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Long-term Changes in the Pelagos, Benthos and Fisheries of the North Sea

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With 7 Text-Figures

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Abstract

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Pronounced changes have occurred in the fisheries, plankton and benthos of the North Sea over the last five decades. Attribution of the relative contribution of anthropogenic versus natural hydrometeorological modulation to these changes is still unclear. As a background a summary history of our understanding of the state of health of the North Sea is outlined. We then focus on two contrasting periods in the North Sea, one between 1978-82 (cold) and the other post 1987 (warm) when pronounced alterations in many ecosystem characteristics occurred. The scale of the changes in the second of these periods is sufficiently large and wide ranging for it to have been termed a regime shift. A combination of local, regional and far field hydrometeorological forcing, and in particular variability in oceanic inflow, is believed to be responsible for the observed changes. Finally attention is drawn to the poor status of North Sea fish stocks where 7 stocks are documented as being fished outside safe biological limits. This situation is primarily believed to be a consequence of overfishing, but may have been exacerbated by environmental change.

Introduction

The North Sea has an extensive catchment draining an industrial and intensively farmed hinterland, a major fishery and many shipping movements and is subject to maritime pressures from oil and gas exploitation. All these anthropogenic activities, combined with natural variability, including a strong influence from the adjacent Atlantic, have a considerable impact on the ecosystem(s). As a generalisation, the North Sea can be divided into three interacting divisions: summer stratified waters in the north, a tidally mixed water column in the south and haline stratified waters over the Norwegian Trench. Assessing the baseline biological characteristics of these different systems, and how they have changed over time, and distinguishing between anthropogenic and naturally modulated change, has proved difficult because few long-term studies have been carried out and understanding of ecological interactions at the scale of a regional sea is still poor.

Four assessments (Quality Status Reports, QSR) of the state of health of the North Sea have been carried out, one in 1984, 1987, 1993 with the fourth report published in December 2000. In the 1987 QSR (ANON. 1987) contamination and eutrophication were identified as the key issues to be addressed on the basis of the scientific know-

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ledge at that time. One of the consequences of the assessment was a decision made by ministers at the Second International Conference on the Protection of the North Sea, London, 1987, to reduce inputs of nitrogen and phosphorus by the order of 50% between 1985 and 1995. The Minister's decision was politically based as the scientific understanding of eutrophication issues or of the effects of contamination at the time was not sufficiently advanced to give clear guidance to decision-makers. In particular the biological effects of eutrophication were not clear (e.g. NSTF 1993). In the case of nutrients the 50% reductions were not fully implemented by the 1995 deadline and have still not been achieved for nitrogen. Five years later in 2000 the quantitative consequences on North Sea ecosystems of the reductions that have been made are still not fully clear (OSPAR Commission 2000 a, b). One very positive outcome of the initiative by the Ministers however, has been a pronounced improvement in the quality of coastal waters and their associated catchments through substantial reductions in contaminants and nutrients as direct and riverine inputs and emissions to the atmosphere as well as considerable upgrading of sewage and agricultural waste treatment. The North Sea initiatives have also had a large influence on the development of the environmental legislation of the European Union. Other anthropogenic impacts have been less studied e.g.

1. The consequences of hydroelectric power production on the marine environment through the alteration of the normal seasonal cycle of river discharges (SKRESLET 1986) and exceptional discharges in summer months (REID 1997).
2. The effects of introduced species through for example competition, displacement and change to bentho-pelagic cycling (EDWARDS et al. 2001 a).

In the 1993 QSR (NSTF 1993) and 2000 QSR (OSPAR Commission 2000 a, b) alterations to the benthic and possibly the pelagic compartment by the fishery was identified as a further key factor in long-term ecosystem change.

