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# PLANKTON, FISHERIES AND CLIMATE CHANGE – INSIGHTS INTO OCEAN ECOSYSTEMS

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## Summary

This paper examines long term changes in the plankton of the North Atlantic and northwest European shelf seas and discusses the forcing mechanisms behind some observed interannual, decadal and spatial patterns of variability with a focus on climate change. Evidence from Continuous Plankton Records suggests that the plankton integrates hydrometeorological signals and may be used as a possible index of climate change. Changes evident in the plankton are likely to have important effects on the carrying capacity of fisheries and are of relevance to eutrophication issues and to the assessment of biodiversity. The scale of the changes seen over the past five decades emphasises the importance of maintaining existing, and establishing new, long term and wide scale monitoring programmes of the world's oceans in initiatives such as the Global Ocean Observing System (GOOS).

## Introduction

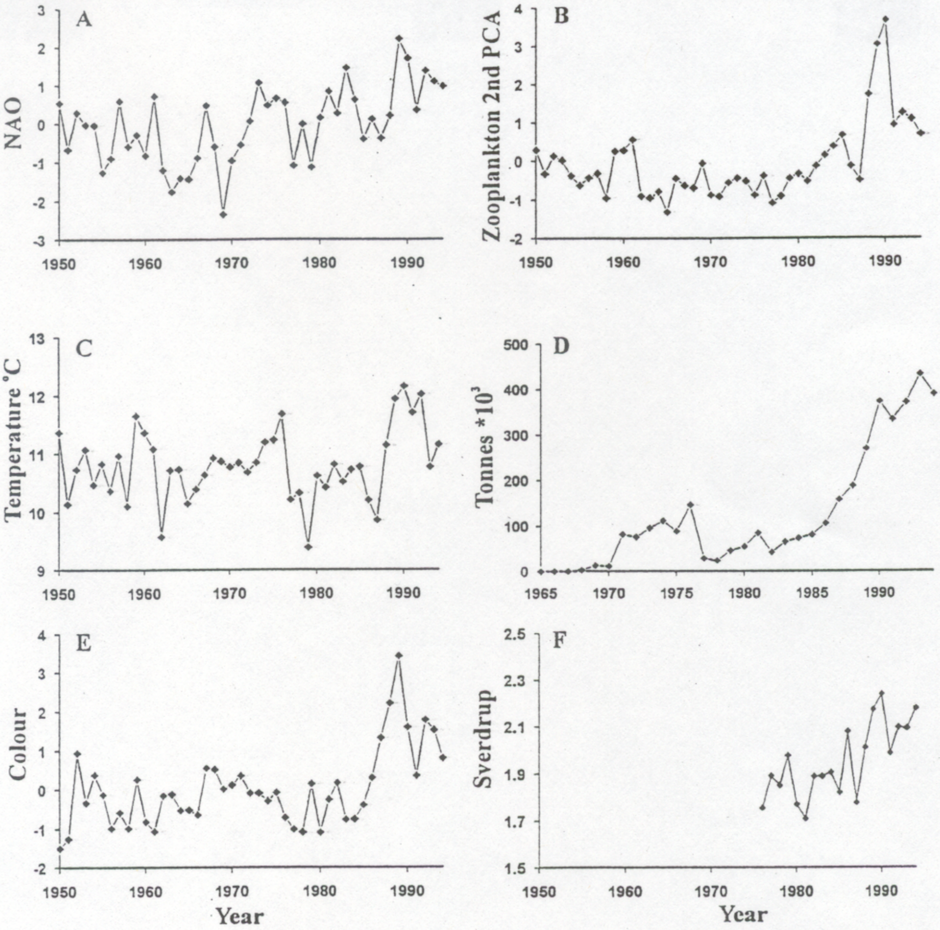
The Second Assessment Report of the IPCC (Houghton *et al.*, 1996, IPCC, 1995) concluded that there is a discernible human influence on global climate above the noise of natural variability. There is now little doubt that climate is changing, but the rate and extent of change and where impacts will be greatest is still unclear. The last decade has been the warmest since at least 1400 AD with associated major extremes of weather events and ended with the global mean temperature for 1999 as the fifth warmest on record. Other than changes to sea level and coral reefs, both international (IPCC, 1997) and UK (DETR, 1998) reports on climate change have so far placed little emphasis on the potential impact on the ecosystems, biological resources and biodiversity of North Atlantic and north west European shelf seas.

