Marine Ecological Status Report

The ecological status of the marine pelagic environment based on observations from the global Continuous Plankton Recorder survey

Monitoring the health of the oceans since 1931

2010

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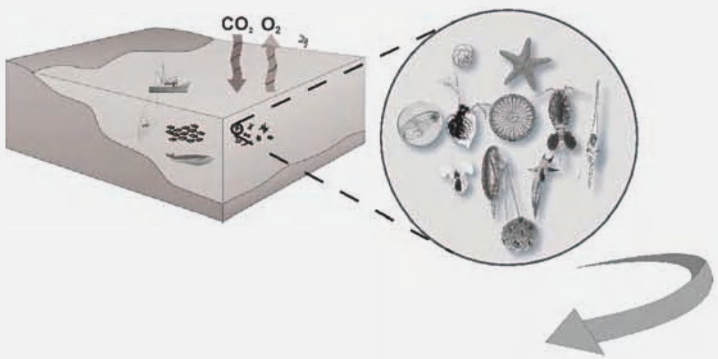
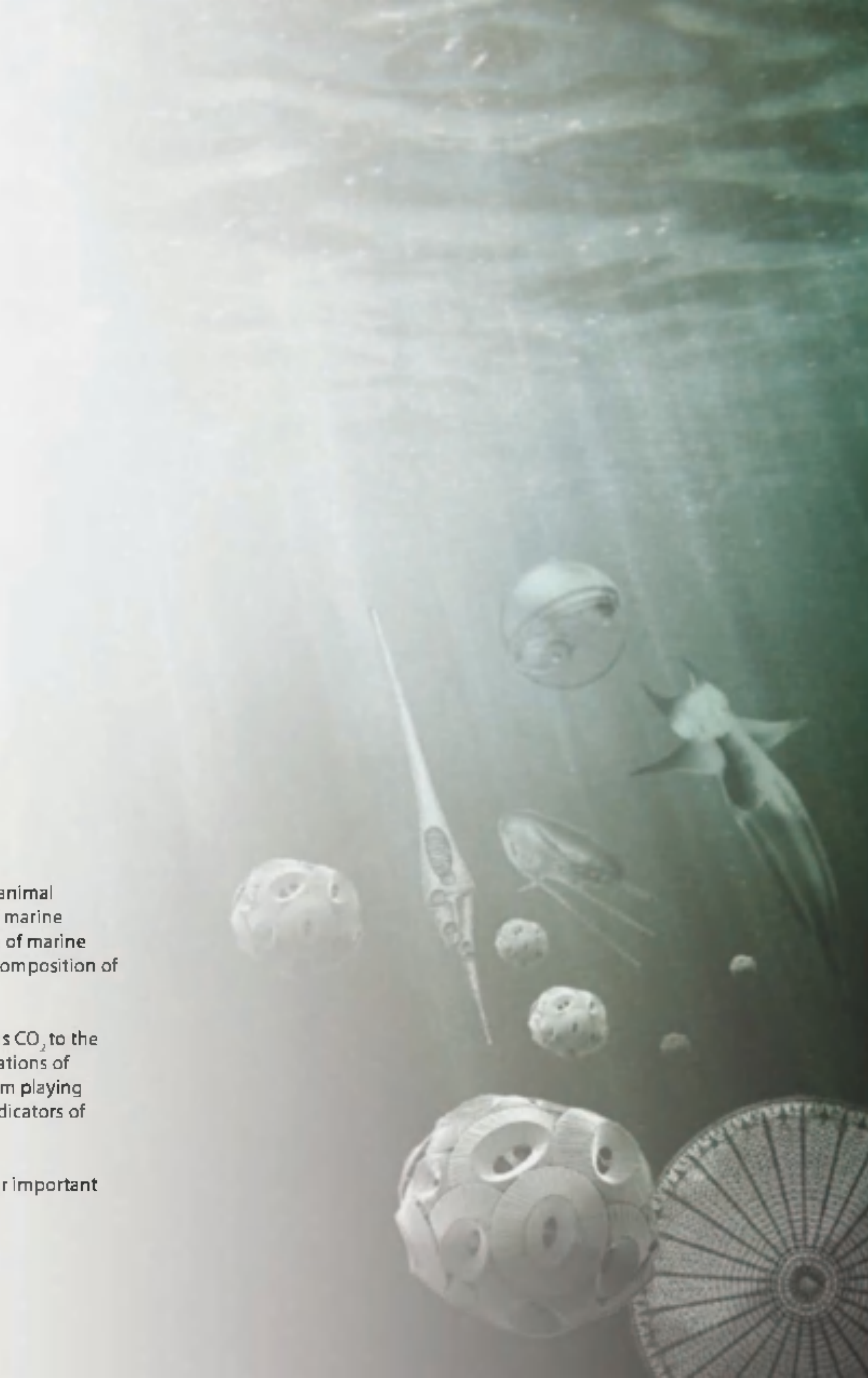


Plankton as indicators of the health of the oceans

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 marine environment and provides information for important marine management issues such as climate warming impacts, biodiversity, pollution and fisheries.