Superimposed on these human forcing factors is a wide natural hydroclimatic variability. The turnover time of the North Sea is rapid due to strong tidal mixing and the estimated flushing time for the whole area is approximately one year (OSPAR Commission 2000 a). A major outflow along the Norwegian coast (incorporating the Baltic outflow, runoff from Norwegian rivers and a contribution from the southern North Sea) is compensated by inflows from four main sources (East of Shetland), a deep inflow at the eastern edge of the Norwegian Trench, through the Orkney Shetland Channel and Dover Strait. It is established that the Atlantic provides >90% of the nitrate and phosphate to the North Sea (NSTF 1993) and yet, until recently, variability in the rate of this inflow was not perceived to be an important factor in North Sea ecology (LINDEBOOM et al. 1995; CORTEN 1999; REID et al. 1992). Local meteorological forcing such as the strength and direction of winds and evaporation on sea surface temperature also has a substantial effect on the North Sea system (DICKSON et al. 1988; TAYLOR & STEVENS 1983).

In the past research on long-term changes in North Sea ecosystems has focussed on documentation of trends and identification of possible factors contributing to the trends. A good example of this type of study is the work of AEBISCHER et al. (1990) who showed parallel long-term trends in plankton and seabirds and attributed the cause to changes in the frequency of westerly winds.

In climate studies change through time may not be reflected in the form of a progressive trend, but in series of years (not necessarily continuous) that have a similar and unusual character; years in between are of average character. This phenomenon is known as 'clustering' (LAMB 1988). Here we document two periods of years where major changes appear to have occurred in the North Sea, one between 1978 and 1982 (cold) and the other post 1987 (warm). In the latter case the changes are considered sufficiently widespread and long lasting to be termed a regime shift (REID et al. 2001 a). A combination of local, regional and far field hydrometeorological forcing is believed to be responsible for the observed changes.

Long-term Changes in the North Sea

The North Sea is the most studied Large Marine Ecosystem (LME) in the world. The first detailed surveys were initiated at the end of the 19th century and the International Council for the Exploration of the Sea (ICES) played an important part in co-ordinating surveys at the beginning of the 20th century. There are however, few systematic long-term studies. Some relevant reviews of the biology and fishery resources include: phytoplankton (REID et al. 1990), zooplankton (FRANZS et al. 1991), benthos (KRÖNCKE 1995), roundfish, flatfish, pelagic fish (SERCHUK et al. 1996), gadoids (HISLOP 1996), fish by-catch (VOOYS & MEER 1998), general (LINDEBOOM et al. 1995; CLARK & FRID 2001) and the Arhus, Mariehamm and Arhus revisited symposia of ICES (HEMPEL 1978; MEINCKE et al. 1984; DANN & RICHARDSON 1996).

North Sea Regime Shift circa 1988

REID et al. (1998) described an almost two fold annual increase in the levels of Phytoplankton Colour (a visual estimate of chlorophyll) as measured on the silks of the Continuous Plankton Recorder (CPR) survey, an increase which included a >90% rise in colour intensity during the winter months of the year. This coarse evidence for a stepwise increase in 'chlorophyll' levels in the North Sea after 1987 could at face value have been taken as strong evidence for eutrophication (Fig. 1). The changes were however North Sea wide and were also seen to the west of the British Isles in oceanic waters (EDWARDS et al. 2001 b). They must, therefore, be a consequence of a major hydroclimatic event. A number of associated physical and biological changes circa 1988 have since been considered as a regime shift by REID et al. (2001 a). The term regime shift has been used to describe large decadal scale switches in the abundance and composition of plankton and fish (HARE et al. 2000).

Besides Phytoplankton Colour, individual species of phytoplankton and zooplankton, fish catches, (horse mackerel), sea surface temperature (SST) and modelled inflow into the North Sea were all shown to have increased at about the same time (Fig. 2). The total heat content of the North Sea has also increased since this time (POHLMANN pers. comm.). Changes in the distribution of herring (CORTEN & VAN DE KAMP 1992) and a substantial increase in the biomass of the benthos off the Frisian Islands from 1989 (KRÖNCKE et al. 1998) have occurred (Fig. 3). Pronounced changes in the community composition of the benthos have also been observed, at about the same time, off the northeast coast of England (WARWICK & CLARKE pers. comm.). The one-year lag implies a delayed trophic response by the benthos possibly due to the time taken for deposition of planktonic detritus. This observation also suggests that there has been an increase in the quantity of detritus settling to the bottom and possibly changes in pelagic/benthic cycling. Associated changes in the composition of phytoplankton with an increase in numbers of large diatoms e.g. *Coscinodiscus* spp. and *Odontella* spp. would give added credence to this observation (e.g. EDWARDS et al. in 2001 a). Other (non-continuous) benthic time series (e.g. WIEKING & KRÖNCKE 2001; THATJE & GERDES 1997; JOSEFSON et al. 1993) that were not sampled on a regular annual basis also provide evidence for an increase in the numbers of species and benthic biomass after the mid 1980s. The change around 1988 may not just be confined to the North Sea. For example, VUORINEN et al. (1998), again with a discontinuous time series, show that a substantial change has taken place in the relative biomass of copepods to cladocera in the Baltic Sea sometime after 1985. There have also been marked reductions in the stocks of cod in the Baltic since this time.

