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Report of the Study Group to Review Ecological Quality Objectives for Eutrophication

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International Council for the Exploration of the Sea

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1 INTRODUCTION

The Study Group to Review Ecological Quality Objectives for Eutrophication [SGEUT] co-chaired by Gunni Aertebjerg, Denmark, and Ted Smayda, USA, met on 17 – 19 May 2004 at ICES headquarters. In attendance were 11 participants from seven countries (Annex 1). Tonje Castberg, Norway, served as Rapporteur. The agenda is given as Annex 2.

SGEUT discussed five Ecological Quality elements (EcoQs) related to eutrophication, the terms of reference given in Annex 3:

1. EcoQ element (m) – changes/kills in zoobenthos in relation to eutrophication
2. EcoQ element (q) – phytoplankton chlorophyll in relation to eutrophication
3. EcoQ element (r) – phytoplankton indicator species for eutrophication
4. EcoQ element (t) – winter nutrient (DIN and DIP) concentrations
5. EcoQ element (u) – oxygen

Also considered was the UK Working Paper on EcoQOs prepared by Painting et al., and titled "A UK Working Paper to the ICES Study Group to Review Ecological Quality Objectives for Eutrophication" (Annex 4). Extractions from the MCWG reports concerning eutrophication for the years 2002, 2003 and 2004 were considered (Annex 5).

SGEUT participants focused on analysis of work undertaken by OSPAR with respect to EcoQO's-eutro and the OSPAR Comprehensive Procedure. The need for reformulation of the EcoQOs and introduction of new EcoQ elements/EcoQO to supplement or replace existing elements and objectives was also evaluated. In this and in all discussions, the EcoQ elements were evaluated as an integrated and coherent set sensitive to the required metrics, time and geographical areas within OSPAR purview. SGEUT was handicapped by the limited data available for existing EcoQs submitted for its review. Accordingly, the scope and application of the EcoQOs had to be treated primarily as a theoretical exercise. In this, SGEUT relied heavily on the scientific expertise of meeting participants and their research results in their respective regions. This was aided by presentations of four scientific overviews of EcoQ elements:

1. Changes/kills in zoobenthos (m): Lene Buhl-Mortensen
2. Phytoplankton indicator species (r): Tonje Castberg
3. Winter nutrient (DIN and DIP) concentrations (t): Justus van Beusekom
4. Oxygen (u): Tore Johannesen

The overview on chlorophyll (q) was provided by an ad hoc discussion by SGEUT participants, including the presentation of field data at selected sites. In addition, Dr. Suzanne Bricker of the USA NOAA/NCCOS office presented the report of the U.S. National Estuarine Eutrophication Assessment, and relevant to EcoQOs, OSPAR and WFD. She provided considerable expertise and effort in reviewing EcoQ elements as an integrated set (Annex 6). The following sections present the results and recommendations of SGEUT deliberations.

2 GENERAL RECOMMENDATIONS

Application of the EcoQ eutro elements as an integrated set

It is recommended that the five EcoQ eutro elements be applied as an integrated set. However, the cause and effect principles used by OSPAR (Figure 1 annex 3 EUC 03/5/5-E) should be amended as follows. Toxic algal blooms in response to eutrophication should be considered to be secondary rather than primary responses. Primary production in respond to eutrophication should be incorporated as a new and primary response EcoQ element. Organic matter should be treated as having a direct effect on zoobenthos (through deposition) in addition to the indirect effects recognised. Integration of the EcoQ elements should be developed along the same principles used in the model applied by the National Estuarine Eutrophication Assessment of the US National Oceanic and Atmospheric Administration (see Annex 5).

Annual cycles of pelagic EcoQ elements

It is recommended that when ever sampling of eutrophication EcoQ elements is accomplished at "key stations" all pelagic EcoQ elements (chlorophyll, phytoplankton species, nutrients and oxygen) should be sampled at the same time using standard oceanographic methods. This is in order to determine the annual cycle of the pelagic EcoQs, which may give important support for the assessment of all of the eutrophication EcoQ elements including zoobenthos. For example, even though the EcoQ elements on nutrients and oxygen focus on winter and late summer concentrations, respectively, the annual cycles can in them selves give valuable information on the function of the ecosystem, and give important information for assessment of the other eutrophication EcoQ elements.

Nutrient loads as a new EcoQ element

The eutrophication EcoQ elements have to be assessed in relation to the nutrient loads to the system. As a supporting element for this assessment it is recommended that riverine nutrient loads per month should be compiled and made available. The riverine nutrient loads could be developed into a new EcoQ element when normalised to runoff. It is also recommended that atmospheric nitrogen deposition should be compiled on a monthly basis, and where relevant the possibility to determine transboundary nutrient transports should be evaluated in order to be able to determine the monthly nutrient supply to a specific area.

Primary production as a new EcoQ element

Chlorophyll a is used by OSPAR as an EcoQ element for phytoplankton biomass, as it is easy to measure both manually and automatically, and due to a large availability of data and time series. However, the carbon to chlorophyll ratio is highly variable over seasons with the lowest values during winter/spring and highest during the highly productive summer season. There is also evidence, that the chlorophyll concentration response to changing nutrient loads is less pronounced than the primary production response (Markager & Storm 2003), probably due to grazing from filter feeders. When not limited by light, the primary production mirrors more directly the availability of nutrients, and is therefore more directly linked to the nutrient loads and concentrations than chlorophyll concentrations. It has been shown, that increased nutrient loads and concentrations in Danish waters increased both the size of the spring bloom and the level of production during summer (Rydberg et al. in press). It is recognised that intercomparisons of primary production have shown large methodological problems, which have to be solved before primary production can be established as a new EcoQ element for the OSPAR area. However, it is recommended that existing time series should be continued without changing methods so that the time series will not be broken.

Time series workshop

EcoQ elements (q, r, t, u) deal with phytoplankton biomass (chlorophyll), indicator species, their responses to nutrients and their impacts on oxygen levels, respectively. Realistic settings of their objectives and reference points require that they be based on an adequate database from long-term time series measurements. The intrinsic variability of plankton systems blurs the detection and application of the metrics needed for EcoQOs. Regional variations in responses also are a problem. At the moment it is difficult to assign reference points for EcoQ elements because available time series data have not been analysed from this perspective. The SGEUT recommends that it convenes a workshop to evaluate available time series data sets for the OSPAR region and ICES area. It is estimated that there are 10 to 12 long term data collection sites in these regions of greater than 15 years duration, and where high quality parallel measurements of nutrients, phytoplankton abundance, species composition, primary production and oxygen have been made. SGEUT will identify these sites and scientists relevant for the workshop. A set of directed questions will be formulated for analysis by participants using their own data sets for presentation at the workshop. Participants (20-25) will include those working within the Water Framework Directive (WFD) initiative, SGEUT members and other investigators. This comparative ecological analysis of these regional time series will allow SGEUT to provide to OSPAR and other organisations more representative reference data for EcoQO application. The results presented at the workshop will be published in a peer reviewed journal.

3 REVIEW OF THE FIVE ECOQ ELEMENTS

3.1 EcoQ element (m) Changes /kills in zoobenthos in relation to eutrophication

Recommendations

The zoobenthos community provides an integrated response to processes in the water column and thus is important as an EcoQ element. However, EcoQOs for this element needs further development and implementation.

To be able to document the maximum effects of eutrophication on the zoobenthos, sampling should be undertaken just after the annual bottom oxygen minimum period.

EcoQOs for element (m), changes/kills in zoobenthos in relation to eutrophication, should be developed in concert with the EcoQOs for density of sensitive (e.g. fragile) species (o) and density of opportunistic species (p).

A marine benthic biotic index for use as a measure of the ecological quality of benthic communities in response to changes in nutrient and organic fluxes should be applied.

		COMMENTS	
1	**Issue Eutrophication**		
2	**Element m**	Changes/kills in zoobenthos in relation to eutrophication.	
3	**ICES criteria**		Commentary (i.e., pattern of fails still makes this useful for communicating to non-specialists on health of system, or useful monitoring tool to trigger additional research)
	Relatively easy to understand by non-scientists and those who will decide on their use	Y	Changes in zoobenthos are already widely in use in monitoring of human impact on the marine environment.
	Sensitive to a manageable human activity	Y	Responds in the scale of months.
	Relatively tightly linked in time to that activity	Y	
	Easily and accurately measured, with a low error rate	Y/N	Monitoring experience shows that, with standard sampling regime, changes are measured with low error.
	Responsive primarily to a human activity, with low responsiveness to other causes of change	Y	Main sources of stress to the zoobenthos are human activities, e.g., fisheries, nutrients, chemicals.
	Measurable over a large proportion of the area to which the EcoQ metric is to apply	Y	Measurable in all waters where eutrophication is a problem.
	Based on an existing body or time series of data to allow a realistic setting of objectives	Y/N	It is feasible to provide objectives, but would need further development and could be related to an index on quality of the zoobenthos community (see point 10).
4	**Ecological relevance/basis for the metric**	The zoobenthos community provides an integrated response to processes related to eutrophication in the water column and in the sediments thus responses in the zoobenthos community are useful as an EcoQO of eutrophication. It should be related to the other eutrophication EcoQs.	
5	**Current and historic levels (including geographic areas)**	From OSPAR integrated report 2003 on the eutrophication status. For a number of OSPAR regions, the frequency and spatial coverage of monitoring for indirect / other possible effect assessment parameters need to be reconsidered. Where changes/kills in zoobenthos and fish kills as affected by eutrophication has been used by Contracting Parties, this parameter has been applied in a qualitative descriptive way.	
6	**Reference level**	No kills of species or substatial changes in the benthic community.	
7	**Limit point**	Kill of species.	

8	**Time frames**	*Detection of change*	Depending on depth it may be on the scale of months to years.
		Management advice	Annually monitoring. Preferably when the oxygen concentration is low, normally summer-autumn.
9	**Advice on EcoQO options (scenarios)**	*Scenario 1*	No irreversible changes.
		Scenario 2	No change in functional group structure and species composition in the benthic community.
		Scenario 3	Moderate change in functional group structure and species composition in the benthic community.
10	**Monitoring regimes**	For sampling see: Rumohr, H. 1999. Soft bottom macrofauna: Collection, treatment, and quality assurance of samples (Revision of No. 8). 19 pp. For monitoring of hardbottom benthos video transects and photo documentation are widely used but a standard prosedures are not available. For an example of index useful to monitoring EcoQ, see Appendix 1.	
11	**Management measures to achieve EcoQO**	Reduction of nutrient discharges from diffuse sources, point sources and atmospheric deposition.	

Discussion

The usefulness of EcoQOs for zoobenthos in connection with eutrophication

Increased production in the water column due to eutrophication may be hard to track due to rapid changes in hydrography and nutrients being trapped as phytoplankton biomass that is often advected into other areas or sink to the bottom. The zoobenthos community provides an integrated response to processes in the water column and thus it is vital that good EcoQOs are developed and implemented. There is a large and growing experience from monitoring in the scientific community that can be used as guidelines for EcoQOs on zoobenthos. Several indices for benthos have been developed. A recent review on this is provided in the 2004 report from the Study Group on Ecological Quality Objectives for Sensitive and for Opportunistic Benthos Species, SGSOBS. (see at http://www.ices.dk/iceswork/wgdetailace.asp?wg=SGSOBS). A precautionary management of the marine ecosystem is possible only through the development of EcoQ measures/indices based on the tolerance of both sensitive and robust species.

Confusion with other factors

The effects on the zoobenthos from hypoxia and increased organic load can sometimes be hard to discriminate from changes due to other sources of disturbance (sediment contamination, dredging, disposal of dredged materials, bottom trawl fishing, etc.). This risk of misinterpretation of the cause of changes in the zoobenthos community is substantially reduced when monitored together with the other categories, e.g., nutrients, phytoplankton and near-bottom oxygen concentration.

Monitoring

For phytoplankton it has been suggested that the high production period is the best sampling time. However, to document the maximum effects of eutrophication on the zoobenthos, sampling should be undertaken just after the bottom oxygen concentration has reached its yearly minimum. Due to the oxygen demand for decomposition of the organic matter resulting from high production in the water column, bottom oxygen concentration is often at its lowest in late summer-autumn in many areas. Thus, many eutrophic coastal areas lose species during this period. However, species may re-enter into estuaries and fjords during late winter or early spring depending on local topography and hydrography. Monitoring benthos only during spring or early summer may not provide a correct picture of all the effects of eutrophication on zoobenthos.

EcoQOs m, o, and p should be interconnected

With respect to zoobenthos we have the following EcoQ elements:

b. presence and extent of threatened and declining species [also non-benthos]

m. changes/kills in zoobenthos in relation to eutrophication

n. imposex in dogwhelk *Nucella lapillus*

o. density of sensitive (e.g., fragile) species

p. density of opportunistic species

When determining the metrics to be developed for the EcoQO elements (o) and (p), OSPAR suggests considering the following possibilities:

1. an index for opportunists or sensitivity

2. a metric based on the proportion of species that are opportunistic or sensitive

3. the density of selected indicator (sentinel) species

EcoQOs on element **m.** changes/kills in zoobenthos in relation to eutrophication should be developed in concert with EcoQOs for **o.** density of sensitive (e.g., fragile) species and **p.** density of opportunistic species. The change in the benthic community from consisting of a high proportion of sensitive organisms to a community dominated by opportunistic species is a general response to environmental stress. The classical study by Pearson and Rosenberg (1978) based on responses by the benthic community to a gradient in eutrophication/load of organic matter is still the theoretical basis for our understanding and identification of the progressive stepwise changes in zoobenthos as a response to any stress.

OSPAR figure

Some changes are suggested to OSPAR figure showing main cause/effect relationships between the assessment parameters.

Suggested changes to Figure 1, Annex 3 EUC 03/5/5-E

Direct negative effects of increased sedimentation of organic matter on zoobenthos. In an early state of eutrophication, the benthic community will increase in biomass due to more food available. In a later state, particles may cause clogging or burial of some species, e.g., sponges and corals.

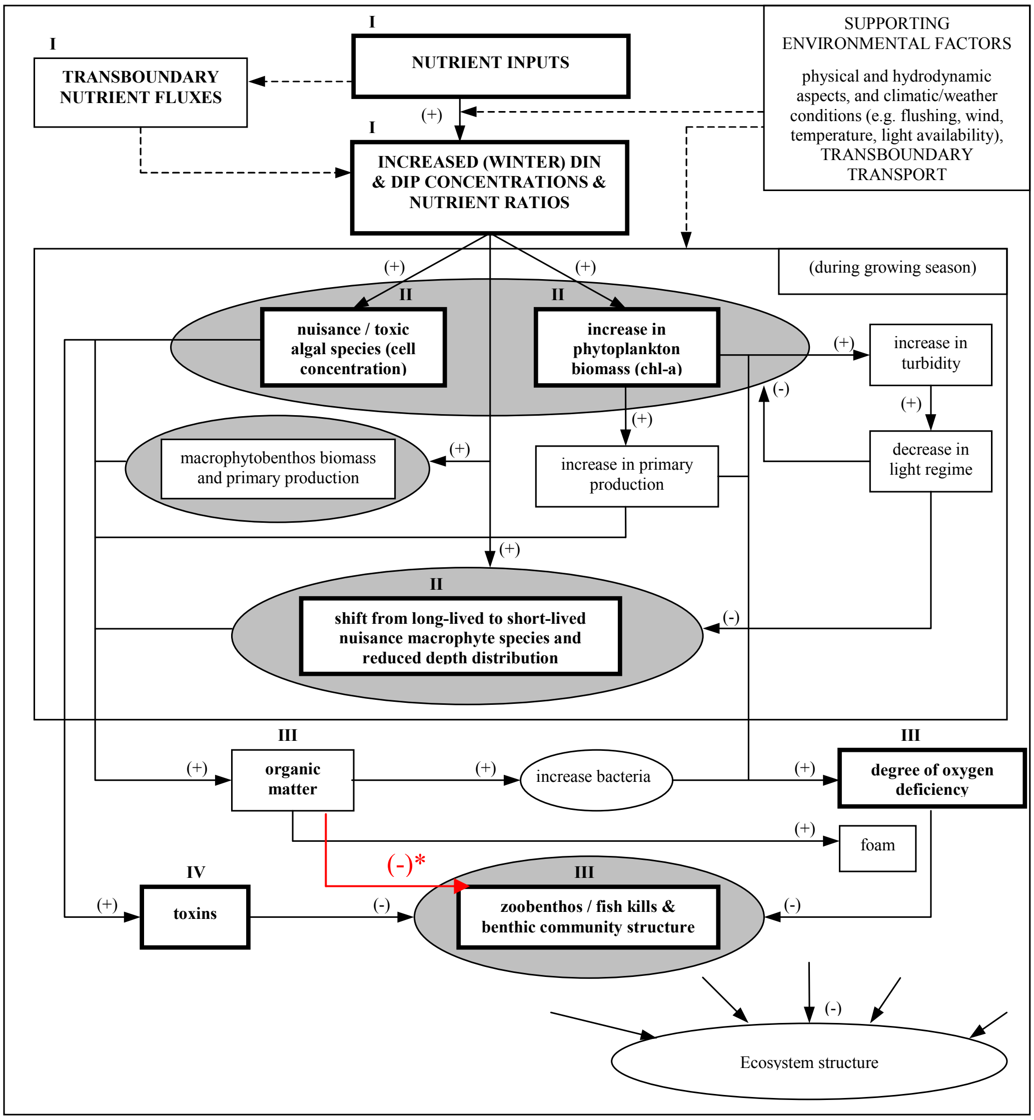

Figure 1 of Annex 3 of EUC 03/5/5-E. Suggested change is shown in red.