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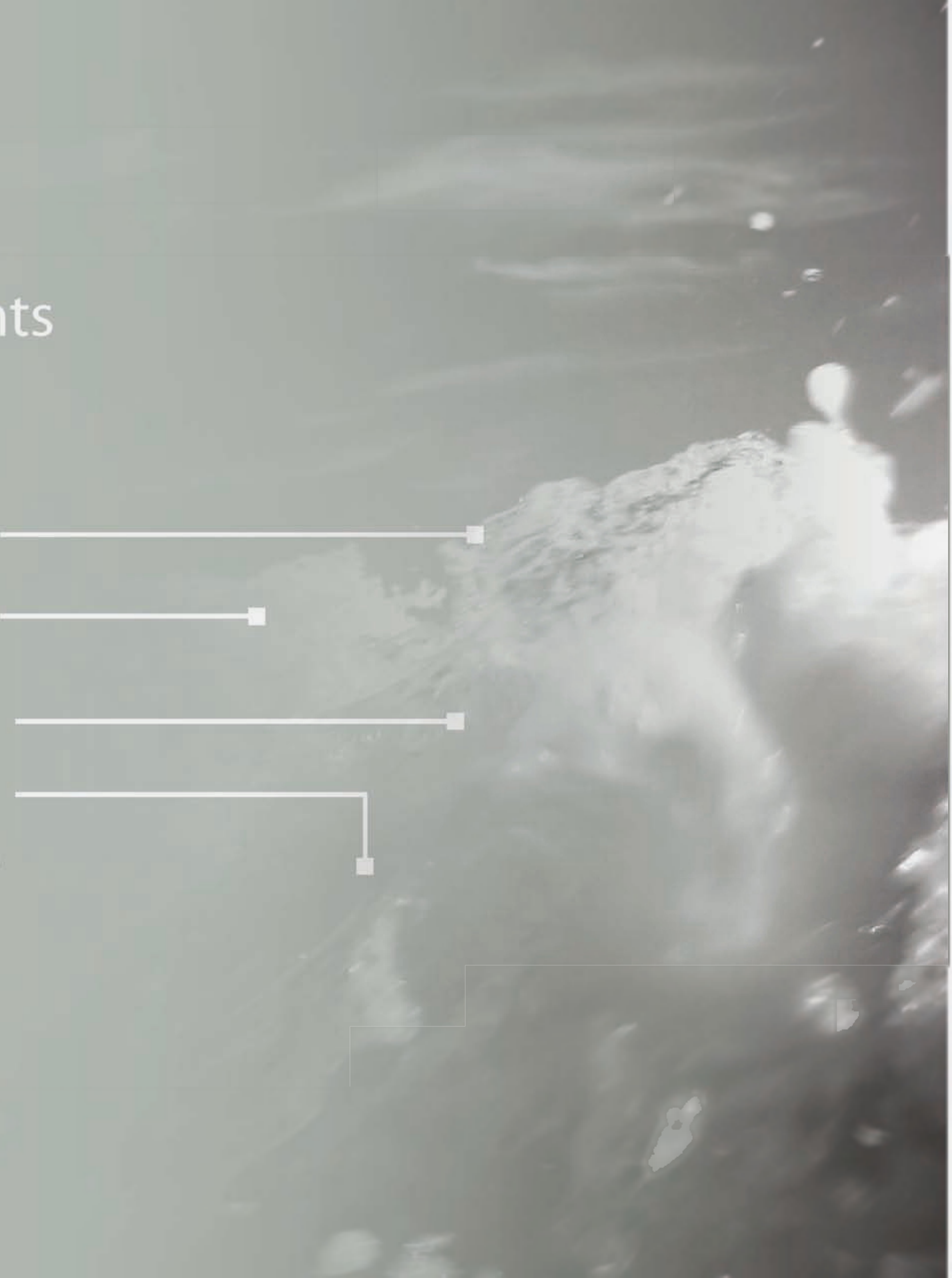
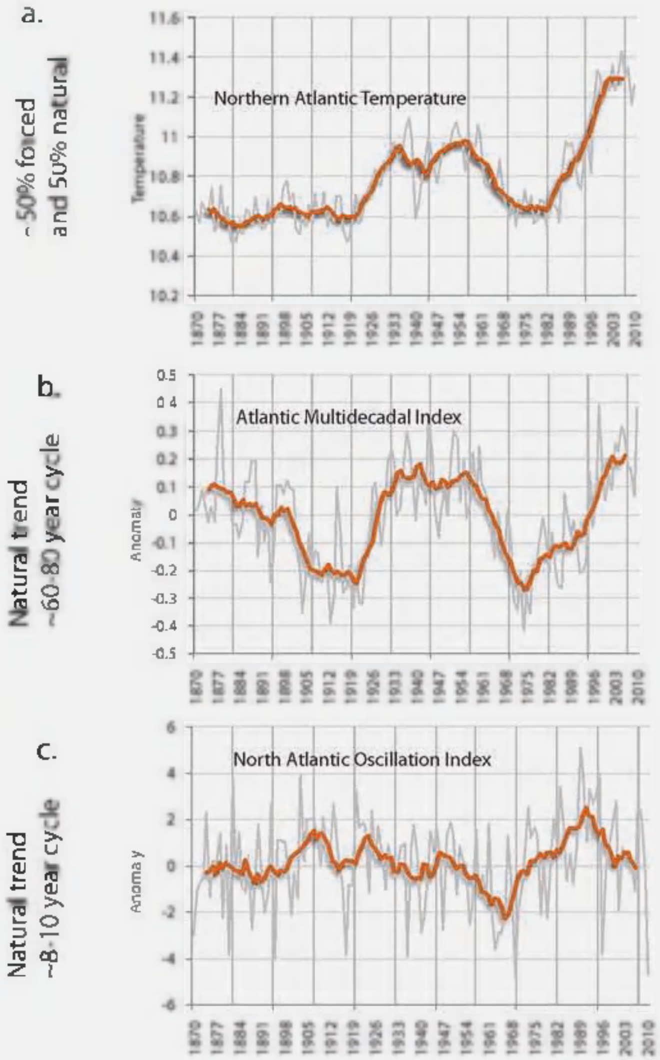


