Review and Evaluation of Marine Environmental Impact Indicators and their Application in Ireland

REPORT PREPARED BY:

Rick Boelens

John Gray

Aengus Parsons

REPORT EDITED BY:

Evin McGovern

Marine Institute

Marine Institute
Foras na Mara

NDP
NATIONAL DEVELOPMENT PLAN

NDP Marine RTDI Desk Study Series

REFERENCE: DK/01/006 • 2004

ISSN: 1649-5063

Your Plan – Your Future

This Project (Grant–aid Agreement No. DK/01/006) is carried out with the support of the Marine Institute and the Marine RTDI measure, Productive Sector Operational Programme, National Development Plan 2000 – 2006.

Further copies of this report may be obtained from:

Marine Institute Galway Technology Park
Parkmore Galway Ireland

telephone 353 91 730 400
facsimile 353 91 730 470
e-mail institute.mail@marine.ie
website www.marine.ie

Alternatively you can download a PDF version from the following website:

www.marine.ie/marinertdi

Table of Contents

Summary

This report, the first of its kind commissioned in Ireland, explains why national administrations responsible for marine environmental protection, and those who monitor the sea and its resources, need to consider carefully the choice of marine environmental indicators. This is because our understanding of the health of the oceans comes almost entirely from monitoring patterns and trends in particular marine features, according to the indicators selected. It is therefore evident that indicators are also important instruments of marine policy formulation and review.

Some countries and agencies separate environmental indicators into 5 categories representing Driving Forces, Pressures, Status (or State), Impacts and Responses - the so-called DPSIR system of indicators. This system is directed mainly towards analysis of environmental-economic performance. This report concentrates on status and impact indicators as used for environmental quality assessment; a small number of pressure indicators are also addressed.

In practical terms, indicators constitute the principal link between questions raised by politicians and the public concerning the state of the sea and its resources and the scientific studies by which such questions can be answered. They are the basis of marine environmental assessment e.g. Quality Status Reports (QSRs), such as that completed by Ireland in 1999.

The report explains the meaning, derivation and purpose of environmental indicators and their critical role in marine environmental protection. A core set of indicators is proposed for national application covering ecological conditions, environmental hazards and impacts, hazards to human health, changes of potential socio-economic importance and changes in marine climate. Altogether, seventeen groups of indicators are identified and specific examples of relevant measurements within each group are provided. The central approach of the report is to analyse the extent to which these 17 groups of indicators are represented in systems of marine environmental assessment adopted by Ireland, in Europe, the north-east Atlantic region and around the world.

The range of indicators used for purposes of the 1999 QSR was comparatively diverse and covered all the proposed core set indicator groups. However, in the case of over half of the 80 measurement types assessed for the QSR, data availability was either limited or poor. The EU and OSPAR indicators are less comprehensive - indicators relating to human health and socio-economic and aesthetic values are not as well represented as other categories. A review of indicators applied or under consideration in countries and regions outside Europe suggests that, in general, greater attention is given to the status of living marine resources, and associated hazards and impacts, than to factors potentially affecting human health and

socio-economic conditions. However, this may be more a reflection of the division of responsibilities between environmental and other agencies than a preoccupation with ecological conditions. An unexpected finding is that none of the non-European indicator sets appear to be concerned with patterns and trends in offshore activities (resources exploration and exploitation, shipping etc.) or the biological impacts of climate change. Overall, the core set of indicators developed in Chapter 3 of the report is shown to be broad in scope, practical, consistent with regional requirements and a good basis on which to build a national programme of marine environmental monitoring and assessment.

An inescapable conclusion from the review of marine environmental indicators both in Europe and elsewhere is that they are currently receiving unprecedented attention from governments and environmental agencies. This is because they are now recognised as essential tools in meeting mandates to protect and manage the sea, its ecosystems, resources and amenities. There is considerable activity to develop and test indicators that would improve the basis of marine environmental assessments as well as indicators that can be used to assess the performance of governments in meeting economic targets without compromising the quest for sustainable development (i.e. response indicators). It is recommended that the relevant Irish agencies establish specialist groups to periodically review indicators applied for monitoring purposes, to confirm their relevance and value, to evaluate the reliability of associated measurements and to make any necessary adjustments to procedures for sampling, analysis and data interpretation. This could be carried out in the context of the recently established multi-agency Marine Monitoring Forum.

In response to deficiencies in the national marine environmental data-base identified in the 1999 QSR, the report devotes special attention to indicators that would help to fill gaps in information on biological responses to environmental impacts, including effects on habitats and communities, and conditions in the coastal zone. The component of Ireland's monitoring programme dealing with measurements of chemical contaminants is comparatively well developed and, subject to adequate capacity to meet the additional data requirements of the EU Water Framework Directive, should be able to provide all of the data needed for pollution assessment purposes. On the other hand Ireland has not to date made sufficient use of indicators that determine the status of populations and communities of marine organisms. Thus, the report includes an in-depth review of methodologies for detecting patterns and changes in benthic (bottom-dwelling) communities and concludes that relatively simple procedures, requiring minimal taxonomic expertise, can provide reliable and cost-effective information to supplement chemical monitoring. It also contains an inventory of biomarkers - a rapidly expanding range of techniques for detecting biological responses to particular types of environmental changes and contaminant exposures. Several biomarkers for which methodologies are sufficiently well developed for routine use are proposed for inclusion in national monitoring programmes. It is recommended that provision be made as soon as possible for the training of operators needed to implement these biological procedures.

Details of 19 indicators that are either not included among those applied by Ireland to date, or have not been applied adequately, are given in a separate chapter of the report. For reasons stated above, special attention is given to indicators of the status of populations and communities, to impacts on coastal areas and changes in marine climate. A number of the selected indicators focus on organisms at the top of the marine food chain, such as seabirds and marine mammals, while others examine key species such as seagrasses that sustain important marine habitats and invasive species that may threaten biodiversity. Whereas methodologies exist for most of these indicators, a few will require further research and development. All are considered of genuine benefit to a national programme of marine monitoring and assessment. In each case, a justification for the indicator, the availability of relevant data, means of interpretation, quality control requirements and a value-for-money assessment, are provided.

There are various procedures by which indicators may be grouped, aggregated or integrated to provide greater insight into particular conditions or to improve abilities to assess complex environmental situations by multi-factorial analysis. To date, the main use of aggregated indicators has been in international comparisons of environmental-economic performance. However, simple ranking and rating procedures applied to selected indicator groups, and procedures for weighting and combining indicators to provide indices of particular environmental conditions, have considerable potential for use in assessment and management. These warrant further research.

Whereas a carefully selected and well-balanced set of indicators is a major step in ensuring the effectiveness of a marine environmental monitoring programme, failure to take account of natural variability in planning the programme can result in unusable data and a serious wastage of resources. Two clear requirements are the rigorous application of data quality assurance procedures (QA) and meticulous attention to the statistical aspects of sampling design. Some knowledge of the variance associated with each property or condition to be monitored should be obtained before measurements commence. The report gives guidance on these issues and firmly recommends that a trained statistician be made available to assist in the design of all repetitive monitoring activities.

Finally, the report notes that climate change is already affecting the environment of the NE Atlantic; it is manifested by increases in sea temperatures, storm intensity and wave height. This will undoubtedly cause insidious changes in the region's marine ecosystems and will present significant challenges to the design of monitoring programmes and the interpretation of long-term datasets. The nature and rate of marine climate change must itself be accurately monitored and the findings assimilated into the design of monitoring generally.

1.0 Introduction

1.1 Why Are Indicators Important?

Marine environmental indicators are important to Ireland because:

- they provide insight into the health of our marine and coastal ecosystems;
- they identify unusual and potentially harmful conditions & trends;
- they are part of the process of complying with international commitments (e.g. EU, OSPAR, Law of the Sea etc.) for protection of the marine environment;
- they are a means to monitor the efficacy of regulatory and management actions;
- they provide information for marine policy formulation; and
- they extend our understanding of the sea and guide marine research.