Evidence from the Continuous Plankton Recorder (CPR) survey (Fromentain & Planque, 1996, Reid, et al., 1998a, Reid and Planque, 1999) suggests that plankton can integrate a range of hydrometeorological signals and may act as an index of climate change. This survey, which started in the North Sea in 1931, expanded to the Atlantic in 1939. Post war >171,000 samples have been analysed in the core area of the survey covering the Atlantic between 35° and 75°N with the greatest sampling concentration in the north east Atlantic and North Sea. This extensive spatial and temporal (>50 years) coverage at a monthly sampling frequency, provides a unique resource with which to document marine environmental change. Using data from the CPR survey, long-term changes in the plankton of the north east Atlantic and North Sea are outlined and examined in relation to observed climatic variability over the last five decades. Events examined emphasise the importance of oceanic advection into shelf seas and the role of the eastern margin current at the shelf edge. On the basis of rising levels of $CO_2$ and temperature and links to the North Atlantic Oscillation (NAO), a prognosis of future change in the north east Atlantic and its effect on plankton is outlined.

## Long–term trends in the plankton of the north east Atlantic

By tradition, the first Principal Component derived from a multivariate analysis of all the samples analysed in the north east Atlantic and north west European shelf

**Figure 1. Graphs of annual means modified from Reid et al. (1999b). (a) A standardised plot of the NAO, (b) Zooplankton (CPR, second principal component) for the North Sea, (c) Sea Surface temperature for the North Sea, (d) Horse Mackerel catches from the North Atlantic between 45°N and 65°N, (e) Phytoplankton Colour (CPR) for the North Sea and (f) Modelled inflow into the North Sea.**



has been used as an index of the abundance of the plankton in the North Atlantic region. The dominant pattern seen for both the phyto and zooplankton in the north east Atlantic and North Sea (Reid & Planque, 1999) has been a downward trend with a slight increase in the North Sea after the 1978-82 minima. Approximately 60% of the species/taxa identified exhibit this downward trend. The second component for these two regions shows an increase subsequent to the mid 1980s, reflecting the regime shift in the North Sea referred to later and possibly a response in the Atlantic to the colder temperatures experienced in this area over these years. The seasonal cycle for the plankton has also changed substantially over the last 50 years. These changes were exemplified for Phytoplankton Colour (a visual estimate of chlorophyll a) by Reid (1998a).