Appendix 1

Marine benthic biotic index EcoQ element m

In recent years, several benthic biotic indices have been proposed for use in estuarine and coastal waters in order to determine the natural and man-induced impacts. One of them, named AMBI (AZTI Marine Biotic Index), was created by Borja et al. (2000) and has been applied to different European geographical areas, experiencing various human impacts (Borja et al., 2003a). The AMBI offers a "pollution classification" of a particular site, representing the benthic community "health" (sensu Grall and Glémarec, 1997). The theoretical basis of AMBI is that of the ecological adaptive strategies of the r-, k-, and T-selected species (McArthur and Wilson, 1967; Pianka, 1970; Gray, 1979) and the progressive steps in stressed environments (Bellan, 1967; Pearson and Rosenberg, 1978).

Species should be classified into five ecological groups, based upon sensitivity/tolerance to pollution (or disturbance): (i) Group I: very sensitive; (ii) Group II: indifferent; (iii) Group III: tolerant; (iv) Group IV: Second order opportunistic; and (v) Group V: First order opportunistic. A formula (see Borja et al., 2000) permits the derivation of a series of continuous values, based upon the proportions of the five ecological groups amongst the species composing the benthic community.

The AMBI has been validated against a series of chemical contaminants (Borja et al., 2000), both in estuaries and coastal habitats. It has been verified successfully in relation to a very large set of environmental impact sources (38), both physical and chemical, including drill cutting discharges, submarine outfalls, harbour and dyke construction, heavy metal inputs, eutrophication processes, engineering works, diffuse pollutant inputs, recovery in polluted systems under the impact of sewerage schemes, dredging processes, mud disposal, sand extraction, and oil spills (Borja et al., 2000, 2003a, 2003b; Caselli et al., 2003; Forni and Occhipinti Ambroggi, 2003; Nicholson and Hui, 2003; Bonne et al., 2003; Muxika et al., 2003; Gorostiaga et al., 2004; Salas et al., in press).

The most recent impacts checked were (Muxika et al., submitted): (i) relationships with anoxic processes in Sweden; (ii) a good gradient shown in oil-based mud drilling impact, in the North Sea (with a high significant correlation with total hydrocarbons); and (iii) harbour dredging impact.

The AMBI is very easy to use, having freely-available software, including a continuously updated species list, incorporating more than 2,700 taxa (http://www.azti.es/ingles). Even with these advantages, some problems have been identified by users of the AMBI as a "tool" for detecting and evaluating impacts (see Borja et al., 2004b).

Further, the European Water Framework Directive (WFD; Directive 2000/60/EC) develops the concept of Ecological Quality Status (EQS) for the assessment of the quality of water masses (Borja et al., 2004a). Recently, equivalence between the AMBI values and the "Ecological Status" classification has been proposed (Borja et al., 2003b, 2004b). This was based upon the interpretation of the normative definitions in the WFD for the ecological status of coastal and transitional waters, in relation to the benthic invertebrate fauna (see Borja et al., 2004b).

3.2 EcoQ element (q) Phytoplankton chlorophyll *a*

Recommendations:

Chlorophyll is a useful indicator of nutrient conditions and should be included in the suite of eutrophication indicator variables. Although there is no fixed relationship that can be generally applied, there is a positive trend whereby concentrations are seen to increase with increasing nutrient inputs.

Reference conditions should be determined by type and threshold or limit points which will be dependent upon the local conditions in the different types of systems.

1	Issue	Eutrophication	
2	Element	Phytoplankton Chlorophyll *a*	
3	ICES Criteria		
	a) Relatively easy to understand by non-scientists and those who will decide on their use	Yes	Assumption is that, as nutrient loads increase, the phytoplankton growth will be stimulated resulting in greater amounts of Chl a – like fertilizing a field, but it is complicated and does not work in all places
	b) Sensitive to a manageable human activity	Yes in clear waters No in turbid waters See comments about exceptions	Chl a will respond to management in clear-water areas, but not in other areas where waters are turbid (parts of the Wadden Sea), or where grazers, viruses and other controlling factors keep Chl a low. In these areas, the nutrient load increases the secondary production signal rather than the primary production signal.
	c) Relatively tightly linked in time to that activity (i.e. nutrient loading)	Yes (if no other limiting factors) No (where other factors are limiting, i.e., light and or grazing)	See comment b). There may be lag effects.
	d) Responsive primarily to a human activity, with low responsiveness to other causes of change	Y/N See comment c).	See comment b) and c). There may be additional complications from climate change.
	e) Easily and accurately measured, with a low error rate	Yes	Analytical and sampling procedures are very well known
	f) Measurable over a large proportion of the area to which the EcoQ metric is to apply	Yes	
	g) Based on an existing body or time series of data to allow a realistic setting of objectives	Yes (in clear waters) No in turbid or other situations (i.e. high grazing)	
4	Ecological relevance/basis for the metric	Yes Chl a responds directly to nutrients through growth, consumes oxygen during decomposition and is consumed by grazers.	
5	Current and historic levels (including geographic areas)	If possible, use historic data. If not available, use modelling results or offshore data.	
6	Reference level	See comment 5) These should be made relevant to the area that is being described.	
7	Limit point (thresholds)	Need to be developed.	See discussion
8	Time frames	Need to be developed	See discussion

9	Advice on EcoQO options (scenarios)		
10	Monitoring regimes[1]	Should take at least monthly samples; the spatial coverage should be adequate to describe the conditions within the entire water body.	
11	Management measures to achieve EcoQO	Reduction of nutrient discharges from diffuse sources, point sources and atmospheric deposition.	

Discussion

The value of chlorophyll as an EcoQ element was vigorously discussed. Contrary to the general view that chlorophyll is a reliable and stable measure of phytoplankton biomass, significant regional variations and variability in annual and seasonal chlorophyll levels characterize North Sea habitats. There are also pronounced regional and local (i.e. within the same habitat) differences in interannual chlorophyll patterns, long-term trends, time, magnitude and duration of the annual bloom maximum, and in the primary factors controlling chlorophyll abundance and dynamics. Some examples of this complex behaviour discussed by the group include the following. Dose-response curves: for Northern and western Wadden Sea, there is a direct correlation with nutrients supplied from the Rhine River. Winter Chl *a* levels are in some areas temperature-sensitive, and there is an inverse relationship between Chl *a* and winter temperature. For Flodivegan, along the Norwegian Skagerrak coast, there is no long-term trend in Chl *a,* which is characterized primarily by variability. Sudden fluctuations in Chl *a* occur which do not appear to be related to measureable nutrients. There was also a low correlation in Skagerrak coastal waters between primary production level and Chl abundance during the productive season. Lag effects can occur before perceptible changes in chlorophyll can be detected in response to eutrophying conditions. This impediment may be further compromised by the effects of climate change, including changes in temperature and river runoff volume. Thus, chlorophyll dynamics are an ecosystem-regulated response and not the result of a simple, linear response, e.g. nutrients to phytoplankton growth to biomass (i.e. chlorophyll). Rather, this linkage can (and is) controlled variably by the type and abundance of the grazer communities, both the pelagic herbivores and microbial loop components and benthic filter feeders, and physical oceanographic conditions. This ecosystem complexity makes it difficult to recommend a specific chlorophyll threshold level for general use, the periods and frequency of measurement during the annual cycle to be followed, or to encourage the search for a common chlorophyll standard for regional application. Rather, a pragmatic approach is recommended that takes into account the overall local, seasonal and interannual chlorophyll patterns, the local nutrifying and habitat conditions, including riverine discharge, thus characterizing the ecosystem under consideration. To detect and apply representative chlorophyll criteria for use as an EcoQ indicator, it is essential that representative yearly chlorophyll determinations be made for a period of at least 10 years to detect signals of change that are masked in the intrinsic variability characterizing phytoplankton cycles and species successions. The quest to establish specific chlorophyll levels for EcoQ application to the different ecosystem types in the North Sea region is a high priority activity. This endeavour would be greatly facilitated by a retrospective analysis of time series data available for this region, an activity which is strongly encouraged.

<u>Suggested enhancements</u>: Inclusion of primary production measures (eg C^{14}, fluoresence based determinations, Smart Buoys, etc.). High-density low blooms (HDLBs) can be very harmful but would not be alerted based on Chl a. Thus, the Phytoplankton Indicator Species should also be included in the metric. Carbon equivalent of Chl a would be useful to know in these circumstances. Carbon production rates associated with Chl a concentrations should be determined relevant to the yield-dose relationships and amount of materials being produced for grazers and potential oxygen consumption.

3.3 EcoQ element (r) Phytoplankton indicator species for eutrophication

Recommendations:

Reanalysis of existing time series should be done with emphasis on groups of algae, species or ratios between functional groups that can be linked to nutrient loads.

Relationships should be determined locally where time series are available, and thresholds should be determined according to natural variation in each area. Levels of action should deviate consistently from reference data, and persist over time. Local indicators to be determined could be amplitude, duration, frequency and spatial extent of regular blooms, diatom/flagellate ratios and occurrence of a set of functionally defined algal species shown to respond to nutrient loads.

Harmful algae blooms most often have no direct relevance to eutrophication, and should be regarded as a secondary effect of eutrophication.

		COMMENTS	
1	**Issue**	Eutrophication	
2	**Element**	Phytoplankton indicator species for eutrophication 1.Elevated levels of known nuisance phytoplankton species in specific areas 2. Composition and abundance of phytoplankton community (functional groups)	
3	**ICES criteria**		
	Relatively easy to understand by non-scientists and those who will decide on their use	Y	1. Individual species – easy to understand 2. Grouping of individual taxa into functional groups has less noise than individual species dynamics (especially if linked to primary production).
	Sensitive to a manageable human activity	Y	1. Individual species have been demonstrated to be related to known human activities in certain areas. 2. Certain functional groups will respond to eutrophic conditions in a consistent pattern. Potentially the use of functional groups can smooth out noise in the link between phytoplankton groups and eutrophic conditions.
	Relatively tightly linked in time to that activity	Y	Phytoplankton is the initial and most relevant response to nutrient enrichment. Type of change can be composition, abundance or production rates. Should choose species that are fast responders.
	Easily and accurately measured, with a low error rate	Y	Needs good and frequent long-term sampling to avoid large errors in data (high natural variability). Reliable with good reference data for each region. Laboratory analysis is accurate with specialist people; however, it is time consuming. Automated measurements can be supplements for phytoplankton data (e.g. Smart Buoys, CPR).
	Responsive primarily to a human activity, with low responsiveness to other causes of change	Y/N	In defined regions, with known nutrient loading data, response can be linked to nutrient enrichment. May be more difficult to link in open waters with high water exchange. Potentially, climate change can be an influencing factor as well.
	Measurable over a large proportion of the area to which the EcoQ metric is to apply	Y	Yes, measurable over all waters

	Based on an existing body or time series of data to allow a realistic setting of objectives	Y/N	Only for certain regional areas. However, most areas have had phytoplankton sampling to some extent so potentially there is under-analysis of existing time series. High quality time series should be reviewed for functional group trends and links to nutrient parameters.
4	**Ecological relevance/basis for the metric**	Phytoplankton is the primary response variable to nutrient change and as such is fundamental for any other associated effects. Understanding of phytoplankton dynamics (both individual species and functional groups) and primary production is essential in defining ecological structure. However, phytoplankton dynamics are highly variable in space and time, and need to be related to specific regions and functional seasons. Observed changes need to be stable over time to be conclusive. Advise caution in using HABs as indicators of eutrophication.	
5	**Current and historic levels (including geographic areas)**	There exist a few long high quality time series on phytoplankton occurrence (>25 years)	
6	**Reference level**	Dependent on region. Expert groups responsible for monitoring in each region should define reference conditons and action levels for issues of concern. Also, regional information will define choice of indicator (indicator could be individual species or functional group or relative abundance or a set of such). This is similar to the process being undertaken for WFD for estuaries and coastal waters.	
7	**Limit point**		
8	**Time frames**	*Detection of change*	Observed changes need to be stable over time to be conclusive. Should deviate substantially from reference trend. Dependent on the natural variability in the area, the effect could occur after 5 to 10 years.
		Management advice	
9	**Advice on EcoQO options (scenarios)**	*Scenario 1*	
		Scenario 2	
		Scenario 3	
10	**Monitoring regimes**	Selection of main "observatories" supplemented by other data from dispersed stations such as chl a, fluorescence data, satellite data.	
11	**Management measures to achieve EcoQO**	Reduction of nutrient discharges from diffuse sources, point sources and atmospheric deposition.	

Discussion

The use of individual phytoplankton species or groups as environmental indicators has been a classical objective of phytoplankton ecologists. These efforts have been very unsuccessful, but this may partly be a consequence of inadequate databases or time series in regions vulnerable to, and experiencing increased nutrient loadings or other changes to chemical water quality. With regard to increased inorganic and organic nutrient levels, euglenids frequently appear to be present in low abundance consistent with experimental evidence that this group has a predilection to occur in nutrient disturbed watermasses. However, euglenids are generally relatively rare in phytoplankton communities and cannot serve as reliable nutrient indicator species. In some waters, i.e., the Dutch Wadden Sea, *Phaeocystis* has become a major bloom species in response to the multidecadal increase in nutrient loading that has occurred. However, elsewhere this species produces significant blooms in unenriched habitats which compromises its general use as a nutrient enrichment indicator species. Chrysochromulina is the only species in the monitoring programme in Flødevigen that has been shown to correlate with N/P ratios, but since other factors also influence its variable occurrence, the use of N/P ratios as a predictor of either its toxic blooms or diagnostic of nutrient-enriched habitats is untrustworthy. There is inconclusive evidence from UK waters that the diatom/flagellate ratio may be an indicator of increased nutrient loading. Although the evidence is not encouraging that phytoplankton indicator species or community floristic responses to increased nutrient loading will be found, they do point the direction that research should take to confirm or reject the thrust of the EcoQ element that such species (communities) occur and can be applied. In evaluating this, such relationships should be determined locally for regions where time series are available, with potential thresholds determined giving due consideration to the natural variation of the proposed indicator species, community or functional group ratios in each area. Where a potential floristic indicator is found, the proposed levels of altered behavior used to initiate EcoQ-based action should deviate consistently from reference data, and persist over time. The indicator should have regular occurrence, be abundant in given seasons, and have a clear preference for the environmental conditions in question upon eutrophication. Local, potential indicator responses that should be examined include bloom amplitude, duration, frequency and spatial extent of regular blooms of the prospective indicator species diatom/flagellate ratios, and the possible occurrence of a set of functionally defined algal species that respond to nutrient loading. The data should be analysed using appropriate statistical and time series procedures having detrending methodology, and also take into account available ecophysiological data available for the candidate indicator species of interest. There is information in existing long-term data series available for European and U.S. coastal waters that can be mined in the search for phytoplankton indicator species, communities and functional group responses to elevated nutrient levels and other anthropogenic modifications of water quality. We suggest that SGEUT organize an international workshop specifically dedicated to analyses of long-term data sets for the possible identification of such phytoplankton indicators and hypothesized by EcoQ element (r).

