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Viewpoint

A UK perspective on the development of marine ecosystem indicators

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Abstract

This paper reviews the suite of marine ecosystem indicators currently in use or under development in the UK to support the major national and international biodiversity and ecosystem policies. Indicators apply to a range of different ecosystem components, and range from those that can only be used for high level environmental health monitoring, to those which actively support management. Assessment of indicators against a management framework of driving force, pressure, state, impact and response, has shown that there are many indicators of state for ecosystem components, but relatively few for pressure of human activities on the environment, or of the socio-economic response to those pressures. This outcome, a result of unplanned sectorally driven indicator development, is not a co-ordinated contribution to marine environmental management and must be addressed if we are to avoid high monitoring costs and duplication of effort.

Keywords: Indicators; Ecosystem components; DPSIR; Monitoring; Objectives; Biodiversity

1. Introduction

Indicators of environmental status are an integral part of the management systems put in place to ensure sustainable development of the marine environment, and are important both for communication and for supporting the objectives of an ecosystem approach. Renewed interest in this topic in the UK has been driven largely by commitments made for the achievement of international ecosystem targets. Principle amongst these are the undertakings in the World Summit on Sustainable Development (WSSD), and at OSPAR/HELCOM 2003, that by 2010 we will halt biodiversity decline, and encourage the application of the ecosystem approach for the sustainable development of the oceans (OSPAR, 2003; UNEP, 2004).

Since the 1970s there has been ad hoc development of a range of objectives and targets for components of the marine environment such as nutrient discharges from rivers, contaminant loads of water and sediment, and the size of fish populations, and these are routinely reported nationally (CEFAS, 2003) and internationally (OSPAR, 2000b). In addition to the development of these activity-specific indicators, there is also ongoing collection of low-resolution environmental health data for a wide range of issues such as air quality, energy consumption, and greenhouse gas emissions. These data support objectives related to the long-term improvement in condition, and the assessment of progress of such measures is often made in terms of positive or negative trends rather than specific targets (Defra, 2003).

Many indicators for the UK marine environment have been incorporated into a larger suite of nearly 150 sustainable development indicators covering socio-economics and ecology (Defra, 2004a). Trends in the 15 headline indicators are identified by red, amber and green 'traffic lights', to highlight those areas where there

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has been significant improvement, little or no change, or significant deterioration. Four of these headline indicators relate to managing the environment and resources (climate change and energy, air, water and radioactive waste, and landscape and wildlife), and none are based exclusively on the marine environment. Additions and updates to these indicators are available on www.sustainable-development.gov.uk/indicators.

To assess recent progress in improving marine environmental quality, seven indicators have been chosen to represent a broad range of conservation objectives for the coasts, seas and oceans of the UK (Defra, 2003) (Table 1). These indicators do not provide a comprehensive description of marine ecosystem status and do not support all the objectives that UK is committed to, however, this will be addressed as part of the Governments' consultation on a new strategy for sustainable development in the UK (Defra, 2004a).

Recently, the ecosystem-based approach to management has been advanced through the selection of desired states of the physical and biological components of the ecosystem, and the imposition of management measures aimed at achieving them. One of a number of approaches, the use of measures of the state of the natural environment has resonance with the general public, for whom this is the ultimate expression of success or failure of management. Despite the difficulties that can be experienced in identifying causal links between human activity and environmental state descriptors, it is nevertheless expected that such indicators will ultimately contribute to the effective control of activities that impact the ecosystem (EU, 2002; OSPAR, 2003).

Desired state for selected species and habitats is a major component of the ecological goals and objectives for representative parts of the marine ecosystem in both the EU and international conventions such as OSPAR (DEHLG, 2004; OSPAR, 2003; UNEP, 2004). The EU Marine Strategy will provide an over-arching vision, high level principles and strategic goals, and will bring together several existing EU objectives which contribute to the protection of the marine environment (EU, 2002). For example, the EU Water Framework Directive requires that member states assess the ecological status of transitional and coastal waters by 2006, and aims to prevent deterioration and achieve "good status" in all bodies of surface water and groundwaters by 2015 (EU, 2000). The EU Habitats and Birds Directives require the conservation of listed species and habitats, principally through the establishment of the Natura 2000 site network, to ensure the maintenance of habitats and species at favourable conservation status (EU, 1979; EU, 1992).

