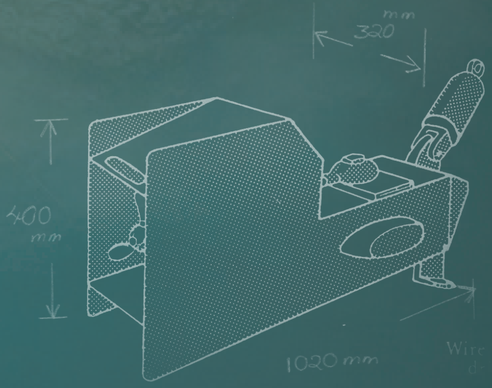
Ecological status report

2007/2008

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

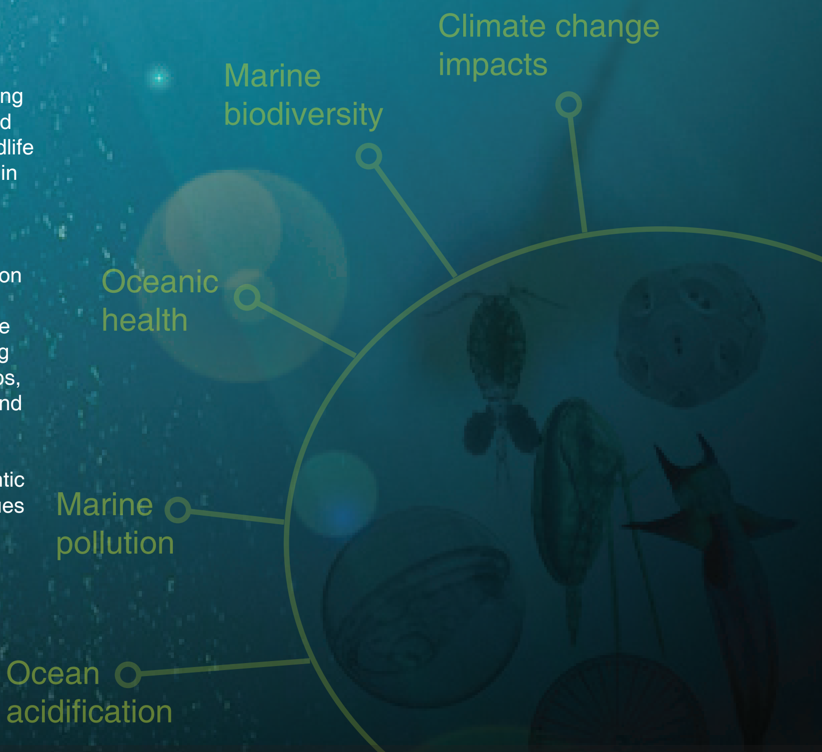


Plankton as indicators of the health of the oceans

At the base of the marine foodweb, the free floating plant life of the sea (phytoplankton) 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 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.



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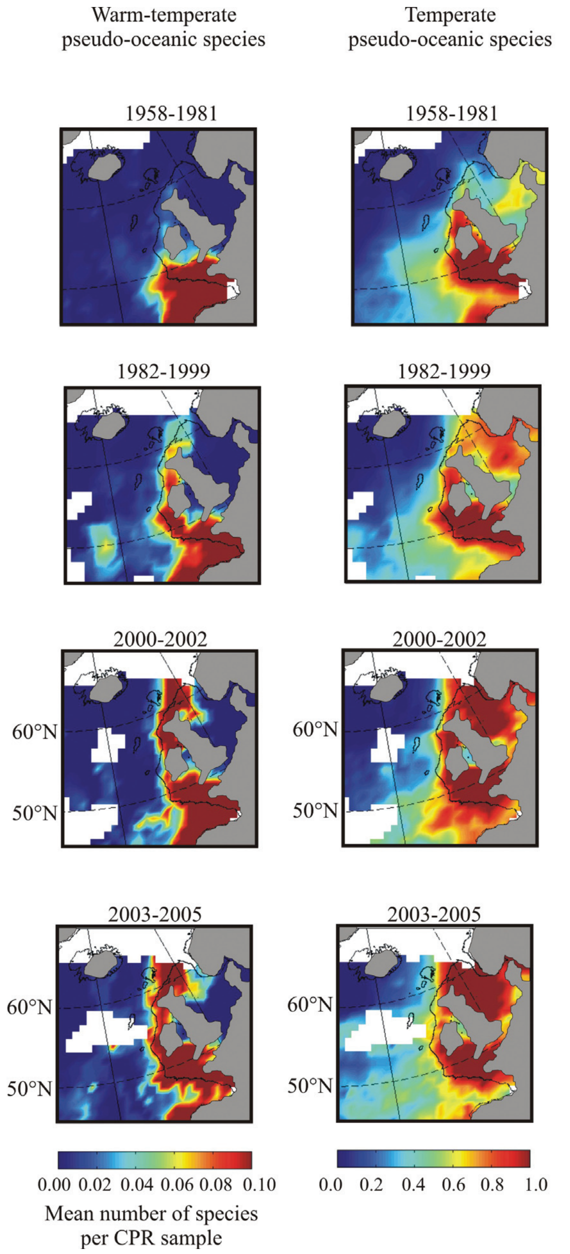
1. Indicators of climate change impacts