Coinciding with the 1988 regime shift a number of species more typical of warm water latitudes have increased in the North Sea, to the extent that a small fishery on the 'Mediterranean' red mullet is now operational for the first time in the central North Sea (DUNN & REID in prep.). The subtropical cladoceran, *Penilia avirostris* became extremely abundant in the German Bight in the warm year 1999 in samples taken both at Helgoland and by the CPR survey. At this time the surface to bottom water temperatures in the German Bight were >18°C, the temperature above which this species hatches from its benthic resting eggs (GREVE pers. comm). It is worth noting that the regime shift circa 1988 also coincided with the timing of the seal epidemic in the North Sea and the toxic *Chrysochromulina* bloom in the eastern North Sea (REID 2000). Finally, in both 1988 and 1998 the southern

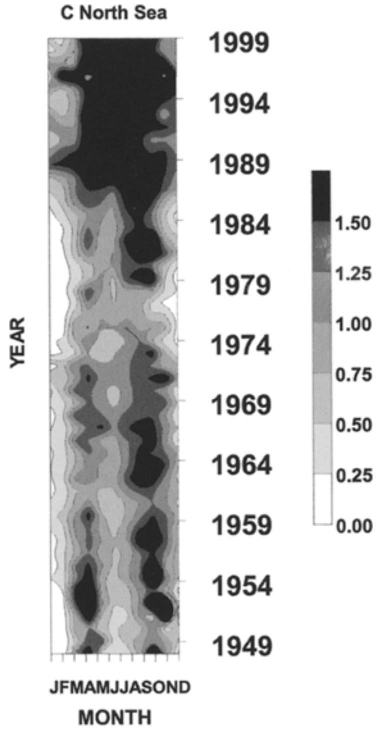

Fig. 1. Contour plot of the mean monthly value of phytoplankton colour for the central North Sea (1948-1999).

doliolid, *Doliolum nationalis*, and other associated oceanic species were recorded in substantial numbers in the North Sea for the first time since 1911 (LINDLEY et al. 1990; EDWARDS et al. 1999).

Pronounced changes in nutrients and oxygen levels in the Skagerrak also coincide with the regime shift (DAHL & DANIELSEN 1992). Concentrations of nitrate, orthophosphate and silicate increased substantially throughout the deeper waters of the Skagerrak as levels of oxygen declined. These changes are further evidence for a suggested increase in the sedimentation of plankton subsequent to the regime shift although they could be caused by an alteration in the exchange with the Baltic. Diatomaceous detritus would have been rapidly recycled by bacteria to give the high silicate and reduced oxygen concentrations. These conditions are also thought to reflect a prolonged period of poor deep-water exchange and limited cascading of cold North Sea bottom water into the Skagerrak in winter months (DAHL & DANIELSEN 1992).