Table 1
Headline (H) and core marine (M) indicators relating to the status of the marine environment currently reported on by UK Government in the England Biodiversity Strategy (Defra, 2003)

TYPE	CODE	INDICATOR
Pressure	H6	UK fish stocks fished within safe limits
Response	H8	Public attitudes to biodiversity
State	M1	Populations of coastal and sea birds
State	M2	Condition of coastal SSSIs
State	M3	Status of coastal and marine BAP priority species and habitats
State	M4	Marine biodiversity status (to be developed)
Pressure	M5	Inputs of hazardous substances to the marine environment
Pressure	M6	Levels of cetacean by-catch in UK waters

The OSPAR Commission also has obligations for protection and conservation of ecosystems and biological diversity, and is co-ordinating the development of Ecological Quality Objectives (EcoQO) for the marine environment (OSPAR, 1998). Contracting parties are currently involved in a pilot trial of 10 EcoQO, and their associated indicators, that will be completed in 2005 (Appendix A).

A recent international review of biodiversity indicators to support the development of a headline indicator set for the European Environment Agency identified 655 biodiversity-related indicators over 12 different sectors (EEA, 2002). Although many used the same basic data, the development of operational indicators has been slow, suggesting that the best way forward might be to select a limited suite of well understood short-term indicators, and develop a more comprehensive set over a longer time-period (EEA, 2002). This set of headline indicators will be supported by a larger number of lower-level indicators specific to EU and international biodiversity policy objectives. The set contains familiar biodiversity indicators related to status of threatened and protected species, the extent of designated areas and trends in species distribution and abundance (Appendix B).

Some of the indicators required to support the objectives of an ecosystem approach are currently under development in the international science community, but others will be needed. A major difficulty is the lack of measures of whole ecosystem function, and an incomplete understanding of how the various components of the ecosystem interact. This paper summarises the current development and reporting of indicators in the UK across a range of ecosystem components, and assesses the extent to which they will make a useful contribution to supporting the objectives of an ecosystem approach. It will highlight how these indicators have many different roles and operate at many different levels, and will show that there are gaps and overlaps in the existing suite of indicators.

2. Indicators of ecosystem components

The ultimate aim of many of the high level policies is to provide a healthy marine ecosystem that can sustain human demands on environmental goods and services. Unfortunately the current level of understanding of the marine ecosystem is insufficient to derive robust and meaningful measures for the entire ecosystem, and it cannot yet develop management approaches that could deliver this higher level of environmental protection. So, although it is important to strive for a healthy ecosystem, we can currently only achieve this by managing specific human activities that adversely affect components of the environment. The most important task is therefore to develop the tools needed to contribute to the management of human activities in the marine environment, by providing indicators that measure the extent of impact of an activity on part of the ecosystem.

These decision support or 'performance' measures will require significant resources for monitoring and reporting in order to provide data at high frequency and over large spatial scales. In addition to these decision support indicators, there are a large number of more general descriptive measures, such as species diversity and biomass, which are not closely linked to specific manageable activities. Although these can provide useful environmental trend data, they cannot contribute to a management framework for the marine environment.

In this section, the marine environment has been subdivided into the following components: physical and chemical environment (including habitat), plankton, fish, benthos, seals, cetaceans and seabirds. For each component, recent progress with indicators is summarised and assessed in terms of their ability to contribute to management.

2.1. Physical/chemical environment and habitat

The status of the oceans and seas refers not only to the water column but also to the concentrations of contaminants in biota and sediment. The recent focus of marine water quality assessment has been on nutrients and hazardous substances in coastal and offshore waters, to address the OSPAR objective to cease the discharges, emissions and losses of hazardous substances by 2020. The need to monitor a range of substances listed by OSPAR and EU Directives has led to the development of a series of indicators that can be used to judge the achievement of assessment criteria (OSPAR, 2000b). Current indicators of chemical quality are based on the use of ecological quality standards (EQS), which are concentrations below which a substance is not believed to be detrimental to aquatic life, and ecotoxicological assessment criteria (EACs) which are concentrations above which there may be impacts on biota. These are determined using acute toxicity tests on organisms at different trophic levels. Background reference concentrations (BRCs) were adopted by OSPAR in 1997 for contaminants in seawater, sediment and biota, as assessment tools for use in Quality Status Reports. Assessments made against both EACs and BRCs should be treated with caution, as precise links between contaminant concentrations and biological effects have not been resolved, and require biological investigations in the field (OSPAR, 2000a).

