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The management of nutrients and potential eutrophication in estuaries and other restricted water bodies

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Abstract

Conceptual models are derived to indicate the signs and symptoms inherent in nutrient changes to brackish, estuarine and coastal areas of restricted circulation. These give a structured approach to detecting adverse symptoms of hypernutrification and eutrophication at all levels of biological organisation, from effects at cellular levels to the ecosystem approach. The conceptual models illustrate the bottom-up approaches to the detection and control of potential problems and the importance of top-down responses. The bottom-up approaches incorporate mechanisms with regard to inputs, retention of nutrients, biogeochemical cycling and the primary production response. The top-down approaches include the detection of responses in high-profile components of the marine system, such as fisheries, sea mammals and wading birds and seabirds, which are often of paramount socio-economic or conservation importance. The management of the above causes and consequences, and following from the adoption by signatories to proposals given by the Paris Commission (PARCOM), can be accomplished by the derivation of Ecological Quality Objectives (EcoQO) and Ecological Quality Standards (EcoQS). These are given here as a development from the Environmental Quality Objectives and Standards (EQO/EQS) approach. Such EcoQO and EcoQS are regarded as as an aid to monitoring and management of estuaries and coastal waters. That management includes recent proposals within European legislation aimed at monitoring and managing the health and integrity of coasts and estuaries, for example the implementation of the Nitrates, Species & Habitats, and Water Framework Directives. The paper, therefore, discusses both the quality and quantity of data involved in the science required by managers and the way ahead for assessing and managing the fate and effects of nutrients. Using European and U.S. examples, the paper introduces the major challenge of how the concerns highlighted can be addressed by policy action.

Introduction

National and international bodies are increasingly required to consider the causes and concerns relating to eutrophication in the estuarine, coastal and marine environment and to provide management responses. This requires a structured approach by, firstly, defining the problem to give the basic understanding, the concerns by the public and the scientific and marine environmental management community and by determining the source of the problem. Secondly, the diagnosis of ecosystem pathology can both describe and assess the presence and severity of effects. Management tools for addressing these include the adoption of objectives and standards, the development of reference conditions and indicators to determine if those conditions are met, monitoring protocols and, eventually, the ability to have an increasing predictive capability using conceptual and numerical models. Thirdly, countries both singly and in tandem have to develop and implement policy strategies for addressing the problems although, as shown below, these are merging and leading to overlap. Those strategies should include controls on nutrient inputs.

The effects of excess nutrients in freshwaters have been well understood and documented since the mid-

20th Century. In contrast, an awareness of the potential importance of eutrophication in the coastal and marine environment has been developing only since the early 1980s (de Jonge & Elliott, 2001). Since then, the scientific determination and understanding of eutrophication and how it might be controlled through policy and regulation started to be incorporated in coherent frameworks both in Europe, through the Paris (OSPAR), Helsinki (HELCOM) and Barcelona Conventions, and in the U.S.A. through the National Oceanic and Atmospheric Administration (NOAA). Overall budgets of nutrients have been calculated for certain sea areas (as shown in the Quality Status Reports produced by OSPAR) (OSPAR Commission, 2000) although these reflect the adequacy of the data, which are good for point sources but poor for atmospheric and other diffuse sources.

A review of the available information (e.g. de Jonge & Elliott, 2001) indicates that whereas many scientific studies research in detail the causes and initial effects of the eutrophication, public and nature conservation concerns relate to high profile events. The latter include fish kills, closed fisheries, the reduced biodiversity of habitats, seabed de-oxygenation, reduced aesthetic quality of the coastal environment and even complete ecosystem collapse over extensive fjords and seas. These can be regarded as a set of causes leading to primary and secondary effects (Table 1). In turn, because of these events and public perceptions, scientists, policy makers and regulators are required to take an holistic view towards understanding the problems and producing remedial actions (see below).

Defining the problem

In addressing any problem, it is necessary to define and agree the terms used. The OSPAR Strategy to Combat Eutrophication (OSPAR, 1999) defines eutrophication as "*the enrichment of water by nutrients causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned, and therefore refers to the undesirable effects resulting from anthropogenic enrichment by nutrients as described in the Common Procedure*". This definition, therefore, not only gives the cause but also the symptoms of effect. If it is accepted that aquatic systems have an assimilative capacity, i.e. the ability to absorb change or inputs before impacts are seen, then the definition of eutrophication by Schramm & Nienhuis (1996) is also of relevance: "*the process of natural or man-made enrichment with nutrient elements, mainly of nitrogen and phosphorous, beyond the maximum critical level of the self-regulatory capacity of a given system for a balanced flow and cycling of nutrients*".