The stepwise changes in nutrients observed in the deep water of the Skagerrak are also reflected in the Helgoland Roads time series in the German Bight (HICKEL et al. 1996). A pronounced increase in silica and in the NO_3/PO_4 ratio occurred in 1987. This change was associated with a sharp rise in the flagellate (>20 µm) to diatom ratio. The timing of this event appears to be one year ahead of the increase in CPR Phytoplankton Colour as measured in the open North Sea and two years ahead of the changes in the deeper waters of the Skagerrak. Helgoland is heavily under the influence of the River Elbe outflow and part of the change at this site is likely to be

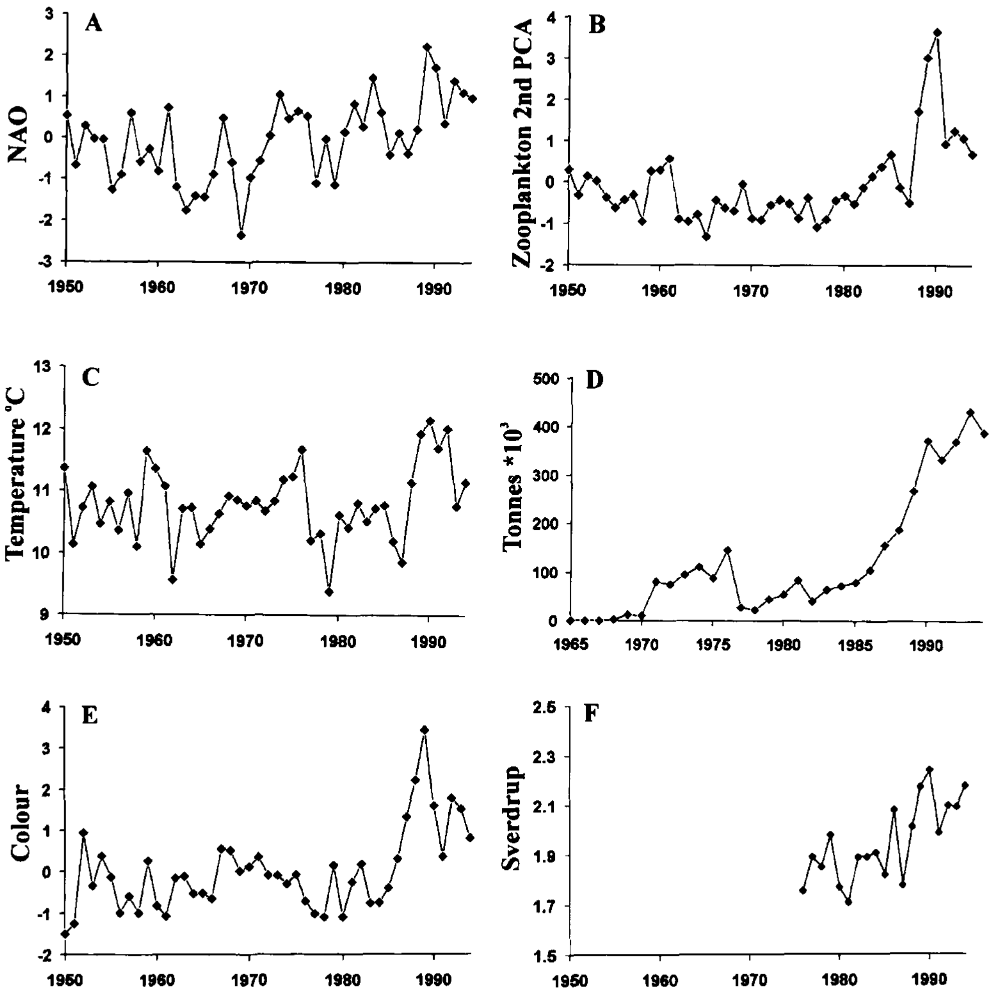

Fig. 2. Annual means: (A) the North Atlantic Oscillation (NAO) index, standardised; (B) Zooplankton (CPR, second Principal Component, representing especially *Calanus helgolandicus*, Decapod larvae, *Corycaeus* spp. and *Evadne* spp.) for the North Sea. Thirty taxa included in the analysis (see REID & HUNT 1998); (C) Sea surface temperature for the North Sea (ICES data); (D) Horse mackerel catches from the north east Atlantic between 45°N and 65°N; (E) Phytoplankton Colour (CPR) for the North Sea; (F) Modelled inflow into the North Sea (REID et al. 2001 a).

attributable to increased river flows and higher nutrient loads in the 1990s (RADACH 1998). The atmospheric forcing that presaged the circa 1988 regime shift may have had an earlier impact on catchments through higher rainfall and runoff. Higher runoff into the southern North Sea in 1987 may have primed the later oceanic inflow due to the development of an enhanced 'estuarine' circulation (REID et al. 1992). The maximum areal coverage of Norwegian coastal water, measured by SVENDSEN & MAGNUSSON (1992), occurred in 1987 supporting the idea of a higher outflow of low salinity water in the eastern North Sea in this year.