A range of indicators of effects of contaminants in the environment, so called 'effects' indicators, are currently being developed, including fish disease, the enzyme biomarker EROD, oyster embryo bioassay, sediment bioassays, and imposex in dog whelks (CEFAS, 2003). Further work is needed if these indicators are to show progress towards cessation targets for particular contaminants, and to understand the impact on marine ecosystems of mixtures of hazardous substances in low concentrations.

Annual estimates of direct riverine and total inputs of contaminants to marine waters and sediments are routinely reported as part of the OSPAR riverine inputs and direct discharges (RID) programme and to meet the requirements of a number of EU Directives (OSPAR, 2000a). The aim of each survey is to monitor 90% of the riverine and direct inputs of each pollutant from all main river systems, and sampling occurs approximately monthly at a sampling point close to the tidal limit. Annual trend changes are not generally considered to be reliable as variability in annual rainfall can influence flushing rates. Despite these difficulties, they have been incorporated by the England Biodiversity Strategy into a national pressure indicator describing inputs of hazardous substances to the marine environment (Defra, 2004a). These pressure indicators, which will respond directly to human action, are likely to be a useful tool for management.

In OSPAR, a set of five EcoQO for nutrient enrichment and potential eutrophication effects, derived from the OSPAR Comprehensive Procedure, are currently under test in the North Sea, comprising winter nutrient concentrations, phytoplankton chlorophyll *a*, phytoplankton indicator species, oxygen concentrations and changes/kills in zoobenthos (Appendix A). The identification of waters that are, or may become, eutrophic (i.e. suffering from an 'undesirable disturbance') is a demanding task, but fortunately there is a good understanding of whether nutrient pressure is leading to accelerated plant growth in the marine environment, that in turn could lead to undesirable impacts. It is essential to be able to complete this chain of cause and effect if anthropogenic and natural environmental change are to be distinguished and these indicators are ever to be used for management. As part of the development of the OSPAR eutrophication EcoQO, it is likely that greater emphasis will need to be placed on assessing the natural susceptibility of different water bodies and distinguishing between coastal and offshore environments, and development of longer (>20 years) time-series of data for assessing the significance of anthropogenic inputs versus natural variability. Finally, there is 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.

Descriptions of change in relation to marine processes and climate in the UK have recently been provided by the Inter-Agency Committee on Marine Science and Technology (IACMST) (IACMST, 2001). At a UK level, climate indicators have no direct role in marine ecosystem management but can provide useful contextual information. Reporting on climate trends is undertaken by several regional bodies, and these compare recent weather and the condition of coastal, offshore and oceanic waters with historic data (Defra, 2003; FRS, 2003). The best known datasets refer to UK coastal sea surface temperatures and to sea surface salinity (IACMST, 2001). A wide range of other datasets relating to, for example, air temperature, wave height, rain fall and mean sea level all provide trends which reinforce these measures. The number of datasets and their variability suggests that there is a need for rationalisation of existing data to produce key headline indicators of climate change, and protocols for data collection and quality control (IACMST, 2001). There are no indicators describing the rate of change in extent or status of broad-scale marine habitats, largely because there are inadequate historic data, and insufficient contemporary monitoring or mapping to provide a detailed current description. This is being addressed by the UK conservation Agencies with reports due in 2005 and 2007 (Defra, 2004d). In inter-tidal and coastal waters there are opportunities to make use of condition monitoring of the Natura 2000 network, and co-ordinate these with other local monitoring activities of habitat biotic and abiotic features, for example those undertaken by the National Marine Monitoring Programme (CEFAS, 2001).