The above definitions differ from that of hypertrophication (nutrient pollution) which may be regarded as "*over-enrichment or excess supply of nutrients beyond the maximum critical self-regulatory level to an extent that detrimental processes cause irreversible changes in aquatic communities, as long as nutrient levels are not reduced*" (Schramm & Nienhuis, 1996). In turn, this differs from the term hypernutrification which is regarded here simply as "*nutrient contamination – an excess of nutrients being present without adverse effects being manifest, the latter being the result of some other limiting factors*". The latter condition is particularly important and evident in estuaries which will have high levels of nutrients but those cannot be used to provide excess algal growth due to the high turbidity producing light limiting conditions.

Conceptual model of causes and effects

The actual and potential problems of nutrients and eutrophication can be defined and considered with reference to 'symptoms of ecosystem pathology', as the primary and secondary symptoms of change. These are used to produce a conceptual model of cause and effect and to indicate generic as well as site specific responses both according to geographical scale (extent of effects) and duration. The conceptual model can be considered as linking bottom-up causes versus top-down consequences (Fig. 1a, b). The former includes the physical nature of the system, the input levels and the initial biogeochemical cycling, whereas the top-down consequences include the effects on the macrobiological system: the macroinvertebrates, macrophytes, fishes and birds. As such, the higher order (top-down) effects may be more easily observed both by scientists but also by the public. Such changes, for example fish kills due to anoxia, therefore have a higher public perception but the understanding of those responses relies on knowledge of the bottom-up causes. As indicated above, the main problems occur in areas of restricted water exchange, such as the Baltic and Black Seas, fjordic and lagoonal systems, and those areas into which nutrients have been

