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THE IMPACT OF NUTRIENTS IN ESTUARIES

Proceedings of a Workshop held at the Headquarters of English Nature, Peterborough, on 23rd May, 1995, under the auspices of the National Rivers Authority and English Nature.

D.B.Nedwell
University of Essex
Department of Biology
Colchester CO4 3SQ.

Commissioning Organisations

National Rivers Authority
Rivers House
Aztec West
Almondsbury
Bristol BS12 2UD

Tel: 01454 624400
Fax: 01454 624409

Co-funded by:

English Nature
Northminster House
Peterborough
PE1 1UA

Tel: 01733 340345
Fax: 01733 68834

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This is an "interim" report, and as such its dissemination is restricted. It will be released internally within the NRA and English Nature, and externally to Workshop participants only, for comment and information.

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The primary use of this document is to enable the scoping of objectives for Phase II of R&D Project A01(95) 6.

Contractor

This document was produced by:

Professor D.B.Nedwell
University of Essex
Department of Biology
Colchester CO4 3SQ.

Tel: 01206 873333
Fax: 01206 873598

NRA Project Leader

Further information can be obtained from the NRA's project leader for this project - Robin Chatterjee (TAPS Centre, Peterborough, NRA Anglian Region - Tel: 01733 464416), or Alastair Burn at English Nature (at the above address)

PARTICIPANTS

National Rivers Authority

Dr Alastair Ferguson (Anglian/National Centre for Toxic and Persistent Substances)
Mr Robin Chatterjee (Anglian/National Centre for Toxic and Persistent Substances)
Mr Simon Leaf (Bristol Head Office)
Mr Barrie Harbott (Anglian)
Mr Andrew Wither (North West)
Dr Peter Jonas (Southwestern)
Mr Mark Johnson (Anglian)
Dr Mark Everard (Bristol Head Office)
Mr John Pomfret (Contractor)

English Nature
Dr Alastair Burn

Conservation Council for Wales
Dr Rod Jones

SNH
Dr Scot Mathieson

JNCC
Dr Keith Hiscock

River Purification Boards
Dr Tom Leatherland (Forth)
Dr Richard Park (Forth)
Dr Ken Pugh (North East)
Mr Peter Holmes (Clyde)

Minsitry of Agriculture Fisheries and Food
Dr Stephen Malcolm

Department of the Environment
Mr Andrew Osborne

World Wildlife Fund for Nature
Dr Sian Pullen

Universities

Dr Malcolm McGarvin (Aberdeen)
Dr Stewart Evans (Newcastle)
Prof. Peter Evans (Durham)
Dr Tim Jickells (East Anglia)
Ms Katie Prastka (East Anglia)
Prof. David Nedwell (Essex)
Dr Graham Underwood (Essex)
Mr Mark Trimmer (Essex)
Dr R. Hartnoll (Liverpool)
Prof. John Raven (Dundee)
Dr Andrew Lawrence (Hull)
Dr Duncan Purdie (Southampton)
Prof. Steven Hawkins (Southampton)

Institute of Oceanographic Sciences

Dr David Hydes

Sir Alistair Hardy Foundation for Oceanographic Sciences

Dr Chris Reid.

WELCOME

Dr Keith Duff (Chief Scientist, English Nature)

Estuaries form about a third of the Sites of Special Scientific Interest (SSSIs) in England, for which English Nature has responsibility. In addition EN has identified some 27 non-statutory Sensitive Marine Areas which include both estuarine and marine habitats, some of which have been proposed as possible Special Areas for Conservation. There is a need to know more about the effect of nutrient enrichment in estuarine environments, and English Nature is collaborating with the National Rivers Authority in developing a strategy for management and conservation in the estuarine and coastal region. Research priorities necessary to develop such a strategy must be decided by informed debate, and input from all interested parties has been invited, exemplified by the wide area of interest of those attending the workshop.

INTRODUCTION

Dr. Mark Everard (Water Quality Planner, National Rivers Authority, Head Office)

The National Rivers Authority (NRA) is responsible for the protection of the water environment throughout England and Wales. This includes some 175 estuaries. In pursuing the sensitive management of these estuaries, the NRA needs to be informed by the best available science, but must also take account of the uses to which these estuaries are put as well as other related initiatives affecting them (for example, the 27 Sensitive Marine Areas identified by English Nature). The NRA and English Nature have jointly arranged this workshop in order to obtain the views of a range of experts in the field, and also to ensure that our strategic thinking is convergent.

Before embarking on our study of the effects of nutrients in estuaries, it is useful to make some observations about the nature of the estuarine ecosystem. Estuaries may be large, readily identifiable systems. They are, however, difficult to define precisely, and particularly at their boundaries with the open ocean or with river systems. Designations relating to estuarine systems may be prone to political expediency in the absence of an adequately precise scientific definition.

In considering the ecology of estuarine systems, it is perhaps more fruitful to think of them as ecotones between rivers and coastal seas. This not only helps us understand why a precise definition is elusive, but also emphasises the fact that they are dynamic systems, energetic and stressed.

Estuaries are also diverse systems owing to a range of seaward and landward influences, as well as the nature and usage of the estuary itself. Seaward influences include tidal range and sediment feed, whereas the most important landward influences arise from the geomorphology, size and land use in the upstream catchment. These catchment effects are key factors determining the discharge, flux of nutrients, sediments and other substances entering estuaries. Both the seaward and landward factors combine to produce wide variations in turbidity, natural trophic status, salinity gradients, stratification, etc. This variability is further impacted by the size, bathymetry and hydrology of the estuary itself (including whether the estuary is flushed or enclosed), as well as the usage of the estuary for navigation, leisure, industry or urban development. This wide variability in environmental and anthropogenic parameters gives rise to a great deal of background `noise' in estuarine systems.

The effect of nutrient enrichment has to be discriminated from this inherent noise. For the NRA's part, it is helpful to assess the impact of nutrients on the functional responsibilities of the Authority, and to put them into context with other influences upon the Estuary. The impact of nutrients, for example, has to be considered in relation to other water quality parameters such as sanitary pollution, heavy metals, and pesticides in determining management requirements and priorities.

If the problem is hard to define, it is then perhaps even harder to control. In determining management decisions relating to nutrient control in estuaries one is faced with the fact that, unlike many of the more common pollutants that the NRA has to deal with, nutrient elevation is not necessarily a result of urbanisation in the catchment but may arise by large measure from diffuse agricultural inputs. Inevitably, control measures must involve organisations other than the NRA or the statutory conservation agencies.

A range of drivers make it necessary to get an understanding of the impact of nutrients in estuaries.

1. *Statutory reasons for nutrient control which are legal obligations.*

- Statutory Water Quality Objectives for special ecosystems (Water Resources Act, 1991).

- EC Directives binding on member states. There are 5 directives of which 3 are very important:-

  Urban Wastewater Treatment directive operates on reducing pollution from wastewater treatment works, and in Sensitive Areas for Eutrophication (SAEs) member states are required to reduce nutrient input. No SAEs are yet designated in England and Wales, although there are 46 potential candidate SAEs for 1997.

  Nitrates directive requires control of nitrate into nitrate-vulnerable zones. There are currently no nitrate-vulnerable estuaries in England and Wales.

  Habitats and Species directive. Sixteen of the sensitive marine areas have been proposed as sensitive areas for conservation (SACs) under this directive and some assessment of the effect of nutrient will have to made in these areas.Likewise, some 85 Species Protection Areas (SPAs) under the Birds Directive may require review under the terms of the Habitats and Species Directive.

  Bathing Water directive doesn't deal with nutrients directly, but adverse trophic effects are within the 'aesthetic parameters' for that directive.

  Ecological Quality of Waters directive is at the draft stage, and any conclusions on the indicators of nutrient impact will provide valuable input.

2. *The North Atlantic Treaty* requires signatories to reduce inputs of substances to the North Atlantic. Specifically under the North Sea Conference, states generally agreed to reduce nutrients by 50% between 1985 and 1995, however the UK made no formal commitment to this.

3. *Non-statutory reasons for nutrient control.*

- NRA eutrophication control strategy, which needs to be directed by good science.

- Support for the Sensitive Marine Areas (SMAs) identified by English Nature.

- Management of SSSIs

- Fisheries requirements (Fin and Shell fish) - control of red tides, dinoflagellates, paralytic shellfish poisoning

- General quality assessment scheme of NRA; monitoring to obtain picture of the trend of nutrient concentrations around the country.

- Conservation needs

  General duty to conserve
  RAMSAR convention sites
  Birds directive sites
  Agenda 21 biodiversity
  Recommendations of the Royal Commission on Environmental Pollution

Purpose of Workshop. The workshop arose from the NRA Research and Development programme, with cofunding from English Nature. A need was recognised to assemble scientists and policy-makers to try to decide the importance of nutrients in estuaries. This requires us to

- understand the extent of nutrient elevation in estuaries

- understand the natural background variability of nutrients against which elevation is measured.

Then to identify

- the effect of nutrient elevation on a quantitative basis, although a qualitative basis is probably the best achievable in many cases at the moment.

- effects of nutrient elevation in the different types of estuaries.

- other research needs to elucidate effects of nutrient elevation.

- priorities for action.

- cost-benefit analysis of control or management actions.

EFFECTS OF ELEVATED NUTRIENTS ON PHYTOPLANKTON

Dr Chris Reid (Director, Sir Alistair Hardy Foundation for Ocean Sciences, Plymouth)

There are not many studies of phytoplankton in UK estuaries over a full seasonal cycle. The one exception is the Firth of Forth study where work by the FRPB has been carried out over a number of years. We know little about the occurrence of phytoplankton in estuaries, nor the impact that they have on the estuarine ecosystem. This is to some extent due to the high turbidity found in many UK estuaries, and a perception, therefore, that phytoplankton are of limited importance.

A characteristic seasonal cycle in coastal waters around the UK is a spring bloom of diatoms peaking at about May, diatoms decreasing as silicate is removed from the water. Diatoms may reappear in the autumn. After the spring diatom peak there is typically a bloom of microflagellates (often *Phaeocystis spp.*) which is usually intense but short-lived. This is followed by a dinoflagellate peak in the summer months, particularly in areas where the water column becomes stratified and nutrient limited. Many other groups of phytoplankton are involved in the seasonal cycle, but their contribution is less marked or less well understood.

This seasonal pattern is driven by the cycle of light, peaking around June, interacting with nutrient availability. Nutrient fluxes from UK rivers into North Sea estuaries peak around February, with maximum rainfall, and this has a major effect on seasonality in coastal waters. In contrast, river estuaries on the Norwegian coast show maximum nutrient fluxes in spring (May) when snow melt transports high nutrient concentrations. These seasonal effects are likely to have a large impact on nutrient transport through estuaries into the North Sea.

Are nutrients elevated in estuaries and coastal waters ? In most European rivers nutrients clearly are elevated above the mean levels of the last 40 years. In the Rhine, for example, phosphate concentrations increased until the late '80s, when phosphate-based detergents disappeared, and then decreased. Particulate phosphate and ammonium also peaked in the 1980s, and then decreased somewhat, concurrent with the introduction of secondary sewage treatment. Nitrate has shown a continued rise in both the Rhine and Elbe up to 1990, by 2 orders of magnitude compared to the 1950s. Some UK rivers show similar trends for nitrate. Nitrate concentrations in river water increase with increased river flow rate, whereas phosphate decreases. The N:P ratios, therefore may vary dramatically on a seasonal basis and contribute to the variability and abundance of different algal groups in the seasonal succession..