2.2. Phytoplankton/zooplankton

Plankton are an important element in the marine environment because they are fundamental to the productivity of higher trophic levels, and are indicative of both environmentally driven change as well as man-made undesirable disturbance (Planque and Reid, 1998). The seas around the British Isles have been sampled by the Continuous Plankton Recorder (CPR) for the past 70 years, although there is currently no systematic sampling in inshore waters. Recent development of indicators using these data includes the total abundance of small copepod species, the abundance of the boreal copepod *Calanus finmarchicus*, changes in the ratio of *C. finmarchicus* and *C. helgolandicus*, and phytoplankton colour, an index of plankton biomass (Edwards et al., 2001). These data also support a description of trends in indicators of harmful algal bloom species and introduced non-indigenous species.

Proportions of *C. finmarchicus* and *C. helgolandicus* in samples show changes in the relative importance of these two large copepods that respectively represent the boreal and warm water faunas of the N Atlantic (Planque and Reid, 1998; Reid et al., 2003). Copepod populations fluctuate readily in response to changing climatic conditions. An index to describe long-term variability in phytoplankton biomass around the UK could also be provided by the analysis of phytoplankton colour. Initial analysis of colour index trends from the CPR suggest that hydroclimatic forcing is responsible for observed patterns, rather than the extent of eutrophication, and this will reduce its utility in marine management. Further development of this indicator is required, particularly to take sampling frequency into account (Beaugrand and Reid, 2003; Reid et al., 2003).

Regional indicators of copepod assemblage structure have also been recommended for monitoring changes in the structure of the pelagic ecosystem in relation to climate change, and to support water quality assessments for the EU Water Framework Directive. Progressive shifts in the distribution of these organisms provide convincing visual indications of change in state, but further work is needed to identify the processes that contribute most to the changes over time (Defra, 2004d).

2.3. Benthic invertebrates

Benthic organisms are a source of food for higher trophic levels, and their relative abundance is indicative of both environmentally driven change and man-made disturbance. The majority of adult benthic species are also either sessile, sedentary or move over limited territorial ranges which, along with longevities typically exceeding a year, make them good indicators of the environmental quality. Studies at local scales (e.g. Rees et al., 2003) highlight the benefits of using benthos as indicators of activity-specific impacts as there is usually a greater potential to control for the confounding effects of natural environmental variability and other human activities.

Recent work has suggested that identifying state indicators of benthic communities and/or habitats over larger areas will be a major challenge (ICES, 2004c,d) principally due to limited historical data with sufficient geographical coverage. Since the extensive, quantitative North Sea macrobenthos survey in 1986 (Künitzer et al., 1992), monitoring effort in the UK has been maintained largely by the NMMP, which has combined approaches across several regulatory agencies. A re-appraisal of the status of macrobenthic communities in the North Sea (ICES, 2004c) has also identified the extent of recent sampling effort by a number of contributing agencies.

Investigation of one of the proposed OSPAR EcoQOs relating to the benthos, namely the density of opportunistic and sensitive (e.g. fragile) species, suggests that there will be problems with making this operational due to our current lack of understanding of the links between the effects of human activities and changes in populations of such species (ICES, 2004b). Among the most suitable alternatives could be indicators of selected structural fauna which, by their more responsive nature, would more easily allow effective management action to be taken (ICES, 2003). The other EcoQO identified for the benthic community, the presence of imposex in the dog whelk, *Nucella lapillus*, is an indicator of the effects and persistence of organotin compounds on benthic organisms, and is supported by sample data from coastal waters in several European countries, Appendix A (Gibbs et al., 1987; Stroben et al., 1995).

The UK Environment Agency is currently leading the development of a benthos community classification scheme to meet the requirements of the Water Framework Directive in estuaries. The assessment in estuarine and coastal waters will focus on the development of indices of benthic invertebrate status. The lack of compatible historical data will be a problem when establishing reference levels, but standardised Quality Assurance of recent NMMP monitoring effort will contribute to future indicator development (CEFAS, 2003).

2.4. Fish populations

There are commitments under OSPAR (Appendix A) and the revised Common Fisheries Policy to develop indicators that relate specifically to marine fisheries. The only indicator currently in use relates to the percentage of fish stocks around the UK fished within safe biological limits (Defra, 2003), although progress has been made with the OSPAR EcoQO to ensure that estimates of spawning stock biomass and fishing mortality comply with their respective reference points (ICES, 2004a).