The study group expresses concern over the use of harmful and nuisance species as direct responders to elevated nutrients depicted in the conceptual cause and effect diagram used by OSPAR (Figure 1, annex 3 EUC 03/5/5-E). We find no convincing evidence that HAB events are nutrient enrichment driven events, either generally or for individual HAB species. HABs do not generally have the desired properties as indicator species, i.e., *Dinophysis* and *Alexandrium* rarely form dense blooms; they occur systematically also in nutrient-poor areas, and the mechanism of their toxicity is poorly understood. There is better evidence that certain nuisance species blooms may be more reliable indicators of increased nutrient loading, and this aspect should also be evaluated in the recommended workshop on retrospective analyses of time series data for phytoplankton nutrient enrichment indicator species.

3.4 EcoQ element (t) Winter nutrient concentrations

Recommendations:

Winter nutrient concentrations directly respond to nutrient loads and therefore are a very useful EcoQ element.

The term “winter” should be locally defined as a time window of 2 months immediately prior to the mean onset of the spring bloom. The “winter concentrations” should reflect the maximum concentrations available for the spring phytoplankton bloom. A local protocol should be defined to exclude samples for assessing winter concentrations if an early spring bloom occurs.

Assessments should include the entire water column and salinity gradient in order to be able to determine the concentrations at a specific salinity, i.e. 30.

Local expert groups should be involved in setting local reference levels and determining local trends.

		COMMENTS	
1	**Issue**	**Eutrophication**	
2	**Element**	**Winter Nutrient concentrations (DIN, DIP)**	
3	**ICES criteria**		
	Relatively easy to understand by non-scientists and those who will decide on their use	Y	The winter nutrient concentrations in coastal water are in most cases directly related to the nutrient load to the area. The effects of the loads are smilar to fertilizing a meadow.
	Sensitive to a manageable human activity	Y	Ban on P detergents in some countries is reflected in reduced river input and lower DIP concentrations. Better agriculture practice has led to reduced N input and DIN concentrations in certain areas. Improved wastewater treatment has supported these developments.
	Relatively tightly linked in time to that activity	Y	Present trends in continental rivers show a decrease after measures have been taken to reduce input, and decreased concentrations of nutrients are observed in some areas. The response can be masked by the variations in annual river runoff.
	Easily and accurately measured, with a low error rate	Y	Yes, standard oceanographic methods.
	Responsive primarily to a human activity, with low responsiveness to other causes of change	Y/N	Concentrations per se are sensitive to coastal runoff, but in many cases concentrations can be normalized by regression analysis to a standard salinity and runoff.
	Measurable over a large proportion of the area to which the EcoQ metric is to apply	Y	Samples are easily taken and measured. This is standard in most monitoring programmes.
	Based on an existing body or time series of data to allow a realistic setting of objectives	Y/N	Most available data are from the period after eutrophication started. Scattered historic data and budget approaches allow one to reconstruct historic input data and, from them nutrient concentrations.
4	**Ecological relevance/basis for the metric**	High relevance, as nutrients are at the basis of phytoplankton biomass formation.	

5	**Current and historic levels (including geographic areas)**	Today, we have elevated concentrations to a varying degree in most coastal areas. Compared to historic levels: The EcoQO should be developed on a local scale.	
6	**Reference level**	Two options: either use offshore (unaffected) values or a salinity-dependent approach based on reconstructing or extrapolating to historic loads.	
7	**Limit point**	Need to be elaborated on a local scale	
8	**Time frames**	*Detection of change*	About ten years If correction for runoff is possible, maybe five years
		Management advice	Annual measurements focusing on winter concentrations and on annual cycles. Winter has to be specified regionally, i.e. two months prior to the normal onset of the spring bloom. Regionally specific chlorophyll limits beyond which winter nutrient data should not be included in assessments have to be defined as the spring bloom may start earlier.
9	**Advice on EcoQO options (scenarios)**	*Scenario 1*	
		Scenario 2	
		Scenario 3	
10	**Monitoring regimes**	High spatial coverage in winter focusing on the salinity gradient. Higher frequency and geographical coverage at coastal stations where higher dynamics can be expected.	
11	**Management measures to achieve EcoQO**	Reduction of nutrient discharges from diffuse sources, point sources and atmospheric deposition.	

Discussion

Winter nutrient concentrations are the direct response to the nutrient load and thus very useful as indicators of the eutrophic status of the marine environment. The “winter concentrations” should reflect the maximum concentrations available for the spring phytoplankton bloom. Therefore the term “winter” should be locally defined as a time window of 2 months prior to the mean onset of the spring bloom. A local protocol should be defined to exclude samples for assessing winter concentrations if an early bloom occurs. This treshold should be defined as a certain level above the average winter chlorophyll concentration. The assessments should include the entire water column.

Local expert groups should be involved in setting local reference levels and determining local trends. The time scales involved to get meaningful trends from measured data ranges from 5-10 years. Part of the interannual natural variation in winter nutrient concentrations can, at least in some areas, be removed from the data before assessing the trend by normalising the data to an average riverine freshwater runoff.

Whenever possible, coastal observatories of nutrients should resolve the entire annual cycle, including silica as the limiting nutrient for diatom growth, as changes in the shape of seasonal cycles give information on changes in the local biogeochemistry related to eutrophication. When chlorophyll is measured or phytoplankton samples are taken, nutrients (including Si) should be measured as supporting parameters. We note that the potential as an indicator is only then fully developed when reviewed together with the other eutrophication EcoQOs.

3.5 EcoQ element (u) Oxygen

Recommendations:

Oxygen can be used as an EcoQO for eutrophication, but may not be relevant for some areas where a cause-effect relationship cannot be established.

Oxygen saturation may be more useful than concentrations in some areas, e.g. where temperatures are high or highly variable.

Measurements should be taken as close to the bottom as possible.

Measurements should be obtained during the annual minimum (autumn), but the annual cycle in oxygen should also be described.

Potential oxygen minimum at intermediate depths should be identified.

Pre-eutrophication levels, reference levels and limit points should be specified regionally.

		COMMENTS	
1	**Issue**	Eutrophication	
2	**Element**	Oxygen	
3	**ICES criteria**		
	Relatively easy to understand by non-scientists and those who will decide on their use	Y	Higher nutrient load gives higher production of organic matter, which increases the oxygen consumption by decomposing. May not be relevant in some areas where cause-effect relationships can not be established., e.g. in bottom water along the Norwegian Skagerrak coast
	Sensitive to a manageable human activity	Y	
	Relatively tightly linked in time to that activity	N	
	Easily and accurately measured, with a low error rate	Y	
	Responsive primarily to a human activity, with low responsiveness to other causes of change	N	Bottom water oxygen concentrations are determined by a number of different processes besides consumption, i.e. vertical mixing, stratification, horizontal bottom water exchange, etc.
	Measurable over a large proportion of the area to which the EcoQ metric is to apply	Y	
	Based on an existing body or time series of data to allow a realistic setting of objectives	Y/N	For some areas time series dating back to the 1960s or longer exist.
4	**Ecological relevance/basis for the metric**	It varies regionally, depending on cause-effect relationship	
5	**Current and historic levels (including geographic areas)**	Regional specific values.	
6	**Reference level**	Regional specific pre-eutrophication levels.	
7	**Limit point**	Regional specific limit points. Use concentrations or saturation as applicable.	
8	**Time frames**	*Detection of change*	*5-10 years*
		Management advice	*?*
9	**Advice on EcoQO options (scenarios)**	*Scenario 1*	
		Scenario 2	
		Scenario 3	
10	**Monitoring regimes**	Few representative stations sampled at standard depths during annual minimum (autumn), and more instensive sampling during critical periods (blooms and stratification). Sampling and analyses are comparably inexpensive.	
11	**Management measures to achieve EcoQO**	Reduction of nutrient discharges from diffuse sources, point sources and atmospheric deposition.	

Discussion

It is generally assumed that gradually increasing input of nutrients to the marine environment results in gradually increasing algal biomass, increasing sedimentation of organic matter, increasing oxygen consumption in the bottom waters and subsequently reduced oxygen concentrations. Accordingly, there has been concern about the impact of reduced oxygen concentrations on bottom fauna and demersal fish. And there are numerous reports of decreasing trends in oxygen concentrations in the bottom waters as a result of eutrophication (e.g. Officer et al. 1984; Justic et al. 1987; Andersson and Rydberg 1988; Rosenberg 1990), and adverse effects on bottom fauna (Rosenberg and Loo 1988) and demersal fish (Baden et al. 1990) have been observed. Studies of temporal changes in oxygen trends are mostly carried out by linear regression analyses, which will support the presumption of a gradual dose-response function between nutrient load and oxygen concentrations. However, whether applying direct biological parameters, such as algal biomass and algal species composition, or indirect parameters, such as oxygen consumption and oxygen concentrations, to assess the impact of eutrophication on marine ecosystems, it is essential to know the exact dose-response relationship as well as the natural variability of the various parameters.

The question of temporal pattern in oxygen concentrations has been addressed by Johannessen and Dahl (1996a, 1996b), who analysed oxygen trends at 31 stations from the Norwegian Skagerrak coast, among which several have been sampled regularly since 1927. They found decreasing oxygen concentrations at all analysed depths ≥10 m along the entire study area. The temporal pattern was different for intermediate depths (e.g. 30 m) and bottom water. At intermediate depths, oxygen concentrations did not show marked changes until the mid-1960s, followed by a linear decrease right up until 2001 (updated). In the bottom water there was no marked change in oxygen until the beginning of the 1970s, but then the concentration decreased rapidly within a few years. After the rapid decrease, oxygen concentration in the bottom water has remained at this lower level.

Hence, intermediate depths at the Norwegian Skagerrak coast seem to respond gradually to increasing nutrients loads. Bottom waters showed an abrupt drop in oxygen in the middle of the 1970s with no trends before and after the drop, suggesting that sedimentation does not respond in a gradual dose-response manner to eutrophication. Aure et al. (1996) estimated that oxygen consumption increased by ca. 50% in one of the fjordic basins on the Norwegian Skagerrak coast at the time of the abrupt drop in bottom water oxygen, and Andersson and Rydberg (1988) reported a similar increase in oxygen consumption of the deep water of Kattegat between 1971 and 1982.

The indication that there is not a gradual dose-response relationship between eutrophication and oxygen consumption and oxygen level raises questions on the usefulness of oxygen measurements in bottom water to detect increasing eutrophication in these waters.

In other areas such as the Kattegat and the German Bight a cause – effect relationship can be established, and oxygen can be used as an EcoQ element.

In waters where temperature (and salinity) is highly variable seasonally, oxygen saturation may be more useful than concentrations, as fish and zoobenthos react to the oxygen saturation rather than the actual oxygen concentration.

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ANNEX 1

Study Group to Review Ecological Quality Objectives for Eutrophication
ICES, Headquarters, 17-19 May 2004

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ANNEX 2

SGEUT meeting at ICES Headquarters

17 May 10.00 hrs to 19 May 16.00 hrs 2004

Draft Agenda

1. Opening of the meeting

2. Input from other groups/organisations

3. Review of the five EcoQ elements, their scope and application
   - 3.1 EcoQO element (m) Changes/kills in zoobenthos in relation to eutrophication
   - 3.2 EcoQO element (q) Phytoplankton chlorophyll *a*
   - 3.3 EcoQO element (r) Phytoplankton indicator species for eutrophication
   - 3.4 EcoQO element (t) Winter nutrient (DIN and DIP) concentrations
   - 3.5 EcoQO element (u) Oxygen

4. Review of the application of the five EcoQ elements as an integrated set

5. Prepare draft advice on the use and implementation of the current integrated set of five EcoQ elements in the whole OSPAR area

6. New EcoQ elements: for each of the five EcoQ elements, reconsider the formulation of the EcoQO, determine whether a more specific EcoQO is needed in terms of its specification to the metric, time and geographical area, and as necessary propose a more specific EcoQO (or EcoQOs)

7. Adoption of the report of the meeting

ANNEX 3

2ACE05 A **Study Group to Review Ecological Quality Objectives for Eutrophication** [SGEUT] (Co-Chairs: Ted Smayda, USA, and Gunni Ærtebjerg, Denmark) will be established and will meet at ICES Headquarters from 24–26 May 2004 to:

a) in relation to the five Ecological Quality Elements related to eutrophication, i.e., EcoQ element (m) Changes/kills in zoobenthos in relation to eutrophication, EcoQ element (q) Phytoplankton chlorophyll *a*, EcoQ element (r) Phytoplankton indicator species for eutrophication, EcoQ element (t) Winter nutrient (DIN and DIP) concentrations, and EcoQ element (u) Oxygen [OSPAR 2004/1]:

   ii. review these EcoQOs, their scope and application, and means for their use as an integrated set and considering their parallel use as assessment criteria in the OSPAR Comprehensive Procedure (COMPP),

   iii. provide the basis for the advice on the use and implementation of the current integrated set of five ecological quality elements and related EcoQOs to the whole OSPAR maritime area,

   iv. reconsider the formulation of the EcoQO, determine whether a more specific EcoQO is needed in terms of its specification to the metric, time and geographical area, and as necessary propose more specific EcoQO(s);

b) consider new EcoQ elements/EcoQOs (e.g. nutrient budgets, nutrient ratios, macrophytes) related to eutrophication, and as necessary propose new EcoQOs which could be used in addition to or as replacement for the EcoQ's considered in a).

SGEUT will report by 1 June 2004 for the attention of ACE and ACME, as well as the Marine Habitat and the Oceanography Committees.

Supporting information:

Priority:	High
Scientific Justification:	This is in response to an OSPAR request. OSPAR has already undertaken a considerable amount of work with respect to the assessment of the degree of eutrophication, especially in the North Sea. The Study Group should as a first step analyse in detail all of the work undertaken by OSPAR, especially with respect to EcoQO's-eutro and The Ospar Comprehensive Procedure.
Resource Requirements:	Meeting room at ICES Headquarters required.
Participants:	Experts in eutrophication issues (physics, phytoplankton, benthos, marine chemistry). OSPAR should encourage participation of their own experts in this field. Scientists from outside of the OSPAR area would be particularly valuable to this group
Secretariat Facilities:	The Secretariat will be involved as normal in general professional and secretarial support, and the Secretariat should provide direct assistance during the workshop. The Secretariat might provide web space for the proceedings.
Financial:	
Linkages to Advisory Committees:	ACE, ACME
Linkages to other Committees or Groups:	OCC, MHC, WGPE, BEWG, MCWG, WGECO, to whom it will make its report available.
Linkages to Other Organizations:	OSPAR
Secretariat Cost Share:	OSPAR:100%

Assessing the suitability of OSPAR EcoQOs vs ICES Criteria

A UK working paper to the ICES Study Group to Review Ecological Quality Objectives for Eutrophication (SGEUT) May 2004.

S.J. Painting, S.I. Rogers, D.K. Mills, E.R. Parker, M.J. Devlin, H.L. Rees, S.P. Milligan and P. Larcombe

Contract AE1148
May 2004

Contents

1. SUMMARY

Ecological Quality Objectives (EcoQOs) form an important framework for applying the ecosystem approach to the management of human activities affecting estuarine and coastal waters. Five Ecological Quality elements have been agreed (Bergen Declaration 2002) for monitoring nutrient enrichment and potential eutrophication effects in the marine environment (North Sea and OSPAR-wide). Desired levels (EcoQOs) have been proposed for each of these elements, *viz*. winter nutrient concentrations (t[1]), phytoplankton chlorophyll *a* (q[1]), phytoplankton indicator species (r[1]), oxygen concentrations (u[1]) and changes/kills in zoobenthos (m[1]). These EcoQOs incorporate attributes which are considered to be most representative of water quality, and which are easily observed, amenable to quantitative analysis, and provide the first indication of biological response to nutrient enrichment.

The objective of this report is to provide a preliminary evaluation of the suitability of the EcoQOs for the coastal and offshore waters of England and Wales. The evaluation is based on ICES criteria that good indicators should be easy to understand, should show a cause-effect relationship with manageable human activities (*i.e*. should be sensitive to, tightly linked to, and primarily responsive to these activities), and should be relatively easy to measure and monitor.