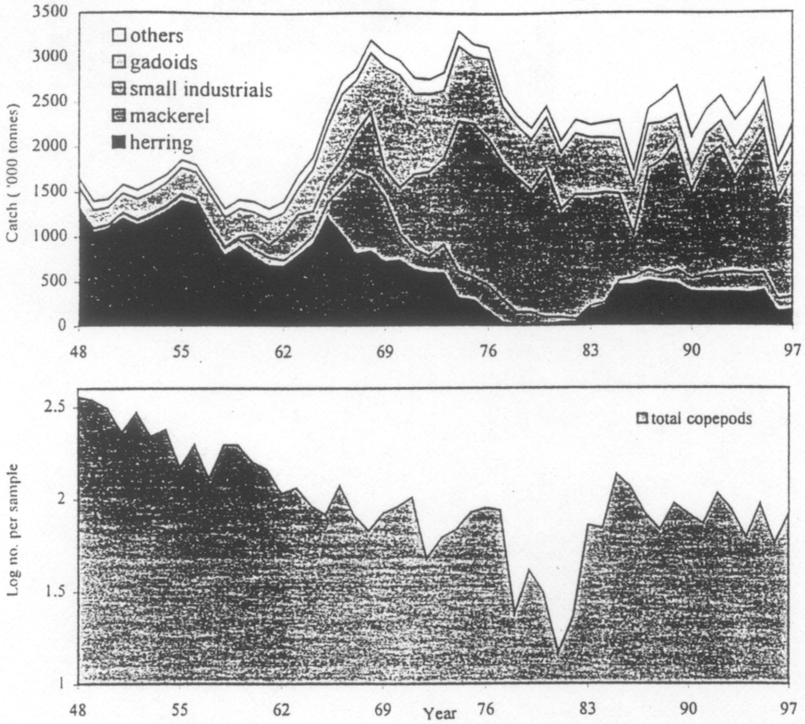
## North Sea Regime Shift

Reid, *et al.* (1998b, in press a) proposed, on the basis of pronounced changes in phytoplankton, zooplankton, fish, sea surface temperature and oceanic inflow (Fig.1) that a regime shift had occurred in the North Sea after 1987. The shift coincided with the highest and most consistently positive North Atlantic Oscillation (NAO) index for over a century and included evidence for a possible increase in the advection of warmer waters in the eastern margin current from Iberia and to the west of the British Isles. Changes in the benthos off the coast of the Friesian Islands (Krönke, 1998), with an apparent lag of about one year, provide further evidence of this change. Northerly flow in the eastern boundary/shelf edge current appears to be intermittent and shows strong interannual variability. Peaks in flow coincide with major incursions of oceanic plankton into the North Sea (Holliday and Reid, submitted). The changes that have taken place in the North Sea ecosystem have been reinforced by a further major oceanic influx in 1999 (Edwards, *et al.* 1999).

## North Atlantic Oscillation (NAO)

The NAO is the dominant mode of atmospheric behaviour in the North Atlantic and over Western Europe. Its effects are most pronounced in winter months. An index of change in the oscillation is calculated as the difference between the normalised December to March sea level pressures measured in Iceland and Lisbon (Hurrell, 1995). The occurrence of

**Figure 2. Time series of the landings of selected fish species (top) together with the total copepod abundance on CPR samples (bottom) for the North Sea.**



a high or low NAO pattern has a pronounced effect on wind strength, temperature, circulation, wave height and precipitation in surface and deeper waters (Dickson, 1997, Reid et al., 1998a) as well as impacting plankton (Fromentain & Planque, 1996; Reid & Planque, 1999) and higher trophic levels such as the salmon (Dickson and Turrell, 1999). The NAO is strongly positively correlated with sea surface temperature (SST) in the North Sea and negatively in the Irminger Sea (Reid & Planque, 1999).

## Plankton/Fishery Interactions

There have been marked changes in the size and composition of fish landings (Fig. 2) and stocks in the North Sea over the last five decades. In particular, large reductions occurred in the size of herring landings. In the late 1970s, early 1980s, when the herring stock is believed to have reduced to 50,000 tonnes from an estimated 600,000 tonnes in 1948, the fishery on herring was closed. The stock and landings subsequently increased. Figure 2 also shows the replacement of larger pelagic species such as herring and mackerel in landings by small industrial species such as sprat, sandeel and Norway pout. The increase in landings of demersal species after the 'gadoid outburst' in the mid 1960s, reducing to low tonnages in recent years, is also apparent. Coincident with these changes, and especially with the reduction in herring stocks and landings, total copepods and a range of other zooplankton from the CPR survey show a marked decrease in abundance in the years 1978-1982. In a comparison of a range of different fishery, plankton and environmental time series, this 1978-82 event is put forward by Reid, et al. (in press b) as evidence of a top-down impact through size selective grazing from the fishery on the plankton. Such an effect is believed to be most clearly evident when the system is over-stressed by over-exploitation of the key planktivore, the herring (Reid, et al. in press b).

## Introduced Species

In recent years, there has been an increase in the introduction and geographical spread of non-indigenous plankton species into north west European seas (Nehring, 1998). Most are thought to have derived from ballast water exchange, some from shellfish transplants and some may be a consequence of a northerly extension of biogeographic zones as a response to climate change. A number of the introductions may become dominant members of the plankton changing ecosystem structure. Data from the CPR has been used by Edwards, *et al.* (in press) to trace the progressive spread of the large diatom *Coscinodiscus wailesii* from its first record off Plymouth in 1977. This species now extends as far north as Trondheim in Norway, occurs on the western coast of Ireland and has become, at certain times of the year, a dominant member of the plankton in the southern North Sea.