Under the ecosystem approach to fisheries management a more comprehensive assessment should include (a) indicators which relate to fish stock status, (b) indicators which relate to non-target species, and (c) indicators which measure broader impacts on the ecosystem but which will be difficult to separate from impacts causes by other activities (FAO, 2002).

The development of indicators for fish communities in ICES suggests that there are several difficulties that will be experienced in the specification of precise EcoQO (ICES, 2004a). Although work in this field is supported by considerable monitoring effort, data collection to develop fish community metrics will be sample and gear specific, and reference levels can only be identified when there is an understanding of the theoretical basis underpinning the relationship between fishing disturbance and the size composition of the fish community.

Recent work has confirmed that there is a relationship with fisheries for measures of both mean weight and mean maximum length of fish, however, this relationship is not straightforward, not well understood and certainly not tightly linked in space and time. In addition, analysis shows that the statistical power of the major fisheries surveys is low, and cannot report on whether the fish community responds to management measures in a short (<5 years) time period (Nicholson and Jennings, 2003). Further refinement may lead to a qualitative indicator of fish population status that can be used to indicate no more than levels of deterioration or recovery over longer time periods (ICES, 2003).

The simplest approach to using fish size would be to describe the mean size of the catch. If taken from research vessel samples, this measure would relate to both exploited and non-target species, and thus would measure important properties of the marine ecosystem. The measure also has the advantage of being easily understood. A regional subdivision of this mean size index could also be useful to account for different survey gears and the different biogeography of the areas. This approach would also support the requirements in OSPAR to identify objectives for the issue 'fish communities' (Appendix A).

A modification of this index relates to the trophic level that each species occupies, and recent global analyses have shown a declining trend (Pauly et al., 1998). In practice there are some difficulties with making this indicator operational as the trophic level of fish varies between species, and changes with size as fish grow to maturity. Also, a given size-class of a species will often have a different trophic level from one year to the next, which means that trophic level assessments should ideally be done each year, and this is time-consuming. To solve these difficulties, normal practice is to use the same descriptor of species trophic level from one year to the next (Jennings et al., 2002), and under these circumstances it is simpler to use fish size itself, rather than raise fish size by a standard multiplier. There are other problems with using a trophic change index, for example some species occupy lower trophic levels as they get older, and some sensitive, threatened and declining species, such as the basking shark and some species of skates always occupy low trophic levels. Additional indicators would need to be developed for these species categories.

The development of fish community classification schemes to meet the requirements of the WFD are currently in progress, and will take account of species composition and abundance of the fish fauna (Defra, 2004b). This estuarine fish classification scheme will focus on species composition, abundance and age structure, and the numbers of species within functional categories (e.g. estuarine resident, diadromous, marine juvenile migrant, freshwater species). Each measure would respond in a predictable way to environmental stress. Several approaches to establishing reference conditions for these measures are being considered, including the use of historical records, predictive models, expert opinion, or the selection of sites that are least impacted.

2.5. Seabird populations

Seabirds are used as indicators of a number of human impacts. Estimates of seabird population status are available through regional and national monitoring programmes of seabird breeding numbers and breeding success (Defra, 2004d). OSPAR is currently testing an EcoQO related to the proportion of oiled common guillemots among those found dead or dying on beaches, and minor refinement of the analytical methods is required before adopting this indicator. Other measures of seabird population status are suitable for development into EcoQOs, including the number of plastic particles in fulmar stomachs and trends in sea bird populations (ICES, 2004a). The use of a provisional indicator of UK sea bird population status, based on time-series trends of nine sea bird species, is currently under review to take account of new data from a more comprehensive 2004 survey (DETR, 1999) (Table 1).

The breeding success of black-legged kittiwake can be used as an indicator for the bird predators that depend on sandeels (*Ammodytes marinus*) as a food resource (ICES, 2004a) (Appendix A). Development of this EcoQO has suggested that the relationship between fisheries, seabird populations and target/prey species is a complex one, but that refinement of current measures which link breeding success to management action show some promise (Defra, 2004d).

2.6. Marine mammals

There is much more work that needs to be done to develop reliable indicators of cetacean population status. There is currently no UK-wide systematic monitoring of cetacean populations, and no reliable methods of using sightings data to establish population trends. This lack of information on the present levels of seal stocks throughout the North Sea, especially for the harbour seal, is a weakness that will hinder the development of an indicator useful to management. OSPAR is currently developing and testing two EcoQO for seals related to the population trends in the North Sea and the extent of continued utilisation of seal breeding sites (ICES, 2003) (Appendix A).