1.2 Background

Human society needs practical and reliable ways to evaluate environmental quality. It is likely that even the most primitive cultures recognised water unfit to drink and areas unsuited to food production. Today, humans exert unprecedented pressures on ecosystems and resources, both terrestrial and aquatic. Concerted management efforts are needed to protect natural systems that ensure human survival. The knowledge required for effective environmental management (i.e. management that provides for legitimate human uses while maintaining the diversity and productivity of the biosphere) comes only from careful observation of particular environmental properties, functions and conditions.

As shown in Box 1, environmental indicators are a key component of environmental protection. Ideally, the management process for implementing strategies for environmental protection should follow a logical progression from question to answer to action. Scientific input to this process is clearly essential, as is the involvement of policy-makers, legislators and regulators (See for example GESAMP, 1991)

Box 1: Key Steps in Environmental Protection

Specify questions to be addressed.
Select suitable ***indicators*** *& measurements.*
Sample according to pre–set design.
Identify change/abnormality.
Determine significance.
Determine cause
Compare & select management options.

The use of environmental indicators is an acknowledgment that only a small fraction of the biosphere is subject to scientific observation and that knowledge obtained through basic research seldom provides a clear picture of the condition of communities and ecosystems. In effect, indicators are surrogates for a proper understanding of environmental form and function. They represent qualities and values believed to be of special relevance to the environment and human society. A proper scientific understanding of natural systems and the processes by which they function is a prerequisite to choosing suitable indicators.

Although various marine properties and conditions are now established as marine environmental indicators, to some extent their use has been more a matter of expedience than careful consideration of the alternatives. The building blocks of contemporary monitoring programmes can be traced to the 1960s when the western world was alerted to the risks of chemical pollution of the sea, particularly through incidents such as mercury pollution in Minamata and Niigata in Japan and the revelation that certain countries were disposing of industrial wastes by dumping from ships. To a large extent marine environmental monitoring has continued to focus on chemical parameters believed to represent significant risks to marine life and human health and which at the same time are amenable to sampling and analysis with available techniques and resources. Chemical monitoring has been greatly facilitated by continuous strides in the development of instrumentation for the separation, detection and quantification of substances in seawater, sediments and tissues.

Marine environmental monitoring has progressed significantly since the 1960s, both in terms of design and content, yet there is increasing awareness of the limitations that stem from an over-dependence on chemistry as the principle indicator of environmental quality. Chemical measurements tend to be used as surrogates for biological effects – whereas in fact they are merely indicators of biological hazards. Consequently, there is a need to greatly increase the range of biological effects measurements. All coastal states need to address this important issue.

Long-established practices, however, can be difficult to change. Major national and international monitoring programmes are complex, costly and demanding in terms of management and coordination. They have become heavily institutionalised from the political structures that establish and control regional programmes, through national agencies that regulate marine and environmental affairs, to the scientific institutes that are responsible for data collection and reporting. Large budgets and workforces are required to support such programmes giving rise to a predictable, and to some extent understandable, bias towards continuity. Technical considerations may support this process. Some environmental trends are impossible to detect or quantify reliably unless measurements are continued for a decade or more. There is thus a reluctance to curtail well-established programmes, even if new scientific perspectives suggest that the properties measured are no longer relevant or deserving of the expenditures entailed.

Until recently, the choice of marine environmental indicators has been somewhat piecemeal, driven more by policies than science. Whereas efforts are now being made to redress this situation, a cohesive suite of indicators as a basis for monitoring and assessment nationally and regionally, has still to be defined. This is a complex issue and a matter of ongoing debate within the scientific and regulatory communities worldwide. Clearly, no suite of indicators can hope to cover all features and values that warrant protection. Similarly, no single study is likely to provide a complete solution. Both within the EU and the North-Atlantic Region, there is currently much activity to develop indicators for marine, coastal and transitional (e.g. estuarine) systems. International acceptance that the coasts form an integral part of the marine environment is an important advance and greatly extends the range of potential indicators.

Monitoring indicators is not the only way to assess marine environmental conditions. Knowledge gained from scientific research and published in the scientific literature should also be accessed for assessment purposes. Ireland adopted such an approach in preparing its national marine Quality Status Report (Boelens *et al.*, 1999). In this way no facts or features are ignored and there are no preconceptions as to which properties or conditions are most useful or important as determinants of environmental health. The drawbacks to this approach are the sheer scale of information to be assessed and the inevitable inconsistencies in spatial and temporal coverage. Also, it is generally not possible to accurately measure trends in environmental conditions without long-term datasets obtained by carefully designed programmes of sampling and analysis.

An optimum assessment process, therefore, will combine reviews of peer-reviewed scientific literature with detailed analyses of data obtained by monitoring pre-selected indicators.

1.3 Objectives

In general terms the mandate for the present study is to explore the broad issue of marine environmental indicators taking into account past experience, practices at home and abroad, statutory and regulatory requirements and contemporary scientific views on what is feasible and necessary from an ecological standpoint. The ultimate aim is to inform the process of developing new and improved indicators for use in assessing and managing Ireland's marine and coastal areas.

The precise objectives of the study, as prepared by the Marine Institute, are given in full in Annex 1. The main requirements are:

1. To identify and prepare a comprehensive review of marine environmental indicators and their application, both nationally and internationally, in the assessment and monitoring of environmental impact/change;
2. To identify a suite of key marine environmental indicators that may be used in the measurement and monitoring of environmental change in an Irish context; and
3. To identify related issues such as data availability and requirements, methodologies, quality assurance etc.

As part of the study, the project team was required to take into account international practices, requirements and developments in the field of marine environmental indicators that may be relevant to Ireland, as well as work being carried out in Ireland itself. The utility of marine datasets available nationally, new data requirements, possibilities for constructing composite indicators, methodologies and resources for data acquisition, storage and analysis, statistical aspects and their implications for monitoring, were also to be considered. Finally, the study was to highlight any particular problems surrounding the development and use of marine environmental indicators and suggest ways in which these problems might be addressed.

1.4 Approach

The first step towards a suite of indicators is to develop a conceptual framework of environmental features that should form part of any cohesive programme of marine environmental assessment. This requires dialogue between marine ecologists and those experienced in marine conservation, monitoring and resource management. The next step is to apply the framework, in conjunction with knowledge of local environmental conditions, as a basis for identifying a provisional suite of indicators suited to local circumstances. Finally, prior to offering specific recommendations, the feasibility and practicality of the indicators needs to be evaluated in the light of technical and financial considerations and prevailing national and international commitments.

The present study has been organised in accordance with this approach. Accordingly, the following chapter examines the concept of environmental indicators, factors in their selection, the key elements of marine environmental assessment and considerations to be taken into account in developing a national monitoring and assessment programme. The next chapter describes a conceptual framework for developing a core set of marine environmental indicators, drawing on a broad range of professional opinion at home and abroad. Subsequent chapters review existing indicators and associated measurements applied under regional and European programmes of which Ireland is part, as well as indicators used or proposed in other regions of the world. Separate chapters are devoted to biomarkers - a category of indicators of increasing interest and importance, to indicators of benthic community status and to options for developing and applying composite indicators. Finally, the report provides detailed information on selected indicators that have not been routinely applied in Ireland and that are of particular value to marine environmental assessment.

2.0 Environmental Indicators: Their Meaning, Form and Function

2.1 Meaning and Scope

The term 'environmental indicator' has been accorded a broad range of meanings in the scientific literature and it is important to clarify its meaning in the context of this report.

In general terms, this study regards indicators as any measurable feature or condition of the marine environment that is relevant to the stability (medium term) and integrity of habitats and communities, the productivity of living resources, the sustainability of ecosystem services (primary production, maintenance of food chains, nutrient cycling, biodiversity etc.), the quality and safety of seafood and the status of amenities of socio-economic importance. Such features and conditions represent core environmental 'values' to be protected and preserved. Any substantive loss in value will have negative consequences for the environment, human society or both.