## Biodiversity

Approximately 400 different taxa are identified in CPR analysis wherever possible to species level and in some cases to development stages. Using these results, Lindley and Batten (in press) have analysed changes in biodiversity in the North Sea. Species associated with inflow of oceanic water from west and south west of the British Isles have increased in abundance or frequency of occurrence.

**Figure 3. Hypothesised changes in the circulation of the North Atlantic in the alternative scenarios of a prolonged period of (a) high or (b) low NAO index. The bifurcating surface flow north of Iceland in (a) indicates outflow from the Fram Strait. LSIW, Labrador Sea intermediate water, NADW, North Atlantic Deep Water. The shaded lines indicate approximate directions of deep water flow. (c)&(d) Cross sections from N to S in the western Atlantic from Koltermann et al. (1999) in contrasting High NAO (c) and low NAO (d).**

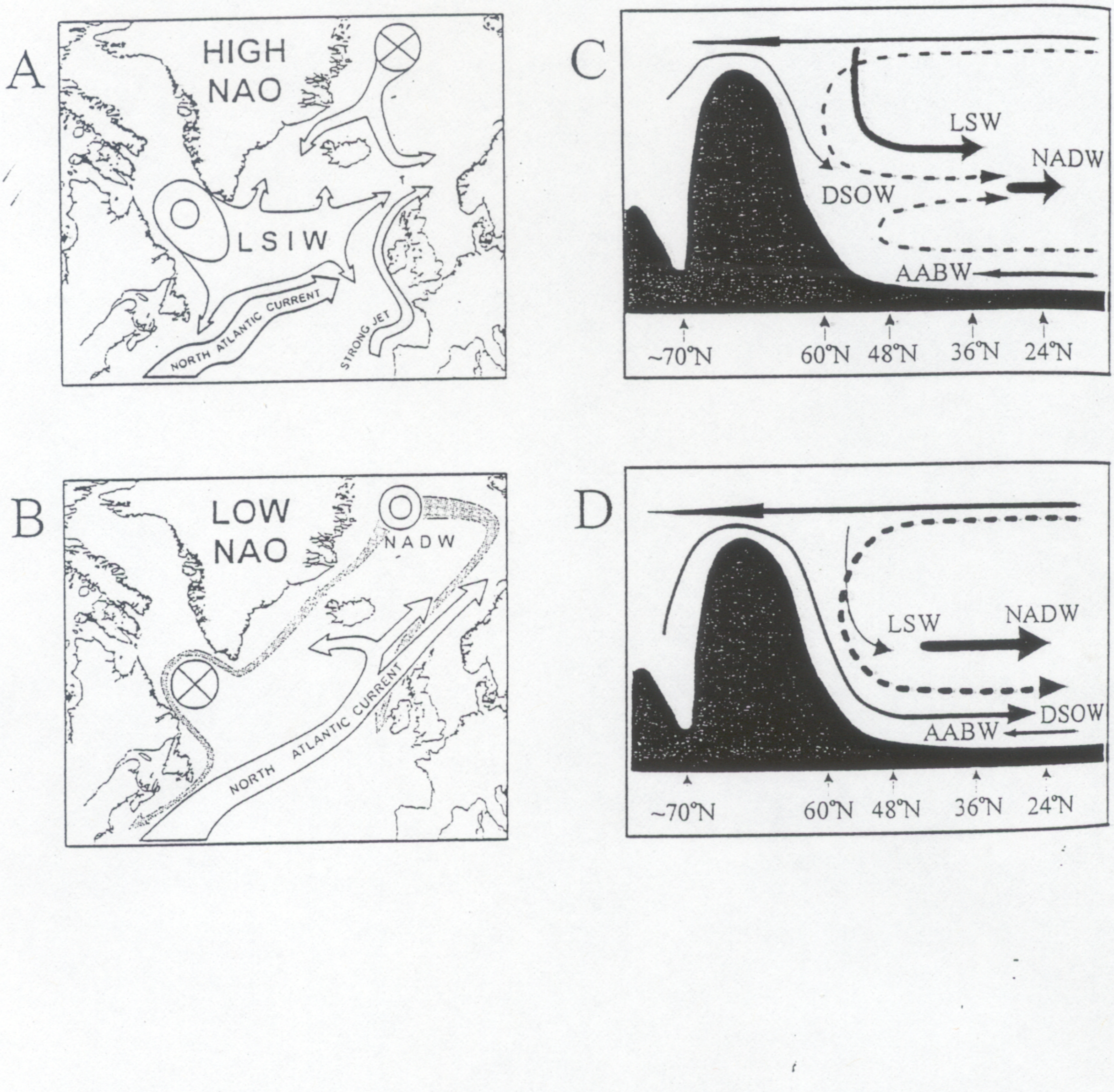
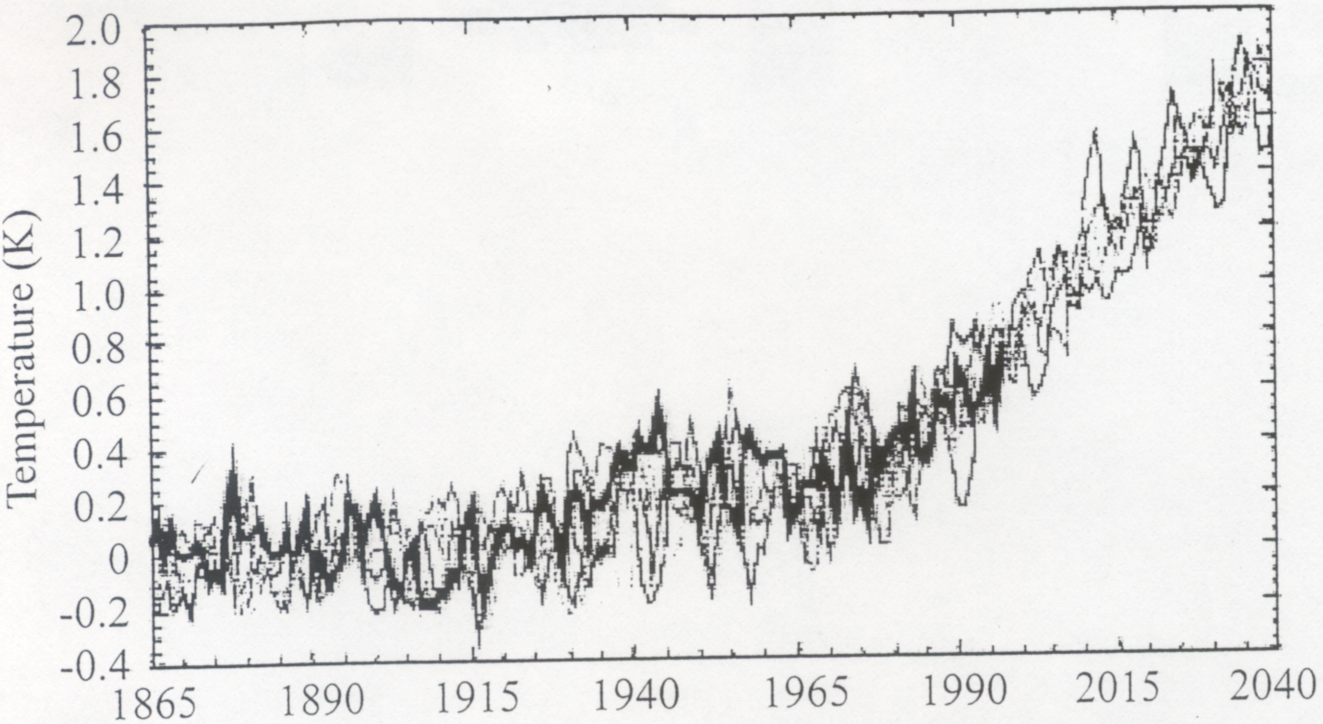