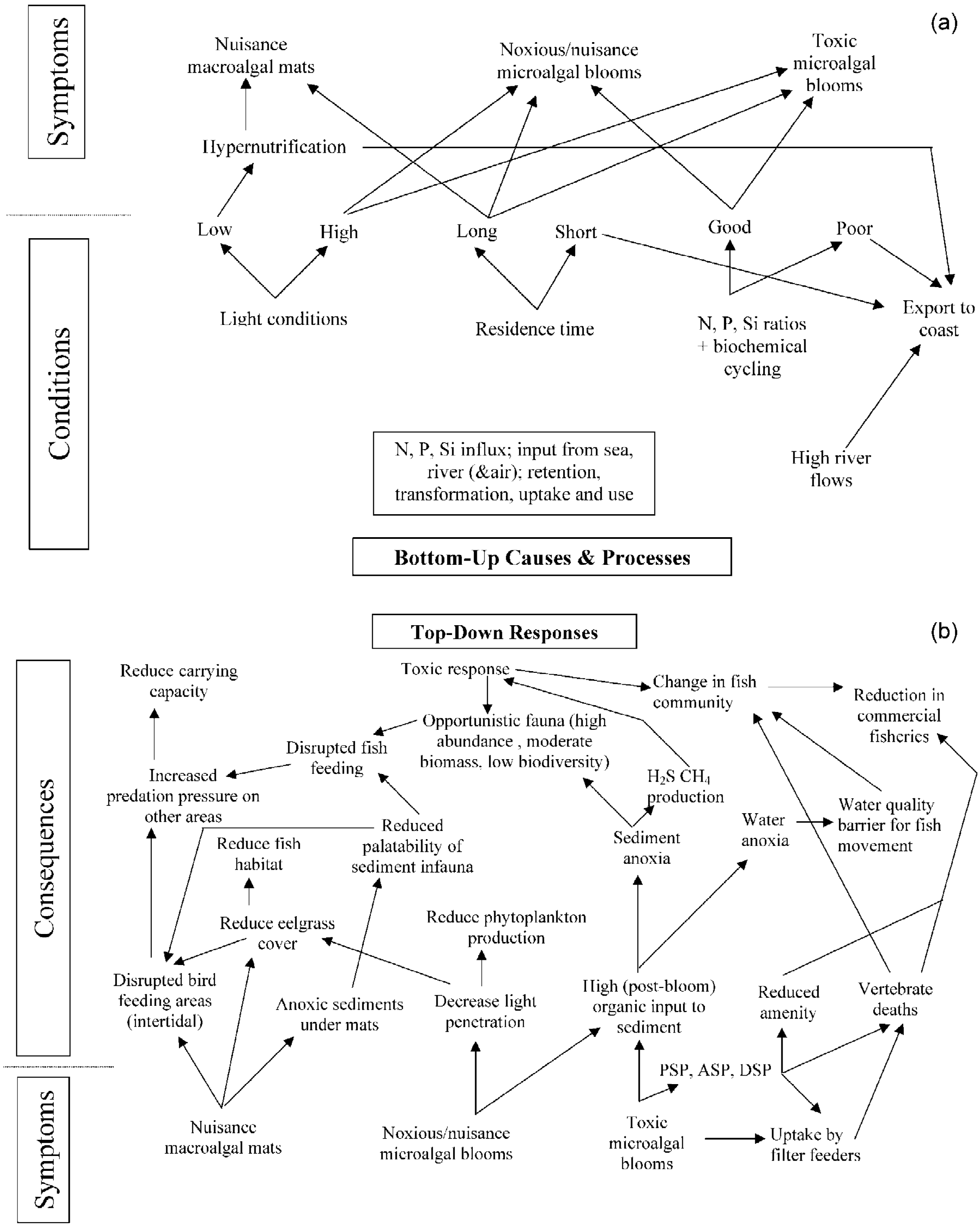

Figure 1. (a) Conceptual model – bottom-up causes and processes for nutrient effects. (b) Conceptual model – top-down responses for nutrient effects and eutrophication (adapted from Elliott & Hemingway, 2002).

Table 1. The causes, primary and secondary effects of eutrophication (developed extensively after an original format by Schramm & Nienhuis, 1996)

Causes	increased nutrient inputs; high residence time/slow flushing rate.
Primary effects	occurrence of blooms of toxic or tainting phytoplankton forms; increasing plant/algal biomass production; occurrence of blooms of micro-algae which may be a nuisance (and cause aesthetic pollution) through foaming (e.g. *Phaeocystis*, *Chaetoceros socialis*); decline or disappearance of certain perennial plants, often replaced by annual, fast growing opportunistic species such as foliose or filamentous green algae (e.g. *Ulva*, *Enteromorpha*); reduced diversity of the flora (and associated fauna); changes to photic regime through shading.
Secondary effects	increased particulate and dissolved organic matter in seawater and sediments; nuisance mat formation to hinder fishing and navigation; nuisance mat formation producing anoxic conditions; increase in microbial community and thus oxygen depletion, leading to hypoxic processes such as H_2S and CH_4 production; development of opportunistic macrobenthic populations and thus changes along the Pearson-Rosenberg continuum; poor water quality, especially water column oxygen depletion, thus affecting fishes and zooplankton; mortalities of higher organisms through effects of neuro-toxins; hindrance to intertidal feeding by wading birds and ducks.

transported from many sources. The latter includes the Skaggerak which receives nutrients in water transported from the North Sea states and atmospherically from the British Isles.

Attributes for the diagnosis of ecosystem pathology

In general, and for wide-scale application, changes in marine ecosystems as the result of human activities can be summarised as seven indicators (developed from Harding, 1992), many of which are reflected in concerns about nutrient enrichment (added in parentheses):

1. primary production (excess micro- and macro-algae),
2. nutrients (and their fate & effects),
3. species diversity (e.g. producing abiotic areas),
4. community instability (changing biotic composition, presence of opportunistic algae and invertebrates),
5. size and biomass spectrum (loss of ecosystem large elements, e.g. fish),
6. disease/anomaly prevalence (e.g. hypoxia-induced ailments in fishes),
7. and contaminant uptake and response (e.g. uptake of toxins).

In relation to the effects of nutrient enrichment, the characteristics of concern include, amongst others: the turnover time, including residence time and flushing rate leading to nutrient retention processes; the broad-scale physiography, its closed or open nature and its seasonality; the dominant physical processes (wind/wave/tidal/density currents, freshwater inflow); the high/low energy nature of the areas producing the hydrographic-sedimentary interrelationships; the biogeochemical processes in relation to hydrographical processes (N, P, C, Si cycling/dynamics); the depositing potential leading to the development of opportunistic populations via organic enrichment; the underlying control on the biological processes, e.g. the effect of turbidity on nutrient depletion; the nature of the area for supporting algal mats and the likely development of toxic or noxious blooms and their consequences; the value for higher predators and their response to eutrophication symptoms; and the carrying capacity for fishes (nursery, migration and feeding grounds) and birds (e.g. overwintering area).

Consequently, in order to determine and understand the extent and duration of the problem, there is the need for a reference framework and methods for defining reference conditions (as also indicated in the new EU Water Framework Directive). Reference conditions can be determined by one of 4 ways: hindcasting (using historical records), a direct comparison with another (pristine) area, predictive modelling, and the use of 'best-guess'/expert opinion. Hence, there is the need for historical budgets against which to compare the present situation as well as and widescale surveillance. However, it is emphasised that the latter should be monitoring focussed on the detection of the above signs and symptoms of nutrient enrichment effects.