Certain programmes of environmental assessment, notably those of the European Environment Agency (EEA), place heavy emphasis on the use of driving force and pressure indicators in addition to indicators of environmental state and impact i.e. quality indicators (See Section 4.5 & Chapter 9). Pressure indicators may include a wide array of inputs and activities with potential to affect the environment, causing varying degrees of degradation. We stress that this study, with one exception (i.e. climate change) is not concerned with driving force or pressure indicators, although we recognise their relevance to environmental management.

As shown in Figure 2.1 an indicator of environmental quality, health or condition will always consist of a specific feature, component or property of the natural environment allied to a specific form of measurement that will record a magnitude or rate of change of particular interest or concern.

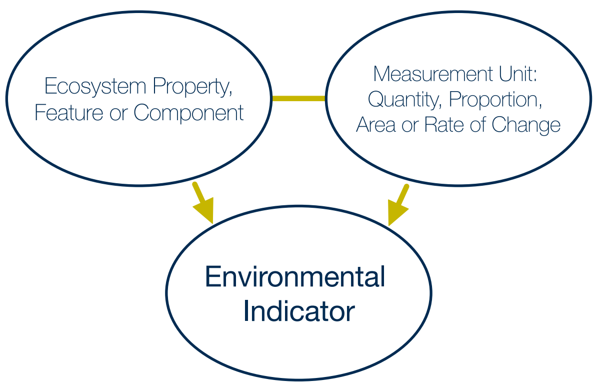


Figure 2.1: Construction of an Environmental Indicator

2.2 Characteristics of an Effective Indicator

In considering the elements of a coastal research and monitoring strategy for the United States, an inter-agency workgroup (USEPA *et al.*, 2000) identified a number of questions relevant to the selection of reliable environmental indicators. These include:

- Can the proposed indicator be readily quantified?
- Is the indicator sensitive to problematic conditions or concerns?
- Can the indicator resolve meaningful differences in such environmental conditions?
- Is there reference information by which to judge the results obtained?
- Can the results be compared across differences in time and space?

Positive answers to these questions will provide reasonable assurance that an indicator is capable of providing information of relevance to environmental protection and management. However, it is also important that the significance of indicator measurements can be readily understood by environmental managers and the general public.

Almost any marine feature may be a reflection of environmental conditions of one kind or another, so the choice of indicators should not be based solely on our ability to measure them, or to detect changes from the normal condition i.e. abnormalities, but also on our understanding of the significance of the changes. Thus, for any environmental variable to be useful as an indicator in monitoring programmes, there must first be adequate knowledge of its role either in an ecological, socio-economic or human health context, its inherent variability (see 2.3.2 below) and a reference value for use in interpreting results. Spellerberg (1991) describes an environmental index as 'a number or quantity compared to an arbitrary standard'.

The choice of indicators will depend on the questions to be addressed. Although a broad set of indicators is needed to cover the many different facets of marine environmental health, the precise indicators used should reflect the interests and concerns of the public and those charged with marine environmental protection.

Questions regarding marine environmental conditions are often rather general in nature and do not necessarily determine the most suitable indicators or approaches to be used. The advice of marine scientists will often be needed to select appropriate measurements and methods. Examples of general questions frequently asked include:

How clean is the sea?
How serious is marine pollution?
Is seafood safe to eat?
Are beaches safe for bathing?
Are seabirds and marine mammals at risk?
By how much are fish stocks depleted?
What are the impacts of oil & radioactivity in the sea?

For all such questions, prior to selecting appropriate indicators and measurements, it is necessary to decide on the time periods and geographic areas to be covered and the degree of impact or change that would be considered significant. This is never an easy task. The higher the frequency and intensity of sampling, the greater the resources required. Practicality and cost considerations are important factors in the selection process.

Considering the immense political interest currently being shown in the state of the oceans, and the number of national and international initiatives to improve knowledge and governance of marine ecosystems, indicators used for assessment purposes need to take into account issues of particular interest or concern. In this regard, the Council of Europe's Parliamentary Assembly notes that the main effects of anthropogenic pressures on the marine environment are degradation of water quality, damage to ecosystems and loss of habitats, over-exploitation of resources and the introduction of non-indigenous species (Council of Europe, 1998). The Assembly identified the following major issues and concerns:

- Impact of land-based activities, pollution in particular;
- Impact on public health;
- Impact on ecological systems;
- Impact on the economy;
- Status of fisheries;
- Aquaculture as a source of environmental problems;
- Threats from the introduction of non-indigenous species;
- Reduction in marine biodiversity; and
- Inadequate integrated coastal zone management,

To summarise, an effective indicator will address specific questions about clearly defined aspects of the environment, be readily understood by society as a whole, involve measurements that can detect significant differences between samples and be practicable in terms of the time and resources required.

2.3 Prerequisites for Monitoring Indicators

The foregoing profile of an environmental indicator raises a number of important technical issues. The first is the need to ensure the accuracy (closeness to the real value) and precision (repeatability) of the measurements made. Closely related to this is the need for careful planning of sampling design (See for example, Thompson, 1999). Lastly, it is imperative to understand, and allow for, the natural variability of the environment and the parameters to be monitored. Natural variability tends to complicate the detection of real differences between measurements at different times and places. All these issues are of immense relevance to the selection and application of indicators; overviews of the key points are presented in the following paragraphs. They are discussed in greater detail in the classic text Managing Troubled Waters (National Research Council, 1990).

2.3.1 Data Quality Assurance (QA)

There is no more important principle in science than the necessity to recognise the errors associated with measurements. In practice, this means that sources of error must be identified and the actual error, or uncertainty associated with the error, estimated so that this can be allowed for in subsequent applications of the data concerned.

Preferably, data quality assurance (QA) procedures should be developed and applied for all measurements used to generate data for environmental assessment and management. However, the need for QA is particularly important for measurements involving technologically complex procedures or equipment and where the amounts (weights, volumes, concentrations, lengths, energy units, etc) to be determined are very small. This is certainly the case in measurements of contaminant concentrations in environmental samples.

Quality assurance must begin with the planning of monitoring activities and continue through implementation to dissemination of results. It consists of two separate but interrelated activities - quality control and quality assessment (Taylor, 1985). Quality control procedures ensure that data are of adequate quality to meet the objectives of the measurements concerned. Quality assessment quantifies the effectiveness of the quality control procedures.

Quality control ensures that sampling, processing and analytical methods are applied correctly and consistently, that complete records are maintained from sample collection to release of results and that similar datasets are comparable in space and time. A good example of data quality control is the set of measures developed for purposes of the UK's marine monitoring plan (NMP) for estuarine and coastal waters (Dobson *et al.*, 1999). Quality assessment ensures that measurement error is estimated and recorded and that bias associated with the measurements can be identified and overcome. It consists of checks both within and between laboratories, including repetitive measurements, sample exchange, use of reference materials and independent assessments and audits.

QA has been an integral part of Ireland's chemical monitoring programme for many years. QA procedures are developed both internally and through participation in the programmes and working groups of ICES and the QUASIMEME scheme (Quality Assurance of Information in Marine Environmental Monitoring). It is important that these QA activities are continued and where possible extended to cover both biological and physical measurements. A workshop with a special focus on quality assurance of hydrographic measurements was held in Dublin in 1993 (ISMARÉ, 1994).

2.3.2 Coping with Variability

Indicators are concerned with environmental change. Changes of most relevance are those that extend beyond the measured or expected range of natural variability. Indicators must be selected for their ability to show the scale and rate of change and, ideally, the cause and significance of change. There is seldom a single cause, however, and it is not always possible to identify the key factor, or combination of factors, responsible.