**Figure 4. Time series of observed (heavy black line) and five simulated measures of global mean surface temperature. (1865 – 1997 observations; 1865 – 2040 simulations) from Delworth et al. (1999).**



Meroplankton have also increased, especially echinoderm larvae, whereas resident holoplankton and those associated with colder oceanic or mixed waters have decreased. These patterns of change are consistent with the evidence for a regime shift to warmer conditions in recent years although there is no strong relationship with the NAO. Using data for 108 calanoid copepods to determine measures of biodiversity from the CPR survey, Beaugrand (pers. comm.) has demonstrated regional variability that does not fit the traditional view of a progressive reduction in biodiversity as latitude increases.

## The Global Conveyor Belt

The northern North Atlantic plays a crucial role in the global thermohaline circulation (Stocker and Schmittner, 1997) as one of the main formation sites of cold dense deep water in the Greenland Sea (Dickson, 1997). It is the sinking of dense surface water that 'pulls' warmer water from the tropics, releasing heat to the atmosphere to maintain the temperature of Europe at well above areas at similar latitudes such as Labrador and South Georgia. The formation of deep water in the Greenland Sea ceased around 1988 and overflow via the Denmark Strait and Faeroe Shetland Channel appears to have reduced. Deep water in the Norwegian Sea is now well below the threshold to overflow into the Atlantic and the water passing out through the channel has a much lower salinity and temperature (Turrell et al., 1999). At the same time, intermediate water with a lower density has increasingly formed in the Labrador Sea. These changes also appear to be connected with the NAO and Reid et al. (1998a) proposed a simplified schematic to represent how circulation patterns may alter in contrasting positive and negative NAO scenarios (Fig.3). It was suggested that penetration of the North Atlantic current into the Norwegian Sea is reduced with a stronger and warmer eastern boundary current in a positive NAO scenario and vice versa. This pattern was confirmed in observed sections presented schematically by Koltermann et al. (1999) who proposed a separation into single and two cell circulations in the two contrasting scenarios (Fig. 3). The decline in the copepod *Calanus finmarchicus,* which reached an all time low in the northern North Sea in 1998, appears to be partially linked to the reduction in Norwegian deep water (Heath et al., 1999).

## Prognosis

Concentration of $CO_2$ in the atmosphere, the main greenhouse gas, changed little for more than one thousand years until 1850 since when, there has been a rapid increase from ~280 ppm to ~380 ppm. On the basis of the projected future rise in $CO_2$, global mean temperatures are expected to rise by a further 1°C by 2040 according to modelled projections (Delworth, *et al.* 1999 (Fig. 4). As a consequence, snow cover in the Northern Hemisphere will decrease markedly and the Arctic Ocean is likely to be free of sea ice in summer months by 2040 (Delworth, *et al.,* 1999). Glaciers are also projected to have disappeared from the Himalayas by the same time (Pearce, 2000).

Using the same $CO_2$ scenario, the NAO is also expected to remain positive until 2040. High meltwater from ice will help maintain the capping of deep-water formation in the Greenland Sea. One proposed consequence of a sustained closure of deep water formation in the Greenland Sea, is a southerly movement of the North Atlantic current and a switch to colder weather in Europe (Rahmstorf, 1997), contrary to the global pattern. Such a consequence would require the current warm eastern baroclinic boundary current to be blocked.

Whatever the climatic consequences of the next few decades, early signals of change are most likely to be seen in the plankton. Climatic changes to terrestrial ecosystems are less easy to distinguish from anthropogenically induced variability. The CPR survey provides a unique baseline against which to assess such change and a resource for use in the development of ecosystem management strategies for shelf seas. Maintenance of the current survey coverage and extension into key areas for climate change such as the Labrador Sea and Norwegian Sea, should be given priority. In 1999, the CPR survey was incorporated into the Initial Observing Scheme of the Global Ocean Observing System (GOOS). On the evidence presented here, establishment of similar regional surveys elsewhere in the world, are needed to assess Living Marine Resources and their potential response to natural and anthropogenically forced change.

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