In principle, the agreed EcoQOs for eutrophication are easy to understand, but recent shifts in our conceptual understanding of eutrophication indicate complex responses to nutrient inputs, which may compromise the suitability of the measures of ecological quality. Quantitative monitoring of water quality criteria in marine waters around England and Wales started on an *ad hoc* basis in the 1960s, providing some time-series for data analysis. While long-term trends in anthropogenic nutrient inputs are evident in the data, few (if any) studies have been able to provide unequivocal evidence of a link with the consequences of nutrient enrichment. This is particularly true for offshore environments. It is therefore difficult to provide conclusive evidence of the sensitivity of biological responses to manageable human activities. Monitoring of nutrient inputs and eutrophication effects is generally feasible and in place (*e.g.* through OSPAR and various directives), but insufficient long-term data-sets are available for the setting of reliable reference points, especially on a regional basis. There is still an urgent need to improve the frequency and spatial coverage of (quality assured) monitoring of nutrients and the direct and indirect effects of nutrient enrichment.

Detailed evaluations of the five agreed Ecological Quality elements in terms of the ICES criteria suggest that the best of the EcoQOs is the concentration of winter nutrients. This is particularly true for coastal environments, where it is feasible that all of the ICES criteria may be met. For offshore waters, it is less likely that all the criteria will be met, as nutrient concentrations are primarily responsive to other processes (*e.g*. due to hydrodynamics) and not directly to human activity. Concentrations of phytoplankton chlorophyll *a* also appear to be a good indicator in environments which are susceptible to nutrient enrichment (*e.g*. clear coastal water). In water bodies which are less susceptible to the impacts of nutrient enrichment, this EcoQO may not meet any of the criteria for demonstrating cause and effect relationships. Reduced susceptibility may be due to factors which limit or control phytoplankton growth, for example light, advective losses and grazing pressure. The EcoQO for zoobenthos (or fish) kills potentially meets all the

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[1] OSPAR and ICES notation for the current integrated set of ecological quality elements used to assess eutrophication effects

ICES criteria for a good indicator although it is difficult to establish unequivocal links with nutrient enrichment.

Detailed evaluations of the EcoQOs for phytoplankton indicator species, oxygen concentrations and zoobenthos changes suggest that these elements do not meet sufficient ICES criteria to be considered good indicators. In specific cases where human activities are clearly evident, it may be easy to demonstrate localised cause and effect relationships between the ecological quality element and human activity, but on a broader (*e.g.* regional) scale this may be more problematic. Indicator species, oxygen concentrations and zoobenthos are easy to monitor, but relatively few data sets are available for regional analyses.

Consideration of specific examples for each EcoQO indicates that greater emphasis needs to be placed on (a) identifying seasonal effects of nutrient inputs and the responses of the phytoplankton community, *e.g*. during the entire growth season (*vs* the spring bloom) summer nutrient concentrations are also important, (b) assessing the natural susceptibility of different water bodies, (c) distinguishing between coastal and offshore environments, and (d) development of longer (>20 y) time-series of data for assessing the significance of anthropogenic inputs versus natural variability. Other potential elements to be considered for EcoQOs include indices of greenness from the Continuous Plankton Recorder and the “Phytoplankton Trophic Index” currently under development through CEFAS.

2. INTRODUCTION

Over the past decade Ecological Quality Objectives (EcoQOs) have been developed to facilitate the development of an ecosystem approach to fisheries and environmental management. One of the key issues in environmental management is the assessment of the risks and impacts of eutrophication in estuarine and coastal waters. Within the EU, a common legislative definition of eutrophication is the "enrichment of water by nutrients especially compounds of nitrogen and phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms and the quality of the water concerned" (Urban Wastewater Treatment Directive, 1991).

Five Ecological Quality elements have been identified for monitoring nutrient enrichment and potential eutrophication effects in coastal waters (Table 1). For each element, desired levels (Ecological Quality Objectives, EcoQOs) have been defined in order to assess potentially negative impacts of eutrophication. These EcoQOs form the basis of assessments under OSPAR and EU directives, such as the Water Framework Directive (WFD). They have been tested during recent and ongoing studies in Europe (*e.g*. Baan and van Buuren 2003, Nielsen *et al*. 2003), and are currently under review by ICES. As agreed by Ministers at the 5th North Sea Conference, the EcoQOs will be tested and developed further in a pilot project for the North Sea. Progress will be reviewed in 2005 and reported to North Sea Ministers. Additional EcoQOs for eutrophication may include riverine and direct nutrient inputs (RID), transboundary fluxes (nutrient budgets), shifts from long-lived macrophytes, including macroalgae, to short-lived nuisance species (*e.g*. Ulva, OSPAR EUC 03/5/2-E (L)). Under its 'Safeguarding our Seas' strategy, DEFRA is committed to testing and reviewing these EcoQOs for the coastal waters of England and Wales. Additional work contributing towards an improved understanding of the linkages between nutrient enrichment and eutrophication is likely to form the basis for further development of these and other EcoQOs.

The objective of this report is to provide a preliminary evaluation of the suitability of the EcoQOs for indicating the risks and impacts of eutrophication in coastal and transitional waters of England and Wales. Within the context of EU directives, a good indicator should respond to anthropogenic influences, be generally present in coastal waters, be measurable with high accuracy and precision, have well-defined reference conditions, be cost-effective, and be easy to communicate to the public. These criteria form the basis of the review currently being undertaken by ICES (see Table 2). For this report, each of the indicators in Table 1 was evaluated against the ICES criteria.

Available data from previously reported work were synthesised and reviewed, and appropriate figures are used here to demonstrate the results of this work. Data on coastal and offshore waters were taken from the First Application of the OSPAR Comprehensive Procedure to waters around England and Wales (Malcolm *et al.* 2002), and from a recent study on the risks and impacts of eutrophication in estuaries (Painting *et al*. 2003). The data used in these studies was obtained from a number of sources including the National Marine Monitoring Programme, the Environment Agency estuary and coastal water surveillance and monitoring programmes, CEFAS research programmes, Port Erin Marine Laboratory surveys of the north-east Irish Sea, and other data held in the ICES databases. The spatial coverage and the temporal coverage of the data varies from year to year, making comparison of trends over time difficult.

For the OSPAR Comprehensive Procedure, assessments were made of the eutrophic status of offshore waters of the southern and central North Sea, the coastal waters of North East England, South East England (Humber to Norfolk, Norfolk to Thames), the Irish Sea/ Liverpool Bay

Region and the Bristol Channel. Estuaries assessed included the Humber, the Wash, the Thames, the Severn and the Mersey. For the study on the risks and impacts of eutrophication in estuaries, additional data were obtained for approximately 40 other estuaries in England and Wales.

Table 1. Ecological Quality Elements and Objectives for monitoring and assessing the biological response to nutrient enrichment (from the Bergen Declaration, 2002).

Ecological quality element	**Ecological quality objective**
(m) Changes/kills in zoobenthos in relation to eutrophication	• There should be no kills in benthic animal species as a result of oxygen deficiency and/or toxic phytoplankton species.
(q) Phytoplankton chlorophyll *a*	• Maximum and mean chlorophyll *a* concentrations during the growing season should remain below elevated levels, defined as concentrations > 50% above the spatial (offshore) and/or historical background concentration
(r) Phytoplankton indicator species for eutrophication	• Region/area - specific phytoplankton eutrophication indicator species should remain below respective nuisance and/or toxic elevated levels (and increased duration)
(t) Winter nutrient concentrations (Dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphate (DIP)	• Winter DIN and/or DIP should remain below elevated levels, defined as concentrations > 50% above salinity related and/or region-specific natural background concentrations
(u) Oxygen	• Oxygen concentration, decreased as an indirect effect of nutrient enrichment, should remain above region-specific oxygen deficiency levels, ranging from 4-6 mg oxygen per liter

Note: The Scheveningen workshop (Skjoldal *et al*. 1999) defined Ecological Quality (EcoQ) as *an overall expression of the structure and function of the aquatic systems*, and Ecological Quality Objectives (EcoQOs) as *the desired level of the EcoQ relative to the reference level*. Reference level was defined as *the level of the EcoQ where the anthropogenic influence on the ecological system is minimal*.

Table 2. Criteria for good Ecological Quality metrics (ICES 2001)

To be useful for management, indicators should be:

1. Relatively easy to understand by non-scientists and other users;
2. Sensitive to a manageable human activity;
3. Relatively tightly linked in space and time to that activity;
4. Responsive primarily to a human activity, with low responsiveness to other causes of change
5. Easily and accurately measured, with a low error rate;
6. Measurable over a large proportion of the area over which the EcoQO element is to apply;
7. Based on an existing body or time series of data to allow a realistic setting of objectives

3. BIOLOGICAL RESPONSE TO NUTRIENT ENRICHMENT (RATIONALE BEHIND INDICATORS)

The general concept of eutrophication assumes a simple dose-response relationship between nutrient input and ecosystem response in terms of the growth of phytoplankton and higher forms of plant life. In general terms, nutrient input is assumed to result in the rapid growth of opportunistic fast growing primary producers and the accumulation of extra biomass which may have a negative impact on the ecosystem. Attributes considered to be symptoms of negative impacts of nutrient enrichment in many ecosystems include blooms of toxic algae, increased growth of epiphytic algae, the growth of macroalgae, the loss of submerged vegetation due to shading, the development of hypoxic (and anoxic) conditions due to decomposition of the accumulated biomass, and changes in the community structure of benthic animals due to oxygen deficiency or the presence of toxic phytoplankton species. The Ecological Quality elements and Objectives for monitoring and assessing the biological response to nutrient enrichment in Table 1 incorporate those attributes considered to be most representative of water quality, and which are easily observed, are amenable to quantitative analysis, and provide the first indication of biological response to nutrient enrichment.

Relatively recent shifts in our conceptual understanding of eutrophication (Cloern 2001) indicate complex responses to nutrient inputs, including both direct and indirect responses, and the role of 'filters' in moderating the response or determining the sensitivity to unwanted effects. These filters include factors such as the light climate and advective losses, which affect the susceptibility of different water bodies to nutrient enrichment. Region- or site- specific reference levels are therefore essential for sensible application of the EcoQOs. This will require considerable effort to improve our knowledge and understanding of the responses of different ecosystems to nutrient enrichment.

Within any given region, *e.g*. the southern North Sea, temporal variability in physical factors plays an important role in limiting or controlling the biological response to nutrient enrichment. This has been incorporated into the current EcoQOs, which propose season-specific reference levels for nutrients and phytoplankton chlorophyll *a,* albeit loosely. Spatial variability also plays a critical role in determining susceptibility to nutrient enrichment, both alongshore and in near-shore *vs* offshore waters. Nutrient inputs and biological responses in coastal waters adjacent to river mouths or sewage outlets, for example, are likely to be different from those in coastal waters which are not strongly influenced by river run-off or point sources. Similarly, nutrient inputs and biological responses in coastal waters are likely to be significantly different from those in offshore waters, where the influence of freshwater inputs is weakest and the temporal variability in hydrographic and biological processes is high. Clearly defined local or salinity-specific reference levels may therefore also be essential for sensible application of the EcoQOs. To some extent, these have been incorporated into the current EcoQOs, but insufficient emphasis has been placed on this point. Certainly, the suitability of the EcoQOs based on the ICES criteria (Table 2) is far more difficult to evaluate for offshore waters than for coastal waters.

Future shifts in our understanding of eutrophication are likely to indicate even greater complexity in the biological response to nutrient enrichment, with multiple stressors (*e.g*. nutrient input, climate change, fish harvesting, toxic contaminants and aquaculture), multiple factors determining sensitivity, and complex feedbacks between the different biological responses in an ecosystem (Cloern 2001). This may compromise the suitability of the measures of Ecological Quality, as defined in Table 2.

4. SETTING ASSESSMENT STANDARDS

The crucial step in making assessments of the eutrophic status of different water bodies is obtaining adequate information about the background and reference values to be applied in the case of each EcoQO. Where there is good historic data for a given area this is a simple process. However, in most European waters the historic record is limited and either proxy evidence or derived values have to be used to set assessment standards (Hartnoll *et al*. 2001, Rodhe *et al.* in prep.). This may have a significant impact on the suitability of the Ecological Quality Objectives as indicators of the risks and impacts of eutrophication.

Setting background and reference levels for estuarine and coastal waters around the UK requires adequate long-term data-sets for each of the EcoQOs, and an understanding of the linkages between nutrient inputs and ecosystem response. For some offshore and coastal sites, data may be available although the linkages are poorly understood. Data series are generally limited, and do not lend themselves to robust assessments of reference levels. Deriving suitable reference levels for use in estuaries and other coastal waters where there is a gradient is even more problematic in the absence of good historical information. This is currently being addressed under the WFD.

For the initial application of the OSPAR Comprehensive Procedure it was assumed that Atlantic water, which enters the shelf seas of northern Europe provides a suitable background condition from which to derive standards for assessment. This assumption was used to set background concentrations and reference levels for nutrient concentrations, nutrient ratios, chlorophyll concentration and potential primary production. In estuaries and coastal waters with defined mixing gradient concentrations, dissolved substances were normalised to salinity 30 and judged against the Atlantic derived standard. For particulate material, such as chlorophyll a concentration, this was not possible and appropriate statistical treatments were applied to the whole water body.

Estuarine data have been analysed in an attempt to identify the key causal processes linking nutrient loadings with biological effect in a number of different estuarine categories, and to develop category-specific standards or thresholds for each of the attributes. Robust relationships could not be easily identified from the available data. A simple model was therefore developed to calculate rates of nutrient input resulting in consequences for which there are already defined criteria such as different levels of primary production (Nixon, 1995) and changes in dissolved oxygen (CSTT, 1994, 1997). The model was based on the approach adopted by the Comprehensive Studies Task Team (CSTT, 1994, 1997), and was used to investigate the growth of phytoplankton in each of the estuarine categories in response to physico-chemical characteristics. The predicted magnitude of primary production in the different estuary types was used in conjunction with Nixon’s (1995) scale to set standards or thresholds for assessing likely trophic status in the different estuary categories.

5. IMPLEMENTATION AND EVALUATION OF ECOLOGICAL QUALITY OBJECTIVES

5.1. Winter nutrient concentrations

Table 3. Ecological Quality Objective for monitoring winter nutrient concentrations (from the Bergen Declaration, 2002).

Ecological quality element	**Ecological quality objective**
(t) Winter nutrient concentrations (Dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphate (DIP)	• Winter DIN and/or DIP should remain below elevated levels, defined as concentrations > 50% above salinity related and/or region-specific natural background concentrations

The availability of nutrients (and the appropriate ratios of different nutrient species such as nitrogen and phosphorus) is one of the key environmental variables controlling the growth of phytoplankton and other primary producers in coastal waters. Other key factors include the availability of light in the water column, and a suitable temperature regime. In UK coastal and estuarine waters, nutrient concentrations are highest in winter, when agricultural run-offs are highest due to increased precipitation. In addition, growth rates of algae and other plants are slow due to poor availability of light and low water temperatures. Monitoring studies indicate that nutrients tend to accumulate in coastal waters during winter months (November to February).

For the OSPAR Comprehensive Procedure, mean DIN and DIP concentrations during winter were compared with mean winter (January/February) nutrient concentrations in Atlantic seawater, *viz*. 7.20 μM for nitrogen and 0.45 μM for phosphorus (Gowen *et al*. 2002). Elevated concentrations were judged to be those that exceed the background concentration by 50% (10.8 μM for nitrogen and 0.68 μM for phosphorus)

For the different areas assessed, the spatial and temporal coverage of the data was highly variable from year to year, making comparison of trends over time difficult. In most eastern regions, monitoring started in the 1960's, providing a reasonable time series for analysis. Along the west and south coasts time series are considerably shorter, but still span approximately 10 years or more. Figures 1 and 2 shows interannual trends in the mean winter concentrations of DIN and DIP along the south east coast, from Norfolk to the Thames. In common with all the areas assessed, winter nutrient concentrations indicate marked temporal variability, which was considered to be due to variability in river run-offs. Variability between assessment areas was also high, presumably due to spatial variability in hydrology and nutrient loading. In general, comparison of winter nitrogen and phosphorus concentrations with the background concentrations assumed for Atlantic water indicated that winter nutrient concentrations were elevated in all the coastal areas assessed, but not in the offshore central and southern North Sea areas. This may indicate that the relative impact of anthropogenic nutrient inputs is higher in coastal waters, as might be expected. It may also indicate that the assumed background concentrations were not appropriate for all the assessment areas. More realistic background concentrations may be calculated from the existing time series of data for each region.