Clearly, some prior knowledge of the variability associated with features to be monitored is essential if sampling is to be designed so that significant differences can be detected. Yet it is still not sufficiently appreciated that, without adequate preliminary research to determine the types and degrees of variability, the chances of designing an efficient and cost-effective sampling programme are considerably reduced. Sampling design must take account of natural variability (See below).

Whereas for some environmental properties it may be possible to draw on decades of research to acquire a good understanding of the variable concerned, in others it may be necessary to initiate new studies to supplement existing knowledge. However, it has to be borne in mind that variability occurs on different time-scales e.g. seasonal, inter-annual, decadal etc., and that datasets covering short time periods (e.g. several years) are of limited value.

Climate Change

In the context of contemporary climate patterns, indicators of climate change such as sea temperature, sea level, storm frequency and rates of coastal erosion, assume particular importance. Indeed, it is arguable that in future the application of indicators in measuring environmental trends and changes may to some extent be frustrated by insidious changes in the physical environment, the dominant regulator of marine biological communities.

Although the reasons are still hotly debated, global climate is changing. For example, the temperature of tropical waters in the northern hemisphere has been increasing at an enhanced rate since 1984 (NOAA, 2000). During the 1980s sea temperature in the English Channel increased slightly but in the following decade there was an increase of almost 1°C; this was far greater than any change in the previous 100 years (MBA, 2003). One manifestation of these warmer sea temperatures has been an increasing influx of 'exotic' species into British waters (O'Connor, 2002). The changing pattern of the North Atlantic Oscillation (NAO) also has a major effect on the climate of the region. The NAO index[1] has shown an upward trend from the 1960s to the early 1990s. This may explain the increasing number of severe gales experienced in the British Isles since the 1970s (UK Environment Agency website). Similarly, the mean winter wave height in the north-east Atlantic increased significantly (by 50% or more) between the 1960s and the 1990s (POL, 2001).

Accordingly, it is of utmost importance to Irish marine science, environmental monitoring and assessment that trends in the climate of Ireland's maritime areas be kept under continuous review so that they can be taken into account in planning and designing research and monitoring projects. This is clearly a long-term activity and one that will certainly benefit from the new network of data buoys being located around the Irish coasts. It is also an activity that needs to involve relevant institutions both within and outside Ireland (See Marine Climate Indicator, Chapter 8).

[1] Difference between the mean winter sea level pressure at Gibraltar and the mean winter sea level pressure at Iceland. A high winter index brings depressions into Northwest Europe and with it higher patterns of rainfall and storms.

Sampling Design

One of the major steps in planning a monitoring programme should be a careful evaluation of sampling design. This is rarely done. With most present-day monitoring programmes a number of sites are picked out and the variables to be monitored are specified. The programme starts and data recorded at various time intervals are reported to a central database. Examples are the monitoring programmes for contaminants of fish and shellfish carried out under the auspices of the OSPAR Convention. Here the data are obtained from a variety of national programmes and submitted to a central database at the International Council for the Exploration of the Sea (ICES) in Copenhagen. The programme has been running from 1978 (Anon, 1989; 1991). Yet how good is such a programme at detecting change?

Nicholson *et al.* (1997) completed a thorough analysis of the data and concentrated on two aspects - analytical variability and sampling variability. In considering variability they posed the following possible management objective:

> *"To identify the sampling frequency and programme duration for detecting, with 90% power, a temporal trend of 5% per year, at different levels of analytical and sampling variability."*

Table 2.1 shows results of the analysis carried out by Nicholson *et al.* (1997). Using a statistical procedure called power analysis they calculated the number of years it would take to detect a trend in the data (increasing or decreasing) based on these two sorts of variability. Analytical variability was found to be relatively small and thus chemical techniques were reliable. Sampling variability, however, was extremely large and led to the result that with moderate sampling and analytical variability it would take 18 years to detect the given trend. With higher sampling variability it will take over 25 years to detect a trend.

Table 2.1: The number of years it will take to detect a trend of ± 0.05 ppm of heavy metal in N. sea fish and shellfish (Nicholson *et al.*,1997).

Analytical Variability	Low	Medium	High
Sampling Variability			
Low	10	12	16
Medium	17	18	20
High	25	>25	>25

Such analyses are rarely done yet are extremely important. The North Sea has been well-covered by monitoring programmes and the Ministerial Conferences have demonstrated a high degree of political will to improve the condition of the area. At the 1987 conference it was agreed that a 50% reduction should be achieved in the amounts of chemical contaminants entering the sea by 1997. This required restrictions on land-based inputs. So now the politicians ask the scientists, what has happened? Has the N. Sea improved? Nicholson & Fryer's (2002) analysis shows that the answer is: Wait 25 years and we will give you an answer!

Clearly, what is needed is to put in place a carefully designed sampling programme. Yet the signs are that the need for such detailed planning has still not been appreciated. For example the EU Water Framework Directive (WFD) does not give any consideration to sampling design. The response of nations to the Directive most likely will lead to monitoring stations being designated which lack a proper foundation in statistical design. Early indications are that in some countries (e.g. Norway) cost rather than science will decide the number of sites to be monitored. Managers need to appreciate that science can help them to design a programme that is able to detect change on the scales (both space and time) appropriate to managerial action.

Setting Management Objectives: Perhaps the first and most important aspect is to set clear objectives for the monitoring programme. Throughout this report we have used the term 'indicator'. Ward *et al.* (1998) have defined an indicator as an index based on measurements collected at some point in space and time. Nicholson & Fryer (2002) use the term indicator-statistic as "a statistic derived from a collection of indicators that is used as a specific output for reporting or decision-making." Phrasing objectives in terms of indicators will help clarify the purpose of a monitoring programme and its relevance to management and policy decision-making (Phillips & Segar, 1986; Underwood, 1996). Whereas design of a monitoring programme is relatively simple for a single indicator, where several indicators are used design is more complicated (Nicholson & Fryer, 2002).

Nicholson & Fryer (1997) suggest setting the objectives as targets of the type. The monitoring programme should be able to detect with 90% power a 5% per year change in the slope of contaminant concentration in the liver of a fish of a given species. The same authors (Nicholson & Fryer, 2002) provide a hypothetical example of the use of such a monitoring programme (Figure 2.2). The indicator is unacceptably high in Period 1. This leads to management action, Period 2. The action yields positive results and the indicator stabilises below the reference value of control samples (Period 3).

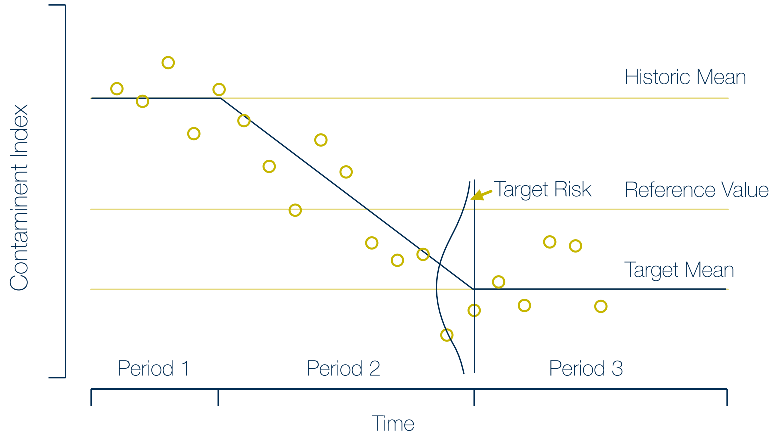


Figure 2.2: Hypothetical Monitoring Programme (from Nicholson & Fryer, 2002).

Thus, we firmly recommend that the objectives of monitoring programmes be considered carefully and stated in as clear terms as possible.

Key factors in sampling design: There are a number of aspects of sampling design that need to be considered. Firstly, the distinction needs to be made between general monitoring of a given spatial scale, such as a bay or an estuary, and monitoring of a gradient. In the first case designs of the Before-After-Control-Impact (BACI) type (Green, 1979) are appropriate.