The inputs of nutrients to the North Sea from UK estuaries are minimal compared to those from the Rhine and Elbe, and are spread out over a much longer section of coast because of the relative size of the rivers. The population density in the Rhine catchment area is matched in the UK only in the much smaller Thames catchment, explaining the much greater impact of the Rhine nutrient inputs to the North Sea. This does not mean that the nutrient levels within the UK estuaries are unimportant, as their ecology may still be perturbed by elevated nutrients. The UK has one of the largest areas of continental shelf in the North Atlantic region, with very dynamic tides. Coastal seas around the UK, from the Ushant front at the mouth of the Channel to the Flamborough front, are usually well mixed throughout the year, and this probably affects the estuaries in this area. Suspended sediment off the East Anglian coast is very high, and has a large effect upon primary production as turbidity limits photosynthesis. Under these light-limited conditions nutrients generally are not stripped from the water by phytoplankton productivity. Similar light limitation of phytoplankton photosynthesis may occur in many estuaries, which tend to be very turbid, although complete light-limitation in turbid waters is not the case, as recently demonstrated by the JoNuS programme in the Wash. Finally, in waters off the UK east coast time-series measurements of nutrients, standardized to salinity, show no evidence for an increasing trend over the last 30 years.

What is the nutrient status of the North Sea ? A feature which has only been realised relatively recently is that recycling of nutrients by bacterial breakdown of organic matter may be as important in sustaining primary production in the North Sea, particularly during summer, as flux of new nutrients through the estuaries to the Sea. In the northern North Sea, the majority of nutrients derive from the North Atlantic: here riverine and atmospheric inputs of nutrients are relatively small. In the southern North Sea, though, the influence of the North Atlantic water is minor. The highest nitrate concentrations (up to 20-30 µM) occur along the Dutch-German coast, with lower concentrations off the UK East Coast. By comparison, in the Irish Sea nitrate concentrations may be as high as 50-150 µM in Liverpool Bay . From the NERC North Sea programme, it was apparent that both chlorophyll and primary production were highest off the German coast, around the Rhine and in the German Bight, and low off the UK East Coast.

The modelling work of David Hydes is very relevant to this consideration for the North Sea. Total available N is lowest in the seawater off the UK coast, and on an annual basis the supply of new nitrogen from riverine and atmospheric inputs is not sufficient to support the measured phytoplankton primary production. In fact, 2 to 3 times the flux of new nitrogen is required to support primary production. The difference must be derived from recycling of nitrogen within the North Sea by bacterial breakdown of partickululate organic matter. This has enormous implications for the potential effects to be derived from the proposed 50% reduction in the output of nutrients to the North Sea. Such a reduction may be very costly to achieve, yet will have a minimal impact in terms of reduced primary production off the UK coast (calculated from the above model as an 8% reduction).

Effects of nutrients on phytoplankton: algal blooms Large foam banks can be produced in summer on Dutch beaches and around Lowestoft, generated by the breakdown of the *Phaeocystis* blooms which occur in these areas every year. Such blooms occurred extensively in the North Sea even in the 1930s, and in the 19th century. The link between *Phaeocystis* and elevated nutrient concentrations in sea water is not proven, but there does seem to be a link between the incidence of blooms in the coastal waters of the Netherlands and the flow of the River Rhine. Part of what is happening may be linked to changes in the ratios of nutrients that are coming down the rivers, rather than changes in the concentration of any one nutrient.

The toxic dinoflagellate *Gyrodinium aureolum* is distributed around the North Sea, particularly off the Norwegian coast, off the south west UK coast, and in the Irish Sea. Blooms of this species have been suggested to be associated with nutrient enrichment, but no direct or consistent link with high nutrient concentrations has been proven. For virtually all 'nuisance' algal species there is a general lack of good evidence of a consistent link between blooms and nutrient enrichment in UK coastal waters and estuaries. The occurence of blooms in coastal waters is often held to be evidence of eutrophication effects, but there is no good evidence from UK examples that this is the case.

The other parameter that is often associated with algal blooms and eutrophication is the occurence of kills of fish and benthic biota. There is a large concentration of reports of such kills around the Kattegat, correlated with blooms of *Gyrodinium* and other algal species, but this sea area is unusual with very strong and almost permanent stratification caused by the low salinity outflow from the Baltic. Reports of 'kills' most often occur where there is strong stratification. In contrast, there have been no blooms of *Gyrodinium* associated with the high nutrient pulses which come down the Elbe, probably due to light-limitation and unfavourable nutrient concentrations for bloom conditions. There may be more reliable evidence for the effect of elevated nutrients probably only in those estuaries where there is progressive increase of nutrient concentrations towards the freshwater end.

Summary. There is no evidence for elevated nutrients in UK coastal waters, and the relative size of UK inputs and new information on the importance of recycling support this observation. In some UK estuaries the situation is less clear because of the processes such as denitrification that take place. But does this mean that higher levels of nutrients in estuaries are having an impact on the phytoplankton ? It is unlikely that they are having any major effect on phytoplankton production, in many cases because of high turbidity. One suggestion is that nutrients are merely transported through the estuary by flushing and their effect is in the coastal zone, although there is no direct evidence yet to support this view. However, phytoplankton can grow in estuaries despite their high turbidity, and more work is required to understand the impact of higher nutrients concentrations on phytoplankton production within estuaries, and the effect this has on net fluxes to the sea.

THE EFFECTS OF ELEVATED NUTRIENTS ON MACROALGAE.

Professor John Raven (University of Dundee)

The discussion of this topic encompasses four questions.

1. What are macroalgae ?

2. Which ones 'bloom' ?

3. Do the bloomers respond specifically to N and P availability ?

4. What next ?

Macroalgae can be defined as photosynthetic organisms that live in the sea and are > 1mm long. The classical taxonomy includes individuals in Chlorophyta, Phaeophyta and Rhodophyta, although the majority are in the Chlorophyta, including species of *Enteromorpha, Ulva, Chaetomorpha,* and *Cladophora;* with *Ectocarpus* in the Phaeophyta.

The characteristics of these bloom algae are

1. Lack of differentiation (resources go into fast growth rates).

2. Potential for rapid growth under high resource conditions (doubling times of days rather than weeks)

3. Relatively short-lived

That is, they are r-adapted species, adapted to exploit transient environments.

The other type of algae are those that tend to be displaced by the 'bloomers'; for example *Fucus spiralis*. They tend to have much slower growth, and longer life span.

This can be viewed in terms of an ecological , rather than taxonomic, classification, such as that used for landplants (Grime, 1979). Grime categorised organisms on the basis of their strategies in response to two factors - stress (the relative unavailability of resources which are required to produce biomass) and disturbance (factors which remove or destroy the existing biomass). The blooming macroalgae fit into the *ruderals* or *ephemerals*, adapted genetically to live in transient habitats. Such species are adapted to resource-rich but transient environments; characteristic of environments with high nutrients combined with high stress (the habitats that they occupy being taken over by another organism, or totally destroyed). That seems to be their natural occurrence in normal environmental conditions. But what is it about eutrophication which permits them to dominate ? Is it specifically their response to N and P ? Or do other factors (e.g. light, temperature, turbidity, etc.) play a part ?

What resource limits primary productivity ? The 'limiting resource' is that which, by a fractional increase, gives the largest fractional increase in net production (rate limitation) or in final biomass achieved (extent limitation). For nutrients, both uptake and assimilation must both be considered. Analysis requires knowledge of

a] Properties of both uptake and assimilation of NO_3^-/NH_4^+ and of $H_2PO_4^-/HPO_4^{2-}$

b] Growth rate as a function of N or P in the algae.

This requires knowledge of both the extracellular and internal concentrations of nutrients, and how they effect growth rate.

Properties of uptake and assimilation are usually described by Michaelis-Menten relationships which usually fit the data well, although there may be truncation at low nutrient concentrations due to diffusion limitation.

Table 1. Half-saturation constant (K_m), maximum uptake rate (V_m) and specific affinity (V_m/K_m) for nitrate, ammonium and phosphate uptake (data after Wallentinus, 1982).

<u>Nitrate</u>

	K_m (μmol dm^{-3})	V_m (μmol g^{-1} dw h^{-1})	V_m/K_m (dm^3 g^{-1} dw h^{-1})
Thin tubular or sheet-like	8.42±4.36 (n=3)	72.2±30.0 (n=3)	10.82±2.63 (n=3)
Filamentous, delicately branched	4.61±1.15 (n=13)	52.2±11.2 (n=13)	13.79±4.70 (n=13)
Leathery blades or cartilaginous branches	21.4±7.5 (n=22)	14.0±3.3 (n=22)	1.32±0.19 (n=22)

<u>Ammonium</u>

Thin tubular or sheet-like	14.9±5.9 (n=3)	172±119 (n=3)	14.6±6.84 (n=3)
Filamentous, delicately branched	21.5±4.1 (n=13)	128±34 (n=34)	10.17±2.1 (n=130
Leathery blades or cartilaginous branches	42.9±14.8 (n=14)	21.4±10.8 (n=14)	1.72±0.12 (n=14)

Phosphate

Thin tubular or sheet-like	1.50±0.45 (n=5)	4.0±1.30 (n=5)	4.15±1.43 (n=5)
Filamentous, delicately branched	1.47±0.25 (n=13)	13.77±2.8 (n=13)	7.18±3.26 (n=13)
Leathery blades or cartilaginous branches	7.24±2.20 (n=9)	0.642±0.13 (n=9)	0.367±0.186 (n=9)

Michaelis-Menten constants have been reported for nitrate, ammonium and phosphate uptake in different types of algae- thin tubular or sheet-like structures such as *Enteromorpha;* filamentous or delicately branched such as *Cladophora* or *Chaetomorpha*; and leathery blades or cartilaginous branches such as *Fucus*.

From the tables it can be seen that the K_m values for uptake of all three nutrients is smaller (greater affinity) for the short-lived ruderal algae than for the long-lived, large algae, while the V_m is higher. Overall, the specific affinity for each nutrient is greater in the ruderals than in the *Fucus*-type algae, suggesting that the bloom-forming algae should be more effective at stripping nutrients from the water at low nutrient concentrations. The bloom-forming algae should perform better in all nutrient conditions than the long-lived algae, at least in the short term.

Growth rate is a function of the cellular nutrient concentration. At high nutrient concentrations there may be a 'luxury' accumulation of nutrients in the algal cells. There is zero growth at a finite minimum nutrient concentration, which is that minimum concentration required for survival. The N and P requirements of macroalgae are also rather different to those for phytoplankton. The Redfield ratios of nutrients show that the C:N and N:P ratios are much higher for the macroalgae than for the phytoplankton.

