.

For example, in the 1990s the seasonal cycle occurred up to 4-5 weeks earlier 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. This trend continued in 2008 with the early seasonal appearance of echinoderm larvae.

Summary for policy makers

Marine climate change impacts

Warmer-water species are currently increasing in the North Sea due to regional climate warming and the North Atlantic Oscillation (NAO). In terms of a productive environment this change is considered detrimental because the warmer-water species are not replacing the colder-water species in similar abundances which has negative impacts on other trophic levels including fish larvae.

Seasonal timing, or 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 to the same extent, therefore in terms of a productive environment, this change is 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*

Marine biodiversity and invasive species

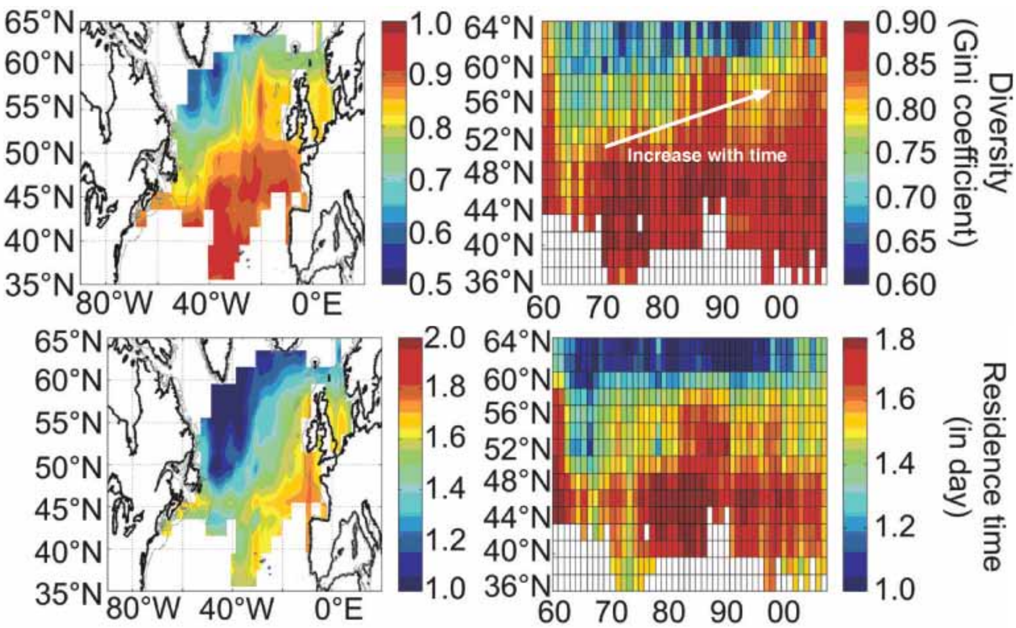
Multi-decadal trends in oceanic biodiversity

At the ocean basin scale biodiversity of pelagic zooplankton copepods is related to temperature and an increase in warming over the last few decades has been followed by an increase in diversity. There is also a direct link between diversity and the size-structure of the zooplankton community. The overall diversity patterns of pelagic organisms, peaking between 20° to 30° latitude north or south, follow temperature gradients in the world's oceans. Similarly, phytoplankton show a relationship between temperature and diversity which is linked to the phytoplankton community having a higher diversity but an overall smaller size-fraction and a more complex foodweb structure (i.e. microbial-based versus diatom-based production) in warmer, more stratified environments. The parallel decrease in size-structure of pelagic organisms with increasing diversity may have implications for marine ecosystem services such as smaller-sized fish communities and reduced carbon drawdown *(PNAS (2010) 107: 10120-10124)*.

Oceanic biodiversity and carbon

Total oceanic diversity (Gini diversity)

Long-term latitudinal changes in species diversity



Mean residence time of particulate carbon

Long-term latitudinal changes in carbon residence time

Relationships between the spatial distribution and long-term latitudinal changes in the diversity of calanoid copepods in the extratropical North Atlantic. Diversity was measured by first-order jackknife performed on the Gini coefficient. Left panel: mean spatial distributions (1960-2007) of copepod diversity and mean residence time above 50 m of sinking copepod particles (in days). Right panel: long-term latitudinal changes in copepod diversity and mean residence time above 50 m of sinking copepod particles. Based on *(PNAS (2010) 107: 10120-10124)*.