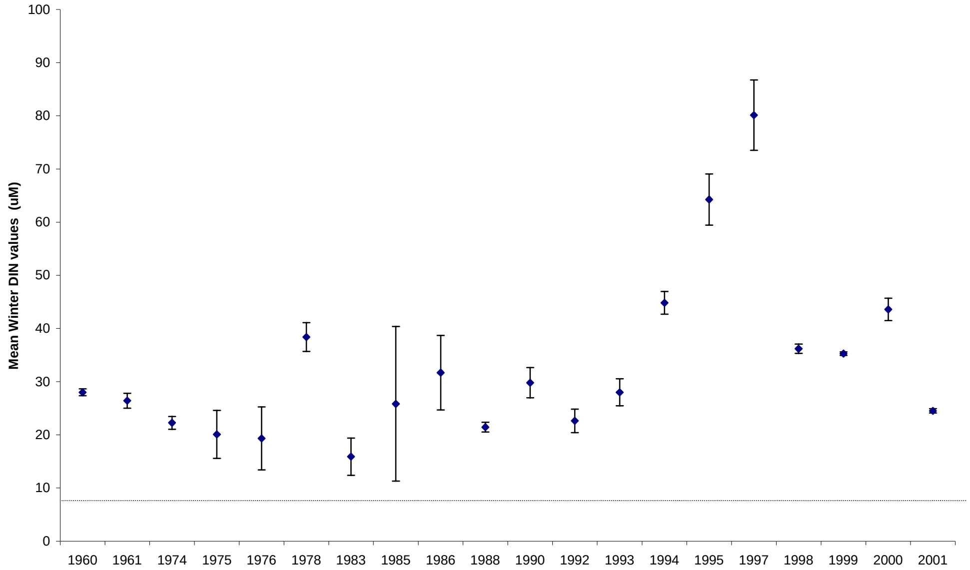

Figure 1. Mean winter DIN concentration (µM) in the Norfolk to Thames Coastal Water Area from 1960 – 2001. The line indicates the reference level (Malcolm *et al* 2002).

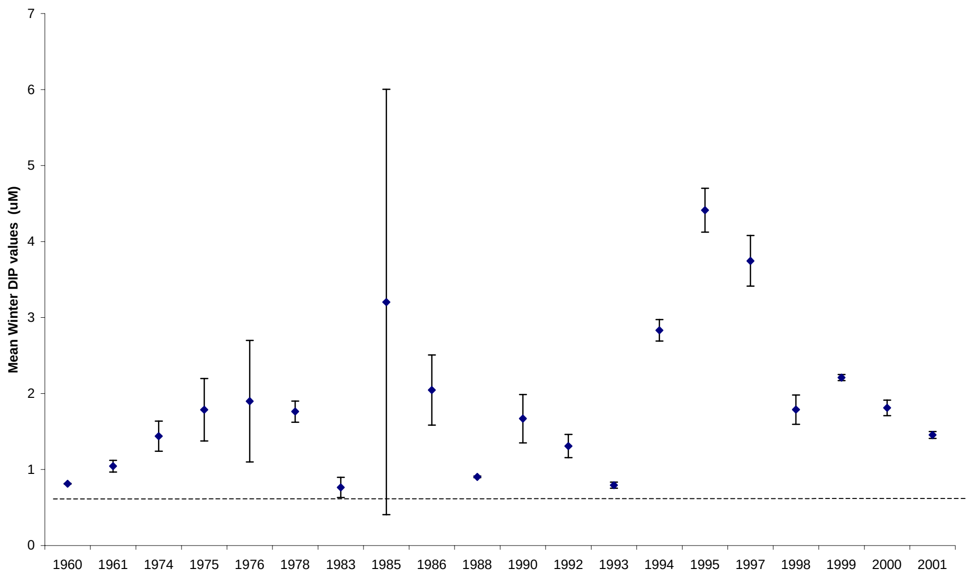

Figure 2. Mean winter DIP concentration (µM) in the Norfolk to Thames Coastal Water Area from 1960 – 2001. The line indicates the reference level (Malcolm *et al* 2002).

In terms of the ICES criteria for good indicators of ecological quality, the use of winter nutrient concentrations as an EcoQO (Table 4) is easy to understand. Cause and effect relationships are easy to demonstrate for coastal waters, but less so for offshore waters. Available data indicate that winter nutrient concentrations in coastal waters are relatively closely linked in space and time to diffuse and point source inputs of nutrients, and are responsive to a large extent to human activities. In offshore waters, linkages of nutrient concentrations (and therefore responsiveness) to human activities are weaker. Consequently, winter nutrient concentrations in estuarine and coastal waters are likely to be sensitive to management of nutrient inputs, but less so in offshore waters.

In situ concentrations of winter nutrients are easy to measure with a low error rate, but it is difficult to distinguish between anthropogenic and natural sources. With a considerable degree of effort, nutrient concentrations are measurable over a large proportion of the area over which the

EcoQO is to be applied. At present, the main limitation to the use of this EcoQO is the availability of long-term data for quantifying the natural variability, and for the realistic setting of objectives, particularly on a regional basis (see Hartnoll *et al*. 2001).

Table 4. Evaluation of the EcoQO for winter nutrient concentrations against those features considered to be qualities of good EcoQOs. Y = Yes, M = Moderate, N = No.

Ecological quality element	a) Understandable	b) Sensitive	c) Linked	d) Responsive	e) Low error	f) Measurable	g) Time series
Winter nutrient concentrations (DIN and DIP)	Y	Y	Y	Y (coastal areas) N (offshore areas)	Y	Y	Y (critical areas) N (other areas)

5.2. Phytoplankton chlorophyll a

Table 5. Ecological Quality Objective for monitoring phytoplankton chlorophyll *a* (from the Bergen Declaration, 2002).

Ecological quality element	**Ecological quality objective**
(q) Phytoplankton chlorophyll *a*	• Maximum and mean chlorophyll *a* concentrations during the growing season should remain below elevated levels, defined as concentrations > 50% above the spatial (offshore) and/or historical background concentration

The primary biological response to nutrient enrichment in aquatic environments, given suitable environmental conditions (such as light availability and water temperatures), is the growth of phytoplankton and higher plants. Assessment of the magnitude of the response should ideally be based on estimates of primary production rates of the different plant groups. For numerous reasons (including limited financial and human resources), measurements of primary production are not included in routine surveys for monitoring water quality in coastal environments. For phytoplankton, it is assumed that biomass may be used as a proxy for net production. Concentrations of chlorophyll *a* in water samples are used as an index of phytoplankton biomass.

Maximum and mean chlorophyll *a* concentrations during the growing season (March to September) are the basic parameters required to assess chlorophyll *a* as an estimate of plant biomass. In the temperate waters of the UK, maximum concentrations are expected to occur in the early part of the season during the spring bloom. The timing of the spring bloom is predictable in most areas.

For the OSPAR Comprehensive Procedure, appropriate standards for assessing chlorophyll *a* concentration were derived from the background nutrient concentrations by making some reasonable assumptions about nutrient conversion to plant biomass. There was considerable uncertainty in the calculated background level due to the wide range of factors that could be used to convert carbon to chlorophyll. From practical experience the UK has adopted 10 $\mu g\ l^{-1}$ chlorophyll *a* as a guide for assessment. It was therefore proposed that for

* offshore waters **10 µg l^{-1} chlorophyll *a*** is adopted as the reference value (implying background value of 6.7 µg l^{-1} and a reasonable C:Chl factor of 0.012) and for
* nearshore waters, where the level of production may be expected to be higher, **15 µg l^{-1} chlorophyll *a*** is adopted as the reference value (implying a background value of 10 µg l^{-1} chlorophyll *a* and a C:Chl factor of 0.02).

The NERC North Sea project described the annual cycle of phytoplankton growth in the offshore southern North Sea. The spring bloom occurs during April and May with peak chlorophyll *a* concentrations exceeding 10 mg m^{-3}. Chlorophyll concentrations decrease to levels of about 2 mg m^{-3} during the summer. Very low concentrations occur during the winter. The maximum spring chlorophyll *a* concentration varied between 2.12 and 12.63 µg l^{-1} and the mean chlorophyll *a* concentration during the growing season varied between 0.66 and 4.18 µg l^{-1} in the period from 1993 to 2000. There was no statistically significant trend in peak chlorophyll a concentrations over time (linear regression, $P > 0.05$). Results showed that in one year (1999) in four the peak chlorophyll *a* concentration exceeded the reference value of 10 µg l^{-1} and that mean summer concentrations were low and below the Atlantic background concentration (Howarth *et al*. 1994)

Similar patterns in the annual pattern of growth and maximum chlorophyll levels were observed from the Smartbuoy *in situ* measurements at the Outer Gabbard in the Offshore Southern North Sea (Fig. 3, CEFAS, unpubl. NMP data).

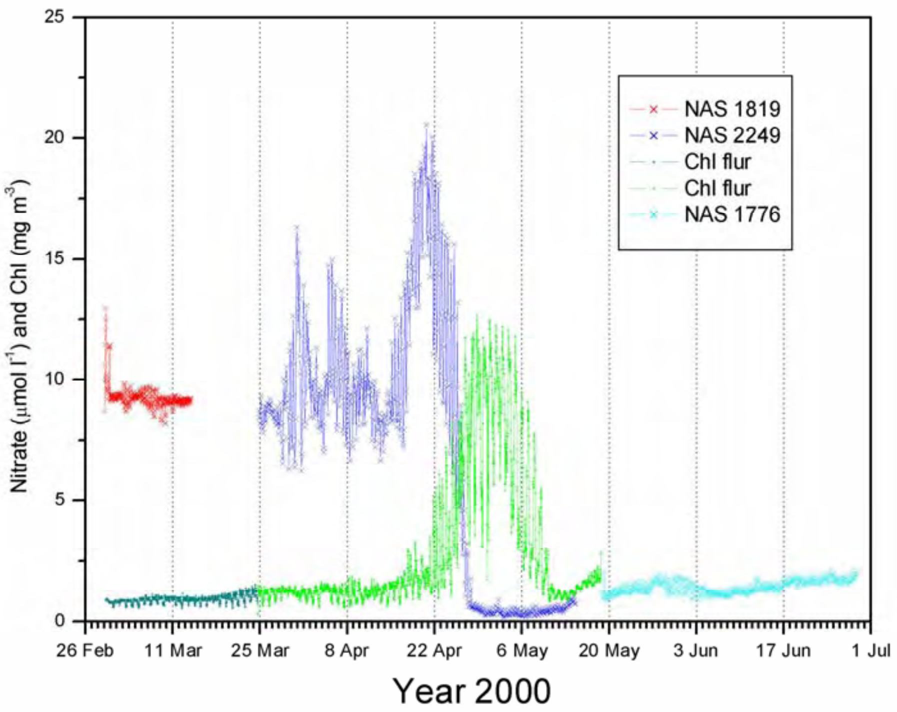

Fig. 3. Smartbuoy data from the Outer Gabbard station in the southern North Sea (CEFAS, unpubl. data). Maximum chlorophyll levels (mg m^{-3}, from chlorophyll fluorescence) peak after nitrate levels (µmol^{-1}, NAS data) have been depleted in early May.

Figures 4 and 5 show changes in chlorophyll *a* concentrations in two regions of England (from Malcolm *et al*. 2002). For the area from the Humber to the Wash (Fig. 4) the maximum spring growing season chlorophyll *a* concentrations were significantly higher than the reference level (15 µg/l) in two of the seven years for which there was good data. The growing season mean chlorophyll *a* concentrations were below the Atlantic offshore background concentration. It was concluded that chlorophyll *a* concentrations are not elevated in the area. Data from the Bristol Channel (Fig. 5) indicate that the reference levels have not been exceeded since 1990.

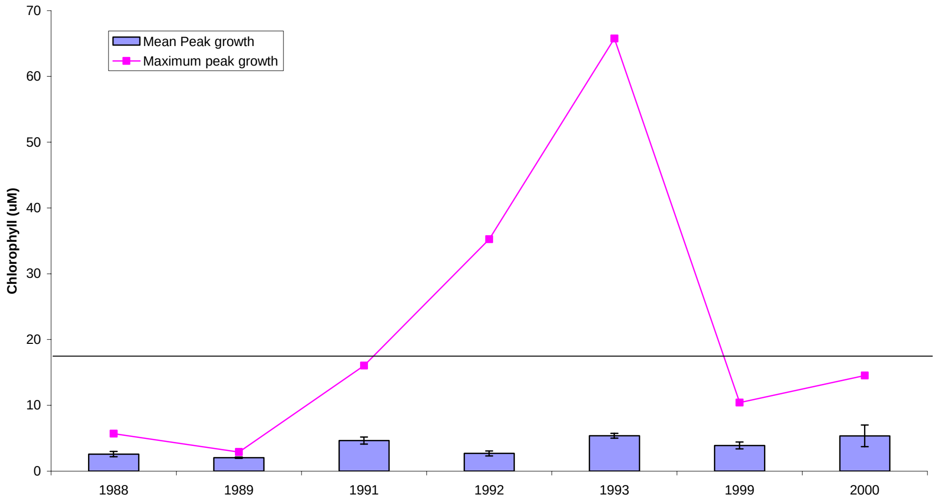

Figure 4. Mean growing season and maximum peak chlorophyll *a* concentration (µg/l) in the Humber to Norfolk coastal water area from 1988-2001. The line represents reference value (15 µg/l).

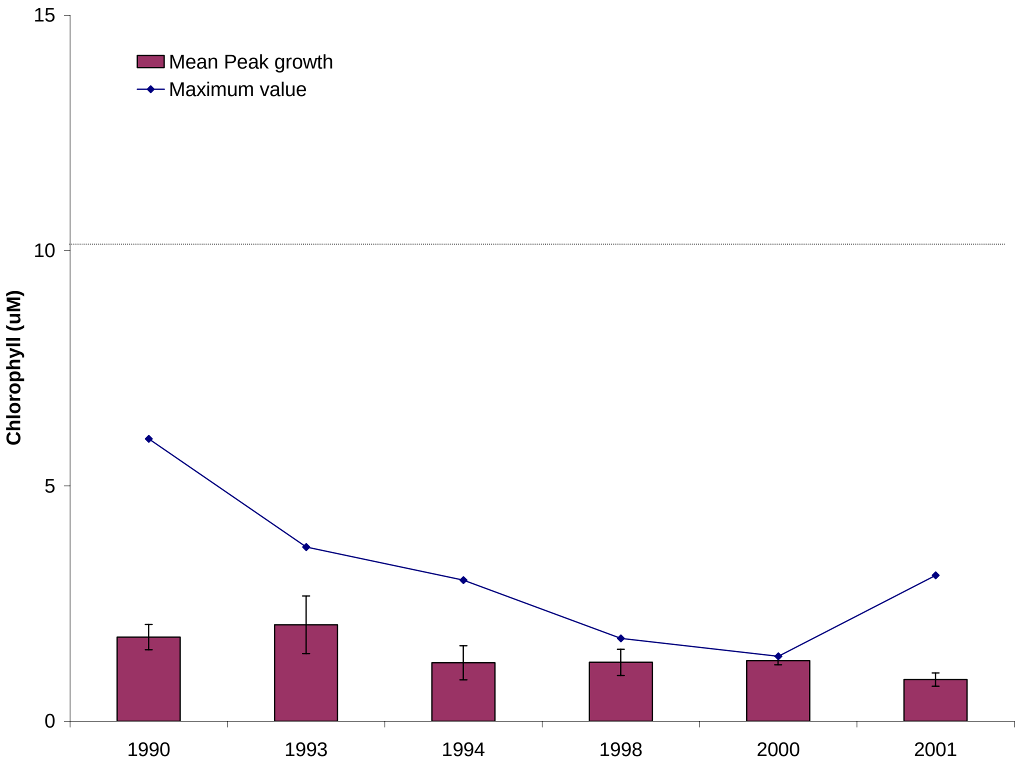

Figure 5. Mean annual and maximum peak chlorophyll *a* concentration (µg/l) in the Bristol Channel from 1993 – 2001. (ICES, CEFAS and NMP data). The line represents lower reference value.