Nitrogen and phosphorus requirements expressed as atomic ratios (from Atkinson and Smith, 1983)

Phytoplankon	106C : 16N : 1P
Thin tubular and sheet-like macroalgae (n=5)	640 (± 229) C : 42 (± 12) N : 1P
Filamentous, delicately branched (n=2)	223 (± 42) C : 33 (± 5) N : 1P
Leathery blades or cartilaginous branches (n=19)	667 (± 98) C : 31 (± 4) N : 1P

The long-lived macroalgal species appear to survive by achieving maximum growth rates at a lower internal nutrient concentration than the bloom-forming species, and by accumulating nutrients intracellularly to carry them through periods of nutrient depletion in the summer. The bloom-forming ruderal species require higher internal nutrient concentrations to attain maximum growth rates, and need more N per unit of C fixed, but this may be offset by their better ability to take up nutrients. The fast-growing, bloom-forming ruderals appear to be able to dominate where persistent nutrient enrichment permit them to outcompete the long-lived algae. Where there is permanent nutrient enrichment the long-lived species lose their competitive advantage and are outgrown by the fast-growing, bloom-forming ruderal species.

Interaction with other nutrients. The extent of growth on a given quantity of resource (e.g. N) requires a stoichiometric input of other resources as required for biosynthesis. *Enteromorpha* (and also *Ulva* and *Cladophora*) can use not only dissolved CO_2 from seawater, but also HCO_3^- which is 50 times more abundant in seawater at pH 8. They are very good at stripping inorganic C from seawater compared to other algae. At least 75% of the 2mM total CO_2 can be used, increasing the pH to about 10. The next question must be whether there an inorganic C limitation on algal growth, influencing the response of *Enteromorpha* and similar algae to high levels of available N and P ? The atomic C:N ratio of 12 in *Enteromorpha* means that use of 1.5 mM CO_2 requires 125 μM N (1.5/12). Available inorganic C could, therefore, theoretically limit the extent of growth of *Enteromorpha* with plausible supplies of combined N (up to 650 μM in the Ythan estuary, for example). Algae such as *Fucus* are less capable of extracting HCO_3^- from seawater. That is, the extent of *Fucus* growth with 125μM N is less than that of *Enteromorpha*. This is even less if the C:N ratio of an alga is greater than that of *Enteromorpha* (as is the case with *Fucus*).

It is more realistic to consider the rates of resource acquisition growth as a function of concentrations of total inorganic C and of NO_3^-/NH_4^+ or $H_2PO_4^-/HPO_4^{2-}$. The K_m for inorganic C ($CO_2 + HCO_3^- + CO_3^{2-}$) in *Enteromorpha* ≈ 0.5 mM dm^{-3} C; V_m ≈ 1250 μmol C g^{-1} dw h^{-1} ; and $V_m/K_m = 2.5$ dm^3 g^{-1} dw h^{-1}. The specific affinity values (V_m/K_m in dm^3 g^{-1} dw h^{-1}) for *Enteromorpha* are, therefore

NO_3^-	11
NH_4^+	15
PO_4^{2-}	4
Inorganic C	2.5

The lower values for inorganic C suggest that the likelihood of growth rate limitation by inorganic C, or PO_4^{2-}, is rather greater than by N.

Conclusions.

1. Based on these data, the likelihood of N or P, relative to C, limitation in *Enteromorpha* is rather less than might be suggested by the 'extent of growth' argument.

2. Kinetic considerations and organism elemental ratios suggest that the growth rates of the bloom-forming species such as *Enteromorpha, Ulva,* or *Cladophora* are less likely to be N or P limited (relative to C limited) than are other common macroalgae.

These conclusions have a number of implications. There is a need to test the tentative conclusions described here under controlled conditions in the laboratory. The implications of the impact of selection of the bloom-forming algae on the rest of the community needs to be examined e.g. is it the build up of bloom algae leading to anoxia in the substratum that causes the death of animals such as *Corophium* under algal mats ? How does the short-lived *Enteromorpha* survive in the winter ? Low temperature apparently limits growth even though NO_3^- is available. What are the interactions of nutrients with low temperature and low light ? Is salinity (or lack of it) a determinant of the success of *Enteromorpha* in nutrient-enriched estuaries ? (Na^+ is needed as a 'driving ion' in the uptake of N, P etc.) The bloom-forming species tend to be tolerant of low salinity, but it is probably not a primary reason for their success in estuarine conditions.

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THE EFFECTS OF ELEVATED NUTRIENTS ON MORE OLIGOTROPHIC ESTUARINE ECOSYSTEMS.

Dr. Rod Jones (Countryside Council for Wales)

In the past conservation agencies have been criticised for not stating the nutrient concentrations required for environmental protection, except in most general terms. Past work has been directed principally towards environments with high levels of nutrient enrichment, and there has been little concern directed at potential changes which increased nutrients will have on low nutrient status (oligotrophic) systems. It is vital that long-term maintenance of these low nutrient systems is not overlooked. A lot more attention should be focused on perturbations in low nutrient systems as well as the already very nutrient-enriched eutrophic systems. There is a need to document and understand any changes going on and the potential impact of management strategies used to combat them. In preparing this talk the lack of information on low nutrient systems was apparent. What information is available has been used to try to delineate some of the low nutrient estuaries in Wales, and then to illustrate some of the apparent adverse changes which increased nutrient concentrations might induce.

There are about 35 estuaries around Wales. Those on the west coast drain high rainfall areas. In general, the soils in the west are low quality, nutrient poor soils, and so water quality might be expected to be good. However, even in the absence of intensive arable land, there is an appreciable input of fertilizer to grassland systems, with 200-300 kg N. $ha^{-1}.y^{-1}$ applied in some areas of Wales; indeed, the flat grazing lands often tend to be found adjacent to rivers and estuaries. The population density in Wales in general follows the distribution of the agricultural land with high levels in the south east. As expected, atmospheric inputs of nutrients (e.g. NO_2) are also linked to the industrial centres of population. There can, however, be episodes of atmospheric inputs which cover the whole of Wales. On the basis of these criteria, the estuaries on the west coast of Wales might be expected to have some of the lowest nutrient concentrations and the best water quality.

Data from rivers have been used to derive some idea of the nutrient status of the Welsh estuaries. These data (Figure 1) shows that there is a group of estuaries, predominantly in Gwynedd, which have very low Total Oxidised Nitrogen (TON) concentrations (< 0.5 $mg.l^{-1}$) in the river water entering the estuaries. In contrast, the West Cleddau and East Cleddau Rivers, entering Milford Haven, have quite high TON concentrations from the intensive agriculture in the catchment, as have rivers in south Wales. The overall annual mean concentrations of TON in all Welsh rivers show very little difference between 1985 and 1992, averaging out at about 1.5 $mg.l^{-1}$, suggesting no consistent trend of enrichment in recent years. The majority of apparently unenriched rivers in Wales have annual mean TON < 1 $mg.l^{-1}$ (Figure 2) with a small number at higher TON concentrations. In comparison, Scottish rivers have a larger proportion with TON <0.5 $mg.l^{-1}$, the majority < 1 $mg.l^{-1}$, although there are a few with > 4 $mg.l^{-1}$. The background TON concentrations in rivers draining catchments with poor soil might be speculated to be ≤ 0.5 $mg.l^{-1}$. In turn, the present concentrations in some of these rivers suggest that the TON concentrations may have increased 2-3 fold above historical background levels i.e. a proportionately high perturbation factor. Identification of the real background concentrations, and the changes that have taken place, are an important bench mark for management strategy for an estuary and its catchment.

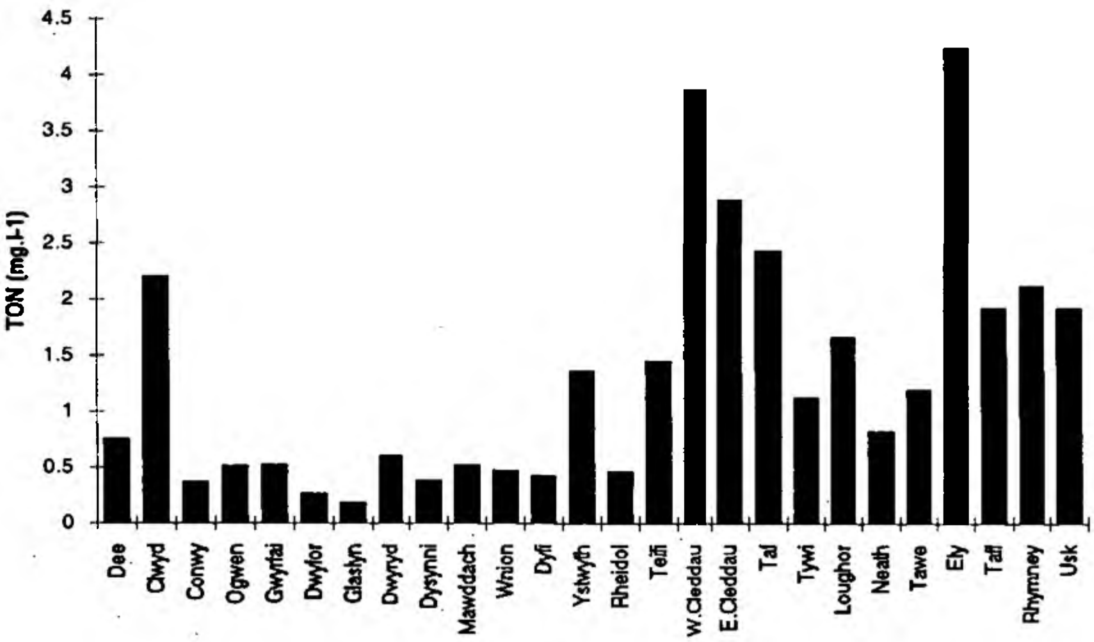

Figure 1. Total Oxidised Nitrogen in Welsh rivers in 1989. (Data from Environmental digest for Wales, Welsh Office.)

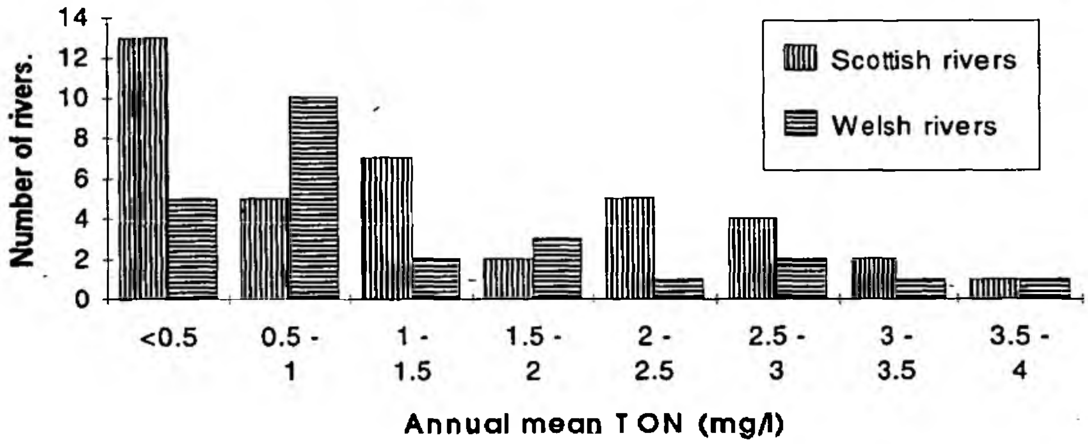

Figure 2. Annual mean TON concentrations in Welsh and Scottish rivers.