a. Biogeographical movements and northward shifts

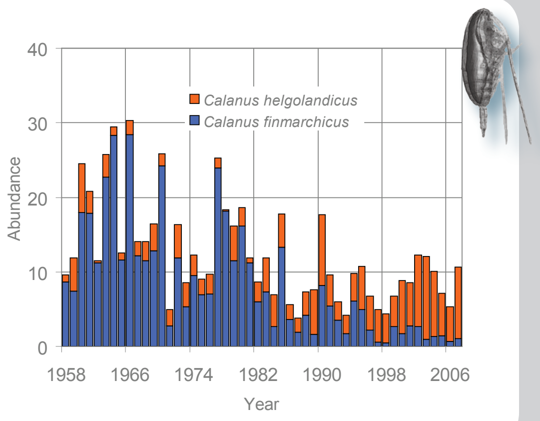
Over the last five decades there has been a progressive increase in the presence of warm-water/sub-tropical species into the more temperate areas of the North-East Atlantic and a decline of colder-water species. This trend seems to be accelerating over the last five years. The mass biogeographical movements 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 to the north and west (see central figure).

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.

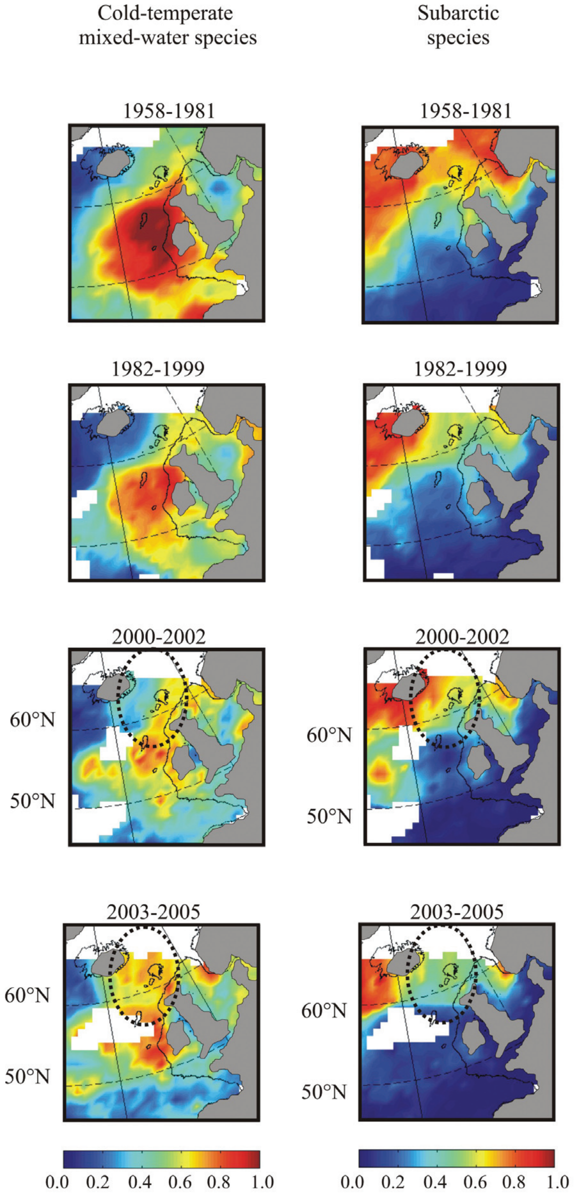
The figure below shows a simple percentage ratio between *C. helgolandicus* and *C. finmarchicus*. 2007 was again dominated by *C. helgolandicus*, a trend that has evidently been accelerating over the last decade. While *C. helgolandicus* is becoming more abundant in the North Sea the overall *Calanus* biomass has 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.



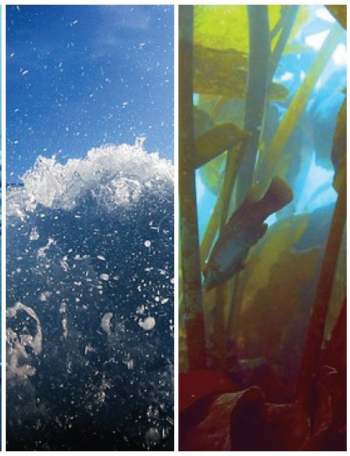
Climate change indicator 2007: *biogeography*



Total annual *Calanus* abundance and a simple annual percentage ratio between a warm-water species (*Calanus helgolandicus*) and a cold-water species (*Calanus finmarchicus*) from 1958-2007. Note: while the warm-water species is replacing the cold-water species the actual total *Calanus* abundance is decreasing.



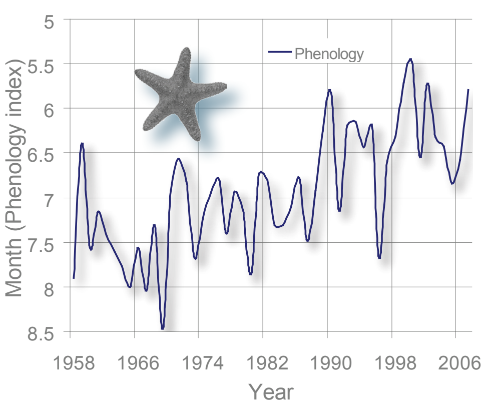
Biogeographical changes in plankton assemblages spanning five decades. Warm-water plankton are moving north and cold-water plankton are moving out of the North Sea.



b. Phenology and the marine growing season

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 at right shows the annual peak seasonal abundance 'centre of gravity index' of echinoderm larvae from 1959–2007 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. 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 2007 with the early seasonal appearance of echinoderm larvae.