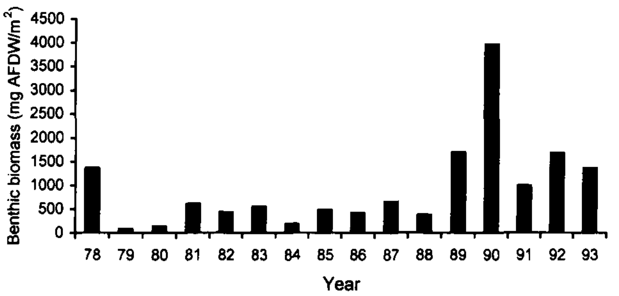

Fig. 3. Means of benthic biomass in the Norderney coastal zone (southern North Sea) for the spring (second quarter of the year) from 1978-1993. – Data from KRÖNCKE (pers. comm.).

North Atlantic Oscillation (NAO)

The regime shift of 1988 approximates to the beginning of the most consistently positive phase of the NAO in more than ~150 years of measured record (DICKSON & TURRELL 2000). The events may be a consequence of NAO forcing at local, regional and far field levels as a direct correlation with the NAO is not evident for many of the variables that change at this time. Higher temperatures in the North Sea are one consequence of a positive NAO index (BECKER & PAULY 1996; REID & PLANQUE 1999). Higher temperatures from 1988 onwards in coastal waters for example, are evident in the Flødevigen time-series (AURE 1999).

Wind strength to the north and west of the North Sea is also strongly correlated with the NAO (REID & PLANQUE 1999) and inflow of oceanic water to the North Sea is primarily forced by regional wind fields (STEPHENS et al. 1998). In the winter of 1995/96 the NAO reversed to a low negative index and this event was reflected in a reduced influx of oceanic water into the North Sea (REID & PLANQUE 1999). Part at least of the changing inflow pattern after 1987 and in particular the major inflow events of 1987/1988 and 1998, appear to have been a response to far field effects influencing the strength and direction of flow in the shelf edge current (HOLLIDAY & REID 2001; REID et al. 2001 b).

Ecosystem Changes Between 1978 and 1982

A large reduction in numbers and average dry weight biomass of zooplankton measured from CPR samples took place in the years 1978 to 1982 (Fig. 4). This event coincided (with a lag) with pronounced changes in the catch of herring and in other fishery statistics and was attributed by REID et al. (2000) as evidence for top down control of the plankton by the fishery. While most plankton groups showed a pronounced reduction at this time euphausiids and *Calanus finmarchicus* increased in abundance, and there was evidence from the CPR survey for an increase in the occurrence of other cold water plankton that are only rarely found in the North Sea including the diatom *Navicula planemembranacea* and the copepods *Calanus hyperboreus* and *Metridia longa* (EDWARDS et al. 2001 b). These copepods undergo strong vertical migration from cold deeper waters in the Norwegian Trench and their occurrence suggests that there was at this time an intrusion at depth of cold oceanic water into the North Sea along the Norwegian Trench. While many researchers (e.g. JOSEFSEN et al. 1993; LINDEBOOM et al. 1995; GREVE 1996) noticed an abrupt change in the North Sea ecosystem in the late 1970s they did not suspect a wider scale impact. During this period there was also an increase in the recording (MOMMAERTS 1985) of algal blooms in the North Sea (which does not necessarily imply an increase in the number of blooms) and higher levels of large flagellates were measured in the Helgoland Roads time series (HICKEL et al. 1996). CORTEN & KAMP (1996) noted that the entire sprat fishery in the North Sea collapsed in the late 1970s and, during the years 1978-1982, the distribution of the sprat stock shifted southward. SVENDSEN et al. (1995) showed that the migration of the western mackerel stock into the North Sea (dependent on Atlantic water transport) was at an all time low in the late 1970s. Various measures of kittiwake egg laying success in the eastern North Sea were also at minima during this time AEBISCHER et al. (1990).