ESTUARY		Average TON ($mg.l^{-1}$)	Flow weighted ($g.sec^{-1}$)	Area weighted ($g.sec^{-1}.ha^{-1}$)
Mawddach	Mawddach	0.30	1.72	
	Wnion	0.52	2.87	
			4.59	0.004
Glaslyn/Dwyryd	Glaslyn	0.41	2.51	
	Dwyryd	0.69	2.90	
			5.41	0.0026
Dyfi	Dyfi	0.78	30.1	0.015
Milford Haven	W. Cleddau	4.18	21.5	
	E. Cleddau	3.04	19.1	
			40.6	0.0074
Teifi	Teifi	1.98	62.1	0.206
Clwyd	Clwyd	3.31	22.2	0.053
Rheidol/Ystwyth	Rheidol	1.52	9.8	
	Ystwyth	0.88	6.6	
			16.4	0.91

Table 1. Average TON inputs in relation to river flow and estuary size.

Apart from river water nutrient concentrations, nutrient fluxes have to be considered in any assessment of nutrient impact upon estuaries. Larger rivers which have low nutrient concentrations may nontheless have significant fluxes to estuaries when the river flow is taken into account. Table 1 shows inputs of TON for a variety of Welsh rivers, in relation to river flow. The size of the receiving estuary must also be considered in assessing any impact of that nutrient flux. In this context, the Mawddach estuary has a low load (0.004 g TON.$sec^{-1}.ha^{-1}$) compared to the Rheidol estuary (0.91 g TON. sec^{-1}. ha^{-1}). In contrast, the Teifi estuary, which does not have particularly high TON, has a high TON flux, and estuarine TON load when normalised for area. This analysis confirms the low nutrient status of the Glaslyn/Dwyryd and the Mawddach estuaries.

The Dyfi, Mawddach and the Glaslyn estuaries are the three main estuaries on the west coast of Wales. These estuaries tend not to support large bird communities, and as a consequence they are usually not protected in their entirety, although parts may be. [The Dyfi estuary, though, is of great conservation value.] They are shallow, and drain completely at low tide so they have very short residence time for water. They are very sandy at low tide, with only small amounts of fines in the sediment to adsorb PO_4^{2-} or other nutrients, and the nutrient-buffering capacity of each estuary is probably low. However, only small amounts of nutrients enter the estuaries in the river water, although there can be large short term variations of nutrient inputs to the estuaries in response to changes in river flow. Grazed saltmarshes surround the estuary, and may contribute significantly to the estuarine nutrient budget.

<u>Conservation concerns</u>. Many ecosystems have developed plant assemblages (including phytoplankton) which are adapted to survive in nutrient poor or nutrient rich environments. If the nutrient status of the environment changes it is not unreasonable to expect the biota to respond accordingly. However, the thresholds for such changes, and the timescales over which they occur, are generally unknown. In many cases we do not yet know the full nature of the biological interest of an environment - for example, in how many UK estuaries do we have good information on the benthic diatom populations ? To what extent do they vary around the UK, and how sensitive are they to changes in the nutrient status ? From a conservation view-point, therefore, considerable information is still required to fully determine these systems in biological terms, let alone define their sensitivity to change.

The discharge of treated sewage effluent into estuarine reaches may significantly influence its nutrient status, and atmospheric deposition may also be significant in some low nutrient systems, particularly where flushing is restricted. Wet deposition of nitrate and ammonium are similar in the UK: averaging 108 and 131 kt $N.y^{-1}$, respectively. Highest inputs occur in the uplands of Wales, northern England and western Scotland at about 30 kg. ha^{-1}. y^{-1}, although locally it may be up to 100-150 $kg.ha^{-1}.y^{-1}$.

A case study of the Glaslyn estuary illustrates the problem. The river Glaslyn has minimal nutrient input from Beddgelert STW, with some limited discharge from intensive agriculture in the lower reaches. A barrage (the Cob) was built across the estuary in 1813, and the area just landward of the barrage has been designated an SSSI. This contains several Red Book species including *Eleocharis parvula* (dwarf spike rush) and *Limosella australis* (Welsh mudwort). The presence of these species may be related to the high water quality and low nutrient status of the estuary, but the P and N levels which are acceptable to preserve these species is unknown. They are small plants which may be crowded out by other species growing more vigorously in the presence of elevated nutrient concentrations.

Coastal sewage discharges may have particularly heavy impacts on these otherwise low nutrient environments. The Menai Strait is unique because of its situation and the tidal rapids in its central section. The intertidal areas support considerable bird populations, with Traith Lavan at its northern end designated a SPA. Measurements of water transparency in the Menai Strait by Secchi disc measurement has shown a long-term trend of increasing turbidity since 1963. Measurements also suggest an increase of benthic primary production. What is the cause of this ? Is it nutrient increase in these coastal waters ? Welsh Water is in the course of improving sewage treatment and relocating treated sewage discharges to Treborth, near the core area of the reserve. Will the increased effluent flow (albeit of higher quality) have an impact on the Marine Nature Reserve ? An initial application for the new sewage treatment works asked for less than a 1:10 dilution of the effluent by seawater, with storm overflow allowable up to 63 times per year. What criteria should be used to determine the treatment requirement, initial dilution and frequency of storm water overflow in such a sensitive area ?

One problem in interpreting any changes in these coastal regions is the lack of appropriate background data sets against which changes in production or turbidity can be measured. Monitoring of changes in the coastal environment may seem expensive, but it is not when compared with the cost of, for example, generating a mathematical model of an estuary. Such data sets are essential to define any long term change.

Conclusions.

1. Low nutrient status, oligotrophic estuaries exist and are systems which are worth preserving in their own right.

2. Water Quality Objectives in the past have had little bearing for long term maintenance of nutrient-poor estuaries.

3. There is a general lack of any rigorous monitoring programmes recording long term biological or chemical changes in estuaries and adjacent coastal waters, and this is particularly so in low nutrient systems.

4. From a conservation standpoint, invariably there is insufficient information given by developers to quantify the impact of new discharges.

5. There is a lack of information on the nutrient concentrations and thresholds necessary to sustain plants and plant assemblages

6. Catchment management plans, and the goals set out in them, are of crucial importance in setting the terms for future conservation of low nutrient systems. It may be appropriate in some estuaries to set a long-term goal of return to background nutrient levels even if this is not a practical proposition in the short term.

EFFECTS OF ELEVATED NUTRIENTS IN ECOSYSTEMS WHERE LIGHT LIMITATION AND DENITRIFICATION BECOME IMPORTANT FACTORS (E.G. IN TURBID ESTUARIES).

Dr Stephen Malcolm (MAFF Fisheries Laboratory, Lowestoft).

It is easier to say something about particular turbid estuarine systems rather than to generalize about turbid estuaries, which probably says something about our state of knowledge of them at the moment. The other aspect of the title - *elevated nutrients*, also provides some difficulty as we don't know much about the baseline above which they are are elevated. The questions of background concentrations are problematical for most systems.

Looking at the systems that we do know on the East coast, a long-term time series from a DoE publication shows, at gauging stations above the harmonized monitoring site on the R. Great Ouse at Bedford, that after an initial increase from the early '60s nitrate concentrations levelled out after about 1980. A peak in 1993 probably reflects the fact that this was a very wet year. These estuaries undoubtedly have attracted increasing nutrient fluxes with time: whether they are elevated or not depends upon where one takes the base-line.

The East Coast estuaries are turbid environments where suspended material from rapid cliff erosion is carried in by the sea. Tidal forcing makes them very dynamic systems, and keeps material in suspension in the water column.

The JoNuS programme was set up in 1989-90 to study the transfer of nutrients from land to sea, as the estuarine system must be understood before discharge limits can be applied to such environments. The initiative stemmed from the North Sea Conference where it was suggested that in coastal areas where there was an impact, the nutrient load would have to be controlled, but the UK felt that it had to know more about what was going on first. The main questions were: "What are the inputs of nutrients to the North Sea; how do these inputs affect nutrient concentrations in the North Sea;, what are the results of nutrient fluxes; do they cause problems; and, do we have to do anything about them ?" It was suggested that estuaries were likely to be critical in influencing the transfer of nutrients from land to sea, and hence on the impact of nutrients.

The inputs of nutrients from rivers are relatively well defined, but what are the outputs to the sea, taking into account all of the processes which can influence nutrient fluxes ? [Atmospheric inputs are less important than riverine inputs to the budget in the coastal sea.] Primary production does occur in these estuaries, but the key processes, at least for N, appear to be interactions with bottom sediments. The Humber has very high loads of suspended material derived largely from offshore (the Holderness cliffs). The riverine input is relatively small. As in many estuaries where there is a tidal asymmetry, material gets trapped in the upper estuary and forms a turbidity maximum. Suspended load can be up to 1400 $mg.l^{-1}$ in the Humber, which is much greater than offshore. There are two major systems draining into the Humber- the Trent and the Ouse, which mix together at Trent Falls. Below this point in the estuary the profile of TON is fairly conservative in this system. The Humber estuary, therefore, doesn't seem to have a large effect on the load of TON arriving at its head in river water. Phosphate has a high 50 μM river endmember input, but there is considerable adsorption and removal of phosphate when it meets seawater, and thereafter there is apparently conservative mixing. Silicate also is conservatively diluted in the Humber estuary, indicating that there appears to be little phytoplankton removal of nutrients in the system. There can be deviations from conservative mixing which indicate significant biological activity. The TON profile along the estuary sometimes indicates possible net removal of TON by denitrification. In winter there may be an addition of TON, possibly from nitrification, matched by NH_4^+ removal. A modelling approach is probably necessary to dissect out these various processes.

An initial budget for the Humber shows increase of freshwater flow up to 1993, reflecting a change from a drought back to normal flows. Inputs of NO_3^- calculated were similar to those calculated by PARCOM (NRA, 1991). Interestingly, there seems to be little observable impact of STW discharges on nutrient concentrations in the Humber.

In the Gt. Ouse, there can be substantial blooms of phytoplankton (> 100 μg chlorophyll l^{-1}), usually through the early spring period and into the summer. This is surprising as, while not as turbid as the Humber, there is still low light penetration in the Gt Ouse. The times when these blooms occur in the estuary coincide with periods of slightly lower turbidity, and may be related to the extension of riverine blooms into the estuary. Why a bloom should occur in this turbid water is not clear but Fichez et al (1992) suggested that the critical depth extends sufficiently deep to permit bloom formation during these periods of reduced turbidity. The River Scheldt is a turbid estuary similar to the Gt Ouse, and blooms are also seen there (see Zwolsman, 1994). There is evidence, therefore, that nutrient inputs into estuaries will stimulate primary production even in turbid estuaries. Biological activity in the Gt Ouse does have an impact on nutrient fluxes, but initial budgets have suggested that < 10% of the annual N flux in the Gt Ouse is removed by phytoplankton primary production. Maximum removal occurs primarily during summer, at times of the year when the TON flux is low, and for a restricted period this may have a proportionately large effect on nutrient flux. If the flux into the estuary has a high N:P ratio, algal removal of nutrients will result in a residual output of nutrients from the estuary which has an even higher N:P ratio.