Invasive species

Because of its extensive geographical coverage and long time frame, data from the CPR have provided invaluable information on the spread of non-native plankton. For example, the invasive diatom *Coscinodiscus wailesii*, which has become a persistent and significant member of the plankton community, has spread from its first record off Plymouth in 1977 throughout all coastal waters of northern Europe and out into the Atlantic in a matter of only 30 years.

A recent review of non-native marine species around the British Isles that includes plankton and HAB species provides more detail on planktonic introductions. The discovery of the comb jelly *Mnemiopsis leidyi* in North Sea waters is of particular concern, even though it has not yet been recorded in the British Isles, because of the very marked impact it appears to have had on fisheries and the general ecosystem when it has appeared in other parts of the world.

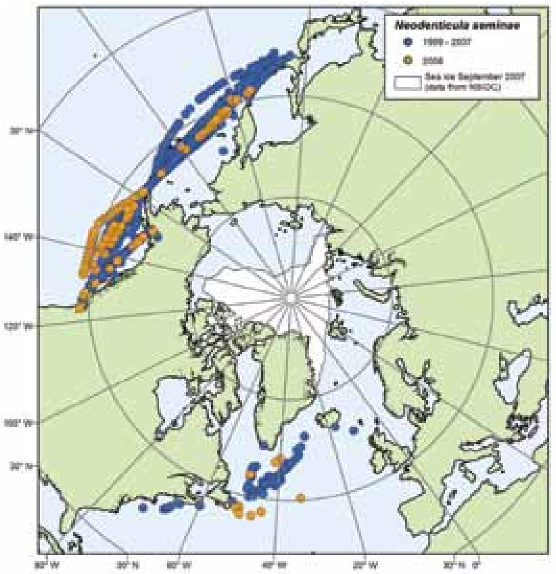
Climate warming will open up new thermally defined habitats for previously denied non-indigenous species (e.g. sub-tropical species in the North Sea) and invasive species allowing them to establish viable populations in areas that were once environmentally unsuitable. Apart from these thermal boundary limits moving progressively poleward and in some cases expanding, the rapid climate change observed in the Arctic may have even larger consequences for the establishment of invasive species and the biodiversity of the North Atlantic (see trans-Arctic migration).

Unusual biodiversity records

Ceratium is a common dinoflagellate phytoplankton taxa. Warm-water *Ceratium* were found unusually close to the UK. During March and September 2009 *C. arietinum, C. lamellicorne* and *C. pentagonum* were found 40-100 miles off the north-west coast of Scotland, the northern-most CPR records for these species ever to be found in the North East Atlantic. *C. hexacanthum* was also found on these samples; however throughout the second half of the year in 2008 this oceanic species appeared to be spreading its north-westerly distribution, with numerous records found in the North West Atlantic. Contrastingly, in 2009 there was only one record of *C. hexacanthum* found in this region, this was on a September route in the South West Labrador Sea. *C. hexacanthum* is relatively rare in the North West Atlantic and its presence may signify the movement of the Irminger current.

The tintinnid *Parafavella gigantea*, a vase-shaped ciliated protozoan, was recorded off the north-west coast of Brittany in July 2009. Usually this species is found much further north in the North East Atlantic and is thought to be an indicator of cold water masses. Larvae of the stalked barnacle *Lepas*, commonly known the goose barnacle, were observed in the northern North Sea in 2009 as well as approximately 100 miles to the northwest of Scotland. Typically having a more southerly distribution, only a handful of previous observations of *Lepas* have been made on CPR samples in this region.

Trans-Arctic migration



It has recently been highlighted that Arctic ice is reducing faster than previous modelled estimates. As a consequence 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, *Neodenticula seminae*, 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 are at present unknown.

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

Summary for policy makers

Marine biodiversity and invasive species

Oceanic plankton biodiversity is increasing in the North Atlantic associated with temperature increases. There is a strong relationship between biodiversity and size-structure in pelagic communities. Increasing biodiversity is associated with a decreasing size-structure of the community. This in turn may have implications for marine ecosystem services such as smaller-sized fish communities and reduced carbon drawdown.

The CPR survey has documented the first evidence of a trans-Arctic migration in modern times which may 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 are at present unknown.