Spatial occurrence of eutrophication

The location of eutrophic or potentially eutrophic areas requires to be determined in order to put remedial strategies in place. For example, within the U.K., OSPAR identified very few areas as of concern for eutrophication: notably the Ythan Estuary, North-east Scotland, and Langstone Harbour, Hampshire, both of which were identified because of excessive intertidal macroalgal mats. Similarly, Seal Sands in the Tees estuary, north-east England, has increasing algal mats such that, as with other intertidal areas, there is concern regarding habitat integrity and the effect on bird and fish feeding as well as under-mat anoxia. Each of these cases reflects the retention of nutrients within the estuaries and harbours. However, in general, and in contrast to large areas of the Baltic and Skaggerak which develop extensive floating algal mats, most U.K. areas are sufficiently well-flushed such that nutrient enrichment does not present a problem. Despite this, other symptoms shown in the U.K. include hypernutrification and dissolved oxygen sags in many estuaries, especially at their turbidity maximum zones, the presence of *Phaeocystis* blooms off the Welsh and Irish coasts, and toxic microalgal blooms off the Scottish coast. It has been speculated that the latter were caused by nutrients from fish farming (MacGarvin. 2000).

The eutrophication signs and symptoms shown in the British Isles are considered here to be minor compared to other areas. For example, the Skagerrak and the Baltic areas have shown a transition from eelgrass (*Zostera*) domination to algal (*Cladophora* and *Enteromorpha* spp.) domination as the result of nutrient enrichment. This in turn reduces dissolved oxygen levels, plaice nursery areas and benthic biodiversity. Similarly, the Black Sea suffered an ecosystem collapse through eutrophication as did the Wadden Sea and Skaggerak/Kattegat in the late 1980s with a bloom of the microalga *Chrysochromulina* (see WHOI, 2001 for maps showing areas affected).

Environmental and socio-economic concerns

The major stakeholders in the marine and estuarine environment have concerns based on their desire for a healthy environment, without an increase in organic enrichment or its consequences. Conversely, and potentially as importantly, there are now also concerns by nature conservation bodies regarding decreases in organic enrichment, especially given the large land-claim of wetlands which previously supported large macrophyte populations and thus would have added detritus to support the estuarine detritus-based food-chains (Elliott & Hemingway, 2002). There are also concerns by nature conservationists regarding the potential loss of habitat (water, seabed and intertidal areas) and its integrity through increased enrichment. If such changes persist then ultimately there is a change in carrying capacity, especially the number of higher predators such as birds and fishes supported by an area.

In addition to the environmental consequences, and under the philosophies of Integrated Coastal Zone Management, it is necessary to take note of changes affecting other uses and users. Increasingly, environmental protection bodies, such as the Environment Agency in England and Wales, are required to incorporate socio-economic aspects into decision and policy-making. Similarly, it is axiomatic that the public and user-groups most often become most concerned when there are socio-economic repercussions of environmental change. The economic repercussions of eutrophication arise from their potential effects and impairment of use (Table 2); the latter may be due to actual or perceived economic importance and consequences (Bricker et al., 1999).

It is necessary to determine near and far-field effects, thus although one habitat such as an estuary may be affected, its role in acting as a sink by re-

Table 2. Socio-economic repercussions of eutrophication symptoms (modified from Bricker et al., 1999)

	Loss of habitat	Increased algal toxins	Fish kills	Offensive odours
Commercial fisheries	√	√	√	
Recreational fisheries	√	√	√	
Tourism	√	√	√	√
Human health		√		
Water sports		√		
Aesthetic values			√	√

ceiving nutrients from upstream as well as acting as a source to the coastal areas requires to be considered. Furthermore, there is the need to quantify the aspects which are quantifiable in economic terms, such as fisheries, but also to quantify the 'un-quantifiable' aspects such as aesthetical characteristics and values. For example, whether it is possible to value the degradation of an area when perceived by those using it for recreation. Similarly, there is the need to determine the value of possible increased fisheries, with the input of organic matter, but also the costs of decreased fisheries/habitat where environmental degradation occurs. There may also be costs due to the losses in any nutrient (cost) budget, i.e. the wasteful or ineffective use or rapid removal from the land of fertilisers. Finally, it is necessary to determine the costs of treatment, mitigation and/or compensation in addressing the problem. As yet, there has been no comprehensive assessment of these economic aspects although the ongoing EU Framework V research programme EUROTROPH will carry this out for a few estuarine and coastal areas (see EUROTROPH, 2001).