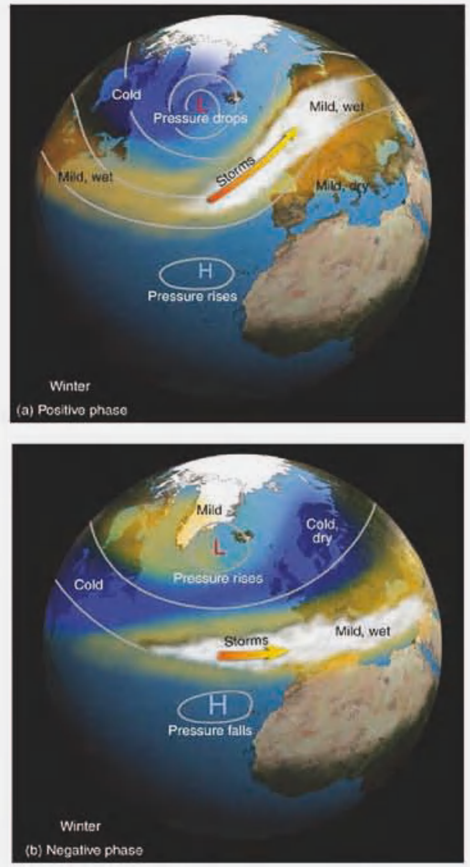
Hydro-climatic indices

Atlantic climate change

Over the last few decades the North Atlantic Temperature has continued to show a strong increase similar to the pattern found in Northern Hemisphere temperatures. The temperature increase is currently mainly associated with increasing CO_2 input into the atmosphere from anthropogenic sources (classed here as external climate change). The last few years, however, have seen a slight decline in temperature compared to the early and mid 2000s. Apart from external climate warming there are a number of natural (classed here as internal climate change) oscillations in Atlantic climate the most important being the Atlantic Multidecadal Index (AMO) and the North Atlantic Oscillation (NAO). The AMO is a natural low-frequency temperature oscillation occurring approximately every 60 years and is usually constructed by removing the linear trend in North Atlantic Sea Surface Temperature. The AMO accounts for approximately a change in SST of 0.4 °C from a low to a high AMO point in its cycle. The NAO is responsible, particularly during the winter months, for much of the variability of weather in the North Atlantic region, affecting wind speed and prevailing direction, changes in SST and moisture distribution and the intensity, number and track of storms. During the last two years the NAO has been uncharacteristically in a very low negative phase contributing to the very cold winters experienced in Northern Europe during 2009/2010 and 2010/2011. Overall, natural climate variability in the North Atlantic can account for approximately half of the temperature change experienced in the North Atlantic over the last 50 years. All these climate indices have been implicated in the changing ecology of the North Atlantic over the last 50 years including rapid biogeographical and phenological shifts in the plankton as well as whole ecosystem shifts.

(a) The North Atlantic Ocean corresponds to an area from Longitude 99.5°W to 19.5°E and Latitude 29.5°N and 69.5°N. Sea surface temperature data were obtained from the Met Office Hadley Centre (http://www.metoffice.gov.uk/). (b) The Atlantic Multidecadal Oscillation index was obtained from the Physical Sciences Division of the National Oceanic and Atmospheric Administration (NOAA; http://www.esrl.noaa.gov). The values are calculated from the Kaplan SST dataset (5° grid). (c) The winter index of the NAO comes from The Climate & Global Dynamics Division (CGD) of the NCAR Earth Systems Laboratory (NESL) (http://www.cgd.ucar.edu/). This index is based on the difference of normalized sea level pressures (SLP) between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland since 1950 for the months of December, January, February and March (DJFM).