Climate change indicator 2007: *phenology*



Inter-annual variability in the peak seasonal development of echinoderm larvae (an indicator of plankton phenology) in the North Sea. Warmer temperatures = earlier seasonal appearance, colder temperatures = later seasonal appearance. The general trend through time is towards an earlier seasonal cycle.

Key summary

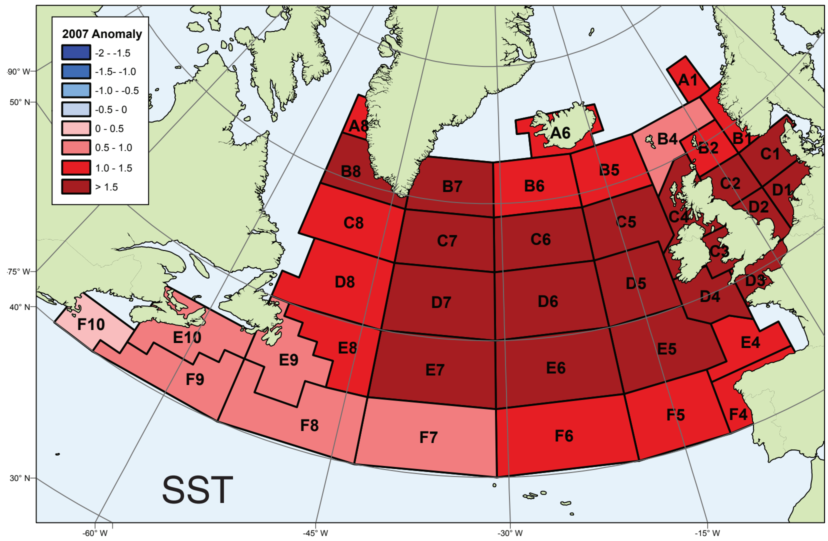
Climate change impacts

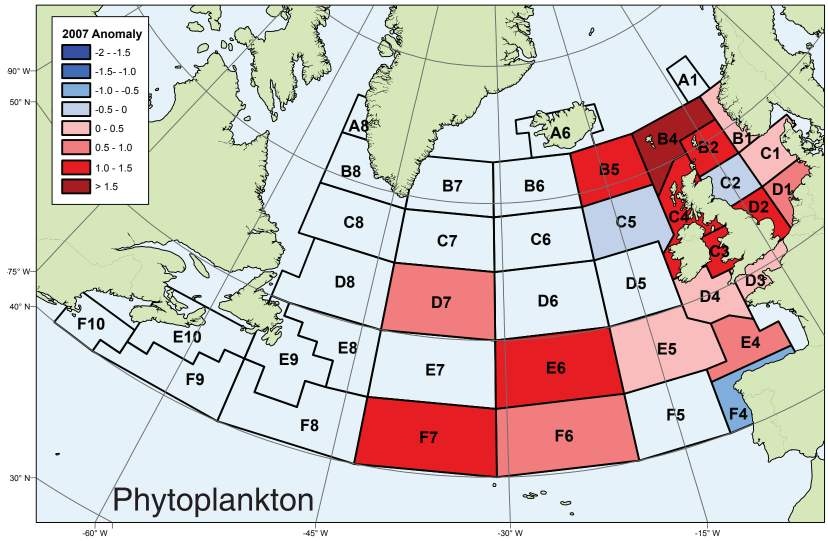
Warmer-water species are currently increasing in the North Sea due to regional climate warming and the NAO. In terms of a productive environment this change is considered detrimental because the warmer-water species are not replacing the colder-water species in similar abundances which has negative impacts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

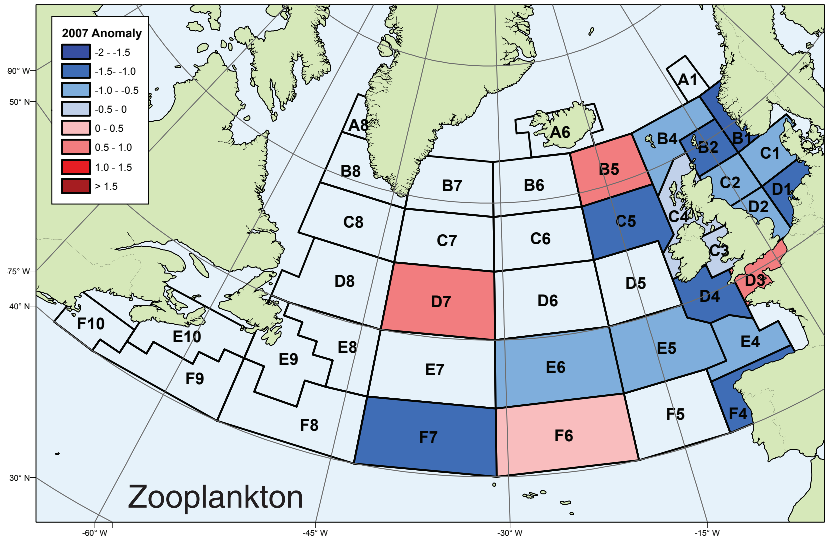
Seasonal timing, or phenology*, is occurring earlier in the North Sea and is related to regional climate warming. For example, some species have moved forward in their seasonal cycle by 4-5 weeks. However, not all trophic levels* are responding to the same extent, therefore in terms of a productive environment, 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*