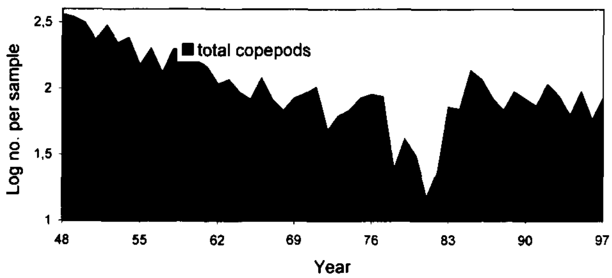

Fig. 4. Long-term changes in the abundance of copepods (log numbers per sample) recorded by the CPR survey for the North Sea from 1948-1997.

Changes in North Sea Fish Stocks

In an earlier study comparing plankton results from the CPR with fishery statistics (REID 1984) showed that a declining trend in zooplankton biomass in the north western North Sea correlated with changes in the total fish catches for the North Sea. The plankton time series in this study ended in 1982 and documented for the first time the minima in the period 1978 to 1982. A plot of fish landings updated to 1997 is given in Fig. 5. Until the mid 1960s total landings averaged >1.5 million tonnes. Following this period until 1977 landings doubled to more than 3 million tonnes at the same time as major changes in the composition of the landings took place. There was a substantial decline in the large pelagic species herring and mackerel and a compensatory increase in small pelagic species such as the sandeel, sprat and Norway pout as well as the gadoids. After 1977 catches reduced to a new ceiling of approximately 2.5 million tonnes with a continuing dominance of small industrial

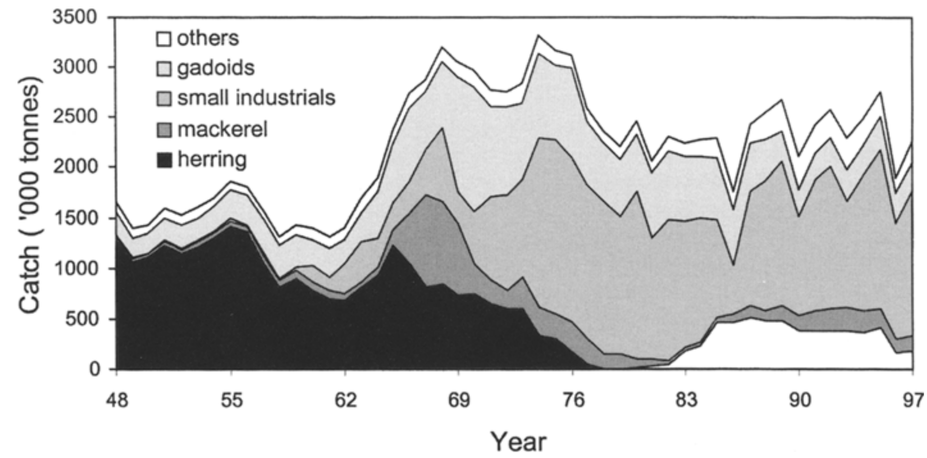

Fig. 5. North Sea fish catch ('000 tonnes): 1948-1997. – Data from ICES.