Figure 2.3 illustrates the changing abundance of marine organisms over a time period in which an impact occurs. Underwood (1996) demonstrated that the design in A would not detect an impact. He suggested that the problem was two-fold. Firstly, that there was a need for more than one control site in order to assess the true variation in the controls (design B). There was a further problem in that in example C there is no change in mean abundance but clearly variance has increased after the impact. This is a common change that occurs with effects of pollutants on abundances of marine organisms. So designs for monitoring programmes must also be able to detect situations where both the mean and variance change. In addition, Underwood (1997) states that there are two major types of response - a pulse response to a sudden change in an environmental variable, which then returns to normal and a sustained slow change over time, which he calls a press response. Underwood (1997) argues convincingly that one must take multiple controls and proposes a Beyond-BACI design. He suggests that complex analyses of variance applied to biological data can unravel the types of response and the spatial scale of the effects. Nicholson *et al.* (1997) and Nicholson & Fryer (2002) give sound advice on how effective monitoring (with the appropriate statistical analyses) can be done using environmental indicators.

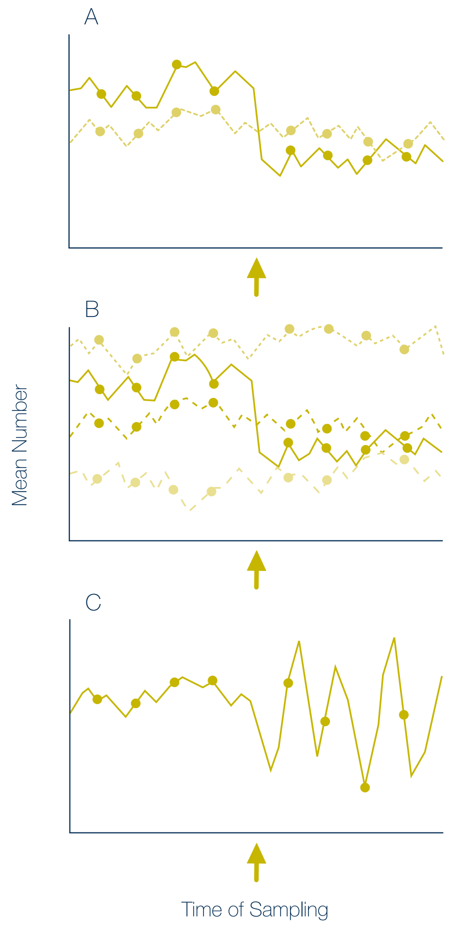


Figure 2.3: Problems with different sampling designs.
A) Before-After-Control-Impact (BACI) design of Green (1979).
B) Multiple control sites.
C) Increased variance.
Broken lines are controls. The arrow shows the start of the impact.

The BACI designs for monitoring programmes are not the only ones available. Gradient designs have been widely used where there are point-sources of contamination or disturbance. Typical designs in relation to effects of oil exploration on benthic communities are discussed by Gray *et al.* (1990). Figure 2.4 shows a typical gradient design for studying the effects of discharges from oil platforms, which is used on the continental shelf of Norway (Gray *et al.*, 1999). Multivariate statistical analyses are widely used to detect effects of such designs (see Chapter 6 and Annex 2).

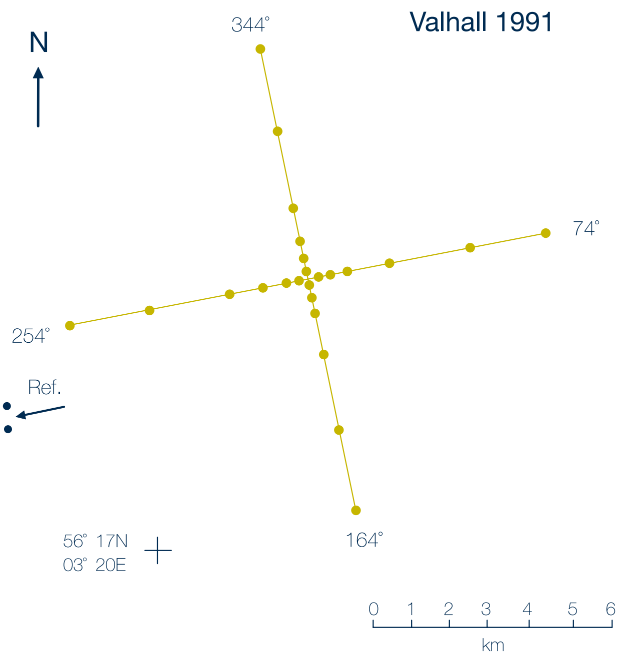


Figure 2.4: Gradient design at Valhall oilfield, Norwegian continental shelf used to detect effects of the platform on the chemistry and biology of the surrounding area.

For both chemical and biological data there should be a pilot study, which is analysed by statisticians to estimate the power to detect change, (Green 1979; Peterman, 1990; Underwood 1997). From such analyses it will be possible to model the spatial scales that are appropriate and the number of replicates needed to obtain data that will be useful to managers (Stewart-Oaten *et al.*, 1986). Such analyses can include costs and so the sampling design can be optimised and made cost-effective.

It is extremely important that sampling design is not neglected.

2.4 Trend Assessment

Statistical tools are also important to assess the significance of an apparent trend. This is, of course, particularly difficult in assessing complex (non linear) trends. One available software tool in this regard is the 'Trend-Y-Tector' developed for trend assessment of OSPAR data. This approach was used in the Marine Institute report 'Winter Nutrient monitoring of the Western Irish Sea - 1990 to 2000' (McGovern *et al.*, 2002) and some of the technical problems considered.

3.0 Developing a Core Set of Indicators

3.1 Purpose and Rationale

In this chapter we propose an approach to developing a set of indicators suited to a national programme of marine environmental assessment. The underlying argument is that indicators used to generate information for environmental protection (i.e. management and policy formulation) purposes, should not be chosen arbitrarily. Rather, the set of indicators should comprise:

i) Variables (i.e. properties and processes) that characterise, sustain and regulate marine ecosystems, including primary producers, communities and renewable resources;
ii) conditions hazardous to marine life, human health and renewable resources, including chemical contaminants and pathogens;
iii) variables and hazards of known environmental and/or health significance, whose variabilities can at least be approximated, and for which standards or other reference values can be defined; and
iv) variables and hazards amenable to cost-effective monitoring, generating dependable data and enabling decisions on the need for, and type of, management intervention.

3.2 General Criteria

Indicators that are most useful to environmental policy-makers and managers are quantifiable, regularly assessed and relate to readily appreciated hazards and values, clearly indicating whether or not measures taken to protect the environment are effective. To be acceptable to national authorities, all environmental indicators must be realistic in terms of practicality and cost.

No set of indicators can be inclusive. To be both pragmatic and affordable, a national marine monitoring programme must be strictly limited in terms of the numbers of determinants, sampling sites and frequencies. Consequently, the selected indicators should focus on properties and processes of known environmental relevance, as demonstrated through scientific investigation.

It is essential that well developed and tested methodologies should exist for each measurement required in indicator monitoring. The methodologies should encompass sample collection, preservation and storage, procedures for examination and/or analysis, data quality assurance (QA), data processing and reporting. Suitable methodologies may not exist for all preferred environmental indicators. If so, research and development to overcome these deficiencies will be needed before the indicator can be included in the current indicator suite.

In summary, considerations to be taken into account when evaluating indicators include:

- Availability of methodologies and quality assurance tools;
- Requisite sampling facilities (e.g. vessels etc.);
- Total load on scientific resources/capacities;
- Field time requirement;
- Seasonality of measurements; and
- Costs of data collection and processing.

3.3 Policy Considerations

This study examines marine indicators primarily from a scientific perspective. However, no credible indicator selection process can ignore prevailing policies for marine environmental protection.