Data on the production of pups at breeding sites is available, particularly for grey seals, and these data could contribute to a useful indicator. While the number of seal births is a sensitive parameter which responds more rapidly to changes in habitat conditions than total population size, it will be necessary to have more information about the underlying processes which lead to variations in these state measures before implementing such as indicator (Defra, 2004d).

Marine mammals are caught accidentally during fishing operations, and bycatches of common dolphins and harbour porpoises in North Sea fisheries have been identified as a concern (Cabinet Office, 2004). For harbour porpoise, the ASCOBANS-IWC limit of 1.7% of the population per year was adopted by OSPAR as an EcoQO, and is currently being piloted. Work to date suggests that the lack of population abundance estimates and historic trends in the North Sea will need to be addressed before making the objective operational (ICES, 2003).

3. Management frameworks

It is becoming increasingly important that indicators currently being developed are considered as part of a single framework that represents the state of the ecosystem (EEA, 2003; OSPAR, 2003). Unfortunately, objectives for the marine ecosystem, and the indicators that support them, are now accumulating opportunistically rather than according to a structured approach. This may leave some important ecosystem properties without any objectives, while for other properties, objectives and their suites of indicators may be redundant or even contradictory (ICES, 2004a). In some sectors, the ecosystem-based approach to management has been developed using adaptive management systems such as the DPSIR framework. This approach, categorising variables of driving forces, pressures, state, impact and response (IIED, 2002) has played an important part in selecting objectives and indicators for environmental quality.

In the DPSIR framework, drivers are those forces that exert pressure on the ecosystem and its components, such as economic and social policies, and natural environmental change. Pressures are the way that these drivers are expressed, such as the emission of pollutants or magnitude of fishing effort. State properties describe the ecosystem and its components, and are generally the focus of societies' concerns in the environment. Although these often describe the physical and biological components of the ecosystem, they can also refer to the levels of employment or the income of an industry. The impact describes the change in state caused by the pressures, such as economic damage or biodiversity loss, and the response describes society's actions to remediate those impacts (ICES, 2004d; IIED, 2002).

The European Environment Agency has adopted an indicator-based reporting system using this framework combined with an issues/thematic approach, and the revision of the OSPAR Joint Assessment Monitoring Programme is also likely to use indicators developed under a similar DPSIR model (EEA, 2003). The UK Environment Agency uses this framework to monitor and report on a range of water quality indicators to support the implementation of EU Directives (EA, 1999). The England Biodiversity Strategy (DETR, 1999) has

Table 2
Mapping a selection of proposed and operational marine ecosystem indicators onto the DPSIR (driving force, pressure, state, impact and response) framework. Ecosystem indicators used are the ten proposed OSPAR EcoQO (bold arial font—detailed description in Appendix A, Table 3), the EU Headline biodiversity indicators (Times New Roman font, Appendix B) and the England Biodiversity Strategy (bold Times New Roman font, shown in Table 1). Indicators under development to assess the favourable condition (Habitats Directive) and good ecological status (WFD) of the UK coastal and marine environment occur in most or all ecosystem components. The focus of these Directives is on measures of state, but the WFD also undertakes pressure and impact assessments

	D	P	S	I	R
physical / chemical habitat		**haz. subs input** RID[4]	**Oxygen** **Habitat quality** **SSSI condition**		
nutrients		RID[4]	**Winter nutrients** nutrients chlorophyll		
phy / zoo plankton			**phyto. Indicators** **chlorophyll a**		
benthos			**sensitive** **opportunistic** **dog whelk**[3]	**zoobenthos kills**	
fish		**fish stock status**	**fish SSB**[1] **fish community** **sand eel / birds**[2] stock status		fleet capacity
seabirds		**sand eel / birds** **oiled guillemots**	**seabird pops** **seabird pops**	**mercury / organochl**	
marine mammals		**cetacean by-catch**	**seal pops** **seal breeding sites**	**porpoise by-catch**	
most or all ecosystem components			**T & D species** **BAP ssp & habs** diversity trends threatened spp		**public & biodiv.** protected areas