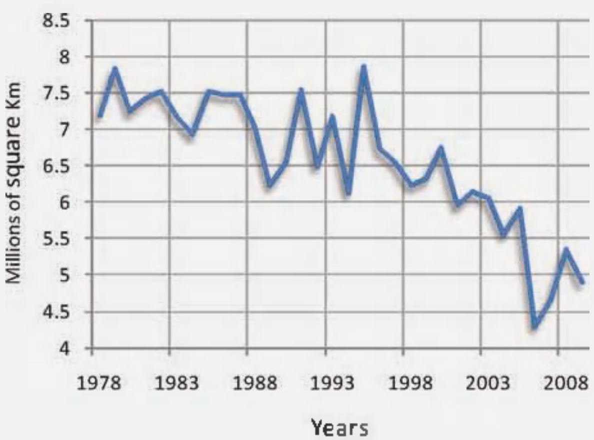




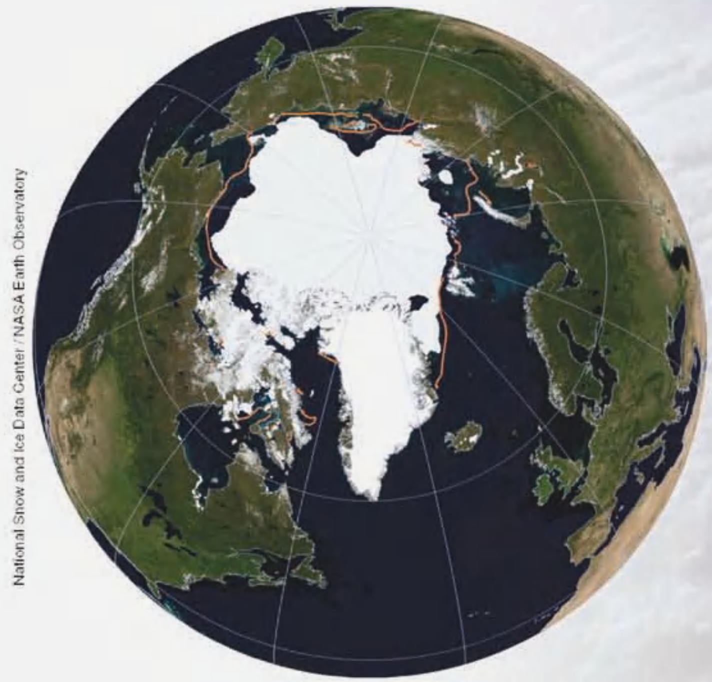
A low-pressure system over Iceland (the Icelandic Low) and the high-pressure system over the Azores (the Azores High) control the direction and strength of westerly winds into Europe particularly during the winter. The relative strengths and positions of these systems vary from year to year and this variation is known as the NAO. A large difference in the pressure at the two positions (positive phase) leads to increased westerlies and mild and wet winters in Northern Europe and its Atlantic facade. A negative phase by contrast, make westerlies track further south and cold high pressure dominate in Northern Europe. From Thomson 2007.

Arctic Sea - Ice cover

The thickness and areal coverage of summer ice in the Arctic have been decreasing at an increasingly rapid rate over the last two decades, to reach the lowest recorded extent in September 2007 (in respect to 1978-2010). In the spring following the unusually large ice free period in 1998 large numbers of a Pacific diatom *Neodenticula seminae* were found in samples taken by the CPR survey in the Labrador Sea in the North Atlantic. *N. seminae* is an abundant member of the phytoplankton in the subpolar North Pacific and has a well defined palaeo history based on deep sea cores. According to the palaeo evidence and modern surface sampling in the North Atlantic since 1948 this was the first record of this species in the North Atlantic for at least 800,000 years. The reappearance of *N. seminae* in the North Atlantic, and its subsequent spread southwards and eastwards to other areas in the North Atlantic, after such a long gap, could be an indicator of the scale and speed of changes that are taking place in the Arctic and North Atlantic oceans as a consequence of climate warming. The diatom species itself could be the first evidence of a trans-Arctic migration in modern times and be a harbinger of a potential inundation of new organisms into the North Atlantic. The consequences of such a change to the function, climatic feedbacks and biodiversity of Arctic systems are at present unknown (see section on invasive species for more information).



Monthly August ice extent for 1979 to 2010. The extent has declined at a rate of 8.9% per decade. Source: National Snow and Ice Data Center.



Ice extent for summer 2010

Sea ice extent for summer 2010. Orange line is the median from 1979-2000. Source: National Snow and Ice Data Center.