Objectives, standards, reference conditions and monitoring

In common with tackling other marine problems, it is necessary to define the habitats at risk and to decide whether to assess all habitats or to prioritise and thus only monitor where problems are likely. This is particularly difficult in the case of diffuse causes of pollution where the causes and thus the effects may be widely dispersed. Then it is necessary to carry out targetted monitoring against a set of indicators which assess specific symptoms. This is regarded here as monitoring *sensu strictu* and thus is distinguished from surveillance; in the latter, field surveys are carried out with a *post hoc* detection of trends followed by the explanation of those trends. The resultant indicators may be derived and used singly or in combination and on a spatial (extent) and/or temporal (duration) basis, on a taxonomic (taxon-specific) and/or non-taxonomic (e.g. environmental) basis, or on a structural (i.e. characters at a single census point) and/or functional (rate processes) basis. This approach includes the setting of objectives and standards (Elliott, 1996) and testing for compliance with them. Hence, the move by the EU Directives and OSPAR towards considering Ecological Quality (EcoQ) and Ecological Quality Objectives (EcoQO). It is suggested here that EcoQO are accompanied by Ecological Quality Standards (EcoQS) as a further tool to be used as a basis for monitoring (see below). However, while such tools, including indicators, attempt to look for a change as a response to nutrient inputs, it is necessary, especially in variable environments such as estuaries, to consider that an environment can have a large capacity for absorbing nutrients before effects are manifested. Such a resilience can be regarded as *environmental homeostasis*.

As an approach to the monitoring and management of waters, and as a precursor to the EcoQO/EcoQS debate, the U.K. has long adopted the EQO/EQS (Environmental Quality Objectives/Standards) approach whereby *objectives* are statements and *standards* are numerical values. EQO/EQS are also incorporated into certain EU environmental protection Directives (Elliott et al., 1999). These have been derived and then used for determining use-related achievement and for chemical and microbiological determinands, e.g. as shown with compliance for the EU Bathing Beaches Directive. Any objective created, as the desired aim for an area such as the ability to maintain an activity such as bathing, requires to be accompanied by one or more standards, for example the levels of coliform bacteria. They should provide reference conditions or an end-point against which effective monitoring is performed such that it is difficult to create monitoring programmes or to see if an environmental quality objective is met unless standards are produced. Consequently, the approach requires monitoring protocols to be rigorously defined.

Under the ecosystem approach now adopted widely, these objectives and standards are now required to address nutrient and eutrophication problems. For example, an objective may be to prevent macroalgal mats forming on intertidal areas because of the resulting effect on the top predators such as fish and wading birds. The latter have a high public and nature conservation relevance. The accompanying standard or reference could be that no more than x% of mudflat should be covered by opportunistic green algae during later summer periods. Similarly, if an adopted quality objective is to allow fish to migrate through an estuary then the accompanying standard could be that dissolved oxygen has to exceed 5 mg l^{-1} (Elliott & Hemingway, 2002). In each case, the monitoring is then designed with sufficient rigour and frequency to detect such a change and management actions are then taken if the standard is breached.

EcoQO, rather than EQO, becomes a more realistic term for addressing the problems caused by nutrient enrichment given that biological and ecological health-related objectives are required. There is the need to separate these from true EQO, i.e. those relating to the human use of the system such as the requirement for an area to support bathing. The extension of EQS to EcoQS requires a large degree of development, for example, whereas EQS are usually derived for chemicals (DO, NH_4^+, trace metals), EcoQS are required for ecological or biological health variables. Despite this, there are few examples of EQO and EQS in legislation and statutory frameworks: the U.K. Water Act 1989 provides for statutory objectives and standards but only those related to European Directives have legal status; the U.K. environment protection agencies have locally adopted such standards, and the EA in England and Wales uses non-statutory estuary quality objectives as a basis for water quality management and licensing. Similarly, the OSPAR signatories agreed at Sintra, 1998, to achieve concentrations near background levels for natural substances and at zero for synthetic substances – this is also a use of EQS, whereby discharge controls and monitoring are directed towards achieving the standards. Finally, it is of note that the Dutch RIKZ has adopted operational objectives towards developing criteria for judging eutrophication, its causes and consequences.

Models as tools for nutrient management

Conceptual, analytical and numerical models help to identify, explain and tackle problems; for example the conceptual models here (Fig. 1a, b) summarise the scientific and conceptual framework and thus they are valuable in presenting the potential problem to managers and policy-makers (Read et al., 2001). In turn, quantifying the links in conceptual models will produce numerical models. There is a hierarchy of the latter ranging from hydrodynamic models (of water movements, flushing rates, etc, and which may be two and three dimensional) to biogeochemical models (e.g. giving chemical processes such as nutrient transformations), population models (showing individual number change such as in microbial or fisheries populations), community models (allowing the prediction of community structure) and finally to ecosystem models such as GEMBASE and BOEDE which aim to summarise ecosystem structure and functioning. However, with progression through this ecosystem hierarchy there is increasing inherent variability (i.e. 'noise') such that it is more difficult to observe a 'signal' as a measure of change, a greater uncertainty of prediction, and a poorer understanding of processes (Read et al., 2001). All of these dictate that there is likely to be less willingness for their use in management.