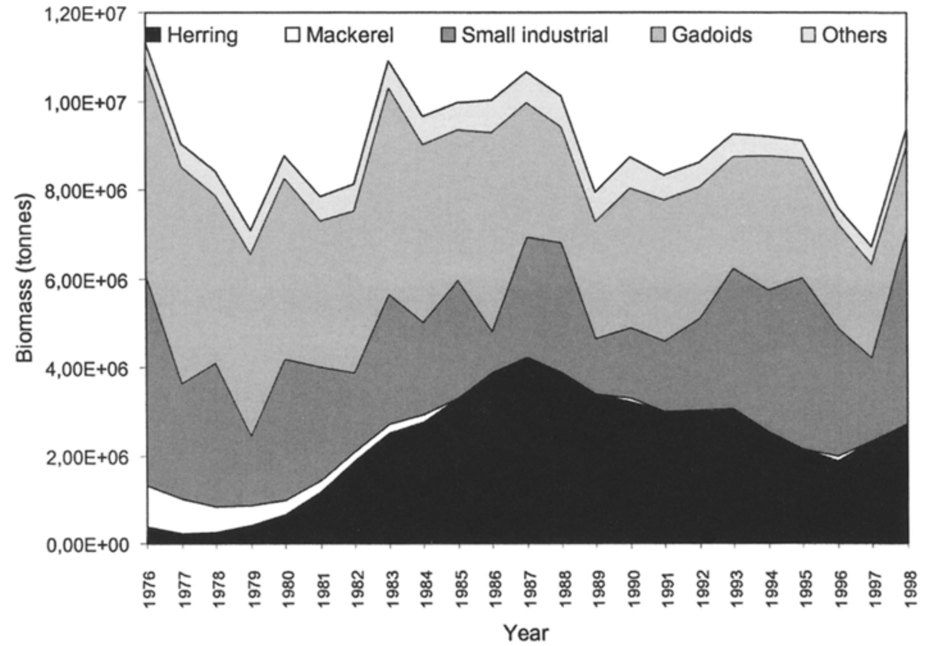

Fig. 6. Biomass of North Sea fish stocks: 1976-1998. – Data from ICES. Mackerel data absent 1985, 1987, 1989, 1991-95 and 1997.

species and some recovery in landings of herring. Using a similar methodology to that in Reid (1984) an estimate of the total biomass of the commercially caught species for which data is available has been calculated (Fig. 6). The data were extracted from the ICES database and are based on Virtual Population Analysis (VPA). The time series is only taken back to 1967, as data for gadoids was only available from this time, with data for small industrial species becoming available from 1976. The VPA calculations that were used to produce the data for this plot are likely to contain considerable error. For example the calculations do not include changes through time in the weight of fish. Interpretation of the plot should thus be treated with caution. It does however suggest that the total biomass of commercial species in the North Sea averages close to ten million tonnes and indicates that there was a substantial reduction in the total biomass of fish in exactly the same years as the minima recorded in CPR zooplankton.

The status of stocks in the Northeast Atlantic is assessed by ICES each year. Management advice, including recommended Total Allowable Catches for fishing areas such as the North Sea, is provided to management commissions, including the European Commission. Most commercial species in the North Sea (ICES area IV) are subject to Total Allowable Catch (TAC)/national quotas/by-catch arrangements. The assessment area varies for each stock and may also include adjacent regions such as the Channel and/or Skagerrak. In 1999 assessments were produced for ten stocks in the North Sea: cod, haddock, whiting, saithe, herring, mackerel, plaice, sole, sandeel, and Norway pout (ICES 2000). A precautionary approach is adopted by ICES in the presentation of its advice. Each year plots of the position of spawning stock biomass against fishing mortality are produced to visually present the status of stocks and recent trends. On these plots a biomass threshold (B_{lim}) and fishing mortality limit (F_{lim}) are defined that should not be reached; as stocks falling below these thresholds are considered to be unsustainable and subject to collapse. To ensure these limits are never reached precautionary reference points are also defined for Spawning Stock Biomass (B_{pa}) and Fishing Mortality (F_{pa}) to signal that urgent management measures are needed to prevent the other thresholds being reached. Fig. 7 shows the 1999 Precautionary Approach Plot for saithe combined for the North Sea (IV), Malin Sea and Rockall (VI) and Skagerrak (III a). The stock is below the proposed safe level of biomass and subject to a higher level of fishing mortality than believed sustainable, i.e. outside safe biological limits (SBL). Seven of the ten North Sea stocks assessed by ICES were fished outside SBL in 1999 with only stocks for the industrial species considered as being at sustainable levels.