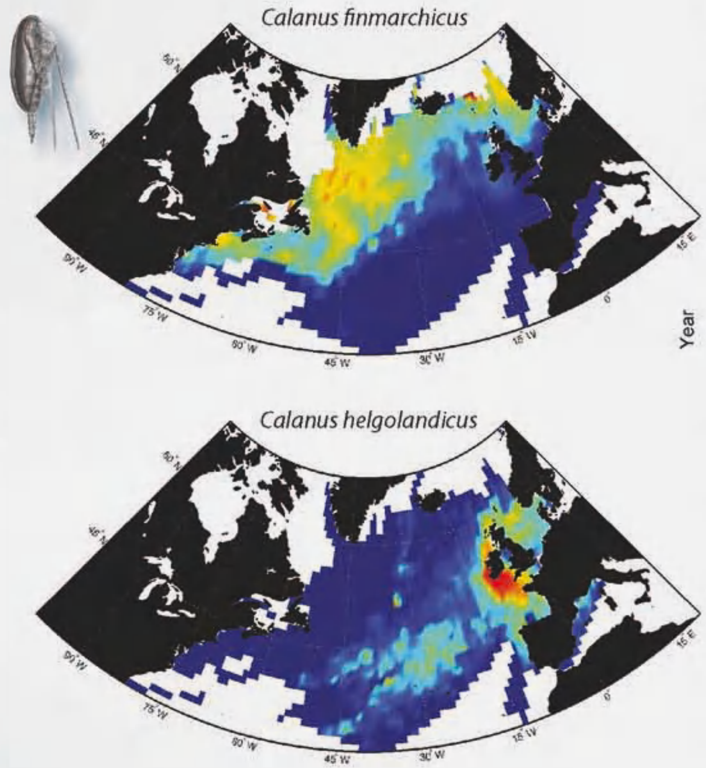
Marine climate change impacts

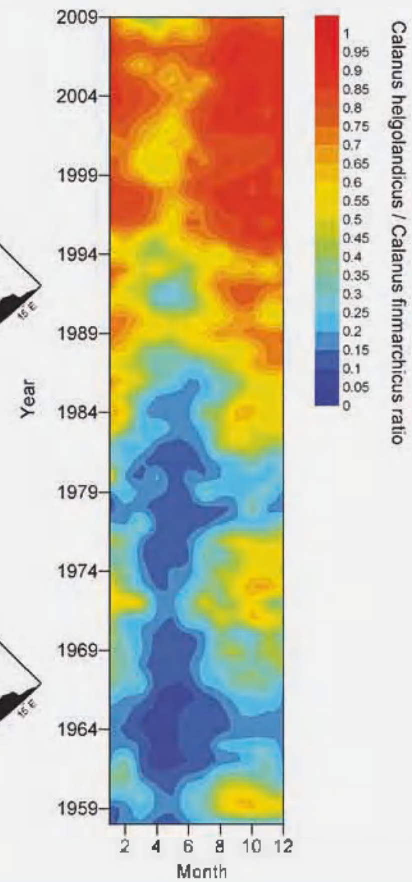
Biogeographic shifts

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.

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 ~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* 2009 was for the first time in twenty years dominated by *C. finmarchicus* in spring. This was a reflection of the particularly cold winter experienced in Northern Europe caused by a very low winter NAO index. 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.