In terms of the ICES criteria for good indicators of ecological quality, the use of chlorophyll *a* concentrations as an EcoQO (Table 6) is easy to understand. In relatively clear coastal and offshore waters, chlorophyll concentrations are likely to show sensitivity to the management of nutrient inputs. In more turbid coastal and estuarine waters, however, this sensitivity is likely to be lower. Available data indicate that chlorophyll concentrations are relatively closely linked in space and time to availability of nutrients in water bodies when other factors, such as light and temperature, are not limiting. Where other factors limit (such as light) or control (such as grazing) phytoplankton growth, linkages are weak. Phytoplankton chlorophyll *a* concentrations in relatively clear coastal and offshore waters are likely to be sensitive to management of nutrient inputs, but less so in water bodies where phytoplankton growth is limited or controlled.

In situ concentrations are easy to measure with a low error rate and, with a considerable degree of effort, are measurable over a large proportion of the area over which the EcoQO is to be applied. At present, the main limitation to the use of this EcoQO is the availability of data for the realistic setting of objectives, particularly on a regional basis.

Table 6. Evaluation of the EcoQ for phytoplankton chlorophyll *a* against those features considered to be qualities of good EcoQOs. Y = Yes, M = Moderate, N = No.

Ecological quality element	a) Understandable	b) Sensitive	c) Linked	d) Responsive	e) Low error	f) Measurable	g) Time series
Phytoplankton chlorophyll *a*	Y	Y (clear coastal) N (turbid coastal and offshore)	Y (no other limiting factors) N (limiting or cont-rolling factors present)	Y (no other limiting factors) N (limiting or cont-rolling factors present)	Y	Y	Y (critical areas) N (other areas)

5.3. Phytoplankton indicator species

Table 7. Ecological Quality Objective for monitoring phytoplankton indicator species (from the Bergen Declaration, 2002).

Ecological quality element	Ecological quality objective
(r) Phytoplankton indicator species for eutrophication	• Region/area - specific phytoplankton eutrophication indicator species should remain below respective nuisance and/or toxic elevated levels (and increased duration)

The presence of certain species of phytoplankton in a given area may be indicative of eutrophication concerns but due to the dynamic nature of the plankton communities, and in many areas the relative lack of consistent data, it is not yet possible to fully use this factor in the assessment. Where good data exist, it is possible to provide an overall description of the community, and how it changes in the growing season, as well as information about the presence and levels of potentially nuisance and toxic species. There are no readily applicable standards.

The Continuous Plankton Recorder Survey can provide useful information over a long time period for many areas. In particular, the relative abundance of diatoms and flagellates in the phytoplankton community may be used as an indicator of change and if the change favours flagellates this may be deemed undesirable because of consequences for the food web. However, these changes may be the result of wider regional climatic change rather than the consequence of nutrient input.

The seasonal cycle of phytoplankton in the North Sea usually consists of a spring bloom dominated by diatoms, a summer period during which biomass is generally lower and production is dominated by flagellates, followed, in some areas, by an autumn bloom (Reid *et al*., 1990; Gowen *et al.*1995). The Continuous Plankton Recorder (CPR) Survey has shown some significant changes over time.

In the southern North Sea, for example, large spring and autumn diatom blooms were typical from 1958 to 1965 (Fig. 6). After 1966 the autumn diatom bloom declined significantly while the overall growth season extended. It is unclear whether this change is linked to anthropogenic

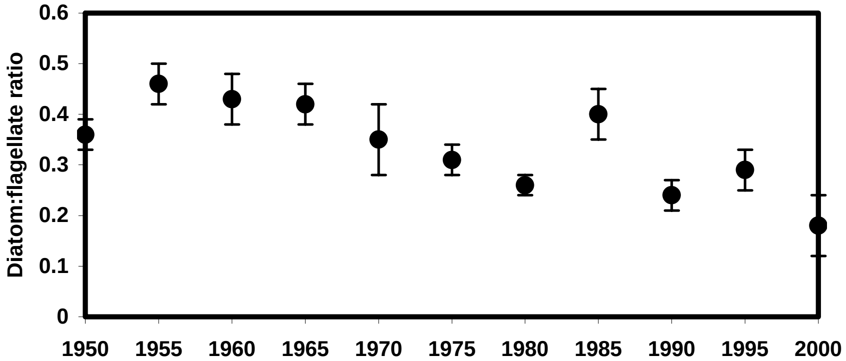

Figure 6. Growing season diatom:flagellate ratios for the offshore southern North Sea from 1950 to 2000.

nutrient inputs or to changes in the transport of Atlantic water into the North Sea in response to climatic shifts.

Mean (growing season) diatom to flagellate ratios reflects the change described above. It would be difficult to conclude whether this apparent change is the result of nutrient input or to wider scale regional changes in response to climatic forcing. The nutrient data (covering a shorter time period) suggests that there has been little change in nutrient concentration though it should be noted that there is a tendency to higher N:Si ratios in 1990's.

In terms of the ICES criteria for good indicators of ecological quality, the use of phytoplankton indicator species as an EcoQO (Table 8) is relatively easy to understand where the impacts of these species may be observed (*e.g.* due to colour changes, foaming on beaches, or noxious odours). In general, the concept is complex and not easy to understand. The growth of indicator species has not been shown to be responsive primarily to human activities. Except in specific cases, it is difficult to demonstrate sensitivity to the management of nutrient inputs, or linkages in space and time to the availability of anthropogenic nutrients.

Indicator species are easy to measure with a low error rate but require considerable effort, and are not routinely measured over a large proportion of the area over which the EcoQO is to be applied. At present, the main limitation to the use of this EcoQO is the availability of data for the realistic setting of objectives, particularly on a regional basis.

Table 8. Evaluation of the EcoQ for phytoplankton indicator species against those features considered to be qualities of good EcoQOs. Y = Yes, M = Moderate, N = No.

Ecological quality element	a) Understandable	b) Sensitive	c) Linked	d) Responsive	e) Low error	f) Measurable	g) Time series
Phytoplankton indicator species	Y and N	N (in general) Y (in specific cases)	N (in general) Y (in specific cases)	N	Y	Y	N

5.4. Degree of oxygen deficiency

Table 9. Ecological Quality Objective for monitoring the degree of oxygen deficiency (from the Bergen Declaration, 2002).

Ecological quality element	Ecological quality objective
(u) Oxygen	• Oxygen concentration, decreased as an indirect effect of nutrient enrichment, should remain above region-specific oxygen deficiency levels, ranging from 4-6 mg oxygen per liter

Decomposition of excess primary production (and biomass) which accumulates in response to nutrient enrichment may result in the development of hypoxic conditions in the water column, or near the bottom. These low oxygen concentrations may, in turn, result in changes in fish behaviour or kills in zoobenthos and/or fish species. These problems are exacerbated in areas subject to organic enrichment.

OSPAR uses dissolved oxygen deficiency as an assessment parameter, with 4 mg l^{-1} as the limit below which there may be fish death or prevention of passage of fish movement. However, concentration alone is insufficient to describe properly the environmental effect as concentration of dissolved oxygen naturally varies with temperature and salinity. Most data available as % saturation, although they are presumably available in terms of mg/l.

Relatively few data are available on oxygen concentrations around the UK. From the first application of the OSPAR Comprehensive procedure, there was no evidence of significant depletion of dissolved oxygen (e.g. Fig. 7). Levels of supersaturation generally reflect significant plant growth during the growing season. Howarth *et al.* (1994) provide a good summary for the southern North Sea which is supported by subsequent monitoring programmes.

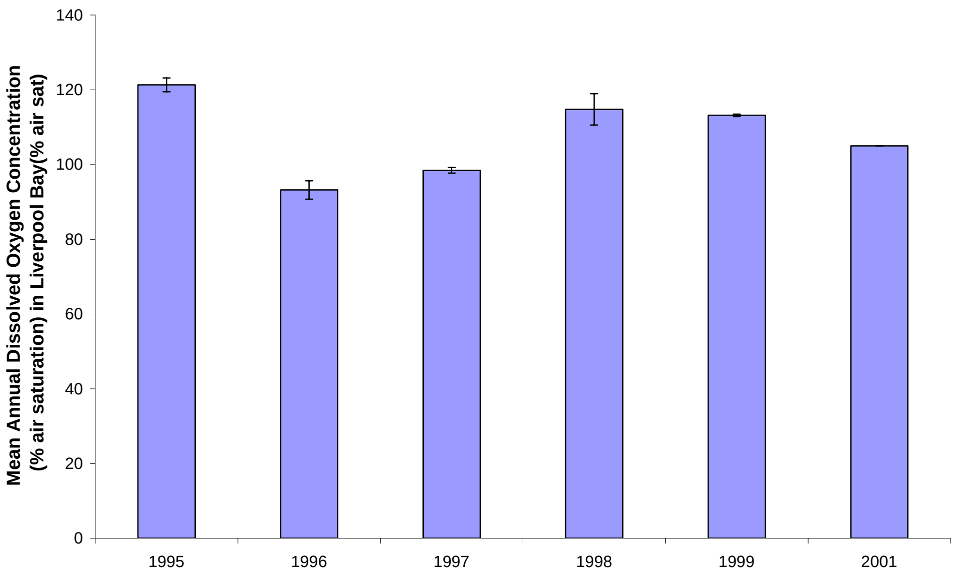

Figure 7. Oxygen concentration (% air saturation) for Mersey Estuarine Area from 1995 - 2001.

In terms of the ICES criteria for good indicators of ecological quality, the use of oxygen as an EcoQO (Table 10) is easy to understand. It is, however, difficult to demonstrate sensitivity to the management of nutrient inputs, or linkages in space and time to the availability of nutrients. Oxygen concentrations are easy to measure with a low error rate but require considerable effort, and are not routinely measured over a large proportion of the area over which the EcoQO is to be applied. At present, the main limitation to the use of this EcoQO is the availability of data for the realistic setting of objectives, particularly on a regional basis.

Table 10. Evaluation of the EcoQ for oxygen against those features considered to be qualities of good EcoQOs. Y = Yes, M = Moderate, N = No.

Ecological quality element	a) Understandable	b) Sensitive	c) Linked	d) Responsive	e) Low error	f) Measurable	g) Time series
Oxygen	Y	N	N	N	Y	Y	N

5.5. Changes in zoobenthos

Table 11. Ecological Quality Objective for monitoring changes in zoobenthos (from the Bergen Declaration, 2002).

Ecological quality element	**Ecological quality objective**
(m) Changes/kills in zoobenthos in relation to eutrophication	• There should be no kills in benthic animal species as a result of oxygen deficiency and/or toxic phytoplankton species.

Oxygen deficiency and/or increased abundance of toxic phytoplankton species in the water column or near the seabed have been shown, in numerous studies in Europe and the USA, to result in changes in benthic communities due to increased mortality of those species sensitive to oxygen concentrations or algal toxins. Long term changes in the biomass and species composition of the benthos may indicate sustained organic enrichment, particularly in the vicinity of specific sewage/industrial discharges. An example of the sensitivity of the benthos to subtle changes in sediment quality is provided by a study of the effects of sewage-sludge disposal and its aftermath off the Tyne (NE England, Fig. 8 and Rees *et al.*, 2003). This study employed quantitative criteria for determining the acceptability of observed changes, which were derived from an empirical model describing the effects on the benthos of organic enrichment (Pearson and Rosenberg, 1978). For example, ratios of abundance for the disposal site (DG) and the southern reference site (REFS) relative to an 'Action Point' for acceptable change indicate that the activity was in compliance for the duration of the disposal activity. Ratios significantly higher than 0 indicate marginal enrichment throughout the disposal period. In the period following cessation, values decline to near-equality. This approach has certain similarities with the goal of the EcoQO approach.

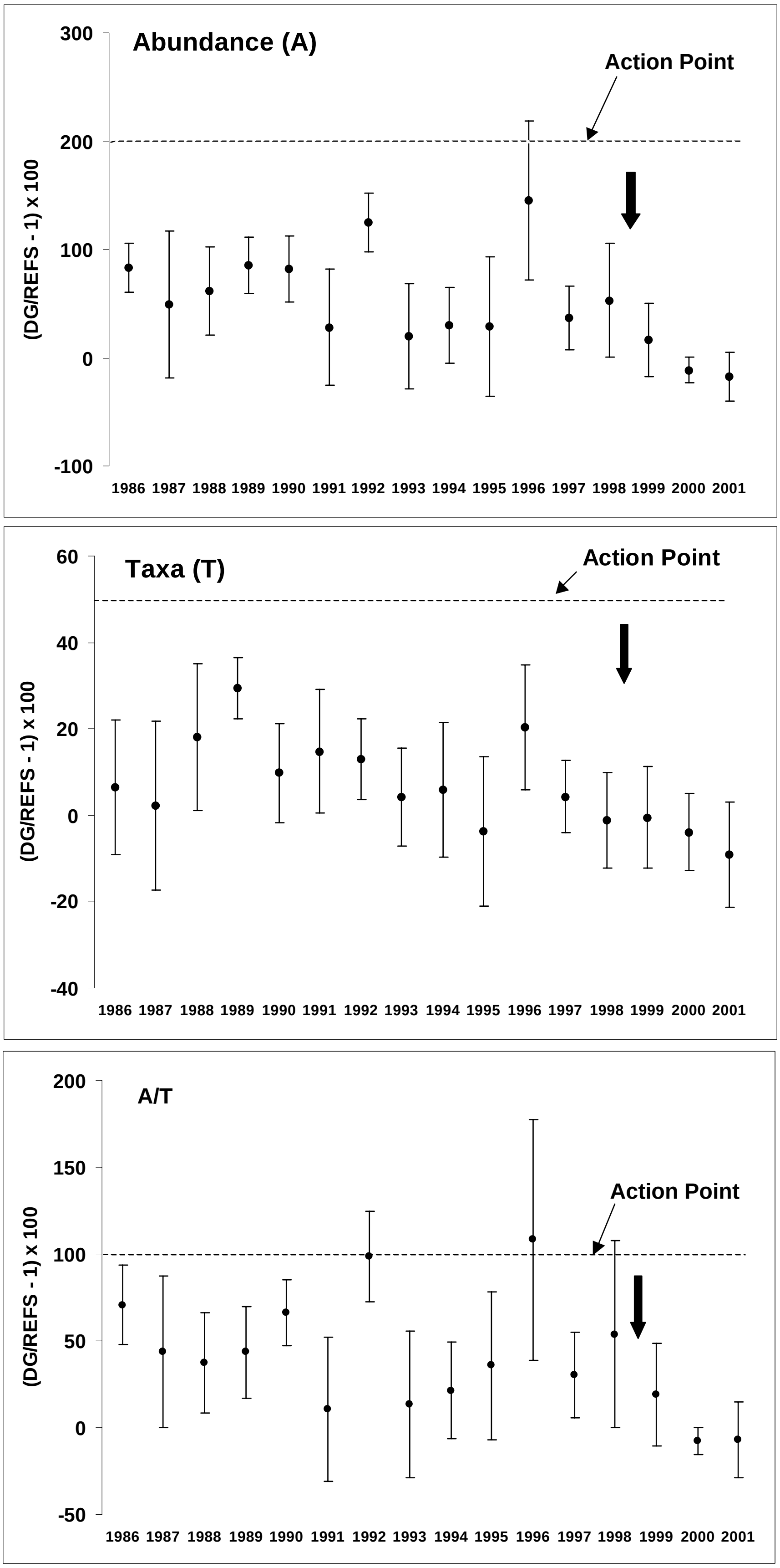

Figure 8. Means with 95% bootstrapped confidence limits for pairwise comparisons of univariate measures at the Tyne sewage-sludge disposal site (DG) and southern reference site (REFS). 'Action Points' denote upper limits for acceptable change. Vertical arrows indicate the time of cessation of sewage-sludge disposal (1998).

There are few recent examples from the OSPAR regions of the UK which indicate death of benthic animals associated with oxygen deficiency or algal toxicity. However, in the former case, there are well-documented examples of changes in the biota associated with historical declines in water quality in certain urbanised/industrialised estuaries, such as the Tyne, Tees and Thames. Investments in sewerage and sewage treatment facilities, along with improvements in industrial effluent quality, have done much to reverse these historical problems. Offshore, long term changes in zoobenthos have been detected (Clark and Frid, 2001, Kroncke and Knust, 1995) but few studies have been able to provide unequivocal evidence of a link with the consequences of nutrient enrichment.