c. Pan-North Atlantic biological indicators







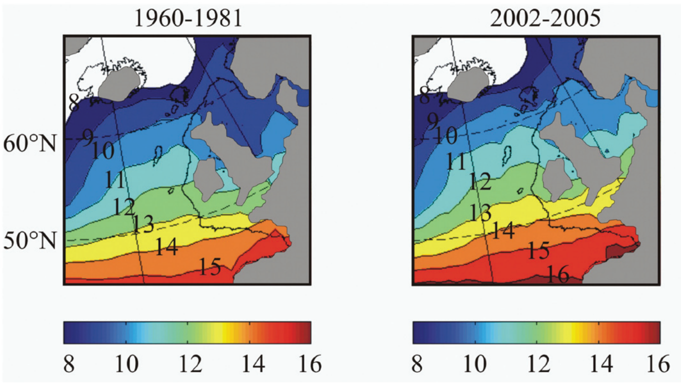
The left-hand figure shows 2007 anomalies for the North Atlantic for sea surface temperature (SST), phytoplankton biomass and copepod abundance based on the long-term trends in these variables from 1958-2007. Generally, the SST anomaly in all areas of the North Atlantic was above the long-term mean in 2007, with the central Atlantic and the North Sea regions particularly high. The difference in the degree of warming between the central/southern and northern North Sea is also evident, with the central/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). In 2007 the Phytoplankton Colour Index was generally above the baseline mean (1958-2007) in most regions, apart from some areas of the North Sea, central Atlantic and Iberian Peninsula. The copepod abundance 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). Due to the lack of monthly sampling in the North-West Atlantic (less than 8 months), no annual means were estimated for 2007.

d. Habitat expansion of the temperate province

During the last fifty years there has been a northerly movement of warmer-water plankton by 10° latitude in the North-East Atlantic and a similar retreat of colder-water plankton to the north (a mean poleward movement of between 200–250 km per decade). This geographical movement is much more pronounced than any documented terrestrial study, mainly due to advective processes and in particular the shelf-edge current running north along the northern European continental shelf.

Similarly the surface isotherms are moving at a rapid rate. Since the 1960s, the 10°C isotherm in the North Sea has moved northwards by an approximate rate of 21.75 km per yr. The 9-10°C isotherm is considered a critical thermal boundary for North Atlantic marine ecosystems as it separates the boreal and temperate provinces (see for example the distribution of sub-arctic species in the central figure on the previous page). The 9-10°C isotherm virtually engulfed the whole North Sea in the 1960s and the main boundary zone can now be found as far north as the Faroe Islands. During the 1960s the North Sea was defined as a cold-temperate boreal province but it can now be regarded as a warm-temperate province.

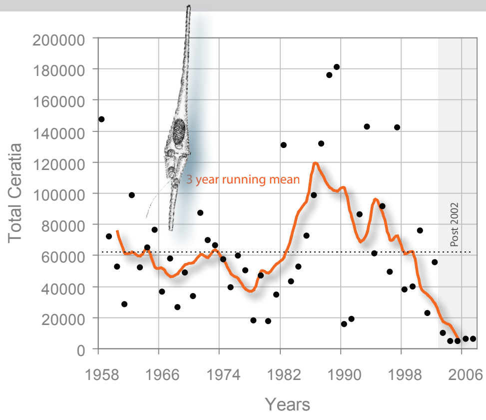
Habitat expansion of the temperate province



The 10°C isotherm in the North Sea has moved northwards by an approximate rate of 21.75 km per yr (53°N-62°N; 2°E; 1960-2005) since the 1960s. *Global Change Biology (2009), doi: 10.1111/j.1365-2486.2009.01848.x*

Special case study 2007/2008

The recent rapid collapse in the *Ceratium* genus in the North Sea



The *Ceratium* genus is a very common armoured dinoflagellate group that is distributed ubiquitously throughout the world's oceans from the tropics to the polar regions and from the oceanic realm to coastal waters. *Ceratium* often dominate the larger-sized fraction of the phytoplankton community during the summer months and may reach bloom proportions, producing red-tides. Due to their sensitivity to temperature, the *Ceratium* genus is widely known as an indicator of temperature changes which are manifested in their morphology, phenology, and biogeographic responses.