OSPAR EcoQO

EU Headline

England Biodiversity Strategy

[1] This EcoQO (reference points for commercial fish SSB and F) can be both State and Impact depending on which reference point is used.
[2] This EcoQO 'Local sand-eel availability to black-legged Kittiwakes' could be either a State of fish stock indicator, or pressure indicator for seabirds (ICES, 2004a).
[3] This EcoQO 'imposex in dog whelk' is a State indicator (ICES, 2004a), but could also be an Impact indicator.
[4] Indicator taken from the OSPAR RID 2000 riverine inputs survey: results from the UK (Defra, 2004c).

used eight 'headline' indicators to illustrate changes in the state of biodiversity (i.e. changes in species populations and habitat condition), and changes to societal responses to these trends (i.e. extent of implementation of policies and action plans) (Defra, 2003).

Although progress is still at an early stage, there are encouraging signs that a process that combines all ecological indicators within the DPSIR framework, and then ensures adequate representation across all major ecosystem components, could provide an example of a workable structure (ICES, 2004d). An example of such an approach (Table 2) clearly illustrates that there has been a focus on the development of state indicators, largely in response to the recent international objectives for ecosystem state described earlier. In contrast, there are opportunities for including more indicators of pressure, impact or response in this framework. Perhaps more importantly, this compilation shows the extent to which there is parallel development of indicators.

4. Discussion and conclusion

One of the problems that Governments still need to address is how to identify the various states of the environment that are acceptable to all parts of society. While some sectors, particularly the NGOs and Conservation groups, are often well represented, a national consensus that represents the views of a broad cross-section of society is not yet fully developed. The science community, and in particular the specialist groups in Government agencies, OSPAR and the International Council for the Exploration of the Seas (ICES), has contributed much to the recent intellectual development of indicators in Europe. Despite recent work to develop measures and associated monitoring strategies, more progress needs to be made to set objectives for the state of the environment. This must be an initiative led by Government to represent all stakeholders, with appropriate advice from science.

The adoption of an objective-based management system for the marine environment will require some adaptation by those sectors of management that have been focussed only on monitoring point- and diffuse-source contaminants and other discharges (CEFAS, 2003). We should not underestimate the difficulties that will be experienced in defining and agreeing acceptable qualities of a healthy marine environment (Hall and Mainprize, 2004; Rice, 2003), or selecting objectives, reference points and indicators to achieve them. Nevertheless, the use of a reference direction in an index (i.e. to show an improvement in status) is a useful first step in the absence of a more specific objective.

The indicators reviewed here have different roles and operate at a range of different levels. Many perform a useful role in communicating trends and status to a wider community. Although most are able to describe change in one or more components of the marine environment, few of them are sufficiently rigorous to directly support management. There is no guarantee that management will be guided as effectively by indicators of ecosystem state as it would be by those for pressure or impact ICES, 2004a,b,c,d. Serious consideration should be given to a greater use of objectives for, and rigorous indicators of, the pressure exerted by human activities on the marine environment.

Recent scientific developments and ongoing work have focussed on developing criteria and appropriate reference points for existing objectives, and planning a wider framework within which a range of indicators could be placed. There is still, however, a need to rationalise activities in national and international fora under each sector or ecosystem component, and to focus attention on those ecosystem components for which indicators are undeveloped.

The development of indicators in the UK and internationally is generally driven by those groups which have responsibility for major areas of environmental policy, and there are many opportunities for coordination which could be further exploited. There is also the need to be more aware of the costs and practicality of collecting the data required for some suites of indicators, and of the statistical power that the planned measures will require in order to detect significant change. Some of these issues can be addressed by increased coordination of marine monitoring activity, and shared experience of the development and operation of indicators across sectors and disciplines. Such coordination will encourage the development a more strategic approach to new and emerging activities and monitoring requirements, and ensure that UK meets its' international obligations for marine ecosystem management and conservation.

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Appendix A

See Tables 3 and 4.