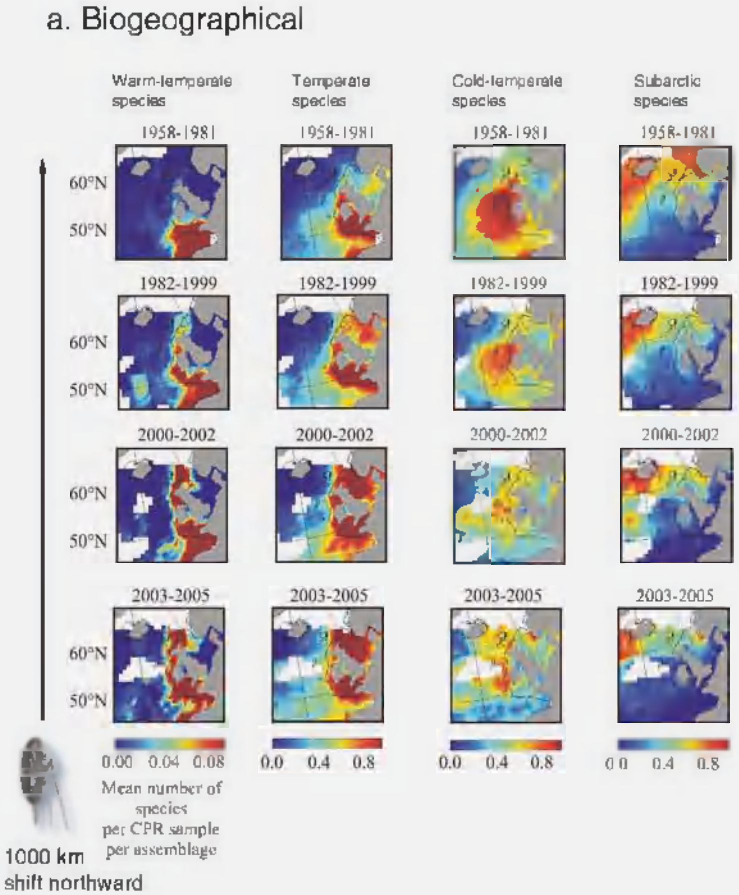




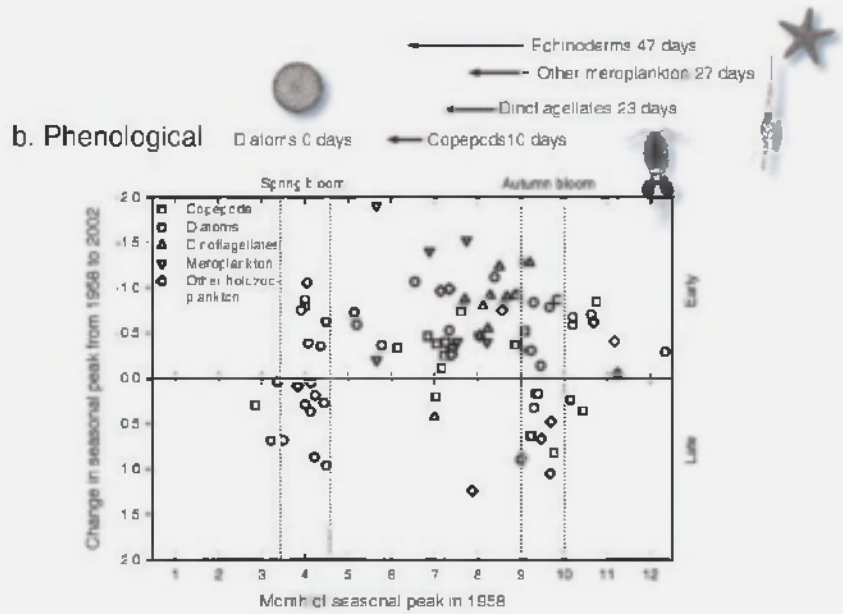
A simple ratio between a warm-water species (*Calanus helgolandicus*) and a cold-water species (*Calanus finmarchicus*) per month from 1958-2009. Red values indicate a dominance of the warm-water species and blue values the dominance of the cold-water species. (0= total *C. finmarchicus* dominance, 1=total *C. helgolandicus* dominance)

Phenology

Phenology - the study of natural phenomena that recur periodically, as migration or blossoming, and of their relation to climate and changes in season. 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. In particular, the trend towards an earlier seasonal appearance of meroplanktonic larvae during the last decade is highly correlated with sea surface temperature. This trend continued in 2009 with the early seasonal appearance of meroplankton up to two weeks earlier.



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.