Numerical models can be stochastic and deterministic in that they reflect the underlying science and involve equations determined by the physics and chemistry interrelationships, for example the exchange between ammonia, nitrate and nitrite depending on the prevailing conditions. In contrast, the models can also be empirical in that they reflect observed patterns and trends but without being based on any theoretical basis. The latter may be based on regression or multiple regression equations which link independent environmental variables, such as water transparency and nutrient concentrations, with a biological (response) dependent variable such as chlorophyll *a* content (Read et al., 2001). With increasing data and a better understanding, the adequacy and predictive capability of these models may increase but again their value in reaching management decisions is still questionable.

Policy strategies – development, merging & overlap

Since the middle of the 20th century, there has been a sequence of policy action in defining and tackling the marine environmental problems of developed countries. In the 1960s, it was realised that there is a problem of pollution; in the 1970s that there was no problem as dilution was a solution (via long-sea outfalls); this was then regarded as being insufficient in the 1980s, and hence end of pipe controls were increased.

In the 1990's it was accepted that the problem was not just related to pollution *per se*, was much larger than acknowledged and that an holistic and ecosystem approach was required together with industrial Environmental Management Systems. At the start of the 21st century, it has been realised that most of the previous solutions relate to the more-easily tackled point-source pollution whereas the problems now mainly relate to diffuse pollution. As such, catchment and open sea solutions and strategies are required. This progression of different strategies was accompanied by a movement from a sectoral approach, in which each activity (pollution, fisheries, coastal defence, etc.) is addressed separately, to a multi-sectoral approach. In the latter, there is the need and desire to consider all activities concurrently, hence the ecosystemic holistic approach.

In essence, it has been accepted that point-source pollution is addressed relatively easily, albeit expensively, whereas diffuse pollution requires a greater degree of co-ordination and wider-scale thinking. Accompanying this sequence of addressing concerns, there have been many initiatives and developments (Table 3) which have some common themes but also have led to confusion and overlap in marine environmental management in NW Europe (Ducrotoy & Elliott, 1997). An increasing number of policy initiatives set the framework and priorities to be addressed, they require the creation of objectives and standards, and they are designating areas for protection and assessing the condition of that area. Some of these initiatives are source-orientated, in that they address the cause of change, whereas others are target-orientated in that they address the effects in biological components.

Because of the actual or potential duplication (see also Ducrotoy & Elliott, 1997), there is a recommendation here of the need to bring together the Oslo and Paris Commission, the EU Directives (for Water Framework, Integrated Pollution Prevention & Control, Habitat & Species Protection, Urban Wastewater Treatment (UWWT), and Nitrates), the International Council for the Exploration of the Sea, and the North Sea Ministerial Conference. In bringing these together, there is the opportunity to remove anomalies in the systems. For example, there is a spatial conflict in areas under control and in procedures which is shown by the limits covered by OSPAR and the Habitats & Species Directive (to the 200 nm limit) and the 1 nm covered by the Water Framework Directive (unless this eventually becomes extended). This is despite the fact that the latter Directive purports to give added protection to areas already protected under other Directives.

Tackling the problem (1): OSPAR in NW Europe

The OSPARCOM has agreed a set of strategies: for the *Protection and Conservation of Ecosystems and Biodiversity (P&CE&BD)*; to *Combat Eutrophication*; to prevent the discharge of *Radioactive Substances* and *Hazardous Substances*; and for the control of *Offshore Oil and Gas* developments and impacts. Within these, it has identified a set of 19 issues of which four have been adopted as the most important: benthic communities, planktonic communities, nutrient budget and production, and oxygen consumption, each of which can be linked to the primary and secondary symptoms of eutrophication (Table 4). It has agreed to use a target-orientated approach (i.e. as an ecological response) as well as a source-orientated approach (reduction in diffuse and point sources). In the terms used above, these are, respectively, top-down responses and bottom-up processes and causes.

As nutrient transport and thus eutrophication are trans-boundary problems, OSPAR has included them as one of their strategies with a general objective – '*to achieve and maintain a healthy marine environment where eutrophication does not occur*'. The strategy is to define problem areas, potential problem areas or non-problem areas, to develop EcoQO by 2002 and to produce a healthy marine environment by 2010. This in turn requires management tools such as indicators and targets as well as adequate and effective monitoring. Hence, OSPAR has adopted a Common Procedure to identify the eutrophication status of marine areas which requires the implementation of integrated target-orientated and source-orientated actions for problem areas. These include determining EcoQO which OSPAR regard as '*the desired level of biological quality relative to the reference level*'. Hence, as interpreted here, there is a requirement by member states, following the Common Procedure, to develop and adopt EcoQO and their accompanying EcoQS for the components at risk (as early warnings of change or the end point of change). Under this rationale, EcoQS can be interpreted as reference levels and as such they overlap with Reference Conditions identified in the EU Water Framework Directive and the Favourable Conservation Status identified in the EU Habitats & Species Directive (Elliott et al., 1999).