From a time series of nutrient and chlorophyll concentrations taken in the Wash, there is some evidence of increasing chl a, related to increasing TON. Suspended particulate load in the Wash is up to 60 mg.l^{-1} and turbidity is high, but a phytoplankton bloom was detected in 1990 with peaks of chlorophyll up to 20-30 μg.l^{-1}. Blooms also occurred in 1991-93, with some evidence of increasing chlorophyll. TON also shows some evidence of increase, particularly in response to heavier rainfall in 1993-4 compared to 1991-3. Blooms will only occur when there is sufficient light, and in the turbid water the blooms tends to be short-lived compared to other areas, with no extended production through the summer. The driver for this appears to be the river flow into the Wash, with higher flow during winter when biological activity was low, and fluxes of TON, silicate and phosphate were all increasing. The TON_X:PO_4^{2-} ratios increase during high flow periods when nitrate is leached, and its load increases relative to phosphate.

There is little information on microphytobenthos in the Wash. In general, the relative importance of benthic microalgal communities to nutrient dynamics in estuaries is poorly understood, although the benthic algal film may control nutrient exchange across the sediment-water interface. Chlorophyll a concentrations and productivity estimates for the benthic mats in the Wash seem to be low compared to other estuarine areas, but the data set for the Wash is restricted and its validity not yet confirmed. There is little information on the impact of nutrients on these systems. Experiments at Gothenburg (Nilsson et al, 1991) have shown that if grazers and macrofauna are removed from sediment, addition of reasonable levels of P and N stimulates increase in the amount of chlorophyll in the experimental systems (compared to controls), suggesting that the microphytobenthos are consuming the additional nutrients that they are given. This raises the question of what additional capacity does the ecosystem have to take up further nutrients, and will this result in a change in the community. Meiofauna cannot use inorganic P and N directly, but they graze on the algal biomass and, in short term experiments at least, respond quickly to changes in algal biomass. This suggests that other components of the community will indeed respond to elevated nutrient concentrations. Macroalgae are not significant in the Wash.

Denitrification is the only process that can lead to a reduction of the load of nitrogen within an estuary, nitrate being converted to gases and lost to the atmosphere. Denitrification is usually regarded as an anaerobic process, although it can occur in the presence of O_2. However, in the Wash and Colne, at least, there is no significant denitrification in the water column, and denitrification is restricted to the bottom sediments. Denitrification is a major process in many estuaries, about 30% of the TON flux being removed in the Wash and about 50% in the River Colne estuary. Work in the Scheldt estuary (Billen et al, 1985) has suggested about 50-60% reduction of the N flux going into the estuary. The actual proportion removed may vary from estuary to estuary, depending upon the residence time of the water, the morphology of the estuary, and the type of bottom. In the shallow turbid East Coast estuaries, with relatively long residence times and extensive mud and sand banks, the attenuation of the N flux may be considerable. The larger the area of the estuary and the estuarine plume, the greater will be the removal of nitrate by the bottom sediments.

There has been some suggestion that N_2 fixation may provide available N to communities where it is the limiting factor. In nutrient-enriched estuaries, though, excess inorganic nitrogen is likely to inhibit N_2 fixation.

Monitoring and the way forward. The JoNuS programme has certainly recommended an approach to monitoring the nutrient inputs to the North Sea. We no longer believe that monitoring of river input alone is sufficient; a lot more needs to be known about what happens downstream. A better understanding of estuarine processes is required at a level similar to that developed from JoNuS: probably involving estuarine models. Currently, such models are estuary-specific, but development of a generic model must be the management goal. The consequences of changes in management practice e.g. from agricultural usage in the catchment, could then be predicted for the receiving estuary.

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SUMMARY POINTS FROM THE PRESENTATIONS.

Phytoplankton

1. There is general lack of information on phytoplankton in estuaries, and their response to nutrients.

2. Nutrient concentrations in the estuarine and coastal zone do tend to be enriched when compared against historical values, but any effect on phytoplankton (primary production rates or species composition) is obscure.

3. There is no consistent evidence that blooms are related to enhanced nutrient concentrations.

4. Internal recycling of nutrients by organic mineralisation may be as important as external nutrient supply from estuaries in maintaining productivity in coastal seas.

Macroalgae.

1. 'Bloom' algae are physiologically adapted to the effective use of high nutrient concentrations.

2. Bloom-forming macroalgae exhibit more effective uptake and assimilation of nutrients than long-lived algae.

3. Some nutrients e.g. available dissolved CO_2, may synergistically influence the response of an alga to enhancement by another nutrient. Synergistic effects of nutrients, and the interaction of nutrient limitation with other factors, are poorly understood

4. We need to undestand the effect of grazing on growth rates ?

Oligotrophic estuaries.

1. Oligotrophic estuaries are very different to the more eutrophic East Coast estuaries.

2. The concentrations and fluxes of nutrients in oligotrophic estuaries are very different from those in turbid estuaries.

3. We need to assess the feasibility of determining 'background' levels of nutrients, and their relevance to estuarine management.

4. It needs to be established whether the same standards can be applied to different types of estuaries, or whether appropriate standards are required for different types of estuaries.

5. Long-term effects of subtle enrichment may be more significant in oligotrophic estuaries than in eutrophic estuaries.

6. The standards required for conservation of individual species may differ from those required for the protection of estuarine ecosystems as a whole.

Turbid, eutrophic estuaries.

1. There tends to be removal of phosphate when river water meets estuary.

2. There may be biological removal of dissolved inorganic N within estuaries, which may vary seasonally and according to each estuary's characteristics.

3. Generally, < 10% of TON is removed by phytoplankton primary production in turbid estuaries.

4. The proportionate effects of benthic microalgal mats on nutrient dynamics are not known, but could be considerable.

5. Up to 60% or more of the TON flux may be removed by denitrification in estuarine sediments. This varies according to estuarine characteristics.

AREAS FOR DISCUSSION.

The afternoon's discussion was focused on a number of questions.

1. Do we know what is meant by eutrophication, or nutrient elevation, in estuaries ? Is it happening ?

2. What are the key indicators of nutrient elevation in estuaries ? Is there agreement generally with the range of effects, and the consequences of elevated levels of nutrients ?

3. Are these impacts the same in all estuaries, or are there fundamental differences between hard-shore, relatively oligotrophic estuaries, and soft-shore relatively eutrophic, nutrient-rich estuaries ?

4. Have the mornings presentations omitted any key areas in our present understanding of the range of impacts of nutrient-enrichment in estuaries, for which evidence can be provided ?

5. Are there any more speculative effects of nutrient-enrichment, for which evidence may be less conclusive ?

6. What more information is necessary ?

7. How do we move towards defining objectives for *Water Quality* and *Conservation* ?

8. Are the requirements for general estuary monitoring/management and specifically conservation-related management the same ?

9. What are the requirements for monitoring/management of estuaries ? What should the NRA/EN do to move toward setting SWQO for special ecosystems in coastal waters and estuaries ?

DISCUSSION

(A. Ferguson) The difficulty is determining where we are in relation to base-line information, either in hard or soft estuaries, and to actually establish ways of demonstrating that we are moving towards established targets. This is a theme that has gone through the morning's presentations, and is something that needs to be addressed.

(B. Harbott) The example of the Welsh estuaries shows that there are some estuaries where moderate amounts of additional nutrients might induce a change in trophic status, but similar changes of nutrients in East Anglian estuaries probably would not matter to the same extent. It would require a very large change in nutrients in E.Anglian rivers to induce a change in trophic status whereas a similar change in nutrients in west coast estuaries could have a large effect of the system and also possibly eradicate rare or protected species.

The NRA has a limited amount of resources. If there is a more deleterious impact, and a shift in the biota, likely in the oligotrophic estuaries from an increase in nutrient load; and that to achieve a 50% reduction in nutrient load in the eutrophic estuaries may have little beneficial effect on the system, it may be a good argument that the limited resources go towards the more sensitive estuaries rather than the ones with already high nutrient loads.

(M. McGarvin) It may be rather difficult to derive that sort of conclusion. There may not be species in danger in the East Coast estuaries but it is known from the Ythan that there may be great effects from the biomass of bloom species on the benthic community. There may be ways of reducing nutrients without large technical cost e.g. by changing agricultural techniques.

(T. Jickells) The Welsh estuaries are typically sandy with large tide range, draining fully at low tide. The threat to marginal communities tends to be from salinity variations rather than nutrients, whereas in the east coast estuaries the tidal and salinity ranges are not so great. The tidal dilution effect in the Welsh estuaries is, therefore, much greater, and the net effect of elevated nutrient flux to the estuary possibly much less.

(J. Pomfret) Returning to the point of lack of information, there are many data sets which are not comparable because of different methods of analysis used, and also different analyses carried out. Why are people concentrating on Total Oxidized Nitrogen (TON) ? When ammonium may be more readily used by algae, why not use Total Inorganic Nitrogen (TIN) ? We need to agree what are the suite of key nutrients to monitor.

(D. Nedwell). A number of points seem to have been raised 1] the relevance, validity and comparability of existing data sets 2] the effect of the rate of dilution of nutrients input into an estuary, and how we monitor the effective concentration 3] what are the background levels for an estuary, and how do we determine them against the background of heterogeneity within the estuary ? Do we have the information to determine these questions ?

(Unknown) Sediments are often regarded as integrators with time of the overlying water column. Maybe a different approach is to measure nutrient concentrations in the porewaters of the sediments, as this exchanges with the overlying water and may provide some integration of the nutrient signal with respect to time.

(D. Nedwell) The problem with that approach is that the rates of change of nutrients within the sediment may be faster than exchange between sediment and water, so that the porewater concentrations of a solute do not reflect that in the overlying water.

Is determining and monitoring the growth-rate-limiting nutrient the important factor ? In moving from freshwater to seawater along an estuary the limiting nutrient for phytoplankton apparently changes from P to N. So how do we determine the growth-limiting nutrient for the primary producers across the full salinity gradient of an estuary ?

(M. McGarvin). The ratios of nutrients (e.g. N:P) is also important, independantly of their concentrations, so we cannot concentrate solely on one nutrient.

(S. Hawkins). Could silicate be used as a more conservative indicator of historical nutrient enrichment ? Estuarine silicate concentrations in the 1950's and '80s were similar, in contrast to phosphate and nitrogen. Silicate does not seem to be affected anthropogenically to the extent of the other nutrients and might be a better conservative indicator of background nutrient concentrations.

(T. Jickells). But there is almost complete silicate depletion in some East Coast estuaries at certain times of the year. Increase in N and P initially could increase production by diatoms, and decrease silicate to the extent that other groups of phytoplankton that do not require silicate could be selected. Is the increase in N and P fluxes therefore affecting the silicate flux down the estuaries into the ocean, and transferring problems to the coastal seas ? The incidence of dinoflagellate blooms could be related to changing estuarine N:P ratios, and the displacement of the diatoms that need silicate. It also emphasises that we should focus not just on the estuaries as problem areas, but also as conduits of nutrients to the coastal seas.

(C. Reid). In the Rhine silica is depleted compared to other nutrients, which may be because of diatom growth prior to discharge to the estuary. It reinforces the point that we must consider the whole system, not just the estuary.

(D. Nedwell). It appears from the morning's presentations that we have a lack of information on both the pristine, background load of nutrients, and the historical record of changing loads for many estuaries.

(D. Hydes). There have been studies where agricultural practices, sewage inputs etc, were rolled back and the background nutrient loads from the pristine forest ecosystem estimated. What we don't know for a particular estuary is what was going on in terms of the biology of the estuary i.e. we might estimate the background nutrient load, but we don't know the background ecosystem. The Welsh estuaries which are relatively unperturbed may give an indication of the original community structure of these estuaries. Where there are areas of localised enhanced nutrient discharge, there is localised high growth. There is a spectrum of environments where impact of nutrients varies. Where nutrients are not rapidly flushed through estuaries there may be obvious growth response to eutrophication within the estuary, but more subtle effects of less obvious nutrient enrichment offshore.