For the stated EcoQO (above), all criteria are easily met since all that is required is the detection of gross effects ('kills'). We advocate a second objective, namely that there should be no unacceptable trends in benthic communities in response to the end products of incipient nutrient enrichment. In the latter case, in terms of the ICES criteria for good indicators of ecological quality, the use of zoobenthos as an EcoQO (Table 12) is easy to understand. It is, however, difficult to demonstrate sensitivity to the management of nutrient inputs, or linkages in space and time to the availability of nutrients. Abundances and species composition of benthic animals are relatively easy to measure with a low error rate, but this requires considerable monitoring effort, and is not routinely done over a large proportion of the area over which the EcoQO is to be applied. Nevertheless, monitoring commitments of a number of North Sea states over the last 10 years or so are beginning to generate consistent, quality-controlled trend data over relatively long time-scales and are therefore increasingly 'fit for purpose' in the present context. Examples include the UK's National Marine Monitoring Programme (NMMP) and the Dutch national monitoring programme (Daan and Mulder, 2003). On a North Sea–wide scale, an ongoing evaluation of the current status of benthic communities, and any changes since an earlier (1986) ICES survey, is also notable (see ICES website). At present, the main limitation to the use of this EcoQO is the availability of site- or habitat- specific cause/effect data for the realistic setting of objectives.

Table 12. Evaluation of the EcoQ for changes in zoobenthos against those features considered to be qualities of good EcoQOs. Y = Yes, M = Moderate, N = No. For an EcoQO based on kills in benthic animal species, all responses are Yes.

Ecological quality element	a) Understandable	b) Sensitive	c) Linked	d) Responsive	e) Low error	f) Measurable	g) Time series
i. Zoobenthos Changes	Y	Y (using predictive models) N	N (in general: risk of confound-ing subtle influences)	Y (with sound sampling design) N	Y	Y (uniform environme nts) N (patchy environ-ments)	Y (for some areas) N (infor-mation is patchy)
ii. Zoobenthos kills	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**

6. CONCLUSIONS

Evaluations of the five EcoQOs for assessing risks and impacts of eutrophication are summarised in Table 13. In general, the indicators are easy to understand, but it is not always easy to demonstrate the cause and effect relationships in response to manageable human activities. Similarly, monitoring of the nutrients and eutrophication effects is generally feasible and in place (*e.g*. through OSPAR and various directives). Adequate time-series of data are available for the setting of reliable reference points in select areas but, in general, insufficient long-term data are available for the setting of reference points on a regional basis.

Detailed evaluations of the five agreed Ecological Quality elements suggest that the best EcoQO (in terms of the ICES criteria) is the concentration of winter nutrients. This is particularly true for coastal environments, where it is feasible that all of the ICES can be met. For offshore waters, it is less likely that all the criteria will be met, as nutrient concentrations are primarily responsive to other processes (such as hydrography) and not directly to human activity.

Concentrations of phytoplankton chlorophyll *a* also appear to be a good indicator in environments which are susceptible to nutrient enrichment (*e.g*. clear coastal water). In water bodies which are less susceptible to the impacts of nutrient enrichment, this EcoQO may not meet any of the criteria for demonstrating cause and effect relationships. Reduced susceptibility may be due to factors which limit or control phytoplankton growth, for example light, advective losses and grazing pressure.

Detailed evaluation of phytoplankton indicator species as an Ecological Quality element suggested that this EcoQO does not meet sufficient ICES criteria to be considered a good indicator. In specific cases where human activities are clearly evident, it may be easy to demonstrate localised cause and effect relationships between nuisance/toxic species and human activity, but on a broader (*e.g.* regional) scale this is not feasible. Indicator species are easy to monitor, but relatively few data sets are available for regional analyses.

Preliminary analysis of available data on oxygen concentrations suggested that this EcoQO also fails to meet sufficient ICES criteria to be considered a good indicator. In specific areas, it may be easy to demonstrate cause and effect relationships, but on a broader/regional scale this is less feasible. Oxygen concentrations are easy to monitor and measure, but relatively few time-series data are available.

The EcoQO for zoobenthos (or fish) kills meets all the ICES criteria for a good indicator, but an EcoQO based on changes in benthic communities is subject to the same limitations as those described for phytoplankton indicator species and oxygen.

Consideration of specific examples and the limitations of each EcoQO suggests that for assessing eutrophication effects, greater emphasis may need to be placed on:

(a) Defining seasons and seasonal effects of nutrient inputs and seasonal responses of the phytoplankton community. For example, during the entire phytoplankton growth season (summer) the availability of nutrients on an ongoing basis may be as important, if not more important, than the winter nutrient concentrations which fuel the initial spring bloom but not subsequent blooms. Within any given region, *e.g*. the southern North Sea, temporal variability in physical factors plays an important role in limiting or controlling the biological response to nutrient enrichment. This has been incorporated into the current EcoQOs, which propose season-specific reference levels for nutrients and phytoplankton chlorophyll *a*, albeit loosely.

(b) Assessing the natural susceptibility of different water bodies. Numerous factors determine the response of different water bodies to nutrient enrichment, including physical processes (such as water column stratification and light availability), the hydro-dynamic regime (including vertical and horizontal advection), and biological processes (such as rates of phytoplankton growth, zooplankton grazing, and filter-feeding by benthic organisms and fish).

(c) Distinguishing between coastal and offshore environments. Spatial variability plays a critical role in determining susceptibility to nutrient enrichment, both alongshore and in near-shore *vs* offshore waters. Nutrient inputs and biological responses in coastal waters adjacent to river mouths or sewage outlets, for example, are likely to be different from those in coastal waters which are not strongly influenced by river run-off or point sources. Similarly, nutrient inputs and biological responses in coastal waters are likely to be significantly different from those in offshore waters, where the influence of freshwater inputs is weakest and the temporal variability in hydrographic and biological processes is high. Clearly defined local or salinity-specific reference levels may therefore also be essential for sensible application of the EcoQOs. To some extent, these have been incorporated into the current EcoQOs, but insufficient emphasis has been placed on this point. Certainly, the suitability of the EcoQOs based on the ICES criteria (Table 2) is far more difficult to evaluate for offshore waters than for coastal waters.

(d) Development of longer (>20 y) time-series of data. These are essential for assessing the significance of anthropogenic inputs by quantifying the natural variability in different water bodies, and for setting reliable thresholds.

Other potential elements to be considered for EcoQOs include indices of greenness from the Continuous Plankton Recorder and the “Phytoplankton Trophic Index” currently under development through CEFAS, although it is not clear at this stage how these indicators could be applied.

Table 13. Evaluation of EcoQ metrics against those features considered to be qualities of good EcoQOs. Fully shaded rectangles fully match the criterion, partially shaded rectangles do not fully match the criterion and limitations are discussed in the section indicated. Y = Yes, M = Moderate, N = No.

Ecological quality element	a) Understandable	b) Sensitive	c) Linked	d) Responsive	e) Low error	f) Measurable	g) Time series
(t) Winter nutrient concentrations (DIN and DIP)	**Y**	**Y**	**Y**	**Y** (coastal areas) **N** (offshore areas)	**Y**	**Y**	**Y** (critical areas) **N** (other areas)
(q) Phytoplankton chlorophyll *a*	**Y**	**Y** (clear coastal) **N** (turbid coastal and offshore)	**Y** (no other limiting factors) **N** (limiting or cont-rolling factors present)	**Y** (no other limiting factors) **N** (limiting or cont-rolling factors present)	**Y**	**Y**	**Y** (critical areas) **N** (other areas)
(r) Phytoplankton indicator species	**Y** (obvious impacts) **N** (in general)	**N** (in general) **Y** (in specific cases)	**N** (in general) **Y** (in specific cases)	**N**	**Y**	**Y**	**N**
(u) Oxygen	**Y**	**N**	**N**	**N**	**Y**	**Y**	**N**
(m) i. Zoobenthos Changes	**Y**	Y (using predictiv e models) N	N (in general: risk of confound -ing subtle influence s)	Y (with sound sampling design) N	Y	Y (uniform environme nts) N (patchy environ-ments)	Y (for some areas) N (infor-mation is patchy)
(m) ii. Zoobenthos kills	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**

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Directives

Water Framework Directive, WFD (2000/60/EC)

Habitats Directive, HD (92/43/EEC)

Urban Waste Water Treatment Directive, UWWTD (1991)

ANNEX 5

Extractions from MCWG reports concerning eutrophication

MCWG 2002

7.4 Uli Claussen: Assessment of the eutrophication status within the OSPAR Convention Area

This presentation described work undertaken mainly within OSPAR and under the EC Water Framework Directive to adopt a new harmonised approach. It underpins the OSPAR strategy to achieve and maintain a healthy marine environment, where eutrophication does not occur, by 2010. In the identification of problem areas for eutrophication, the OSPAR system adopts a two-stage approach, the OSPAR Common Procedure. This involves firstly a screening procedure which identifies non-problem areas. The comprehensive procedure is then applied to reclassify the other areas as either problem areas, potential problem areas, or non-problem areas, based upon more detailed study. Areas subject to the comprehensive procedure will be assessed during 2002, and the assessments will be presented during 2003. Within 5 years of the initial assessment, potential problem areas must be reclassified to either problem or non-problem areas, in order that remedial measures might be implemented in problem areas.

8.4.2 Review studies under way in OSPAR on ecological quality objectives for the North Sea with regard to nutrients and eutrophication effects

The discussion in the subgroup was mainly based on the paper, "Current status of Ecological Quality Objectives for the Greater North Sea with regard to Nutrients and Eutrophication Effects" (EcoQOs-eutro, EUC 01/5/3 – Rev 1).

The subgroup agreed in principle that it was necessary to have objective criteria for assessing nutrient enrichment and ecological quality objectives. However, some of the "Agreed Harmonised Assessment Criteria" require clarification and may not be relevant to all sites at all times.

The OSPAR region—in common with other coastal areas—is subject to large natural temporal and spatial variations in nutrient concentrations. One of the major deficiencies of the proposed criteria is that transboundary nutrient transports are not adequately taken into account. This is particularly important for inorganic nutrients, since the natural fluxes in the North Sea are many orders of magnitude greater than the anthropogenic fluxes, which are also likely to be localised in space and time. Care must therefore be used in interpreting nutrient data, since misleading or inappropriate conclusions may be drawn. For example, "winter concentrations" of nutrients are only appropriate for the description of phytoplankton development in summer if it is confirmed that transboundary effects are not significant over the intervening period. Moreover, the definition of "winter concentrations" is too broad, as this parameter is defined by the status of the ecosystem (maximum accumulation of nutrients and minimum primary productivity) and not by a specific time of the year. The start of the phytoplankton spring bloom may not necessarily occur at the same time for all stations.

The subgroup was also concerned that the criteria listed as "Assessment Criteria" are not necessarily universally applicable and recommended that the listed criteria be checked for relevance to local conditions. For example, natural perturbations such as wind-induced mixing or upwelling need to be considered before deciding whether critical values have been exceeded. The rationale for assigning values to "background concentrations" and "elevated concentrations" is not always clear since we have limited information as to how the ´spatial/historical background concentrations´ were fixed. The relevant information needs to be readily available. In addition, if the normal concentration of a nutrient is low, an increase of >50 % may not be environmentally significant. It is also not clear from the document what criteria will be used to define the boundaries of problem areas (PA). Given these concerns, it is surprising that, in Document EUC 01/5/2-Add.1-E, Item 9), no comments are included under the heading *Remaining problems and suggested actions*.

The scientific background behind the Ecological Quality Objectives, strategies to support their evaluation, and information on their proper use need more clarification and ongoing discussion.

8.4.4 Discuss OSPAR activities regarding the assessment of eutrophication, nutrient concentrations and trends, and how ICES might contribute to this process

Discussions of agenda items 8.4.4 and 8.4.5 were merged since their overall content is complementary and no document was available for discussion under item 8.4.5. Many documents from OSPAR and the EEA were provided for item 8.4.4

just prior to the meeting and some time was therefore required to review these documents. It should be mentioned that discussion under this item is, to some extent, connected with that under Section 8.4.2, above.

The documents from the EEA concerned indicator fact sheets and dealt with nitrogen, phosphorus, and chlorophyll *a* concentrations in rivers and coastal waters. The assessment of concentration trends is achieved using indicators which have been selected to give an answer to policy issues as follows:

EEA Indicator	**EEA Policy issue**
River nutrients	Are nutrient reduction policies resulting in lower levels of nutrients?
Nutrients in coastal waters	Are nutrient reduction policies resulting in lower levels of nutrients?

The subgroup examined the relevance of the policy issues and of the corresponding indicators.

With regard to nutrients in rivers, there is an obvious direct influence of a reduction of inputs from agricultural or urban sources on water concentrations of nutrients. Thus, the policy and the indicator are both consistent.

With regard to nutrients in coastal waters, the problem is more complex. Contrary to the situation for anthropogenic contaminants, nutrients are natural compounds present at significant concentrations in marine systems and they undergo a variety of processes, which can induce large natural variations. These variations in seawater concentrations, in addition to the dilution factor due to the mixing of river water and sea water, may mask any reductions in concentration in the freshwater source. It is therefore questionable whether the policy issue stated for nutrients in coastal waters is relevant. Since eutrophication is the main problem, and nutrients are not contaminants by themselves, the subgroup wondered whether the policy issue relating to nutrients in the coastal waters depends strongly on local conditions.

The subgroup agreed with the EEA statement concerning phosphate and nitrate concentrations in coastal waters that "…trends in nutrient concentrations as such cannot be directly related to measures taken". This does, however, appear to contradict the stated policy issue. The subgroup also considered that it is not possible to make meaningful statements about changes in nutrient concentrations by aggregating data from multiple stations with widely different hydrographic conditions. Presentation of data should always take this aspect into account and, at least, be accompanied with a map showing the location of the stations.

The OSPAR documents under consideration dealt with the assessment of inputs and concentrations. The document from Germany shows that despite a significant reduction of inputs measured in rivers (~30 % over 15 years), no similar trend can be identified in the German Bight. On the contrary, the documents from Denmark, Belgium, and the Netherlands mention a connection between reduction of inputs and concentrations in the medium. However, these countries assess concentration trends in estuaries (Denmark) or at a salinity of 20 (the Netherlands). Hydrographic conditions, residence times, and freshwater proportions obviously differ significantly from one area to another in these examples. This again points out the major effect of local conditions on trend assessments. Therefore, the subgroup call the attention of the bodies in charge of trend assessments to the risk of misinterpretations and biased conclusions that could result from non-comparable data or data products.

MCWG2003

8.4.1 Data available in the ICES databanks will be used to prepare illustrative data products under the OSPAR Common Procedure, and this term of reference will assist in defining the data products. This is further consideration of an OSPAR request concerning EcoQOs for eutrophication. The subgroup will consider more appropriate EcoQOs

As there were not a sufficient number of members of the COSG present at the meeting, it was not possible to undertake the task above. There was only a brief plenary discussion about this agenda item, which is presented below. The item will be reconsidered at MCWG2004.

Concerning the OSPAR request concerning EcoQOs for eutrophication, it was recognised that EcoQOs have to be developed at a local scale, as knowledge of water mass dynamics and of the actual nutrient regime are of major importance for establishing proper EcoQOs for any area. As the content of nutrients in a water mass is strongly connected to plankton blooms and the biological development in the water mass, the use of any specific nutrient concentration for determination of the quality status is also time-dependent.

It was strongly advocated not to use simple numbers for the concentration of the various nutrients as indicators for establishing the quality status concerning eutrophication of a specific area. Examples were given of misleading use of simple numbers where, for example, a surface water mass containing 10 µmol NO_3 per litre was classified as being in bad condition in the context of eutrophication, for an area influenced by Atlantic deep water containing 12–14 µmol NO_3 per litre. The importance of establishing regional specific natural background concentrations and the variability associated with these must also be taken into account in design of monitoring programmes. This is influenced by natural inputs, geochemical and oceanographic factors and mixing patterns. These factors are considered in a report from the Marine Institute, Dublin, which was provided to MCWG members by Evin McGovern.

McGovern, E., Monaghan, E., Bloxham, M., Rowe, A., Duffy, C., Quinn, A., McHugh, B., McMahon, T., Smyth, M., Naughton, M., McManus, M. and Nixon, E. 2002. Winter nutrient monitoring of the western Irish Sea – 1990 to 2000. Marine Institute, Dublin, Ireland. ISSN no. 1649-0053, 73 pp.