Table 3. The OSPAR proposed set of issues translated into the appropriate eutrophication symptoms and signals and the ecosystem at risk

Proposed set of issues	Relevance to eutrophication symptoms/signals	Ecosystem at risk
Reference points for commercial fish species	interference with migration routes	estuaries
	interference with nursery areas	estuaries/sandy beaches
	interference with feeding and refugia	mudflats, saltmarsh
Threatened or declining species	prevention of migration (e.g. shads)	upper estuarine areas
Sea mammals	production of toxic blooms	open coastal
Sea birds	production of toxic blooms	open coastal
	interference with feeding by algal mats	intertidal mudflats
	change in palatability of prey through anoxia	low energy areas
Fish communities	change to herbivores	inshore areas
	interference with use	all marine areas
Benthic communities	movement along Pearson-Rosenberg (Rhoads-Germano) model	sedimentary areas in low energy regimes
Plankton communities	community change	inshore areas
	dominance of certain taxa	inshore areas estuaries
Habitats	habitat integrity	inshore and estuarine areas
Nutrient budget and production	hypernutrification	areas with poor water exchange
	increased input and retention	inshore, estuarine, fjords
Oxygen consumption	increased consumption	restricted circulation areas
	tendency to hypoxia then anoxia	stratified and restricted areas

Together with the need for this strategy to assess the extent of the signs and symptoms of eutrophication, a joint strategy is needed to control the causes of the change. In Europe, this is being tackled for point source discharges, such as via the Urban Wastewater Treatment Directive, and diffuse sources, such as via the Nitrates Directive and the creation of Nitrate Vulnerable Zones (Elliott et al., 1999). However, a difficulty faced by states such as the U.K., where the symptoms are relatively minor compared to elsewhere, is to convince politicians, policy makers, environmental managers and the public that diffuse pollution and the transport of pollution are problems to be tackled on a wide scale. For example, they have to acknowledge that the country contributes to problems experienced elsewhere, for example in Scandinavia.

Tackling the problem (#2): NOAA in the U.S.

The U.S. NOAA has recently produced a comprehensive means of addressing estuarine eutrophication problems (Bricker et al., 1999). It has defined primary and secondary symptoms and then given high, moderate and low scores for each symptom. This has been used to produce a matrix of the symptoms to give an overall expression of concern of eutrophic conditions. Finally, these in turn have produced a regional assess-

Table 4. NW European marine and coastal waters: controls on nutrient inputs and their effects (see text for abbreviations)

		Frameworks	Priorities	Objectives	Area designation	Condition assessment	Standards	Source orientated	Target orientated
1970	EQO/EQS			√			√	√	
1974	OS/PARCOM	√	√					√	√
1979	Wild Birds Directive	√			√	√			√
1991	Nitrates Directive	√		√	√			√	
1991	UWWT Directive	√			√	√		√	
1992	Habitats & Species Directive	√	√	√	√	√	√		√
1992	OSPAR	√	√					√	√
1995	NSeaMin Conference	√	√					√	√
1996	IPPC Directive		√				√	√	
1998	OSPAR Sintra	√	√					√	√
1998	OSPAR Eutrophication Strategy			√	√	√	√	√	√
1998	OSPAR P&CE&BD Strategies			√	√	√			√
2000	Water Framework Directive	√	√	√	√	√	√	√	√

ment, including an analysis of data completeness and reliability (DCR), and hence a national strategy. It is of note that the U.S. evaluation relied where possible on available data but that in many areas, especially those where little monitoring has been carried out, there are few data available. In those cases, the evaluation relied on local knowledge. As such, the approach used indicates that such an evaluation can be carried out using expert judgement where data are lacking and still produce a worthwhile result.

This detailed assessment concludes that symptoms of eutrophication are prevalent in U.S. estuaries; that there is substantial human influence on the expression of eutrophic conditions; that impairments to estuarine resources, and fisheries in particular, are of great concern; that management requirements depend on eutrophic conditions and susceptibility; that without preventative efforts, eutrophic conditions can be expected continually to worsen; that much effort is needed to improve the characterising and understanding of estuarine eutrophication; and that assessment results will be valuable in setting national priorities. While all of these are to be expected, they very well illustrate the value of a comprehensive and objective evaluation of the problem.

Concluding remarks – the way ahead: managing nutrient inputs, fate & effects

With respect to nutrients, any system may show the low level effects of change but within an inherent capacity for absorbing that change (regarded here as 'environmental homeostasis'). In management terms, it is better to take as the end point the aspects of particular socio-economic significance or those significant in human perception, e.g. the aesthetic aspects. Therefore, there is the need to separate causes and symptoms and to regard eutrophication as a set of undesirable symptoms. This includes separating it from hypernutrification (nutrient contamination) but ensuring that it is broader than organic enrichment. The definition and assessment of nutrient effects also have to allow for varying critical levels of inputs, for example in the spectrum between oligotrophic systems and naturally-eutrophic estuaries. It also has to encompass allowing for coastal areas receiving nutrients but where those nutrients are successfully used to enhance productivity without creating undesirable effects. In this, it is also necessary to acknowledge that most estuarine and marine systems are resilient and thus recovery is achievable with a reduction in inputs.

