IMPACTS OF CLIMATE CHANGE ON PLANKTON

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Executive Summary

Major changes have taken place in both the plant (phyto-) and animal (zoo-) plankton of the seas around the British Isles over the last few decades. They include a:

- pronounced stepwise change (regime shift) in marine ecosystems since the mid- 1980s,
- northerly movement of warmer water plankton by 10° latitude in 40 years and a similar retreat of colder water plankton to the north
- Considerable changes in the seasonal timing (phenology) of the plankton have been observed
- pronounced change in the composition and abundance of the phyto- and zooplankton
- large increase (400% for sea urchins) in the larval stages of animals living on the bottom in the North Sea since the mid 1980s
- ~50% increase in phytoplankton biomass and an associated long-term decline in zooplankton biomass that includes a 70% decline in the important copepod genus *Calanus* in the North Sea since the late 1950s
- Increase in biodiversity although the species (mostly copepods) are smaller and production is likely to be less.

The observed changes have been significantly linked to regional hydroclimatic variability (SST, salinity, oceanic inflow, wind strength and direction, visibility, nutrients and water column stability) that is associated with climate warming, the North Atlantic Oscillation and in particular Northern Hemisphere temperature. It is the significant statistical association with the latter index of hemispheric warming that suggests that the changes are a regional response to climate warming engendered by greenhouse gases. The observations for the above bullet points primarily come from the 75 year old Continuous Plankton Recorder survey, but are confirmed by other single point time series such as at Helgoland and through intercomparison with satellite measurements.

Modelling studies are still at an early stage although inclusion of the plankton data in new modelling approaches to fishery assessment is giving promising preliminary results. Likely much higher sea temperatures in UK waters in the future will lead to further large changes in plankton as temperature appears to be a major factor in the composition of communities and in the timing (phenology) of populations.

Other factors such as eutrophication, fisheries and in the future acidification may also contribute to plankton variability, but they are believed, by general consensus, to be less important than hydroclimatic forcing. In contrast the changes in the plankton have had a major impact on fish stocks with a decline in gadoid biomass, especially cod, and can also explain the marked reduction in returns of salmon to home waters. A climate link has also been established between plankton, sandeels and seabirds There is regional variability in the patterns of change seen in the plankton, but the general trends described above are characteristic of all waters around the UK.

Level of Confidence

Medium. A high level of confidence is suggested in the information axis primarily on the basis of information from the Continuos Plankton Recorder survey although there is a great deal of other plankton data that is backing up the messages coming from the survey. Modelling is still at an early level, but preliminary work with GAMS, Neural Networks and intercomparison with satellite derived data is helping to confirm a strong linkage between plankton variability and hydroclimatic change with a strong relationship to temperature. It should not be too long before it is possible to forecast possible scenarios for UK seas with higher sea temperatures. Unfortunately, we cannot derive a confidence level for potential shifts like the mid 1980s regime shift that has had such a major impact on the UK marine environment. Thus on average the information available is high, but the confidence in interpretation moderate.

Key Sources of Information

Charting Progress: State of Plankton section (Reid et al., 2005) in Marine Habitats and Species
http://192.171.163.165/Climate%20Encyclopaedia/pdfs/chartprogress-3.pdf

ICES Working Group: Zooplankton Ecology annual reports other documents
http://www.ices.dk/committe/occ/wgze.htm

SAHFOS Ecological Status Report for 2004/5
http://192.171.163.165/annual_reports/annual%20report%202005/ecological%20status%20(ebook).pdf

SAHFOS web site
http://www.sahfos.org/

Supporting Evidence

Chapter 2 in Charting Progress (Reid *et al.,* 2005) gives a comprehensive assessment of the status of plankton in UK waters (Charting Progress: State of Plankton section in Marine Habitats and Species http://192.171.163.165/Climate%20Encyclopaedia/pdfs/chartprogress-3.pdf). An amended version of the executive summary from this paper, that includes some selected references is given below. Readers are referred to the full report for further information. The recently published report by the ICES Working Group on Zooplankton Ecology (Valdes *et al.,* 2006) provides further information on changes in zooplankton and phytoplankton for UK and adjacent waters.

Plankton are at the base of the food chain and are the source of food for all other marine organisms. The carrying capacity of ecosystems in terms of the size of fish resources and recruitment to individual stocks 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. Through the foresight of the UK government in maintaining funding for more than 70 years a comprehensive coverage of plankton variability has been obtained in the waters around the British Isles over this time by the Continuous Plankton Recorder (CPR) survey.

Assessment of the results from the CPR survey indicates that major biological changes have taken place in the plankton over the last few decades in the seas around the British Isles, apparently greater than at any time over the last 100 years. A pronounced stepwise change (regime shift) has occurred in marine ecosystems since the mid-1980s that is reflected in all components of the ecosystem, e.g. plankton, benthos, fish, birds, nutrients and current fluxes (Reid *et al*., 2001, Beaugrand 2004). At about the same time there has been a northerly movement of warmer water plankton by 10° latitude in 40 years and a similar retreat of colder water plankton to the north (Beaugrand *et al*., 2002). While direct causative mechanisms for these changes are at times not fully established, hydro-climatic variability appears to have played an important modulating role. This overriding natural variability, possibly forced by global climate change, needs to be considered in any assessment of the ecological state of UK coastal waters.