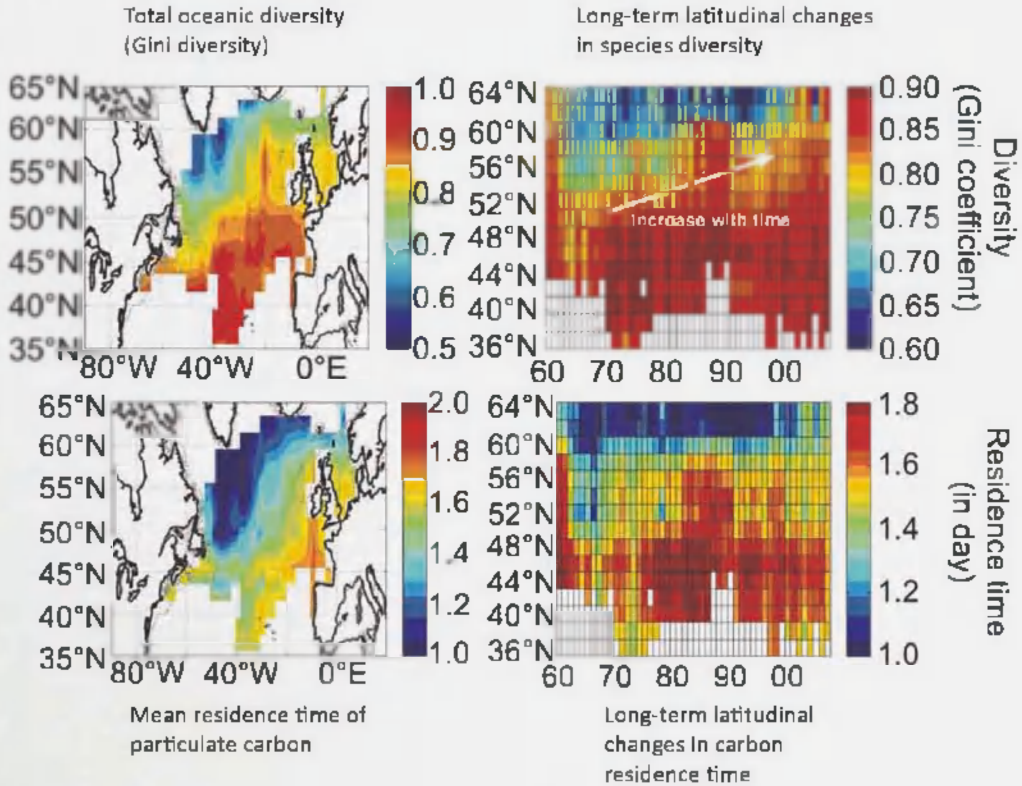


Phenological shifts: the change in the timing of the seasonal peaks (in months) for 66 plankton taxa over the 45-year period from 1958 to 2002 plotted against the timing of their seasonal peak in 1958. Based on *Nature (2004) 430: 881-884.*

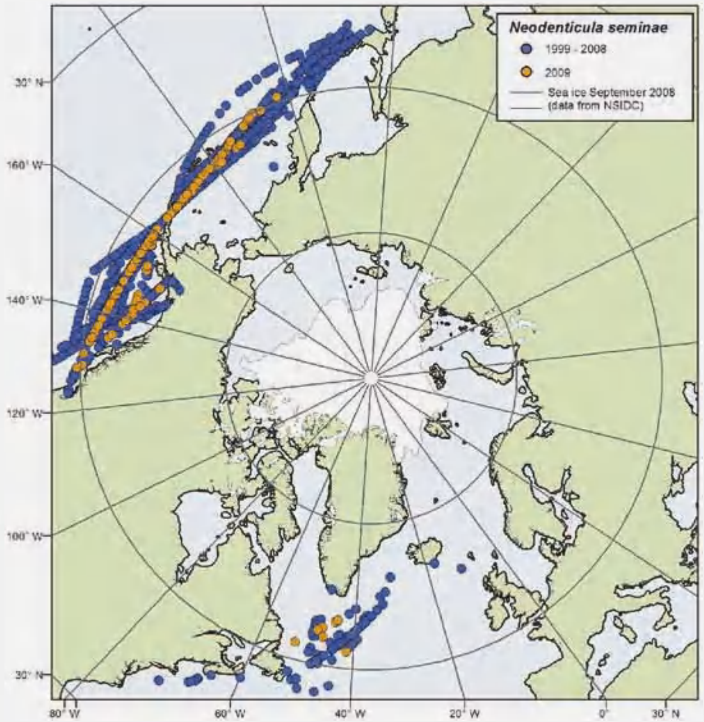
Marine biodiversity and invasive species

Multi-decadal trends in oceanic biodiversity

At the ocean basin scale studies on the pelagic biodiversity of zooplankton copepods are 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° 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*).



Relationships between the spatial distribution and long-term latitudinal changes in the diversity and a size-derived functional characteristic 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)*.



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*

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 left figure: trans-Arctic migration of *Neodenticular seminae*).

Unusual biodiversity records in 2009

Two rare species of calanoid copepods from the North Atlantic were found in 2010: last recorded in 1974, *Euchirella amoena* was found in July in the middle of the subtropical Atlantic and off the coast of New York; on the same coastal sample a *Scaphocalanus echinatus* was also identified. Although not unusual in their distribution these copepods are scarce in the CPR survey having only previously been recorded 3 and 19 times respectively. Similar in size to the aforesaid copepods, *Calanus finmarchicus* is contrastingly one of the most abundantly found copepods on North Atlantic CPR samples and is associated with the Atlantic polar biome. However, in March 2010 there were 2 occurrences of *C. finmarchicus* in oceanic subtropical waters. During the last 30 years *C. finmarchicus* has only been identified 8 times in this region and is typically replaced by its warmer-water sister species *C. helgolandicus*. *Calanus* species are important food items for higher marine animals including fish. *Pacillina arctica incertae sedis*, an organism of uncertain taxonomic placement, was recorded in July 2010 stretching some 80 miles along the coastline of New York. These are the most westerly sightings ever of this suspected ciliate cyst in the CPR survey.

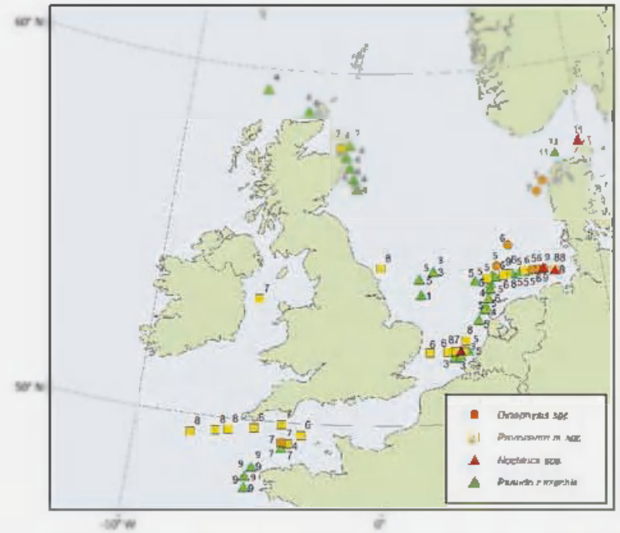
CPR samples in the Northern and Southern hemispheres. Courtesy of Google Earth.