As shown here, it is necessary to consider our confidence in ascribing effects to eutrophication drivers.

There are some good case-histories of the consequences of nutrient inputs, the changes to primary producers and the changes at higher trophic levels. This qualitative approach has produced the conceptual models. However, there are insufficient case-studies, especially of holistic studies, to quantify the sequence of processes. Similarly, there are extensive modelling approaches but one questions whether these are yet sufficient for management at ecosystem level. Linked to this is the use of schemes for classifying marine waters (*a la* the EU Water Framework Directive) and indicators of change related to ecosystem pathology which can be used as management tools.

Recent initiatives, such as by OSPAR and the EU, require reference conditions to be determined based on the causes, signs and symptoms of eutrophication for major ecosystem types. An increasing area of confusion, however, is that these are variously termed trigger values, favourable status, references conditions, indicators or EcoQO/EcoQS/EQO/EQS. Irrespective of the term, they should be linked to monitoring protocols and strategies. Given the nature of the systems to be managed, site specific characters need to be retained but within a manageable set of objectives. This should include identifying those priority ecosystems at risk – by signs, symptoms and causes – which primarily will be inshore areas, areas of restricted circulation and areas likely to have a socio-economic importance or aesthetic, social significance.

As indicated here, there is the paradox that nutrients are required for ecosystem function but an excess of them produces a set of undesirable symptoms, termed eutrophication. Some areas have a high assimilative capacity for those nutrients, often by increased dilution or flushing, whereas others can hold nutrients without showing undesirable symptoms; a third set of areas both retains the nutrients and has physical conditions suitable for creating undesirable symptoms. The latter are the areas which attract attention from the managers and policy makers and thus where there is the greatest political will to address discharges. This has led to improvements by removing nutrients through discharge control.

A second paradox here is that such a perceived improvement in environmental health, i.e. the removal of anthropogenic inputs and excess nutrients, can lead to an overall deterioration in ecosystem functioning. In many estuaries, the removal of anthropogenic organic matter has been accompanied (or in some cases preceded) by a loss of wetlands, usually through land-claim. The latter has resulted in an often-unquantified reduction in detrital inputs, for example the reed-bed and saltmarsh areas lost through land-claim would formerly have been a major source of detritus. Hence, the loss both of natural detritus and anthropogenic organic matter in estuaries, which rely on the detrital pathways for their functioning, should cause concern. In a similar vein, catchment land use and agricultural practices in developed countries result in nutrients being retained less on the land, an increase in water removal from the land and thus greater flushing of estuarine systems. This may reduce the ability of estuaries to act as sinks for nutrients but increase their role as a source to adjoining coastlines.

Our conceptual understanding of such changes is good but less so our quantitative understanding. Despite this, we have the ability (but not necessarily the desire) to make policy decisions based on those inadequate data. The prime difficulty for policy makers and regulators is that whilst eutrophication effects can now be more effectively demonstrated in the coastal environment, the main (uncontrolled) input sources are predominantly diffuse – from land runoff and atmosphere. Hence, addressing these requires different approaches such as changing land practices and reducing combustion products.

It is concluded here that there are several areas for development in order to understand, address and communicate actual and potential problems due to nutrients:

Know the problem: there is the need for effort covering both widespread surveillance (low level) and identified and targeted monitoring;

Research needs: such as in the EU-LIFE ALGAE, MARE and EUROTROPH programmes which bring together the science, modelling and management aspects, including the socio-economic aspects of nutrient and organic reduction programmes;

Lateral thinking: the need for nutrient controls as well as other methods such as the recovery and sustainable use of algal mats (as in the EU-LIFE ALGAE programme where algae are used for paper, cellulose and biogas production as well as fertiliser);

Catchment management: there is the need for catchment nutrient budgets (*a la* the EU Water Framework Directive), and an acceptance of the repercussions of land-use changes such as fast land drainage and the poor land retention of nutrients;

Test the rationale: there is the need to further define the characteristics of the ecosystem, to define EcoQO and EcoQSs, to define the monitoring strategy and monitoring protocols and finally to determine compliance with each of these;

Question the need: for a detailed assessment involving a large data gathering exercise in contrast to the use of 'expert judgement'. i.e. to question what information is required by managers of designated areas or catchments;

Simplify the debate/approach: to get OSPAR to adopt the EcoQO/EcoQS distinction and to get the various bodies to harmonise terms and approaches across their initiatives.

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