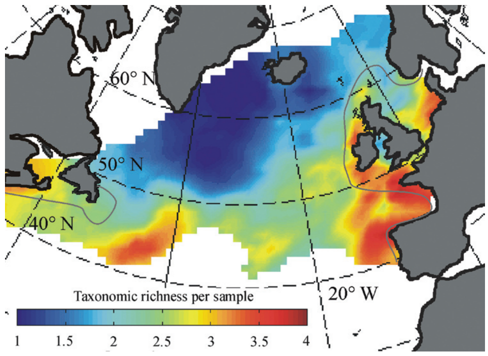
This species-rich genus comprises approximately 80 species globally, 46 of which are routinely speciated by the CPR survey in the North Atlantic's surface waters. *Ceratium* can be so common in the North Atlantic that they can be recorded at a frequency of over 50% on CPR samples; however, in the last few years the abundance of *Ceratium* in the North Sea has rapidly collapsed. While the overall biodiversity of *Ceratium* is increasing in the temperate North Atlantic, a change associated with climate warming, the abundance of its most common species such as *C. furca, C. fusus, C. horridum, C. tripos and C. lineatum* has drastically declined in the North Sea. Since 2003 the abundance of *Ceratium* has been consistently low, consecutively recording its lowest values for 50 years from 2003-2007. It is currently unknown why this trend is collectively shared amongst these species and what would cause such a dramatic decline in *Ceratium*, although various hypotheses are being investigated. No matter the cause of the decline, the degree in temporal consistency can eliminate the possibility that we are observing a simple anomaly and the cause could therefore be of considerable ecological significance in the North Sea.

2. Indicators of biodiversity and invasive species

a. Geographical and long-term trends in 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. In particular, increases in diversity are seen when previously low diversity systems like Arctic and cold-boreal provinces undergo prolonged warming events. 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. Climate warming will therefore increase planktonic diversity throughout the cooler regions of the world's oceans as temperature isotherms shift poleward. However, the relationship between temperature and pelagic fish diversity is far more complex due to other anthropogenic pressures such as overfishing apparently playing a significant role in diversity patterns.

Pan-North Atlantic biodiversity patterns



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 it at its minimum.

b. Invasive species

It has been suggested that introductions of non-native plankton may have important ecological and economic consequences by out-competing native species and/or causing nuisance Harmful Algal Blooms (HABs) at local or regional scales. Such introductions have had major impacts on aquaculture in many parts of the world through poisoning or smothering of farmed organisms and so are of especial concern to the aquaculture industry. It is these concerns and the potential for the inadvertent trans-oceanic transfer of plankton, their resting stages or benthic organisms in the ballast water of ships that led, for example, to the adoption of the International Maritime Organisation (IMO) Ballast Water Management Convention in 2004. The effects of each new introduction are extremely unpredictable and efforts to assess and monitor invasive planktonic species vary greatly. Many species of phytoplankton are difficult to identify just using light microscopy, and are often poorly preserved and require electron microscopy or genetic analysis for definitive identification. Most apparent new introductions are not recognised until they become dominant in the plankton though they may have been present in the past in very small numbers. Evidence to date suggests that new species typically become part of the local biodiversity and do not have a major impact on planktonic diversity through local or regional extinction. However, there is so little historical information available that this latter point is largely based on hearsay.

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 (see section on habitat expansion of temperate province) 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 box).

c. Unusual biodiversity records in 2007/2008

Phytoplankton
The oceanic dinoflagellate *Ceratium hexacanthum* was present on numerous (over 40) samples in the North-West Atlantic, on the Z, ZB and ZC routes, from July to December 2008, with most records in September and October, mainly on the Z route. The number of records on the Z, ZB and ZC routes was: June none, July 2, August 3, September 11, October 18, November 7, December 1. There were 34 records on the Z route, compared with only 7 on the ZB route and 1 on the ZC route, suggesting that *C. hexacanthum* had an unusually northwesterly distribution in autumn 2008. These records are further westwards than any in the last 70 years. *C. hexacanthum* is extremely scarce in the the cold North-West Atlantic and possibly indicates the movement of the Irminger current.

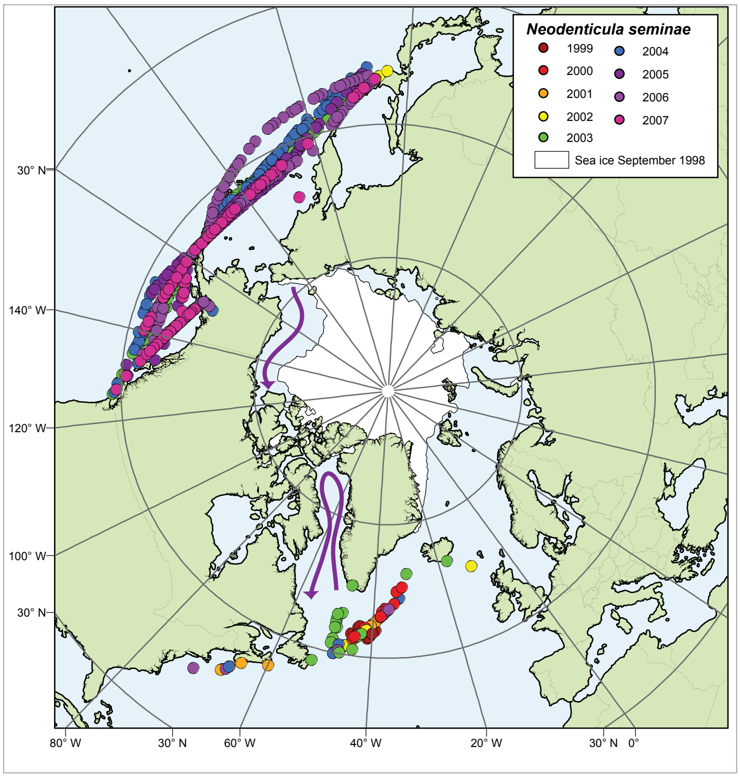
Zooplankton - copepods
Heterostylites longicornis was recorded south of the Grand Banks in September 2008 (449BF 33, at 37°24'N 49°39'W); this is only the second CPR record. *Labidocera aestiva* was found in the Gulf of Maine in October 2008 (332EB 21); there have been ten previous CPR records in the Gulf of Maine. Other scarce copepods recorded included *Candacia curta* found northwest of the Azores in August 2008 (448BD 7, 31 previous records) and *Macrosetella gracilis*, also found northwest of the Azores, in September 2008 (449BD 11, 33 previous records). A male *Hemicyclops aberdonensis* – an unusual Poecilostomatoid copepod – was recorded off the Dutch coast in October 2008 (294LG 3, at 52°32'N 3°48'E). This species lives in association with the burrowing shrimp *Calocaris macandreae*; there have been four previous CPR records. Parasitic copepods of the family Penellidae were found south of Iceland in September 2007 (722V 33) and in the central North Sea in February 2008 (265HE 15).