(R. Park). Any strategy for monitoring estuaries should take account of community structure. This is necessary, firstly, to take account of nutrient effect on the epipelon and distinguish such response from that of the phytoplankton; and, secondly, to give a good baseline for the phytoplankton so that we can monitor any perturbation in that community structure. It would seem that eutrophication isn't a real problem so far in UK coastal waters, at least in terms of enhanced phytoplankton concentrations, compared to the situation in Dutch and Danish waters. We should concentrate on agreeing the optimum monitoring strategy to define the extent of the UK problem.

(K. Pugh). In the context of the 'needs' for monitoring, we need to define first what we want to manage and why. It is only when we have done that we can determine a monitoring strategy. For example, what was the purpose of the JoNuS project ?

(S. Malcolm) Concern for the North Sea and its nutrient status in response to the North Quality Status Report. It was realised that there was no good data to define inputs or fates of nutrients. It was a pragmatic reason for setting up the programme, to provide the information required for management.

(R. Jones). You still have to take a step back and define why you are worried about nutrients, in relation to the management goal. The objectives will vary with the individual situation. For example, in the Menai Straits elevated nutrients may change an otherwise pristine oligotrophic marine community; in other habitats the purpose might be to protect particular vulnerable species.

(S. Pullen). Perhaps it is unnecessary to extensively debate the goals of monitoring and management because the requirement is largely predetermined by policy, but pragmatically to decide how to achieve sustainable use, and within that how to protect biodiversity.

(D. Nedwell). Ideally I would agree with Ken Pugh on the need to define goals, but the precautionary principle and legislation says that we have to assume that we are trying to at least prevent systems becoming any worse, and that is itself a reason for developing a strategy. How do we do it , and prevent things getting any worse ?

(P. Evans and S.Hawkins). How reversible or otherwise are the effects of nutrient enrichment that we see ? We tend to assume bottom-up control by available nutrient concentrations, but experiments are going on in the docks at Liverpool to examine the extent to which changes in the community can be reversed by inducing changes in grazing or filter feeding. Mussel beds have been introduced to reduce algal bloom biomass which has been increased by nutrient-enrichment. Following their introduction, the bottom waters no longer go anoxic in the summer every year, indicating a degree of reversal of the previous condition. This is further indicated by the reappearance of red alga species.

There is a large literature on top-down control of freshwater communities in eutrophic environments, and their change by manipulation of fish and zooplankton. There is little such work in the marine environment.

(D. Nedwell). While these examples give some hope of possible reversal of eutrophication in specific environments, can we aspire to such manipulation and control in the marine environment ? From the discussion so far we are not yet at the point of adequately describing estuarine and marine systems, let alone predicting how they will respond to eutrophication or how to control them.

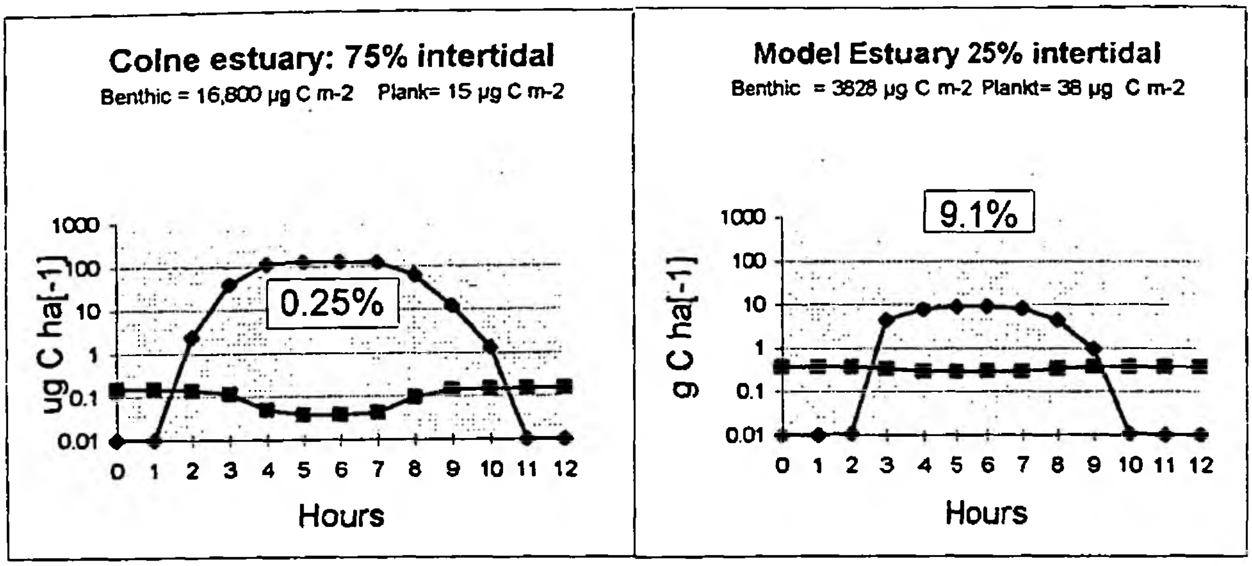
(C. Reid). Knowledge of phytoplankton communities in UK estuaries is very limited. There is a need to review and classify estuaries to algal flora, perhaps zooplankton and grazers. Until we know that, how can we classify or compare estuaries ?

(G. Underwood). There are some things becoming clear about the benthic microalgae, and some modelling has been done at Essex University comparing benthic and phytoplanktonic productivity in turbid estuaries (Figure 1). In turbid muddy estuaries with large areas of exposed mudflats, intertidal benthic production exceeds phytoplanktonic production significantly. The model data shows the amount of carbon fixed per hectare of estuary over the course of a day. Benthic production occurs only when exposed by the tide during the day: the high turbidity of the water restricts the depth of the euphotic zone to < 1m. Phytoplankton production occurs throughout the day in the shallow euphotic zone. The model for the Colne estuary assumes intertidal exposure of about 75% of the estuarine sediment area, and uses values for production representative of those measured in the field. In this scenario, phytoplankton contribute only ¼ % of the day's production during spring tides when the tide is out during the day, and 0.44% during neap tides with high tide at midday.

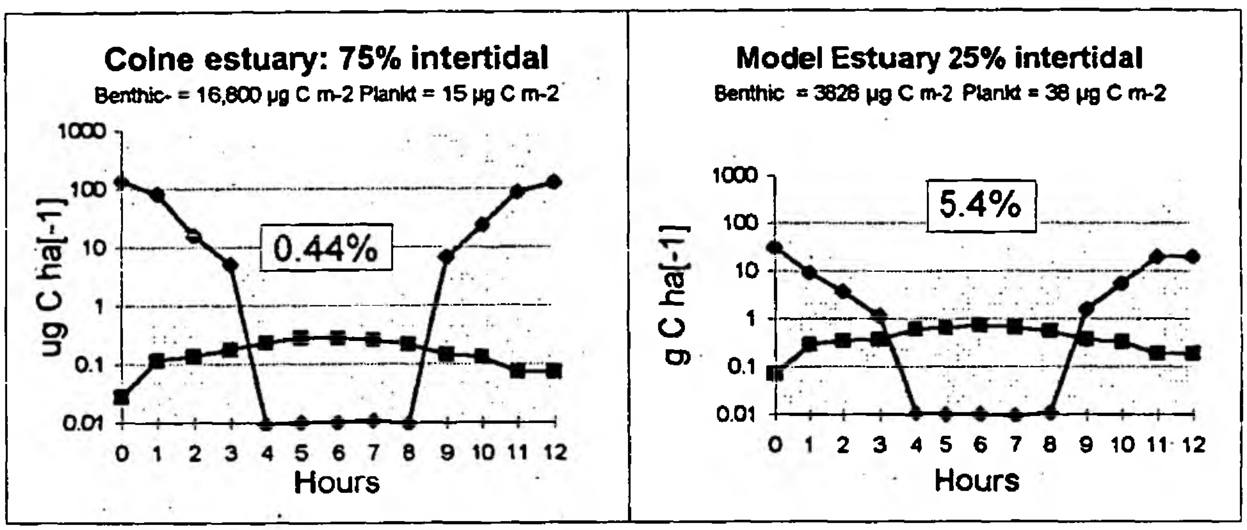
In a 'best case' scenario for phytoplankton, in a model estuary where only 25% of the bottom sediments become exposed at low tide, phytoplankton production is only 9% of benthic production at spring tide and 5.4% of production during neap tides. Therefore, there is a huge amount of primary production going on in the benthic microalgal mats, much more than in the phytoplankton. Benthic primary production in turn provides food for invertebrates, and the invertebrates are important food sources for birds etc. In the past the significance of the benthic community has been ignored, but is clearly of major importance, particularly in turbid muddy estuaries with extensive mud banks, which are often those estuaries of most improtance to conservation.

Not only are benthic microalgal films a food resource important to the ecology of the estuary, but they also affect fluxes of nutrients across the sediment-water interface. There may be large differences between the flux of ammonium out of sediments in the dark, and in the light when it intercepted by photosynthesising algae. In contrast, the flux of nitrate into the sediment increases in the light as it is more rapidly assimilated from the overlying water. Denitrification values in the sediment become lower as O_2 is produced in the surface sediment by photosynthesis.

Fig. 1. Comparison of daily benthic and phytoplanktonic primary production (μg C ha-1 h-1) in the Colne estuary and in a model estuary.



Spring tide : Low tide midday



Neap tides : High tide midday

Note 1. Benthic production (diamond), Phytoplanktonic production (square)
Note 2. Percentage in box, is % contribution of phytoplankton to the daily primary production

When there are high nutrient levels cyanobacteria tend to develop, and these are generally not a good food source for invertebrates, compared to diatoms. Eutrophication in an estuary may increase food abundance for a while by stimulating benthic primary production, but it may subsequently decrease as cynaobacteria develop.

(Unknown) How much of the production is resuspended and exported when the tide comes in?

(G. Underwood) I think about 10%

(R. Park). As they are very close to the nutrient-rich sediment, is there any evidence that benthic algae are nutrient-limited ? It is only when algae are nutrient-limited that there will be a response to nutrient-elevation in the water.

(G. Underwood). Biomass responds to nutrient level. There seems to be some evidence, as with the macroalgae, that CO_2 availability may limit benthic production. Species composition changes with nutrient level although production may not.

(Unknown). Benthic mats are useful in stripping out nutrient fluxes, but not as an indicator of nutrient levels along an estuary.

(G. Underwood). Do we know enough about the structure of these communities to be able to say that their species composition doesn't vary in response to nutrients ? In freshwater, the species of diatoms do appear to respond to nutrient concentrations. It is a lack of information for the marine environment which may prevent similar definition of indicator species.

(Unknown). It is our experience that there are changes in the composition of the rarer species in response to nutrient loads, but the biggest problem is the manpower required be trained in taxonomy, and to process the samples required.

(P. Jonas) The benthic community also has an important role in preventing sediment resuspension.