Current policies at regional and European levels lean strongly towards rigorous protection for all sectors of the aquatic environment, regardless of the type and extent of human activity. The Water Framework Directive (WFD), for example, aims to achieve 'good ecological status' or near-pristine conditions for all saline (transitional and coastal) waters within one nautical mile of the baseline[2]. Areas not meeting such conditions must be restored through targeted action programmes. This is a significant departure from earlier policies that accepted a limited degree of anthropogenic change to accommodate legitimate human activities. In future, exemptions from good ecological status may be permitted only where, for extenuating circumstances, the area is declared to be 'heavily modified' in accordance with Article 4 (3) of the Directive.

Although it is difficult to predict how achievable these new policies might be, there is no doubt they have implications for the type and extent of monitoring needed both to assess the effectiveness of the policies and for Ireland's monitoring activities generally.

The scope of marine indicators required by the WFD, combined with those under consideration within the European Environment Agency (See Chapter 4), is extremely broad. This new, centralised system of environmental assessment involves annual data reporting to facilitate comparisons of environmental conditions across Europe. If fully implemented, these initiatives will necessitate major increases in the scope, frequency, geographical coverage, and indeed cost, of monitoring by European member states.

[2] The baseline that defines the outer limit of the area covered by the WFD is defined for Ireland by the Maritime Jurisdiction Act, 1959 (Straight Baselines) Order, 1959.

Whereas the primary indicators for purposes of the WFD have already been fixed, at the present time the range and application of indicators required by the EEA for integrated environmental assessments remain negotiable. Thus, it is appropriate to suggest a conceptual approach to indicator selection that may help in developing an Irish input to ongoing discussions concerning environmental indicators within the EU. The approach developed in this report does not aim to be comprehensive but to select among indicator options, first on the basis of information priorities and then on practicality and cost-benefit.

A primary consideration in the proposed approach to indicator selection is that, should EU programmes require large increases in sampling intensity and frequency, it would be preferable to restrict the number of indicators to be monitored.

3.4 Developing the Indicator Framework

As illustrated in Table 3.1, a suitable set of indicators can be developed through a tiered (i.e. hierarchical) approach, each tier representing a particular step in building the required knowledge base, as follows:

- Tier 1 - General field of knowledge
- Tier 2 - Indicator focus (feature, process, hazard or change)
- Tier 3 - Specific priority indicators

Tier 1

In the present scheme, the assumption is made that the totality of information required for assessment purposes can be reduced to four basic fields of knowledge, namely:

Ecosystem qualities: The need for information on ecologically important features of marine ecosystems is the basis of marine environmental assessment. This group of indicators includes features and conditions that are responsible for the normal functioning of marine ecosystems as well as conditions known to represent hazards to ecosystem components or with potential to cause changes beyond the range of natural variability.

Human health hazards: Another core function of environmental assessments is to keep under review environmental conditions that have either a direct or indirect bearing on human health. This group of indicators includes human health hazards encountered through water-based recreation as well as those related to the presence of pathogens and toxins in seafood.

Socio-economic and aesthetic values: The principles of environmental protection recognise that rational use of the environment by humans is both necessary and legitimate. Accordingly, environmental assessments should examine the condition of valued resources and amenities and the extent to which they are affected by natural and/or anthropogenically induced change.

Climate change: We have included climate change not from any preconceptions that current climate patterns are abnormal, or a function of anthropogenic activity, but rather that climate exerts a powerful influence on the marine environment and is responsible for much of the variability within marine ecosystems and their components. It is imperative that the design of long-term monitoring takes into account possible changes in marine climate, at least on decadal time-scales.

Tier 2

This is arguably the most critical stage in developing a suite of environmental indicators because omissions could significantly reduce the value of information generated for management and policy formulation. However, as already noted, the list cannot be inclusive and informed judgment is needed in choosing between the many available options.

Tier 2 consists of carefully selected 'themes' representing important marine features, qualities or concerns spanning the four general fields of knowledge identified in Tier 1. In effect, the 17 themes provide the foundation for groups of indicators, examples of which are shown in Tier 3.

In order to encourage an eco-centric approach to environmental assessment, almost half of the selected indicator groups fall within the field of Ecosystem Qualities. They reflect scientific understanding of properties and processes of special importance in regulating and preserving the integrity, diversity and productivity of marine ecosystems, as well as conditions that may threaten marine ecosystems.

The approach taken here is to keep the number of indicator groups to a minimum, as far as possible avoiding repetition and overlap. This has the effect of consolidating related indicators within a group, thereby encouraging comparison of their relative merits and potential contributions to marine environmental assessment. Later, when the results of monitoring become available, these groups might form the basis of aggregated indicators that would improve abilities to discriminate between different kinds or degrees of environmental change (See Chapter 9). In such a way these indicator groups may have an important role in data interpretation.

Subsequent chapters of the report deal with indicators specified under regional arrangements (i.e. OSPAR and the EU) and those used or proposed outside Europe and the NE Atlantic. Wherever possible, from this chapter onwards, tables containing lists of indicators include the corresponding indicator Group numbers from Table 3.1. Linking the indicators in this way should help in comparing and contrasting different approaches to indicator selection and in identifying any new ideas or concepts.

Tier 3

It will be evident that Tier 3 should contain at least one specific indicator for each topic listed at Tier 2. Although there are numerous options, we have chosen to list only the more essential indicators in order to minimise demands on the national monitoring programme. In the more complex cases, such as contamination and eutrophication, there is a need for multiple indicators to cover the various manifestations of the problem.

We stress that the specific indicators proposed in Table 3.1 are not inclusive but nevertheless reflect the views of the project team concerning the kinds of measurements needed to adequately address the themes identified in Tier 2.

As noted in the preceding chapter, this report does not specifically address indicators of anthropogenic pressures that are frequently the cause of environmental degradation. However, in the contexts of both Ecosystem Qualities and Socio-economic and Aesthetic values, we have included a number of environmental hazard indicators that are primary causes of stress in the marine environment and that we firmly believe should be addressed by all marine environmental monitoring programmes. Examples include the quantities of wild fish removed by commercial fisheries, the loads of nutrients and other contaminants entering the sea from different sources, trends in offshore activities and coastal population densities.

3.5 Summary

In summary, this chapter has outlined an approach to developing a core set of marine environmental indicators for national application. We believe the set of indicators presented in Tier 3 of Table 3.1 should provide sufficient information to assess, manage and protect the marine environment.

A selection of less well-established indicators referred to in Table 3.1 is described in greater detail in Chapter 8.

Table 3.1: Conceptual base set of Marine Environmental Indicators on next page.

Table 3.1: Conceptual base set of Marine Environmental Indicators

Tier 1: Field of Knowledge Ecosystem Qualities	Tier 2: Group	Theme/Indicator focus	Tier 3: Specific Priority Indicators	Justification
	1	Status of habitats	Change in area of important marine and coastal habitat types Loss due to reclamation, urban, touristic & recreational developments, port & harbour construction/expansion, aggregate extraction, mariculture etc.	Marine diversity and food chains are built around habitats. Some cover very large areas, others are remote from human interference. Reductions in smaller, biologically diverse habitats should be avoided.
	2	Status of communities	Numbers of species, biomass & abundance in soft-bottom communities compared to reference sites; diversity of communities in protected habitats. Changes in structure & abundance of phyto – & zooplankton. Prevalence of alien species/Rate of new introductions.	Biological communities reflect their habitats. The scale of human-induced changes (e.g. in community structure, biomass etc.) should be compared to natural changes for various habitat types.
	3	Status of populations and renewable resources	Status of fish stocks. Numbers of breeding seabirds. Numbers of seals & cetaceans.	Certain species have special economic and/or social significance. The resilience of populations to human pressures may be exceeded by excessive exploitation or lateral damage.
	4	Hazards to populations & renewable resources	Annual landings by species, stock, area etc. By-catches of non-target fish and cetaceans Native species at risk of extinction. Incidence of unusual mortalities, strandings etc.	Overfishing and by-catches threaten stocks and populations. Trends in catches indicate the productivity and sustainability of the resource.
	5	Hazards of nutrient enrichment	Riverine and point source inputs of N & P. Winter nitrate concentrations in seawater. Summer chlorophyll concentrations.	The effects of excessive growth of phytoplankton due to high loads of nutrients from land may be severe.
	6	Effects of nutrient enrichment (eutrophication)	Abnormal bloom frequency/intensity. Incidence of toxin-producing algae. Prevalence of anaerobic bottom water.	Potential effects of nutrients in vulnerable areas should be kept under review.
	7	Chemical hazards	Trends in loads of priority substances from land & air. Levels of particular priority substances in sediments and selected tissues (e.g. mussels, seabird eggs, cetacean lipids etc.). Incidence of oil spills.	Levels of specified (priority) persistent, higher-toxicity substances that accumulate in sediments & tissues must be kept under continuous review.