Table 3
Ecological issues and elements agreed at the North Sea Conference

Issue	Ecological quality element
1. Commercial fish species	(a) Spawning stock biomass of commercial fish species
2. Threatened and declining species	(b) Presence and extent of threatened and declining species in the North Sea
3. Sea mammals	(c) Seal population trends in the North Sea (d) Utilisation of seal breeding sites in the North Sea (e) By-catch of harbour porpoises
4. Seabirds	(f) Proportion of oiled Common Guillemots among those found dead or dying on beaches (g) Mercury concentrations in seabird eggs and feathers (h) Organochlorine concentrations in seabird eggs (i) Plastic particles in stomachs of seabirds (j) Local sand-eel availability to black-legged Kittiwakes (k) Seabird populations trends as an index of seabird community health
5. Fish communities	(l) Changes in the proportion of large fish and hence the average weight and average maximum length of the fish community
6. Benthic communities	(m) Changes/kills in zoobenthos in relation to eutrophication (n) Imposex in dog whelk (*Nucella lapillus*) (o) Density of sensitive (e.g. fragile) species (p) Density of opportunistic species
7. Plankton communities	(q) Phytoplankton chlorophyll *a* (r) Phytoplankton indicator species for eutrophication
8. Habitats	(s) Restore and/or maintain habitat quality
9. Nutrient budgets and production	(t) Winter nutrient (DIN and DIP) concentrations
10. Oxygen consumption	(u) Oxygen

Table 4
Ecological quality objectives for a set of elements currently under test in the North Sea, and to be reported on in 2005

Ecological quality element	Ecological quality objective
(a) Spawning stock biomass of commercial fish species	• Above precautionary reference points[a] for commercial fish species where these have been agreed by the competent authority for fisheries management
(c) Seal population trends in the North Sea	• No decline in population size or pup production of ⩾10% over a period of up to 10 years
(e) By-catch of harbour porpoises	• Annual by-catch levels should be reduced to levels below 1.7% of the best population estimate
(f) Proportion of oiled Common Guillemots among those found dead or dying on beaches	• The proportion of such birds should be 10% or less of the total found dead or dying, in all areas of the North Sea
(m) Changes/kills in zoobenthos in relation to eutrophication[b]	• There should be no kills in benthic animal species as a result of oxygen deficiency and/or toxic phytoplankton species
(n) Imposex in dog whelks (*Nucella lapillus*)	• A low (<2) level of imposex in female dog whelks, as measured by the *Vas Deferens* Sequence Index
(q) Phytoplankton chlorophyll *a*[b]	• 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[b]	• 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)[b]	• 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[b]	• Oxygen concentration, decreased as an indirect effect of nutrient enrichment, should remain above region-specific oxygen deficiency levels, ranging from 4 to 6 mg oxygen per liter

[a] In this context, "reference points" are those for the spawning stock biomass, also taking into account fishing mortality, used in advice given by ICES in relation to fisheries management.
[b] The ecological quality objectives for elements (m), (q), (r), (t) and (u) are an integrated set and cannot be considered in isolation. ICES will give its further advice.

Appendix B

First set of EU headline biodiversity indicators developed by the European Environment Agency (DEHLG, 2004).

EU headline indicator	Corresponding EEA core indicator
Status and trends in the components of biological diversity	
• Trends in extent of selected biomes, ecosystems and habitats	–
• Trends in abundance and distribution of selected species	BDIV02. Species diversity trends of representative species populations
• Change in status of threatened and/or protected species	BDIV03. Number of globally threatened taxa; proportion of protected species under different instruments
• Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socioeconomic importance	–
• Coverage of protected areas	BDIV010. Cumulative areas of sites over time under international conventions and initiatives
Sustainable use	
• Area of forest, agricultural, fishery and aquaculture ecosystems under sustainable management	FISH01. Status of marine fish stocks
	FISH08. Fishing fleet capacity
Threats to biodiversity	
• Nitrogen deposition	–
• Numbers and costs of invasive alien species	–
• Impact of climate change on biodiversity	–

(*continued on next page*)

Appendix B (*continued*)

EU headline indicator	Corresponding EEA core indicator
Ecosystem integrity and ecosystem goods and services	
• Marine trophic index	–
• Connectivity/fragmentation of ecosystems	–
• Water quality in aquatic ecosystems	WEU04. Nutrients in coastal water WEU13. Chlorophyll in transitional, coastal and marine water

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