(Unknown) From a conservation viewpoint, different algal groups have different functions. Some contribute to sediment stability, while others may provide a food resource for invertebrates. Both of these functions will be important in the maintenance of larger species higher up the food chain. What nutrient levels are sufficiently high to induce instability in the algal community, increase production, and induce a series of 'knock-on' effects on the rest of the community ? Knowledge of this may tie in with the NRA requirement for conservation monitoring.

(M. McGarvin) This is an important point. When do increases in nutrients cause macroalgae to bloom, and subsequently die and settle where they may smother benthic fauna. This seems to be happening now on the UK south coast, and it is extremely important from a management/conservation point of view to know the trigger concentrations for this.

(P.Evans) But at a lower nutrient elevation, below the point inducing nuisance blooms, there are highly productive estuaries which may be sustained by elevated nutrient concentrations, and their high production is important to nature conservation. In some parts of the

Netherlands shellfish farmers have seen their production reduced because of decreased phosphates, which has limited primary production. This may provide a dilemma of use and management, which partly comes down to the use to which an estuary is put. It may have little nature conservation significance or designation, but nevertheless be important for fisheries.

(R. Jones). We have to be careful about designation e.g. the Mawddach estuary has no designation yet is a pristine system. The guidelines for designation of intertidal areas have primarily related to birds, although further guidelines are coming. The importance of an area cannot be dismissed merely because it is not designated. Information may be available, but has not been yet converted to designations.

(P. Holmes). I would like to introduce consideration of the influence of nutrient elevation on the blooms of toxic algae. There have been instances of fish farms wiped out by blooms of toxic algae which appear to be common species which become toxic. Is this induced by nutrient changes ? We seem to know very little about the problem.

(C. Reid). There is little evidence to correlate toxic blooms with nutrient increase. Toxic shellfish have been around for centuries, for instance off the Northumberland coast and Scottish coasts. It was first recorded scientifically for mussells in 1968 when people were hospitalised, but not again until 1989 despite the trend of increased nutrients. It is difficult to associate toxic blooms directly with nutrient régimes.

(D. Nedwell). To summarise, we don't really know the significance of benthic algal mats to nutrient or energy fluxes in these estuaries, although they would appear to be much more important than the phytoplankton in turbid muddy estuaries. However, phytoplankton may be relatively more important in oligotrophic, hard estuaries where the water is less turbid and there is less soft bottom. They may also be important in terms of food resources for higher organisms, and changes in nutrient concentrations in an estuary may effect food availability.

This bring us back to our lack of knowledge of the relative importance of different components of the estuarine community (e.g. benthic vs pelagic; bacteria vs primary producers; etc) to nutrient fluxes in different types of estuaries. Also, understanding how community or ecosystem nutrient fluxes change in response to nutrient loading may not be the same as understanding or monitoring changes in community structure or diversity. For example, we may not see a change in the community diversity although there may be a significant change in the nutrient flux through it, or vice versa. To take two ends of the estuarine spectrum, do we understand the fundamentals of how the communities in hard and soft estuaries work ?

(A. Burn) But the estuarine dynamics and conservation may be interlinked. For example, if nutrient elevation results in greater rates of denitrification in the sediments, does the denitrifier community increase in size. If so does it have any effect on energy or nutrient flow to the rest of the estuarine community ?

(D. Nedwell) There is probably no practical way in which the size of the bacterial components of the estuarine community can be measured or monitored at the moment. Recently developed molecular techniques rely on measuring the amounts of particular gene sequences, characteristic of particular groups of bacteria, in 16S ribosomal RNA recovered from environmental samples. This approach ultimately may permit us to measure the size of particular phylogenetic groups of microorganisms from the frequency of group-specific sequences in nucleic acid extracted from samples, but the technology is not yet sufficiently developed for routine use.

(K. Hiscock) There is a degree of practicality here also. Nature conservation assessments are done on the basis of macroalgae, invertebrates and vertebrates. In terms of special ecosystems and WQOs we need to link those features which are used for nature conservation assessment with physico/chemical factors which might adversely affect that nature conservation interest. That is not to say that we should not use benthic diatoms as possible indicators, but we need a linkage between the indicators that are used for monitoring and management in terms of assessing how important eutrophication is.

(Unknown) The organisms that are used for nature conservation assessments are selective in that they are those that have been used historically, and are those that we know most about.

(K. Hiscock). They are used as a 'signpost'. High diversity of the species used for assessment (e.g. benthic invertebrates) is generally taken as indicative of a rich and diverse ecosystem generally.

(T. Jickells). I am not sure that phytoplankton species are going to be useful as an indicator of nutrient stress. They are opportunistic, and nutrient stress might not show up as a change in species. High turbidity in an estuary, for instance, may obscure nutrient stress.

(Unknown). Also, nutrient régimes can change community structure, even without a change in absolute load. Pulses of nutrients, rather than continuous flow, with no overall increase of load may alter species composition.

(C. Reid). Nutrient ratio can also affect species. Right at the end of the diatom bloom, when silicate is very low, one species of *Rhizosolenia* has a very thin exoskeleton because of lack of silicate. The Helgoland data set, in an area where there was three orders of magnitude increase in nitrate concentration after the 1993 floods, showed no demonstrable change in phytoplankton species throughout this period, except for microflagellates which did increase. The majority of phytoplankton did not respond to nutrient change: light and turbidity had the primary effect within the seasonal cycle.

(S. Hawkins). If we are concerned with estuaries perhaps we should be looking at sediment loading in relation to catchment erosion processes. If turbidity is a major factor sediment erosion will increase the suspended load.

(D. Nedwell). But the major source of estuarine sediment is seaborn, e.g. in the Humber from the Holderness cliffs.

(G. Underwood). Turbid estuaries are themselves valuable natural habitats for specialised species. This was one of the arguments against the Severn Barrage.

(D. Nedwell). All of the discussion so far still points to the two strands required for monitoring

1. Species composition, examples and responses of communities to nutrient loads.
2. How the system works: the relative importance of benthic microalgae compared to phytoplankton.

Perhaps for different estuaries we have to look to different subsystems for indicators. e.g. in a hard estuary the benthos is of less importance than in soft estuaries. We can use indicator species to monitor community diversity response, but how do we measure system response or system perturbation ? What underlying rationale can be used for such monitoring ? Can we just measure nutrient levels, even assuming that the data is sufficient. What alternatives are there ? Are there any ways to measure the efficiency with which the system is coping with the imposed nutrient load ?

(R. Park). To highlight one problem, when measuring nutrient levels in relation to phytoplankton, by the time the data is available one is looking at yesterday's phytoplankton and the way they responded to yesterday's nutrients, unless there has been very little change in conditions the meantime. This is not a good basis for management.

(A. Burn). Rod Jones used annual mean nutrient concentrations averaged over estuaries, and used this as an index of impact. Such a first look is crude but points in the right direction. One might look at means of nutrient concentrations at different times of the year in relation to possible impact on phytoplankton, as opposed to benthic, production. How useful are historic means ? Would seasonal means permit us to look at the whole sweep of seasonal effects, from phytoplankton, through benthic algae, to denitrification ?

(K. Pugh). A three year collaborative research study (between NERPB, MLURI and SOAFD-ML) of past and new nutrient (N, P and Si) data for the waters of the use-contrasted Rivers Dee, Don and Ythan as they pass from their headwaters to their respective estuary (each one close to Aberdeen) is just coming to a close. The nitrate data for the Ythan, whose estuary is covererd with massive benthic mats of *Enteromorpha* during the summer, shows a marked seasonality, and a three to four fold increase over the past thirty years. Much of this can be related to agricultural activity. During a fifteen month period an automatic sampler was located at the HM point on the Ythan to enable daily (4 x 6 hour) composite samples to be drawn; the frequency being increased to hourly (4 x 15 min) during storm events. For part of the study another automatic sampler was located on a moored catamaran halfway along the estuary, and simultaneous monitoring has enabled the collection of a data set which is being examined to show nutrient movement through the estuary. Since there is a continuous record of flow, nutrient fluxes have been calculated on the basis of daily, weekly. monthly etc., sampling. The data collection will help to establish the timing of the major nutrient fluxes in relation to the development of the benthic algal mats. It may be possible to answer a number of questions. For example, 'When river flows are low are sewage inputs more important ?' 'What is the significance to the estuarine community of 'spiked' (storm event) inputs of nutrients compared to the normal background concentration, particularly during the summer when nutrient concentrations are low ?' 'Is it the background concentrations that are more important in the long run ?' The data is currently being processed for report publication.

(T. Leatherland). Most of the data for the Welsh estuaries is not for the estuary itself, but for the river input to the estuary. Most of the nutrient coming into such estuaries will be coming from the sea, not down the river. That is why we must look at the effect of the river over the estuary area as a whole. In winter, the impact of high nutrient fluxes in the estuary may be tempered by low light, and the nutrients transported to sea before having a biological effect. The natural river input of nutrients during the summer months, when there is plenty of light, may be low, reflecting low river flow. The presence of continued sewage inputs, though, will not decrease during summer, may contribute to higher nutrient concentrations, and their influence may be disproportionately high at this time.

(D. Nedwell). The effects of nutrients on phytoplankton may be synergistic. What about the relative importance of different nutrients. Usually Total Oxidised Nitrogen (TON) is measured, assuming that it is the most abundant form. In the Gt Ouse the vast majority of TIN is nitrate, but in the River Colne 50% of the Total Inorganic Nitrogen (TIN) may be ammonium. Can we ignore the difference ? Ammonium may be used by algae preferentially to nitrate even if it is less than 1% of the TIN. Can monitoring of nutrients look only at TON, or are the ratios of NH_4^+ : NO_3^- important ?

(Unknown) At the very least look at TIN, not just TON.

(D.Purdie). In the oligotrophic west coast estuaries the riverine input of nitrogen combined in Particulate Organic Matter is much greater as a proportion of the total nitrogen flux than in the more turbid, eutrophic estuaries. This particulate organic nitrogen may be a significant source of nitrogen in such estuaries, particularly as the estuarine interface between saline and freshwater tends to be a depositional area.

(Unknown) Are there correlations observed between any of the inorganic nutrients measured in estuaries and either chlorophyll concentrations or primary production rates ?

(B. Harbott). The best correlations of chlorophyll or primary production are with temperature or sunlight. In the Gt Ouse estuary in 1990 there was little freshwater flow seaward, and the main impact was migration of high salinity up the estuary with associated species, and the subsequent movement back down the estuary when rainfall increased in later years.

(S. Leaf). A study by Mombé (1992. Estuaries, 15, 563-571.) categorised estuaries into micro- and macrotidal estuaries, and related mean annual nitrate concentrations to the *chlorophyll a* concentration. In microtidal estuaries a significantly higher *chl a* concentration is found than in the macrotidal estuaries.

(Unknown) Is this not merely due to differences in dilution rate ? Twice the tidal range will result in twice the dilution.

(M. Everard). Simon Leaf has highlighted an important point. The NRA have a limited resources for monitoring, modelling and addressing solutions. We have to identify some classification scheme (be it tidal range, or hard and soft, estuaries) to help make sensible management decisions for priority for actions. The kind of question we are trying to answer is "Are these estuaries likely to be nutrient-limited or not ?" If some are not nutrient-limited, resources should be focussed on those that are likely to be nutrient-limited. The idea of hard and soft geologies, reflecting underlying differences in nutrient régimes, may provide a logical division for such decisions. The presentation by Rod Jones would seem to support this idea.