Table 3.1: (continued) Conceptual base set of Marine Environmental Indicators

Tier 1: Field of Knowledge Ecosystem Qualities	Tier 2: Group	Theme/Indicator focus	Tier 3: Specific Priority Indicators	Justification
	8	Effects of contaminants	Biomarkers of exposure & effect (See section 6.4) Endocrine disruption (e.g. imposex, vitellogenin production). Numbers & distributions of oiled seabirds. Incidence of disease (e.g. liver tumors) in demersal fish.	Biomarkers can provide early warnings of damage through exposure to contaminants and should be applied selectively in areas of high exposure (e.g. industrialised bays & estuaries).
Tier 1: Field of Knowledge Human Health Hazards	**Tier 2: Group**	**Theme/Indicator focus**	**Tier 3: Specific Priority Indicators**	**Justification**
	9	Radioactivity	Trends in distributions of reprocessing nuclides in water, soft sediments, seaweed and seafood species. Doses to critical groups (i.e. consumers of fish & shellfish).	Concerns over radioactivity in the marine environment focus on nuclides derived from reprocessing, mainly in the Irish Sea. Levels & critical exposures warrant regular assessment.
	10	Bathing water quality	Incidence of beaches failing pathogen standards. Number of beach closures. Number of Blue Flag beaches.	The safety of sea bathing and the cleanliness of beaches are barometers of 'clean' seas. Essential for public confidence.
	11	Seafood safety	Conc'ns of selected priority substances in commercial species. Prevalence of algal toxins & bacterial pathogens at major shellfish production sites. Annual number of shellfishery closures. Incidence of seafood poisoning.	Data on trends in contaminants, pathogens & toxins that compromise seafood safety, and any related illnesses are essential for management of the fishing and shellfish industries.
Tier 1: Field of Knowledge Socio–Economic & Aesthetic Values	**Tier 2: Group**	**Theme/Indicator focus**	**Tier 3: Specific Priority Indicators**	**Justification**
	12	Extent of offshore structures & activities	No. of exploration and production platforms, wind farm units etc.; tonnages of aggregates extracted.	Offshore activities provide socio-economic benefits but also present hazards to marine life. Trends should be assessed and should influence ecological monitoring.
	13	Coastal development, tourism & recreation	Coastal population trends. Impacts of developments (mariculture, wind farms etc.) on coastal landscapes/aesthetics. Overseas visitor bed-nights in coastal resorts.	Unfettered development of the coasts can result in loss of habitats and amenity value. Measures of the type and rate of development are needed.
	14	Litter	Trends in litter types & quantities per linear beach or unit area of water column or seabed.	A measure of drifting garbage that is hazardous to marine life and devalues public amenities.

Table 3.1: (continued) Conceptual base set of Marine Environmental Indicators

Tier 1: Field of Knowledge Climate Change	Tier 2: Group	Theme/Indicator focus	Tier 3: Specific Priority Indicators	Justification
	15	Coastal erosion	Rate of erosion per coast and substrate type. Loss of dune systems etc. Annual investments in coastal defenses.	These are important manifestations of changing patterns of wind and wave energy related to climate.
	16	Sea conditions	Changes in sea temperature, salinity, sea level, storm frequency. Incidence of flooding, changes in water column structure. changes in primary production in particular sea areas.	Primary indicators of global climate patterns.
	17	Biological impact	Changes in biogeographic zones/distributions. Alterations to native population biology.	Important ecological manifestation of changes in regional climate.

4.0 Internationally Prescribed Indicators

4.1 Introduction

Ireland's membership of the EU and the OSPAR Convention carries commitments in relation to environmental protection and associated monitoring programmes. Thus, since the early 1970s, European and other regional arrangements have determined many of the indicators incorporated within Ireland's marine monitoring programmes.

Data from monitoring activities provide a basis for periodic assessments of the state of the marine environment, such as the recent Quality Status report (QSR) on Ireland's coastal waters and adjacent sea areas (Boelens *et al.*, 1999). This was undertaken as part of an assessment of the Celtic Seas (OSPAR Commission, 2000a) and, ultimately, the entire North-East Atlantic (OSPAR Commission, 2000b). The 1999 QSR was the most comprehensive marine assessment undertaken in Ireland to date. Whereas it employed internationally agreed indicators, it also applied a wide variety of indicators reported in the scientific literature, whenever there was adequate supporting data.

EU initiatives that have significant requirements for marine environmental data are the Water Framework Directive (European Union, 2000) and the indicator-based reporting system introduced by the European Environment Agency (See for example EEA, 2001). Many of the environmental parameters encompassed by these assessment-related activities are not included in Ireland's current monitoring programme. It is therefore evident that, for Ireland to comply with EU monitoring requirements, an expansion and diversification of the national monitoring programme will be needed. Some delays in implementation are likely, however, as many of the necessary methodologies have still to be developed.

In this chapter, we start by summarising the marine environmental indicators used for purposes of the 1999 national QSR so that their value to future assessments can be considered along with indicators employed or proposed by other countries, regional programmes and the scientific community. We also summarise existing and proposed indicators in the frameworks of OSPAR and the EEA which, depending on the outcome of negotiations between the two bodies, are likely to be integrated to a large extent in coming years.

4.2 Indicators Applied for the Irish Quality Status Report (QSR)

The Irish QSR (Boelens *et al.*, 1999) was undertaken as part of an assessment of Region III (Celtic Seas) of the OSPAR convention area. It provided a comprehensive assessment of environmental conditions in Ireland's coastal areas and surrounding seas, describing natural features of the marine area and identifying impacts arising from human activities. The QSR used established OSPAR indicators where relevant, and where reliable data existed, and also undertook scientific literature searches which revealed additional indicators of value to the assessment. In some cases, where established indicators were not available, a new/novel approach was taken. For example, as an indicator of the occurrence of harmful algal blooms (HABs) the average duration of closure (as a % of the year) of shellfish areas, arising from the detection of DSP and/or PSP, was calculated.

This section provides a brief overview of the 'indicators' used in the Irish QSR (Boelens *et al.*, 1999) in accordance with the structure laid out in Chapter 3 (Table 3.1), as follows:

- Ecosystem qualities
- Human health hazards
- Socio-economic and aesthetic values
- Climate change

Indicators are further divided within these categories according to the indicator focus, i.e. Tier 2 in Table 3.1. No attempt is made to comment on the value/usefulness of particular indicators used in the QSR. However, where possible, an indication of the adequacy/coverage of data is given. Data adequacy / coverage is ranked as 'Good', 'Adequate', 'Limited' or 'Poor'.

Although many of the indicators listed here are, what might be termed, 'pressure indicators' (see Section 2.1) they fulfil various OSPAR reporting requirements and are listed as core indicators by the EEA.

