IMPACTS OF CLIMATE CHANGE ON NUTRIENT ENRICHMENT

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Executive Summary

Nutrient supply in the form of nitrate-nitrogen is generally considered to be the key driver of eutrophication in the marine environment. The main source of nitrate is from rivers. Inputs to rivers are complex and largely determined by human activity; legislation should tend to decrease inputs but current world patterns suggests inputs will increase, as do models looking at climate change effects on the UK. Denitrification is the major process removing nitrate from the North Sea. This requires that inputs of ocean waters are critical to maintaining concentrations in shelf sea waters. Microbiological studies and a model suggest increased temperatures may decrease denitrification. Higher concentrations of nitrate may lead to a switch to phosphate as the limiting nutrient. Increased storminess will increase concentrations of nutrients at the ocean surface and may increase supply to shelf seas, but our understanding of the transfer process is poor as hydrographic models do not work well in this region and observations are sparse. Models of productivity in the ocean in a warmer climate suggest increased stratification in summer will limit nutrient supply to surface waters during the productive seasons and inhibit mixing due to storms in winter. Similar model scenarios have not yet been run for shelf seas. The few existing long-term data sets have proved useful in identifying the path of eutrophication and relative impacts in different regions of the North Sea. They are not adequate for identifying climate change in the way that the Continuous Plankton Recorder surveys may have done for plankton. New systems of monitoring using buoys and Ferryboxes have the potential when used with numerical models to improve our ability to deconvolute and quantify the complex set of processes that control nutrient supply and eutrophication.

Level of Confidence

Understanding of climate effects on nutrient concentrations and eutrophication in the North Sea is poor. Insufficient data exists on changes in nutrients with time and over sufficiently large areas to be able to make similar assessments to those done for plankton (CPR work e.g. Beaugrand *et al.,* 2000). If pulses of flow are occurring (e.g. Reid *et al*., 2001) and generating regime shifts then it would be expected that there may be changes in nutrient loads and that changes in biological activity would be feeding back into changes in nutrient concentration cycles. In the only case where nutrients have been considered

as part of an analysis of regime shifts - Weijerman *et al*. (2005) - there is little evidence of shifts in nutrient concentrations consistent with shifts in salinity.
To better understand the likely impact of climate change on eutrophication of the North Sea the key areas that require research are:- (1) Likely changes in river inputs - this research is underway. (2) Better understanding of the role of denitrification - little research on this is currently been done. The paper by Brion *et al*. (2004) shows that estimates of its importance have large uncertainties. The consequences of increasing temperature on the ratio of denitrification to ammonification are only considered in one paper (Kelly-Gerreyn *et al*., 2001). (3) Changes in the flow of Atlantic water may be an important control of the North Sea ecosystem (Reid *et al*., 2001) but numerical models which might be used to assess these changes with climate change have only a poor skill level when determining cross-shelf exchange. (4) The relative effects of increased storminess and increased stratification have not yet been examined for shelf sea systems.

Because of the low availability of historical data and questions about its quality in some cases (e.g. Joint *et al*., 1997), the past is not the key to the future in this area of research. However, new systems of monitoring using buoys and Ferryboxes have the potential when used with numerical models to improve our ability to deconvolute and quantify the complex set of processes that control nutrient supply and eutrophication.

Key sources of Information

See supporting evidence

Supporting Evidence

Nutrient supply in the form of nitrate-nitrogen is generally considered to be the key driver of eutrophication in the marine environment. The main source of nitrate is from rivers. Inputs to rivers are complex and largely determined by human activity. This was well described in a series of papers published in the journal “Biogeochemistry” in 1996; see Nixon *et al.* (1996) and OSPAR documents (OSPAR 2000). Legislation should tend to decrease inputs (OSPAR 2003) but current world patterns suggest inputs will increase, as do models looking at climate change effects on the UK. There is significant research effort looking at likely river inputs both on a global scale (Jones *et al* 1998; Dumont *et al.* 2005) and from UK sources (Wilby *et al* In Press). Denitrification is the major process removing nitrate from the North Sea (Brion *et al* 2004). This requires that inputs of ocean waters are critical to maintaining concentrations in shelf sea waters (Hydes *et al.* 1999). Microbiological studies and a model suggest increased temperatures may decrease denitrification, not only would denitrification not occur but the product of microbial processing would be ammonia which might enhance rates of plankton production (Kelly-Gerreyn *et al*., 2002). Higher concentrations of nitrate may lead to a switch to phosphate as the limiting nutrient.

Increased storminess will increase concentrations of nutrients at the ocean surface (and may increase supply to shelf seas, but our understanding of the transfer process is poor as hydrographic models do not work well in this region and observations are sparse (Huthnance, 1995 and 1997). Insufficient research has been carried out in this area. Use is often made of model assessments of flow (e.g. Brion *et al*., 2004) without due consideration to their accuracy. A general idea of the stability of conditions with time and rate of ocean influence can be gained from the data from the MBA E1 monitoring station (Pingree *et al*., 1977). Models of productivity in the ocean in a warmer climate suggest increased stratification in summer will limit nutrient supply to surface waters during the productive seasons and inhibit mixing due to storms in winter (the paper by Huisman *et al*. (2006) is an example). Similar model scenarios have not yet been run for shelf seas, but are planned as part of the PML contribution to the new NERC programme “Oceans 2025”, this will be part of the continued development of the ERSEM model (see note).

The few existing long-term data sets have proved useful in identifying the path of eutrophication and relative impacts in different regions of the North Sea. In particular the data collected at the Liverpool University’s Isle of Man site known as “Cypris” has provided a valuable in sight into the effect of increased river concentrations on an offshore station. It shows how concentrations increased from the 1950s into the 1970s and have now steadied (Gowen *et al.,* 2002). Work following the assembly of data by the EU-FP-NOWESP project (Laane *et al* 1996a) attempted to link findings from the sites where monitoring has been carried out in the Irish Sea, English Channel and North Sea. This found that similar trends could be detected in the English Channel and North Sea but that conditions in the Irish Sea at Cypris were the product of local conditions (Laane *et al*., 1996). These existing data sets are not adequate for identifying climate change in the way that the Continuous Plankton Recorder surveys (Batten *et al*., 2003) may have done for plankton (e.g., Beaugrand *et al* 2000). Southward suggested concentrations of phosphate in the English Channel at the MBA E1 may be controlled by a climatically controlled "Russell Cycle", however, close inspection of the likely data quality by Joint *et al*. (1997) has called into question the reliability of this data.

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ERSEM

The European Regional Seas Ecosystem Model (ERSEM) is a complex plankton functional type (PFT) model developed in the context of the North Sea but now finding wider application (Baretta *et al,* 1995; Blackford *et al*, 2004). The POLCOMS hydrodynamic model is a three dimensional baroclinic circulation model in this case set up for the UK shelf seas, taking boundary conditions from wider area versions of the same model. It is described in detail in Holt and James (2001). The ERSEM-POLCOMS model demonstrates some skill in reproducing regional observations (Holt *et al,* 2005).

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