Topic

Nutrient enrichment

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Executive summary

The supply of macro-nutrients (nitrate, ammonia and phosphate) is generally considered to be the key driver of **eutrophication** of shelf seas. Current world patterns suggest inputs are increasing, while inputs to European seas may be decreasing. If summers get drier, these inputs may continue to decrease although sudden summer storms may deliver nutrient pulses with consequences that are difficult to predict. **Denitrification** is the major process that removes nitrate from the North Sea. Consequently inputs of ocean waters are critical to maintaining concentrations in shelf sea waters. Studies 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 transfer into shelf seas. Our understanding of the transfer process is poor. 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. The data record changes in nutrient concentration but it has proved extremely difficult to discriminate between the effects of human discharges and those which may be due to climate change through rainfall and ocean transport. 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.

Full review

Coastal waters- river inputs

The supply of macro-nutrients (nitrate, ammonia and phosphate) is generally considered to be the key driver of **eutrophication** of shelf seas. In general ammonia inputs derive mainly from human activities, and less from natural geochemical processes in the terrestrial river catchments. Nitrate inputs also derive from human activities, particularly agriculture, but also from land erosion processes which are a function of rainfall patterns. Current world patterns suggest inputs are increasing, while inputs to European seas may be decreasing. At salinities less than about 34 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 (OSPARCOM 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 with work on specific catchments (e.g.Wilby *et al*., 2006).

Heath (2007) developed a statistical method for modeling the spatial and temporal patterns of oxidised nitrogen (nitrate plus nitrite) riverine fluxes into the coastal waters of northwestern Europe, over the period 1960-2005. **UKCIP02** Climate Change high and low emission scenarios predict that winter precipitation will increase over south-eastern UK while summers are expected to become much dryer. However, there is already evidence that dry summers may also be associated with an increase in storm events. The resultant increased runoff will lead to pulses of nutrients with uncertain consequences in terms of coastal productivity. Overall, annual precipitation is expected to reduce over south-eastern UK. Based on these predicted trends in precipitation, and the historical patterns of discharge and flow-weighted concentration (Heath, 2007) it is predicted that, assuming land-use and anthropogenic sources of nitrate within the catchments remain approximately constant, then annual fluxes of nitrate + nitrate to UK coastal waters of southern and south-eastern UK (North Sea south, Channel and Celtic Sea) should decrease in line with precipitation patterns under both high and low emission scenarios. However, annual fluxes of nitrate and nitrite to coastal waters of northern and north-western UK (Atlantic, North Sea north, Irish Sea) are harder to predict, being more dependent on concentrations in river waters and hence on land-use and **anthropogenic** sources. Radach & Patsch (2007) determined the monthly and annual riverine freshwater, nitrogen (N) and phosphorus (P) loading into the North Sea from Belgium, The Netherlands, and Germany for the period 1977–2000. They found that for continental Europe rivers with inputs to the southern North Sea the annual N loads had decreased by about 17 kt N /yr between 1977 and 2000. The total phosphorus and phosphate loads had decreased from about 80 and 50 kt P /yr in the 1980s to 25 and 12 kt P /yr, respectively, in the 1990s.

Long-term data sets have proved useful in identifying the path of eutrophication and relative impacts in different regions of the North West European shelf. In particular the data collected at Liverpool University's Isle of Man site known as "Cypris" has provided a valuable insight 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 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*., 1996b).

Open waters - ocean inputs

In the Celtic Sea, the English Channel Irish Sea and southern North Sea at salinities greater than about 34, the concentration of nitrate in the water may be more determined by the concentration in ocean source waters. (Hydes *et al*., 1999; Gowen *et al*., 2002). The similarities in variation between sites found by Laane *et al.,* (1996b) suggest that long range processes may be important, such as the variation in transport of ocean water on to the shelf.

At the end of winter, concentrations of nitrate in surface waters of the Atlantic Ocean adjacent to the shelf are higher than those found over much of the shelf (Hydes *et al*., 2004). Limited information is available on how these concentrations vary from year to year and on the variability of the exchange of these waters across the shelf break. Newer time series data show that changes from year to year of 50% are possible (Kelly-Gerreyn *et al.*, 2007) as a result of changes in the depths of winter mixing (Valencia *et al*., 2004).

As part of the description of the variability of the ecosystem in the Western Approaches, Southward (1980) suggested that a climatically controlled "**Russell Cycle**" determines concentrations of phosphate in the English Channel. In 1997 after close inspection of the data and procedures used, Joint et al. (1997) raised doubts about how well the quality of the **MBA E1** data had been maintained. However, data collected in 2006 (Kelly-Gerreyn *et al*., 2007) show that 2006 concentrations were as low the low values recorded from E1 in the 1960s.

Climate change scenarios predict increased storminess. This may increase the depth of mixing in winter and consequently increase concentrations of nutrients at the ocean surface. Depending on the efficiency of the transfer process the supply of nutrient to shelf seas may also be increased. However our understanding of the transfer process is poor. 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. Where model assessments of flow have been used to consider these possibilities it has been done without due consideration of their accuracy of the model estimates (e.g. Brion *et al*., 2004).

Internal processes changing nutrient supply

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 in references).

Denitrification is the major process that removes 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*., 2001). Higher concentrations of nitrate may lead to a switch to phosphate as the limiting nutrient.

Confidence assessments

'What is already happening' - Low

'What could happen in the future' - Low

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 that 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.

Two significant time series providing information over decades are available from the CYPRIS site in the Irish Sea and the MBA E1 site in the English Channel. The CYPRIS data clearly records increases in nutrient concentrations before 1974 and levelling off since then overall concentration of nitrate are less than would be expected due to removal by denitrification in the central Irish Sea (Gowen *et al*., 2002; Hydes *et al*., 2004). The E1 data set has the potential to be more directly influenced by changes in ocean supply. The validity of the inter-decadal changes seen in the data has been questioned (Joint *et al*., 1997), however data collected in 2006 shows that concentrations of phosphate are now similar to the relatively low concentrations observed in the 1960s (Kelly-Gerreyn *et al*., 2007). Continued collection of time series data is required. This should be done in conjunction with new systems of monitoring using buoys and Ferryboxes. They provide the high resolution data required to deconvolute and quantify the complex set of processes that control nutrient supply and eutrophication by the validation and calibration of numerical models.

Knowledge gaps

Refer to confidence section

Commercial impacts

Not stated

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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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