Against this background of 'natural' variability the plankton of the seas around the British Isles that are sampled by the CPR appear relatively pristine and apparently unaffected by anthropogenic inputs of contaminants or eutrophication. However, the CPR survey monitors deeper water offshore. It is nearshore regions that are more likely to be affected by pollution and where there is a priority to distinguish between natural forcing and human impacts. At present there is in general no systematic sampling of plankton in nearshore waters, although this will be required in the future to comply with the EU Water

Framework Directive and other international agreements. The evidence for the statement on eutrophication is provided by the similarity of the patterns of change seen in both coastal and offshore regions of the North Sea and areas to the west of Ireland in the ocean (Edwards *et al*., 2001). The changes in phytoplankton are primarily forced by physical factors. This does not mean that eutrophication does not occur in waters closer to the coast, where the CPR does not sample. Physical factors also clearly dominate the patterns of change in zooplankton. Overall there is no evidence for any impact from contaminants on the plankton at the regional scale.

The seas around the British Isles are biologically diverse in terms of plankton, especially so as the UK is at the node of the limits of distribution of warm temperate and cold boreal faunas. This diversity is reflected in the productivity of the seas in terms of harvested resources. Our understanding of the diversity and ecology of certain members of the plankton, including coelenterates and other 'jellies' and the smaller components from micro to picoplankton is, however, far from complete. There have been clear changes in diversity in recent years as a consequence of the regime shift and the biogeographical shifts. The full consequences of these changes for biodiversity, biogeochemical cycles and living marine resources have still to be determined as have the potential impacts on the 'biological pump'. Ecosystems around the UK appear to have moved into a warmer dynamic regime that is possibly leading to a greater transport of material to the benthos with a faster turnover in the plankton involving the microbial loop. Temperature appears to be a major factor in the composition of communities and in the timing (phenology) of populations (Edwards and Richardson, 2004; Richardson and Schoeman, 2004).

Highly significant relationships have been found between plankton, salmon returns to home waters, cod and other demersal species and three indices of hydrometeorological forcing (Northern Hemisphere temperature (NHT), Sea Surface Temperature (SST) in the eastern Atlantic and the North Atlantic Oscillation (NAO)) (Beaugrand and Reid, 2003). These relationships have been reinforced by a strong link with NHT from the 1980s onwards. As the rapid rise in NHT has been attributed to increasing levels of greenhouse gases it is possible that the recent observed changes in the plankton are a response to global warming. If the predictions of the International Panel on Climate Change (IPCC) of a continuing rise in global temperatures prevail then it can be expected that returns of salmon to home waters will continue to decline, especially at the southern edge of their distribution in Spain and France and possibly in the UK. In recent decades North Sea cod stocks have undergone a pronounced decline as a consequence of overfishing. The radical switch that occurred in the plankton environment of larval/juvenile cod since ~1987 has exacerbated the impact of overfishing on cod as conditions have been highly unfavourable for the survival of young cod. The planktonic copepods that form the principal food of larval cod when they hatch from their eggs have changed in composition, with a reduction in size and biomass and a mismatch in the timing of occurrence of the cod larvae and their favoured planktonic food (Beaugrand *et al.,* 2003). Stocks of the boreal cod, as for the salmon, are also likely to decline if Northern Hemisphere temperatures continue to rise, although it should be remembered that a single year with good recruitment could lead to a rapid improvement in cod stocks.

Part of the sequence of changes that have occurred since the mid-1980s has been an apparent alteration in the current patterns in the North Atlantic, with an increased inflow of oceanic water into the North Sea from a more southerly source. Higher flows in the slope current are implicated. Possibly through increased nutrient supply from the ocean and higher temperatures, phytoplankton biomass and, almost certainly, production has increased in most UK waters, especially in the North Sea and in an area off the shelf to the west of Northern Ireland. Some idea of the scale of the change can be seen in the 90% increase in winter levels of Phytoplankton Colour (a visual index of chlorophyll) post 1987. Good calibration has recently been achieved between this index and SeaWiFS measures of chlorophyll reinforcing the message of the change (Raitsos *et al*., 2005). As the changes occur in both the North Sea and off the shelf they clearly cannot be attributed to eutrophication.

Because of the data rich nature of the CPR archive and the long period over which samples have been taken and analysed, it is possible to determine baseline conditions for a range of planktonic species and indices in terms of abundance, biomass and biodiversity. These indices may be calculated from mean results or changes since the beginning of the time series or from when important changes took place in the methodology of analysis. Results were presented for a set of proposed indicators of the state of UK marine waters. Four general indices of plankton were selected to summarise the main patterns of change (total copepods, abundance of the copepod *Calanus finmarchicus*, ratios of the copepods *Calanus finmarchicus* and *Calanus helgolandicus* and phytoplankton colour). In addition, seven assemblages of copepod plankton were outlined that reflect changes in water masses around the UK. Patterns of change were also described for ‘Harmful Algal Bloom’ species and introduced ‘non-native species’.

Observed planktonic variability emphasises the need to develop an ecological approach to monitoring human impacts and also for a multiscale approach that quantifies some degree of natural variability from a regional scale down to a local scale. Confidence in any assessment of anthropogenic impacts on the biological systems found in UK coastal waters will only be possible if wider pan-Atlantic influences and ‘natural’ variability through time are taken into consideration.

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