Zooplankton – other groups
Zoothamnium pelagicum, a pelagic colonial ciliate, was recorded just north of Scotland in September 2008 (535LR 35, at 58°57'N 4°03'W). This is unusually far north for this species, which is normally found southwest of the British Isles. Nauplii of the stalked barnacle *Lepas* were found in the northern North Sea in October 2008 (355M 19). It is extremely unusual for *Lepas* nauplii to be recorded in the North Sea. The first CPR record of a larva of Sternopidae (Decapoda) was found north of the Azores in October 2008 (450BC 17, at 40°47'N 28°46'W). In August 2008 the warm-water cladoceran *Penilia avirostris* (Cladocera) occurred off New York (330EB 3 and 5) and also in the western English Channel (315PR 5).

d. 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*



The distribution of *Neodenticula seminae* recorded on CPR samples in the Pacific and North Atlantic.

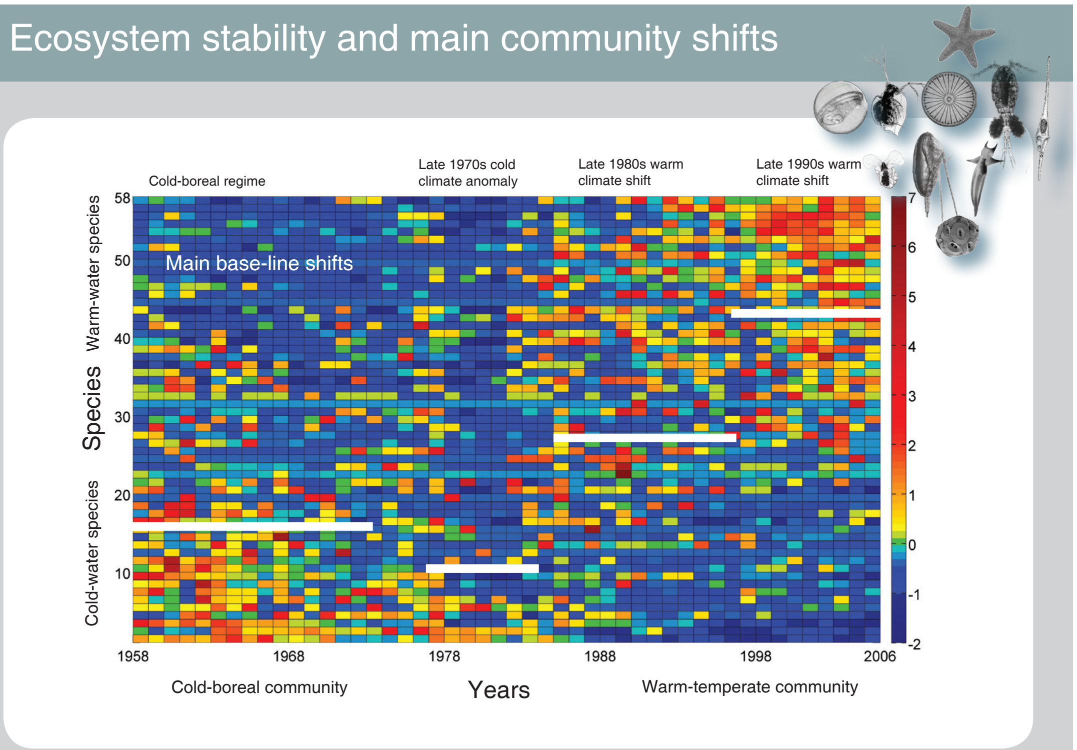
3. Indicators of plankton state, fish and wildlife interactions

a. Ecosystem stability, regime shifts and moving baselines

The concept of ecosystem stability refers to resistance to disturbance, resilience (the rate of recovery after disturbance) and constancy (degree of temporal stability). In this case we are concerned with measuring the temporal stability of ecosystems. The temporal stability of ecosystems is important because climate change does not manifest itself in marine ecosystems as a linear process but can materialise as step-wise shifts also known as 'regime shifts'. This non-linear response can be very rapid; for example, a shift in an ecosystem, which has been stable for many decades, to a new system can happen within a few years. This is exactly what happened to the North Sea ecosystem in the late 1980s where the North Sea changed from a boreal system to a warmer-temperate system within a few years. This dramatic change, first noticed within the planktonic system, soon materialised to encompass change observed across all trophic levels (e.g. seabirds, fish). This phenomena has large implications for the management of our marine ecosystems as management strategies designed for traditionally targeted fish species (e.g. cod) can be left somewhat wanting after such a rapid and dramatic ecosystem shift. For example, since the regime shift the North Sea ecosystem has supported more smaller pelagic fish stocks and a different planktonic community than prior to the late 1980s.