This marked decline in the status of so many fish stocks and in the size and maturity of the fish has been mostly attributed to overfishing and reduced recruitment to density driven biological interactions. Recruitment from eggs to mature fish can show orders of magnitude variability from year-to-year. The crucial phase for survival is the larval stage and the availability of planktonic food has been thought to be crucial to larval success. It is only recently that the importance of environmental forcing to recruitment has been recognised (Svendsen & Magnusson 1992; Svendsen et al. 1995; Dippner 1997). Svendsen and collaborators have demonstrated, using multiple regression analysis that 70% of the variability in recruitment to a number of fish stocks can be explained by hydroclimatic variability in the North Sea although the precise processes involved have still to be determined. The multivariate techniques used by Dippner (1997) suggested that variability in recruitment to four fish stocks is highly correlated with sea surface temperature and the NAO. Corten (1990) and Corten & Kamp (1996) suggested that most of the observed changes in the pelagic fish stocks in the North Sea (particularly the dramatic decline of the herring fishery in the late 1970s) could be explained by a reduction in the inflow of Atlantic water during this period, and to changes in the circulation of the North Sea. The hypothesis that changes in the volume flow of Atlantic water into the North Sea has a controlling effect on fish stocks is supported by the work of Svendsen and colleagues and by the results presented here.

Conclusions

A major change has occurred in the North Sea ecosystem circa 1988 that has affected all trophic levels from phytoplankton to fish and birds. Sea surface temperatures since this time have largely remained above average as a direct response to an exceptionally long and high NAO index. Part of this change may be a consequence of global warming. The timing of this 'regime shift' coincides with the beginning of a period with the most persistent and high NAO index since at least the mid 19th century. The period has also been characterised by the incursion and development of species of plankton normally found in more southerly latitudes. The changes seen can be linked to an increase in the advection of warm oceanic water into the North Sea, which appears to be of a pulsed nature, with especially high inflows in 1988 and 1998 (Holliday & Reid 2001; Reid et al. 2001 b). Combined the evidence available suggests that these events are reflecting changes in the circulation in the North Atlantic with an increase in the importance of the eastern margin current, especially at the shelf edge. The hydrometeorological events that took place in the 1987/88 period appear to have impacted terrestrial and marine systems and are likely to have exacerbated coastal eutrophication effects due to enhanced riverine inputs of nutrients. While the coincident timing of all these events does not prove a relationship, the large-scale nature of the changes suggests that they are part of a regional and possibly Atlantic wide climatic change.

An opposite scenario occurred in the period 1978-82 when influx of upper layer oceanic water appears to have been at a minimum. Temperatures at this time were below normal and the plankton present indicates some incursion of cold oceanic water, possibly at intermediate depths. Reduced biomass of zooplankton occurred at this time and the size of the total stocks of North Sea fish appears to have been at a minimum with stocks of herring declining to 50,000 tonnes from an estimated 6 million tonnes in the early 1950s. There is thus increasing evidence for the importance of environmental regulation of many aspects of fish dynamics.

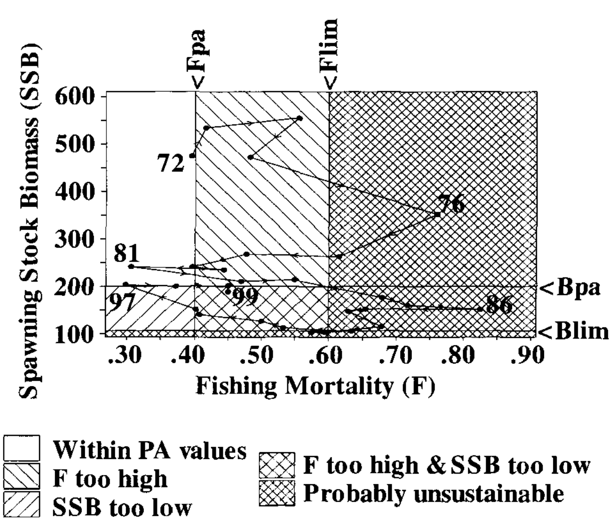

Fig. 7. Precautionary Approach Plot for saithe combined for the North Sea, Malin Sea, Rockall and Skagerrak. – B_{lim}=biomass theshold; F_{lim}=fishing mortality limit; B_{pa}=spawning stock biomass; F_{pa}=fishing mortality.

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