Marine ecosystem and environmental health

Eutrophication and Harmful Algal Blooms (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.

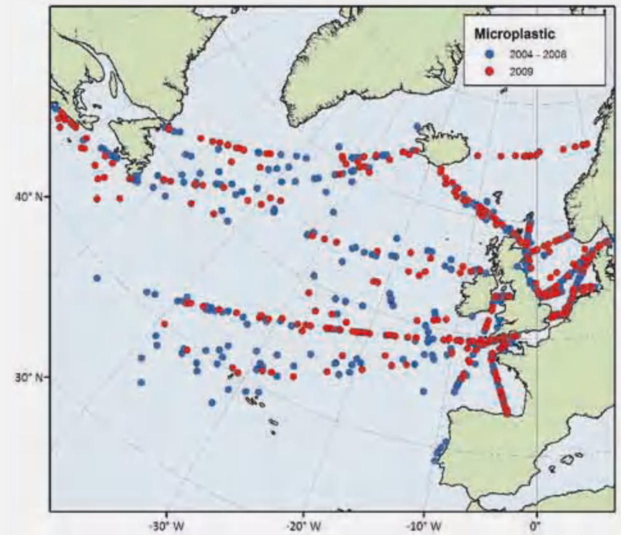
In general, HABs are naturally occurring events although some exceptional blooms have been associated with eutrophication in coastal waters. HAB taxa are generally most numerous along the Dutch coast and off the Danish coast. In particular the red-tide forming species *Noctiluca scintillans* naturally forms extensive blooms during the summer period in these areas as well as in the Irish Sea. Large HABs during 2009 occurred within the range of natural variability and were similar to the long-term average occurrences. However, the large blooms of *Pseudo-nitzschia* spp. that occurred in the southern North Sea were particularly numerous in 2009 and were also exceptionally early (Dogger Bank in January).



The geographical distribution of some exceptional HABs in 2009. Numbers indicate the month of the bloom.

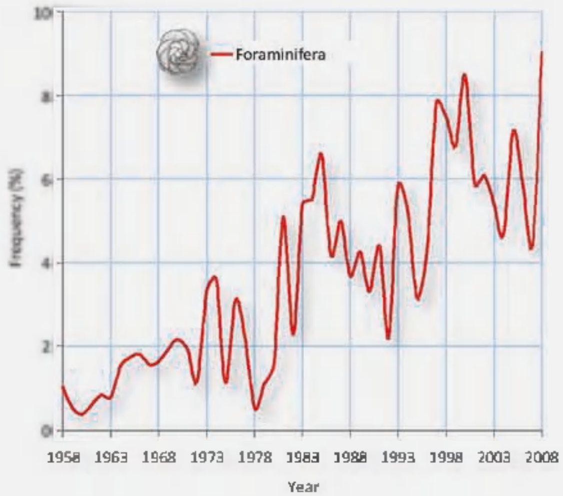
Marine microplastics

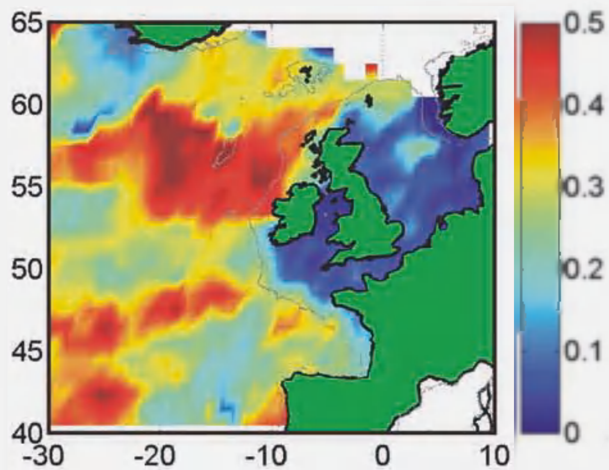
From the presence of microplastics that have been recorded on CPR samples it is clear that microplastics are widely distributed in the North-East Atlantic with the frequency of microplastics increasing towards the coasts (particularly in the southern North Sea). From retrospective analysis of some CPR samples spanning 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.



The geographical distribution of microplastics recorded on CPR samples in 2009 and between 2004-2008. 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





The percent frequency of foraminifera and its main distribution recorded on CPR samples in the NE Atlantic.

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.

Summary for policy makers

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 proving 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.

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