

Climate change, ocean processes and plankton regime shifts

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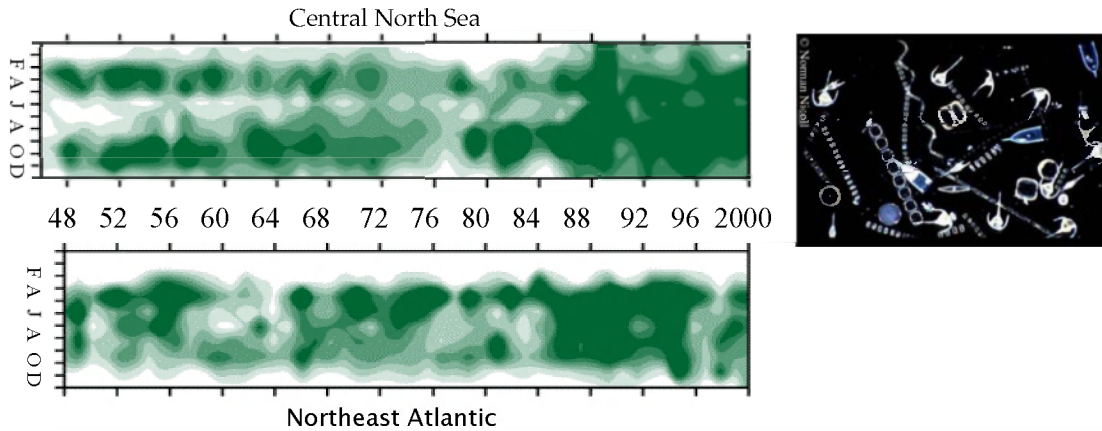
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The third report of the Intergovernmental Panel on Climate Change (IPCC) has shown that the rapid rise in mean global temperature seen in the last century was exceptional in the context of the last millennium. Mean surface (land and sea) global temperatures increased by $0.6^{\circ}\text{C} \pm 0.2^{\circ}\text{C}$ in the 20th century and the heat content of the oceans, integrated to 3 km depth, has increased since 1950. There is now a scientific consensus that these increases are attributable to the even greater rate of increase seen in greenhouse gases. Surface temperatures are expected to increase by a further 1.4 to 5.8°C by 2100. It is likely that changes in temperature at this scale and rate will have a pronounced effect on northern latitudes in the Arctic and, in turn, on the thermohaline circulation of the North Atlantic, which plays such a key role in the 'Global Conveyor Belt'. We may already be seeing evidence of these effects as the sea surface temperatures of the eastern Atlantic are highly correlated with northern hemisphere temperatures over the last 40 years.

In the eastern Atlantic, evidence from the Continuous Plankton Recorder (CPR) survey indicates that plankton are able to integrate climatic signals that may not be the main forcing variable; as such, plankton may be used as an index of climate change. Strong links have been demonstrated between the plankton and both Northern Hemisphere temperature (NHT) and the North Atlantic Oscillation (NAO), the dominant mode of atmospheric variability in the North Atlantic. The colour index of the CPR survey has shown a substantial increase in season length and intensity (Figure 1) and implies increases in chlorophyll and primary production in a wide belt across the North Atlantic and especially in shelf seas. Parallel increases in the benthos imply that sedimentation from the plankton has also increased in the last decade. At approximately the same time in the mid 1980s there appears to have been a step-wise change in physical, chemical and biological characteristics (at all trophic levels) in the North Sea that has been termed a regime shift. This is borne out by cluster analysis, which groups years according to both physical (sea surface temperature and NAO) and biological (phytoplankton, zooplankton and salmon catches) characters. This shows a distinct change from 1987 onwards. Changes in biogeographic zones and in the biodiversity of the plankton are linked to the decadal changes seen in plankton abundance with evidence for a northerly movement of warmer water plankton on the eastern side of the Atlantic and a southerly movement of plankton associated with colder water in the western Atlantic.

While climate variation may be considered to be natural, both the observed and predicted rates of climate change are unusually rapid and human effects on climate now appear to override natural variability. Ocean circulation and temperatures are changing in response. Physical and biological responses by oceans can be rapid and changes can be step-wise in the form of regime shifts. The northeast Atlantic may see large amplitude changes in the future.

Figure 1. Changes in phytoplankton biomass and seasonality in the North Sea and northeast Atlantic as part of a regime shift in associated physical and biological parameters that began in 1987. The left hand pair of diagrams shows phytoplankton biomass (intensity of shading) in relation to month (y-axis) and calendar year (x-axis). An increase in biomass after 1987 is apparent in both the North Sea (upper) and northeast Atlantic (lower).



Climate change and fisheries

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Fisheries are the major cause of mortality for marine fish, once they have reached a catchable size. Most fish stocks have been declining for some time due to fishing. Nonetheless, climate fluctuations are also known to cause extensive shifts in species distribution and local biodiversity. Furthermore, climate change and fishing pressures may interact to exacerbate the risk of collapse of fish populations to below the level at which they can support fisheries.

The demography of marine fish tends to differ from that of terrestrial vertebrates and freshwater fish in several important respects. Marine fish have large population sizes with fewer boundaries to migration, high fecundity once mature, often have a dispersive plankton stage and they undergo large population fluctuations. There appear to be fewer barriers to migration in the sea. Hence, the constraints on distribution shifts in the sea are very different (and probably fewer) than on land or in freshwater systems, and marine populations probably maintain greater genetic exchange. Nevertheless, there is also concern about possible loss of genetic diversity (at least of genotypes), which may in turn reduce the capacity to adapt to climate change.

Fisheries' catch information provides much of our knowledge about fish populations. These data provide evidence for associations between climate change and marine fish abundance and distribution. The annual landings of cod in Greenland have varied enormously over the 20th century, ranging from very small local catches to almost 500,000 tonnes. This shows a close correlation with sea temperature fluctuations between 1 and 2.5°C, warmer temperatures being associated with bigger catches, but catches since the early 1970s have been lower than expected from temperature alone (Figure 1). Changes in the abundance and distribution of other fish species in west Greenland are also associated with the period of warming from the 1920s. New species appeared from 1920 (*Melanogrammus aeglefinus*, *Brosme brosme*,