(M. McGarvin). Is it more to do with flushing ? Some estuaries dry out completely and others may have residence times measured in days.

(D. Nedwell). The recent paper by Balls (1994, Estuarine, Coastal and Shelf Science, 39, 329-352) examined estuaries in Scotland and concluded that biological attenuation of the nitrogen load was influenced most by the flushing time of the estuary. Another important observation was that rivers with catchments having intensive agriculture and low freshwater input, such as the Don and Ythan, have estuarine waters with nutrient concentrations (nitrate and phosphate) higher than in adjacent seawater. In contrast, those rivers with mineral-poor soils, low populations and low agricultural intensity tend to have waters with nutrients lower than in the coastal seawater.

How are we to decide whether a particular estuary is affected by elevated nutrients ? Rather than using nutrient concentrations *per se* could we measure the relative increase in primary production in response to addition of known concentrations of nutrients. This is similar to the *relative preference index* used to determine the relative importance of different nutrients to phytoplankton growth. It may permit us to say something about the ability of the phytoplankton community to cope with additional nutrient loads.

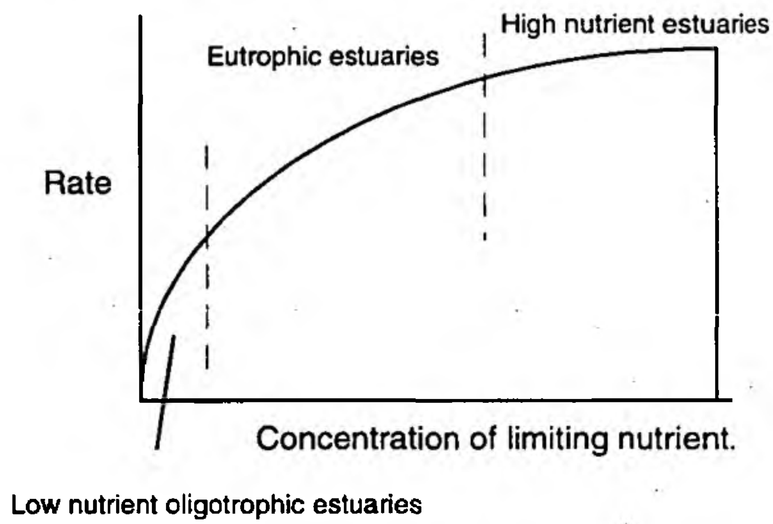


Figure 2. The response of biological systems to high or low nutrient concentration.

In oligotrophic systems the algae are operating at low nutrient levels and nutrient addition will have a proportionately large stimulatory effect. In contrast, in nutrient-rich environments the algae will be operating some way to the right, higher up the curve, and the response to nutrient addition will be proportionately less. In the extreme, nutrient-saturated case the algae will be operating at the top of the curve and further nutrient elevation will have no further stimulatory effect. Would this sort of approach permit us to examine the degree to which different nutrients are limiting (or not) to algal growth, and permit us to measure the response of the algal communities to nutrient enhancement ?

(C. Reid). In the ocean, the IRONEX project has used a similar approach to investigate the effect of iron on production. It does seem a valid way to investigate limiting factors.

(A. Burn). The problem is, though, as presented this morning, that we don't know what the critical components are in the estuarine community. While the approach might be fine for phytoplankton, how do you draw a similar curve for benthic algae ? It brings us back to the general use of phytoplankton as the major indicator of eutrophication, whereas they may not be the most critical component of the system, and there may be other responses which cannot be measured in that way.

(D. Nedwell). But can we identify general trends of changes of communities in response to nutrients, although predicting changes of individual species may be beyond our scope at the moment. For example, what factors preferentially induce increase of the cyanobacteria which may cause problems.

(M. Everard). We need to prioritise our estuaries into those which are nutrient-limited and those which aren't. For those which are nutrient-limited, and therefore sensitive to eutrophication, prioritise them on the basis of their use, including conservation purposes. This gives a clear decision framework in deciding where to use resources.

(B. Harbott). The European Directives work the other way around - suggesting that estuaries with already elevated nutrient concentrations are those for concern. In two or three years we will be discussing this with the Department of the Environment with respect to reduction of nutrient levels discharged to sensitive marine areas. The criteria for identifying these 'sensitive areas' include elevated algal concentrations (chlorophyll a), high diel changes of dissolved oxygen concentrations, elevated nutrient concentrations, etc. These conditions are most likely to be found it already fairly eutrophic estuaries, where removal of nutrients from discharges is likely to have minimal effect on the nutrient levels in the area. If a similar effluent was discharged in one of the oligotrophic estuaries it would have a major effect, yet these estuaries would not be 'sensitive areas' under the definition used. For a relatively straightforward management plan and an effective use of resources, we might be better to concentrate on those estuaries which are low nutrient, and have been for a long time.

(M. Everard). Can anybody identify an estuary where an increased nutrient load would not cause an ecological effect ?

(D. Nedwell). What is an 'ecological effect' ? Is a movement of a natural community's range up or down an estuary in response to changed nutrient flux a 'significant effect' ?

(A. Burn). What do we mean by nutrient-limited ? The Wash would not seem to be nutrient-limited, but it shows responses to nutrient pulses. Can we say what a nutrient-limited estuary is?

(D. Nedwell). The question has been posed as to whether there are any estuarine systems which are really nutrient-limited. We need to define what we mean by 'estuary' in relation to nutrient-limitation. If 'estuary' is extended to mean estuarine and coastal system, I would suggest that, overall, all are nutrient-limited as high nutrients are diluted out or biologically removed on moving toward the seaward end. Which nutrient is limiting may also change along an estuary, presumably from P to N. Does this mean that we cannot use basic nutrient concentration data for monitoring purposes ? Can we use nutrient concentrations related to salinity ? There does not seem to be any suggestion that we have the information required to set consent levels in terms of simple nutrient concentrations.

(T. Jickells) This highlights the area for concern about nutrients, which is actually offshore. The estuaries, because of their turbidity, do not have high production and if they have high nutrients they are going to mitigate the nutrient load. Any estuary channels nutrients, and it is offshore, where turbidity is less , that the major effects of nutrient enrichment are likely to be seen. That is why JoNuS had a different focus to the discussion today - it examined the flux of nutrients down an estuary and the impact on the associated coastal sea.

(A. Ferguson). The progress report from the last North Sea Conference will highlight that the above questions may remain largely unanswered for the forseeable future. If we cannot be certain about these key questions where do we go from there ? There is general European agreement on eutrophication policy, at least at a political level, that more nutrients will have a deleterious effect, so the baseline is to prevent further increases. If it is a hopeless problem to untangle cause and effect in the estuarine and coastal system, then perhaps pragmatically reducing estuarine nutrient inputs via control of agriculture or STW effluents in the catchment areas may be the best and cheapest solution. This may not be very helpful to the scientists on the monitoring side, but it may be a useful message to the policy-makers.

(D. Nedwell). In some areas there does seem to be a possible rationale for further work on a monitoring strategy using indicator organisms e.g. microflagellates as indicators of high nutrients, diatom spp. as indicators. Can we develop a monitoring strategy with these as indicators. Again, should research be examining which components of the estuarine community are important in regulating estuarine nutrient fluxes ? The role of the benthic microflora is poorly understood.

(S. Malcolm) Do we have information on the structure of estuarine diatom communities; whether there are any consistent differences or similarities of community structure between different estuaries; or whether historically there has been stable community structure ? In freshwater sediments historical changes can be followed by changes in the occurence of the frustules of indicator species down sediment cores, but the dissolution of diatom frustules in marine sediments prevents the use of such stratification.

(S. Pullen). There is a lack of a succinct summary of the effects of nutrient enrichment that can be demonstrated from available information, and lack of prediction, even if only at a very general level, of the future possible effects of nutrient enrichment in estuaries and coastal areas. We need a review of the information already available on estuarine and coastal systems in order to authoritatively summarise the data available, to define what we do know about the effects of nutrient enrichment on the biological communities in estuaries, and to define where are the major gaps in information.

(D. Nedwell). There are a number of reviews in the process of being written, but this will probably be from the point of estuaries in general, not particularly conservation-related.

(Unknown) Are there any estuaries that are going to change rapidly in nutrient status, for better or worse, over the next 4-5 years, which might provide the potential for a good monitoring experiment before and after nutrient enrichment ? Alternatively, are there any small estuaries which could be experimentally perturbed by the addition of nutrients, and the response of the system followed.

(Unknown) There are no new sewage discharges planned. However, reduction of nutrient inputs into the Tees showed that the turbidity dropped, and it might be possible to follow further changes in the biotic community with time in response to decreasing nutrient load. Areas where barrages are being built (e.g. Cardiff) may also provide study sites to follow changes as nutrients accumulate in the absence of flushing.

(M. McGarvin) Studies in the 1930s tipped fertilizer into Loch Sween and followed the biological consequences. This also may provide information on response to nutrients.

(D. Purdie and others). In relation to reliable data sets, long term monitoring can give a good background against which to measure perturbations- e.g. a harmonized monitoring carried out in the Tees made measurements every 0.5 hours. However, long term monitoring can generate vast amounts of data that is difficult to collate and interpret. The acquisition of large data sets which cannot be assimilated and digested is not of value. A lot of data is already available, but it needs collating and analysing. Initially at least, probably more data is not required.

(R. Park). The idea of examining model hard and soft estuaries with continual monitoring in itself requires prior studies in order to determine optimum positions for automatic or routine samples and analyses designed to get background information.

(B. Harbott). I have been involved with the production of a report on data from a harmonised monitoring programme. The value of the nutrient data was less than was originally hoped for, but further collation and dissemination of the data will be going on in the next few months. The data is, however, for the bottom of the river, which is quite different to that required for estuaries.

A few estuaries could be identified where we feel, intuitively from our expertise, that there is a risk of damage being done if the nutrient status changed substantially. These estuaries should include examples of both ends of the spectrum of trophic effects in estuaries.

SUMMARY POINTS FROM THE DISCUSSION

1. There is a lack of basic information in key areas required to define baselines; not enough information to tell us what we need to monitor and why.

2. Particularly in estuaries, our understanding of the levels, fluctuations and impacts of different nutrients is unclear. Part of this difficulty is distinguishing the effects of nutrient elevation from natural variations due to tide or season. Relating nutrient concentration to salinity may be helpful, and nutrient ratios should also be taken into account.

3. There is a lack of knowledge as to what are key, limiting nutrients in estuaries, originating from a lack of understanding of the estuarine systems involved.

4. The relative importance to nutrient budgets of subsystems within estuaries is unclear. Particularly, the role of benthic biofilms may be important, but is poorly understood.

5. There is no objective basis presently available for defining quality standards with respect to nutrient concentrations or loadings in estuaries, either in terms of the impact of increased loading on the estuarine system nor in respect of limits for conservation.

6. There is general agreement that there is a fundamental difference between oligotrophic and eutrophic estuaries, but the definition of this difference is not clear. It may be in terms of tidal effects, residence time, or underlying geology, and is likely to influence the capacity of the estuaries to respond to elevated nutrient load. Future work should concentrate on a comparison between these two major estuary types.

7. There may be biological groups or species which are indicators of nutrient elevated estuaries, but further work is required to define these in any useful way.