More information: *PNAS (2010) 107: 10120-10124; Global Change Biology (2007)13: 1910-1921*

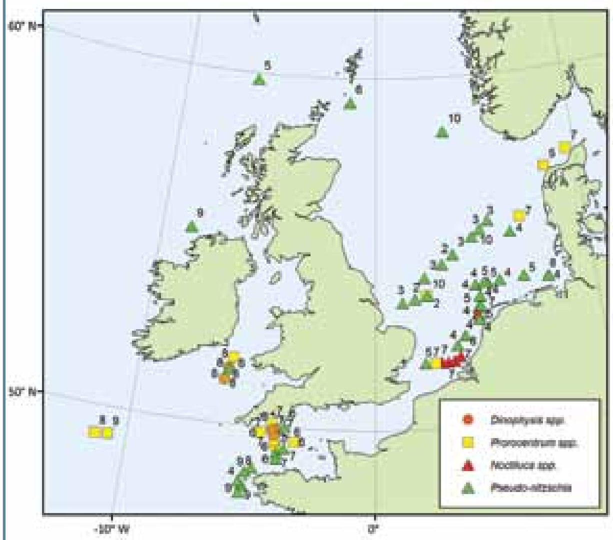
Marine ecosystem and environmental health

Eutrophication and HABs

There has been a considerable increase in phytoplankton biomass (Phytoplankton Colour Index) over the last decade in certain regions of the North-East Atlantic and North Sea, particularly over the winter months. Increased phytoplankton biomass may be an indicator of eutrophication; however, similar patterns of change have been found in both coastal and offshore waters. In the North Sea a significant increase in phytoplankton biomass has been found in both heavily anthropogenically-impacted coastal waters and the comparatively less-affected open North Sea despite significantly decreasing trends in nutrient concentrations. The increase in biomass appears to be linked to warmer temperatures and evidence that the waters are also becoming clearer (i.e. less turbid), thereby allowing the normally light-limited coastal phytoplankton to more effectively utilise lower concentrations of nutrients (*Limnology and Oceanography (2007) 52: 635–648*). These results may indicate that climatic variability and water transparency may be more important than nutrient concentrations to phytoplankton production in the North Sea. Despite the overriding influence of climate, elevated nutrient levels may be of concern in some localised areas around European seas.

In general, HABs are naturally occurring events although some exceptional blooms have been associated with eutrophication in coastal 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 as well as in the Irish Sea. Large HABs during 2008 occurred within the range of natural variability and were similar to the long-term average occurrences. However, the large blooms of *Pseudo-nitchia* spp. that occurred in the southern North Sea were particularly numerous in 2008 and were also exceptionally early (starting in February). 2008 also recorded exceptionally low *Dinophysis* spp. numbers particularly for the North Sea.

Harmful Algal Blooms

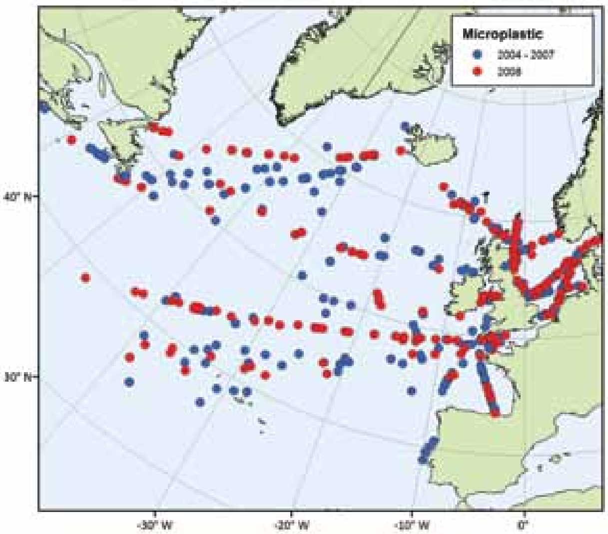


The geographical distribution of some exceptional HABs in 2008. Numbers indicate the month of the bloom.