Obviously, for adaptive management purposes, it would be an advantage in monitoring for climate change impacts if we could anticipate these non-linear abrupt ecosystem shifts. Recently it has been speculated that the variability of a system's behaviour changes in advance of regime shifts (measured by a system's rising variance). Using this concept SAHFOS has developed new statistical tools to measure ecosystem variance as a function of temperature and has identified a critical thermal boundary (existing between 9-10°C where maximum variance in biological variables occurs, although the window of change can be between 8-12°C) in the North Atlantic (*Ecology Letters (2008) 11: 1157–1168*). Marine ecosystems that exist around this annual mean temperature can experience an abrupt shift if they undergo a small temperature increase, as seen by the biological variables chlorophyll, plankton diversity, plankton size range and cod distibution. This explains why a relatively small temperature increase in the North Sea (~+1°C) was met by a rapid ecosystem shift in the late 1980s while the response in the Celtic Sea and English Channel was not as dramatic as these systems were already above this critical thermal threshold. With these new tools an indicator can be developed to monitor stability of ecosystems to anticipate these non-linear shifts. This combined with adaptive marine management strategies should be used to accommodate these rapid shifts in the future.

Ecosystem stability and main community shifts



50 species meta analysis of commonly recorded plankton in the central North Sea ordered by Principal Component Analysis (standardised abundance) and plotted through time. Species with a similar environmental affinity are grouped together by the first principal component. Main baseline shifts are also highlighted.

4. Indicators of marine ecosystem and environmental health

a. Harmful Algal Blooms and eutrophication

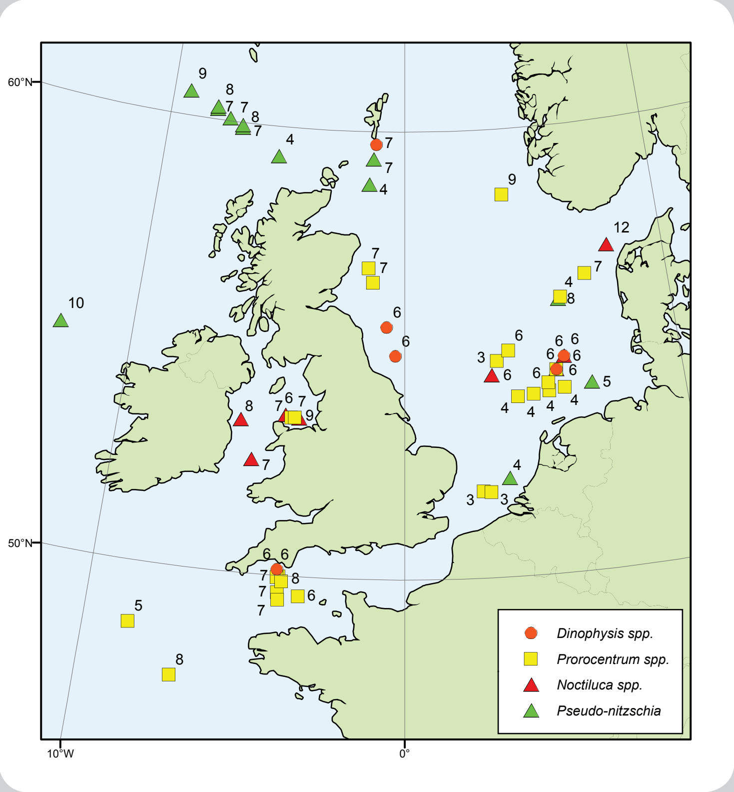
Although the CPR monitors plankton populations at a lower frequency than automated instruments such as the Cefas Smartbuoy, its long time-series and comprehensive spatial coverage combined with the measurement of 500 plankton taxa allow CPR data to reveal long-term changes missed by smaller scale instruments. Crucially, CPR data can provide baselines against which to measure changes. For example, 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.

Special case study 2007/2008

Large Harmful Algal Blooms recorded by the CPR survey in 2007

As well as providing an index of phytoplankton biomass (Phytoplankton Colour Index), the CPR survey identifies approximately 170 phytoplankton taxa. Apart from geographically extensive blooms, such as those by Coccolithaceae, of particular note are the occurrences of Harmful Algal Blooms (HABs) in European waters. 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 2007 occurred within the range of natural variability and were similar to the long-term average occurrences. However, the large blooms of *Prorocentrum* spp. that occurred off the Dutch coast and on Dogger Bank during March and April can be considered very exceptional as this genus normally prefers strongly stratified conditions during the summer.