(This is available for download from: http://www.marine.ie/information+services/library+services/marine+institute+publications/marine+environment+and+health+services/mehs4.pdf)

Attention was also drawn to the more than twenty years of monitoring nutrients in the Kattegat and the difficulties of drawing conclusions concerning nitrogen sources and fluxes from this extensive monitoring.

MCWG 2004

8.4.2 Consider requests from the Chairs of SGEUT for information relating to the work of the study group

The MCWG discussed the request from ICES to comment on the tasks set out for the Study Group to Review Ecological Quality Objectives for Eutrophication (SGEUT), and noted that this issue has been a topic of discussion in the MCWG for many years. For the use in this Study Group meeting scheduled to be in held the ICES Headquarters from 25–27 March 2004, it was proposed that the SGEUT should refer to the earlier MCWG reports in which eutrophication is discussed. The reports are present in the ICES Headquarters and MCWG propose that due to the limited time available before the scheduled SGEUT meeting the ICES Secretariat should compile the parts concerning eutrophication and nutrients from previous MCWG reports and present them to the SGEUT.

MCWG has strongly recommended that regional approaches should be taken, based on the specific environmental conditions of the particular area. It is emphasised that the selection of EcoQOs concerning eutrophication in an area have to be based on a thorough knowledge of the actual conditions of the specific ecosystem.

OSPAR has defined eutrophication to be:

"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." (OSPAR, 2000)

This definition given by OSPAR has to be interpreted in that due consideration should be given to the ecosystems of the particular area of concern. This means, for example, that setting one certain common specific number for the winter concentration of nutrients for the whole OSPAR area will not be in agreement with the OSPAR definition of eutrophication. Each area has to be considered individually so as to ensure that the definition is in agreement with the natural conditions for that specific area.

The EcoQOs selected by OSPAR are, in principle, suitable for the description and characterisation of the degree of eutrophication of the marine environment. However, to apply them for the description of eutrophication in a specific, regionally limited area, additional information and definitions are essential, e.g., a definition of 'winter concentration' of nutrients, as cruises from different countries do not always occur at the same time of year.

A disadvantage of the proposed EcoQOs is that they can be used in exactly the same way to describe both natural conditions (e.g., in upwelling areas) and conditions influenced by anthropogenic activities. Therefore additional criteria are essential to discriminate between natural and anthropogenic effects. Due to the interanual natural variability due to the hydrographic, meteorological and biological conditions, this variability has to be taken into account by setting up area specific criteria including the component of time, e.g., decreasing or increasing trends over a period of time (e.g., over several years).

Another disadvantage of the selected objectives is that they take into account measurements which have to be performed at different times of the season, e.g., nutrient concentration has to be measured in winter (when little or no plankton growth occurs), while relevant chlorophyll *a* concentrations have to be measured in spring or summer during plankton blooms. Despite the missing clarification (whether the chlorophyll *a* concentration has to be measured at the highest density of cells – a criterion that is very difficult to control) or as an integrated value over a specified period of time, the assumption that the winter concentration of nutrients and the concentration of chlorophyll *a* during summer are directly related has to be demonstrated for each individual region. In areas which have a short residence time for water, particularly, it will be very difficult to demonstrate such a linkage, particularly if no continuous records of the hydrographic processes prevailing in that area are available.

Although the proposed EcoQOs can be taken as a rough indicator of eutrophication, which may result from anthropogenic activities, additional parameters should be introduced in order to provide a more quantitative description of the situation. To avoid one of the major disadvantages described above (the measurement of parameters at different times of year) objectives should be set that allow conclusions to be drawn from measurements performed over a shorter period of time, and which are closer to the biological and chemical processes involved in the effects caused by eutrophication. It is questionable whether the selected EcoQOs are sensitive enough to describe changes in the degree of eutrophication adequately. As an excess of nutrients, once introduced into a ecosystem with restricted water exchange (i.e., with a long residence time of water), can be recycled for several years, the nutrient concentration will change only very slowly following a reduction of inputs. If targets for the reduction of eutrophication are defined, this aspect has to be taken into account, again on an area-specific basis.

The central point concerning the effects of 'eutrophication' is the enhanced production of organic material, as well as its subsequent degradation and remineralisation. From this point of view it is essential to analyse not only the chlorophyll *a* concentration and phytoplankton indicators, but also the production of organic material, e.g., carbon, nitrogen and phosphorous fixed in organic material (TOC, TON, TOP). It is likely that these parameters will react more sensitively to changes of inputs into the ecosystem as they stem from the relevant processes which follow eutrophication, as described above. They can also be determined in the same water samples which are used for the other parameters, avoiding the misinterpretation of results from measurements performed at different times.

For practical reasons, the measurement of the partial pressure of CO_2 should also be considered as a possible parameter which could help to describe the effects of eutrophication, as the consumption of CO_2 is directly related to the production of organic material. Another advantage of using measurements of pCO_2 is that it can be performed automatically over longer periods of time, so as to provide an integrated estimate of the production of organic material.

ANNEX 6

Study Group to Review Ecological Quality Objectives for Eutrophication
ICES Office Copenhagen May 17-19, 2004
Description and Recommendations for Integration of Ecological Quality Elements
Objective of Integration

The intent of integration of EcoQ components is to characterise the overall ecological quality of a system in relation to nutrient related eutrophication with regard to reference conditions indicative of good quality. This should include an integration, for the whole system, of the severity of the problem (based on specific indicator variables), the frequency of occurrence of problems (ie annual, episodic or persistent), and the spatial extent of observed problems (indicated by specific indicators at high or problem concentrations). Each indicator also should be an integration of the frequency of occurrence, severity of concentration or problem occurrence and the spatial extent of the problems observed within the system. The overall system score should incorporate biological elements such as Chl a and other producers which respond directly to nutrients, and biological and chemical elements that are indirect responses, such as dissolved oxygen depletion and changes in the benthic community.

The integration of indicator variables should indicate the causes of observed problem conditions and some expectation of what the future conditions might be, given different management scenarios. This is a Pressure-State-Response approach that can inform management to implement appropriate measures. The integration of individual indicator variables into an overall metric or index of eutrophication should be able to evaluate the success of management measures, i.e. show the success of management over time, including incremental changes for those systems that require management to improve the condition from one rating to the next highest one (i.e. from moderate to good).

Methods for Integration OSPAR/ASSETS

1 INTEGRATION OF INDICATOR CHARACTERISTICS INTO A SINGLE INDICATOR SCORE OR RATING

For each of the indicators, an index should be developed to represent a combined rating of the severity in concentration, the spatial coverage within the system of higher level problem conditions, and the frequency with which these problem levels are observed (eg annual, periodic or persistent). For Chl a, the indicator should include typical high concentrations combined with the spatial extent of high concentrations and the frequency with which these concentrations occur in order to give an integrated rating for Chl a that includes relevant characteristics. The concentrations should include the highest levels (but not the maximum values since the intent is to use values that are representative of typical high values [eg. those that are typical of the winter spring bloom, which is often the highest concentration of the year] as determined by either percentile 90 approach or by calculated mean of growing season concentrations – something that is representative which single highest values are not). These characteristics (concentration, spatial coverage of highest concentrations, and frequency of occurrence) are then combined by a logic decision tree, as in the National Estuarine Eutrophication Assessment (NEEA, Bricker et al 1999) and in ASSETS (Bricker et al, 2003, see example below for Chl a). The intent is to provide an integrated rating that combines characteristics that are relevant and informative about the condition as it relates to nutrient enrichment and eutrophication. As another example, the NEEA/ASSETS uses a combination of characteristics for Nuisance and Toxic blooms that includes the occurrence of nuisance and harmful blooms, the duration of the blooms and the frequency of occurrence of the blooms for a combined index for the nuisance and toxic bloom indicator (see method description in NEEA at http://spo.nos.noaa.gov/projects/cads/nees/Eutro_Report.pdf or in ASSETS at http://coastalscience.noaa.gov/documents/assets.pdf).

IF	AND	AND	THEN	
Concentration	Spatial Coverage	Frequency	Expression	Value
Hypereutrophic *or* High	High	Periodic	High	1
	Moderate	Periodic	High	1
	Low	Periodic	Moderate	0.5
	Very Low	Periodic	Moderate	0.5
	High	Episodic	High	1
	Moderate	Episodic	Moderate	0.5
	Low/Very Low	Episodic	Low	0.25
	Any Spatial Coverage	Unknown	Flag A	0.5
	Unknown	Any Frequency	Flag A	0.5

From Bricker et al 1999 is the logic decision method for developing a single rating for Chl a concentration, spatial coverage and frequency of occurrence. Each of the 6 variables used for NEEA/ASSETS has a similar decision logic for determination of an indicator rating. The primary symptoms (Chl a, epiphytes and macroalgae) are averaged and the highest value is taken for the secondary symptoms (SAV, DO, Nuisance and toxic blooms)

2 INTEGRATION OF INDICATORS INTO A SINGLE SYSTEM SCORE OR RATING

The intent of this is similar to combining the most relevant characteristics of each indicator variable to produce an index for each EcoQ element. In short, that is to provide the most information possible about relevant indicator conditions which can be combined into a single indicator that provides an integrated rating about eutrophication related conditions. Two methods are described here: the one-out all-out that is used by the OSPAR Comprehensive Procedure, and the more integrative matrix method employed by NEEA/ASSETS. Both methods use a Pressure – State approach but the NEEA/ASSETS also include a Response component that estimates potential future conditions.

Components of OSPAR/ASSETS

I. Causative Factors (OSPAR)/Pressures/Overall Human Influence(NEEA/ASSETS)

This component should reflect the pressures on a system, i.e. the factors that influence the expression of problem conditions with increased nutrient loads. This should include some measure of nutrient inputs to the system, either loads (which are often difficult to estimate) and/or nutrient concentrations specifically within the winter season though this should be used carefully since nutrient concentrations can be misinterpreted due to changes due to various biological and chemical processing once loads reach the system. *The OSPAR method also includes nutrient ratios but these are sometimes difficult to interpret. The NEEA/ASSETS specifically excludes concentrations, but uses a mode to determine the contribution from land (assumed to be human related) and ocean that also includes a measure of natural susceptibility.*

II. Direct Effects (OSPAR)/Primary Symptoms (NEEA/ASSETS)

This component reflects the group of indicator variables that respond directly to nutrient inputs, the producers, and includes indicator variables of Chl a, phytoplankton sentinel/indicator species (i.e. HABs). *OSPAR and NEEA/ASSETS use macroalgae also.*

III. Indirect Effects (OSPAR)/ Secondary Symptoms(NEEA/ASSETS)

This component reflects undesirable conditions that are related to nutrient inputs, but are not direct responses such as the depletion of dissolved oxygen accompanying decomposition of high biomass and changes in the zoobenthic community in response to biochemical changes in bottom sediments and water. *OSPAR and NEEA/ASSETS also use submerged aquatic vegetation (SAV) as an indicator. NEEA/ASSETS uses Nuisance and Toxic blooms as an indirect or secondary symptom and separates them rather than calling them HABs.*

IVa. Integration: OSPAR

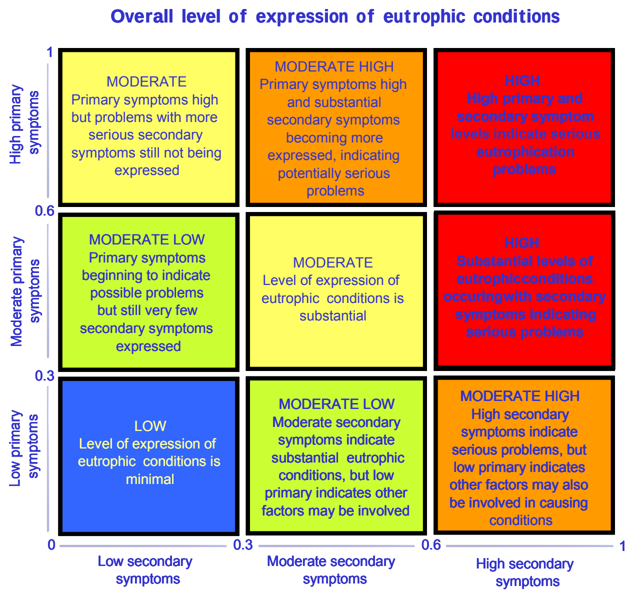
The three OSPAR method groups (I. Causative Factors, II. Direct Effects and III. Indirect Effects) are rated either +, ?, or –, where the rating for the group is dependent upon the ratings of each component within the group. The OSPAR uses a one-out all-out rating system whereby a rating of a + (indicating levels above the threshold that indicates undesirable conditions) in one component within the group will make the entire group a + or problem indication.

For the integration of the three groups (I. Causative Factors, II. Direct Effects and III. Indirect Effects), it is also a one-out all-out principle providing one of three possible assessment ratings, Problem Area (PA), Potential Problem Area (PPA where there are ?'s in addition to –'s) or Non Problem Area (NPA).

IVb. Integration: NEEA/ASSETS

1. The NEEA/ASSETS integration starts with the integration of characteristics of each of the six indicator variables (Chl a, epiphytes, macroalgae, SAV, Nuisance and Toxic Blooms, and Dissolved Oxygen) to provide an integrated rating for each indicator (see figure above). The results for the Primary Symptoms (called Direct Effects by OSPAR) are averaged to give a single rating for the Primary Symptoms. The highest value (using the precautionary principle) is used to provide a single rating for Secondary Symptoms (called Indirect Effects by OSPAR).

2. The Primary and Secondary scores/ratings are then combined by matrix to get a single value for the state component which is termed the Overall Eutrophic Condition (OEC, see matrix below and see method description in NEEA at http://spo.nos.noaa.gov/projects/cads/nees/Eutro_Report.pdf or in ASSETS at http://coastalscience.noaa.gov/documents/assets.pdf).



3. The Pressure (OHI) – State (OEC) – and Response (DFO) results are combined into a single rating. The OHI (Overhall Human Influence) describes the predominant source of loads from ocean or land in combination with the natural susceptibility of the system. This rating is a combination of the ability to flush and dilute nutrient loads. The OEC or state component describes conditions in the water body, and DFO (Determination of Future Outlook) describes the expected future conditions dependent upon expected changes in loading as a consequence of changes in watershed population and land use etc. The resultant ratings are combined by

matrix to provide a single rating of either High, Good, Moderate, Poor, or Bad (see figure below and ASSETS at http://coastalscience.noaa.gov/documents/assets.pdf).

Grade	5	4	3	2	1
OHI	Low	Moderate low	Moderate	Moderate high	High
OEC	Low	Moderate low	Moderate	Moderate high	High
DFO	Improve high	Improve low	No change	Worsen low	Worsen high

Metric	Combination matrix	Class
P	5 5 5 4 4 4	High (5%)
S	5 5 5 5 5 5	
R	5 4 3 5 4 3	
P	5 5 5 5 5 5 5 4 4 4 4 4 3 3 3 3 3 3	Good (19%)
S	5 5 4 4 4 4 4 5 5 4 4 4 5 5 5 4 4 4	
R	2 1 5 4 3 2 1 2 1 5 4 3 5 4 3 5 4 3	
P	5 5 5 5 5 4 4 4 4 4 4 4 3 3 3 3 3 3 3 2 2 2 2 2 2 2 2 2 1 1	Moderate(32%)
S	3 3 3 3 3 4 4 3 3 3 3 3 5 5 4 4 3 3 3 4 4 4 4 4 3 3 3 2 3 3	
R	2 1 5 4 3 2 1 5 4 3 2 1 2 1 2 1 5 4 3 5 4 3 2 1 5 4 3 5 5 4	
P	4 4 4 4 4 3 3 3 3 3 3 3 2 2 2 2 2 2 1 1 1 1 1	Poor (24%)
S	2 2 2 2 2 3 3 2 2 2 2 2 3 3 2 2 2 2 3 3 3 2 2	
R	5 4 3 2 1 2 1 5 4 3 2 1 2 1 4 3 2 1 3 2 1 5 4	
P	3 3 3 3 3 2 2 2 2 2 1 1 1 1 1 1 1 1	Bad (19%)
S	1 1 1 1 1 1 1 1 1 1 2 2 2 1 1 1 1 1	
R	5 4 3 2 1 5 4 3 2 1 3 2 1 5 4 3 2 1	