Marine litter

From the presence of microplastics recorded on CPR samples it is clear that microplastics are widely distributed in the North-East Atlantic with their frequency increasing towards the coasts (particularly in the southern North Sea). From retrospective analysis of some CPR samples spanningcg three decades it appears that microplastics are increasing in frequency through time (*Science (2004) 308:834*). The incidence of monofilament netting snagged by the CPR towed body also seems to be increasing, particularly in the southern North Sea.

Microplastics



The geographical distribution of microplastics recorded on CPR samples in 2008 and between 2004-2007. While the distribution largely reflects CPR sampling frequency it does show that microplastics are widely distributed in the North Atlantic including the offshore oceanic environment.

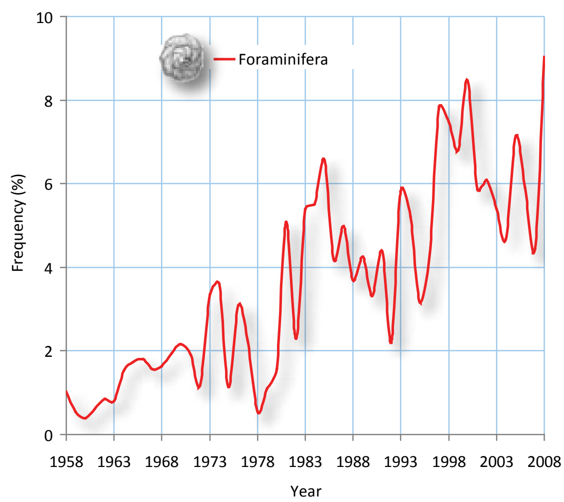
Ocean acidification

Changes in temperature have direct consequences on many physiological processes (e.g. oxygen metabolism, adult mortality, reproduction, respiration, reproductive development) and control virtually all life-processes from the molecular to the cellular and from the regional ecosystem level to biogeographical provinces. Temperature also modulates species interactions (e.g. competition, prey-predator interactions and foodweb structures) both directly and indirectly; ultimately, changes in temperatures caused by climate change can lead to impacts on the biodiversity, size structure, carrying capacity and functioning of the whole pelagic ecosystem. While temperature has direct consequences on many biological and ecological traits it also modifies the marine environment by influencing oceanic circulation and by enhancing the stability of the water column and hence nutrient availability. Under many climate change scenarios, oceanic primary production is predicted to decline due to nutrient limitation.

While temperature, light and nutrients are probably the most important physical variables structuring marine ecosystems, the pelagic realm will also have to contend with, apart from global climate warming, the impact of anthropogenic CO_2 directly influencing the pH of the oceans. Evidence collected and modelled to date indicates that rising CO_2 has led to chemical changes in the ocean which has led to the oceans becoming more acidic. Ocean acidification has the potential to affect the process of calcification and therefore certain planktonic organisms (e.g. coccolithophores, foraminifera, pelagic molluscs) may be particularly vulnerable to future CO_2 emissions. Apart from climate warming, potential chemical changes to the oceans and their effect on the biology of the oceans could further reduce the ocean's ability to absorb additional CO_2 from the atmosphere, which in turn could affect the rate and scale of climate warming.

Presently in the North Atlantic certain calcareous taxa are actually increasing in terms of abundance, a trend associated with climate shifts in the Northern Hemisphere temperature (see above figure of foraminifera frequency). However, there is some observed evidence from the Southern Ocean that modern shell weights of foraminifera have decreased compared with much older sediment core records with acidification being implicated *(Nature Geoscience (2009) doi:10.1038/ngeo460)*. It is not yet known how much of an effect acidification will have on the biology of the oceans in the 21st century, whether rapid climate warming will override the acidification problem, and whether or not species can buffer the effects of acidification through adaptation. The CPR survey is providing a critical baseline (both in space and time) and is currently monitoring these vulnerable organisms in case in the future these organisms begin to show negative effects due to acidification.

Ocean acidification



The percent frequency of foraminifera recorded on CPR samples

Summary for policy makers

Marine 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 North-East Atlantic as a whole is generally not considered to be eutrophic. 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 regions.

It has also been found that the number of microplastics collected on CPR samples is increasing and the frequency of occurrence. Bloom timing of some Harmful Algal Bloom species are related to regional climate warming.

The plankton community is continuing to evolve in time with large changes (regime shifts) occurring in the late 1980s and in 2000 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 (2007) 51: 820-829; Science (2004) 308:834*

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