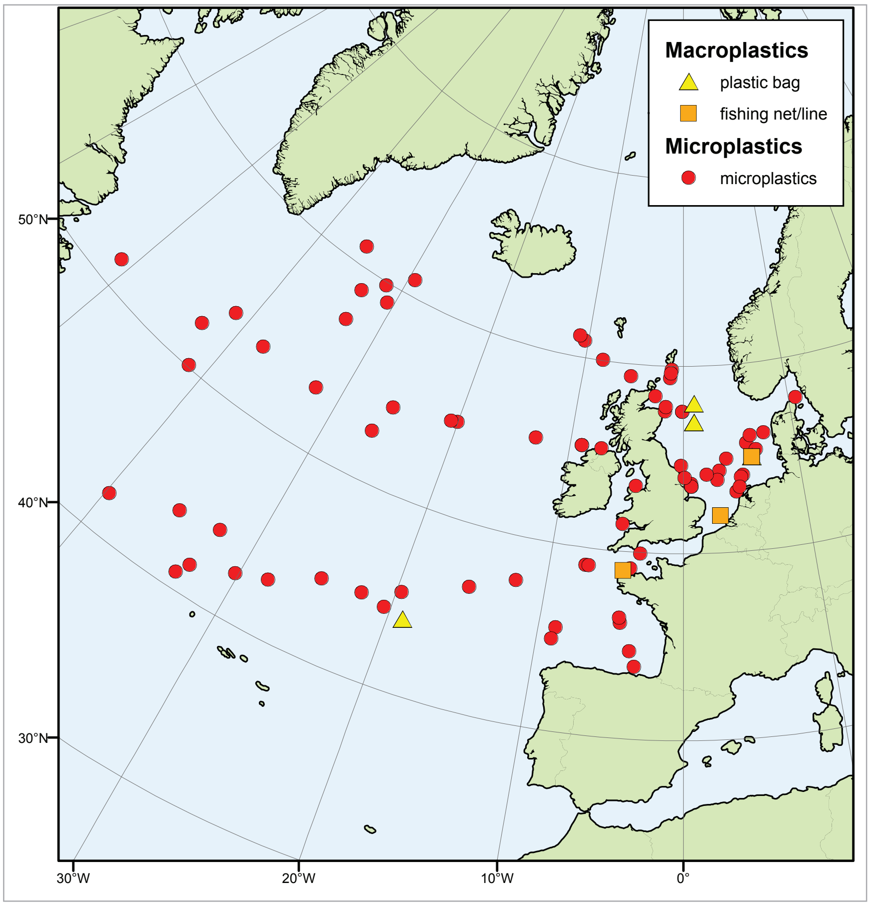
The geographical distribution of some exceptional HABs in 2007. Numbers indicate the month of the bloom.

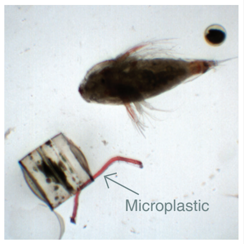
b. Marine litter

The presence of microplastics has been recorded on CPR samples since 2004 (see special case study on marine litter). From this information 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. With this information an indicator can be developed to monitor the presence of microplastics in space and time.

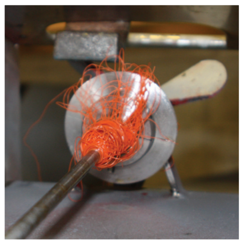
Special case study 2007/2008

Marine litter recorded by the CPR survey in the North Atlantic in 2007





Microplastic recorded on CPR silk (next to diatom and copepod)



CPR propeller jam caused by fishing line (March 2009, North Sea)

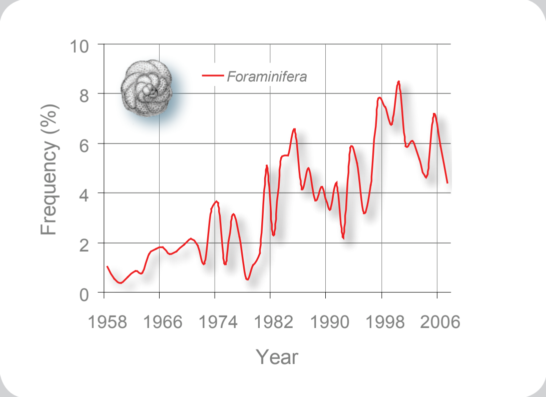
From retrospective analysis of CPR samples from a small area, it was found that microscopic plastic fragments (microplastics) have increased from the 1960s to the present. Since the initial scientific study in 2004 (*Science (2004) 308:834*), microplastics have been routinely recorded on CPR samples. The above figure shows the geographical distribution of microplastics recorded on CPR samples in 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. In collaboration with Richard Thompson from the University of Plymouth we are currently trying to ascertain the origins of these microplastics.The CPR survey also records the fouling of CPRs due to large plastics and monofilament netting which seems to be becoming increasingly common (above figure: macroplastics). Note: these results are of a preliminary nature and should only be used with caution.

c. Climate change and 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.

Ocean acidification



The percent frequency of foraminifera recorded on CPR samples

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.

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 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 and 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*

Indicator summary

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.

Changes in seasonality

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.

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

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.

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 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 to 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 by the bloom producing toxins and/or 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) may be closely timed (match) or out of sync (mismatch). The close seasonal timing of fish larvae with their prey is considered beneficial to fish larvae. **Microplastics**: Microscopic fragments of plastic as opposed to large plastic detritus such as bottles and packaging. The number of microplastics 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 at 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 foodchain (e.g. fish, seabirds, sea mammals).

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