4.2.1 Ecosystem Qualities

Indicators of ecosystem quality used in the Irish QSR are listed in Table 4.1. The information available for assessment of the status of habitats, communities and populations (Groups 1, 2 & 3) was to a large extent either 'poor' or 'limited'. The notable exception to this is the availability of good data on the status of fish stocks and, to a lesser extent, bird populations. Although the Continuous Plankton Recorder (CPR) data provided good temporal coverage there are obvious gaps in the geographic coverage, notably further inshore.

Data availability for assessment of hazards to populations and renewable resources (Group 4) was at best limited and in many cases was confined to specific locations/fisheries. As a consequence of the need to comply with various European directives and other international commitments (e.g. OSPAR Convention), the availability of data for the assessment of the hazards and effects of nutrient enrichment (Groups 5 & 6) is either 'good' or 'adequate'. Similarly, data collection the assessment of chemical hazards can be termed as 'adequate'. Finally, with the exception of the effects of TBT, there were limited data with which to assess the biological effects of individual contaminants or their cumulative effects.

Note: The Indicator Focus numbers refer to Table 3.1.
Table 4.1: Indicators of ecosystem qualities used in the Irish QSR (Boelens *et al.*, 1999).

Indicator	Indicator Focus	Data Availability	Notes
1. Status of Habitats			
Intertidal habitat	Loss of habitat in shellfish growing areas	Poor	
Seabirds	No. of species exceeding national/international thresholds at important colonies	Adequate	
Wetland birds	No. of species exceeding national/international thresholds at important colonies	Good	
2. Status of communities			
Phytoplankton	Key features of community in different coastal areas: – peak chl a standing stock – peak daily production – annual production	Limited	1
	Long-term variability – CPR 'Greenness index'	Adequate	
Zooplankton	Key features of community in different coastal areas: – biomass – % contribution by copepods – copepod species composition	Poor	
	Long term changes – CPR total copepods (Nos/sample)	Adequate	
Kelp (Laminaria spp.)	abundance – qualitative ranking of sites	Limited	2
Introduced species	prevalence	Limited	
Benthos			
	Long-term changes in community composition	Limited	
	Changes in benthic communities in the vicinity of:		
	– Mariculture operations	Limited	
	– Dredge spoil dumping sites	Limited	

Notes: 1. No attempt at time series. 2. Carried out for commercial purposes. 3. Carried out annually for fisheries assessment. 4. SSB compared to the mean for the period of assessment for commercial stocks. 5. An indicator of the stock trend over the last five years.

Note: The Indicator Focus numbers refer to Table 3.1.

Table 4.1: (continued) Indicators of ecosystem qualities used in the Irish QSR (Boelens *et al.*, 1999).

Indicator	Indicator Focus	Data Availability	Notes
3. Status of Populations and Renewable Resources			
Cetaceans	Abundance estimates of small cetaceans in Celtic Sea. Cetacean strandings as estimate of distribution.	Limited Adequate	
Seals	Grey seal population estimate based on pup production at breeding sites.	Limited	
Seabirds	Annual counts of selected seabird species at selected sites. Breeding success – Chicks fledged per nest.	Good Adequate	
Commercial fish species	Abundance – Catch rates of 1 – group demersal species. Status: – Spawning stock biomass. – Stock trend. – Safe biological limits.	Good Good	3 4 5
Potential genetic interaction between farmed and wild salmon	Occurrence of escaped farmed fish in coastal fishery. Percentage of wild juveniles with farmed fish parentage.	Limited Poor	
4. Hazards to populations and renewable resources			
Target and non-target fish	Annual landings of main commercial species from 1973-1995 by ICES Division. Total fishing effort in Irish Sea (1986 to 1991). Fishing mortality – percentage of stock caught during a year for: – age at first entry to fishery (e.g. Cod at age 1) – main age range subject to exploitation (e.g. 2-5 for cod). Total mortality and age composition of catch of Ray species.	Adequate Limited Limited Limited	6 7
Discards	Target species - selected sampling programmes on specific demersal and pelagic fleets. Non-target species - elasmobranchs	Limited	 8

Notes: 6. Landings are not related to effort. 7. Average for 1990-94 for selected stocks of in the Irish, Celtic and Malin Seas. 8. Some discard sampling programmes simply reported total discards whilst others examine age composition of the discards and rate of discarding.

Note: The Indicator Focus numbers refer to Table 3.1.

Table 4.1: (continued) Indicators of ecosystem qualities used in the Irish QSR (Boelens *et al.*, 1999).

Indicator	Indicator Focus	Data Availability	Notes
4. Hazards to populations and renewable resources			
Fishing impacts on mammals Cetacean by–catch in:	Seal by-catch in inshore herring fisheries. – bottom-set gillnet fisheries – tuna drift net fisheries – pelagic trawl fisheries	Limited Limited	9
Fishing impacts on benthos	Estimates of disturbance – total area swept annually by various gears. Benthic community impacts. Species numbers and total biomass, diversity, size composition.	Limited Limited	
Mariculture impacts	Changes in benthic community in the vicinity of mariculture impacts. Chemotherapeutics usage.	Limited Poor	
Cetacean Disease Status		Limited	
5. Hazards of Nutrient Enrichment			
Winter Nutrient Status	Winter nitrate and ortho–phosphorus concentrations (Irish Sea).		Good
Riverine Input	Estimated annual loads of N, P & BOD from principal rivers.	Limited/Poor	10
Point Source Inputs	Annual load of BOD, COD, Total N, Total P & SPM from municipal & industrial sources	Good/Adequate	11
Atmospheric inputs	Annual bulk deposition rates of ammonium, oxidised nitrogen & phosphorus.	Limited	
Mariculture inputs	National load of C, N & P	Limited	12
6. Effects of Nutrient Enrichment			
	Index of trophic status based upon data for: • BOD (Oxidised nitrogen) • Ortho–phosphorus(Total ammonia) • Un–ionised ammonia (Chlorophylla) • Dissolved oxygen	Good	13
Benthic communities	Changes in benthic community in the vicinity of mariculture impacts	Limited	

Notes: 9. Not all by-catch programmes could relate by-catch levels to population estimates. 10. Flow weighted mean annual concentrations multiplied by annual mass flow. 11. The municipal figures were based on p.e. extrapolations. Industrial discharges are based on licensed loads. 12. Inputs are based on estimated production/waste ratios. 13. Indicative values for low, moderate and high concentrations were assigned to each parameter and the overall situation was assessed to identify water bodies that displayed 'occasional', 'regular' or 'persistent' evidence of eutrophic conditions.

Note: The Indicator Focus numbers refer to Table 3.1.

Table 4.1: (continued) Indicators of ecosystem qualities used in the Irish QSR (Boelens *et al.*, 1999).

Indicator	Indicator Focus	Data Availability	Notes
7. Chemical Hazards			
Contaminants in Seawater	Metals (normalised) Trace Organics	Adequate	14 15
Contaminants in Sediments	Metals (normalised) Trace organics	Adequate	16 17
Contaminants in selected tissues	Metals in fish, shellfish, seabird eggs and feathers and mammal livers. Trace organics in fish, shellfish, seabird eggs and mammal blubber.	Adequate	18 19
Inputs of Metals	Municipal and industrial inputs. Riverine sources. Annual loads from dumped dredge spoil. Atmospheric Inputs – annual bulk deposition rates. Inputs from mariculture operations.	Adequate	12 11
Inputs of trace organics	Annual (or daily) loads of selected organic contaminants from: – Municipal and industrial sources – Riverine sources – Dumped dredge spoil	Adequate	12 11
8. Effects of Contaminants			
Oiled Seabirds	Numbers and distribution. % of total beached birds oiled. No. oiled birds per km.	Limited	20
Effects of Metal Contamination	TBT contamination – imposex in dogwhelks. Oxygen consumption rates in periwinkles.	Good Limited	21 22
Effects of Trace Organics Contamination	Cytochrome P450c isoenzyme activity in seabirds (PCB contamination) Glutathione-s-transferase induction in mussel tissues	Limited Limited	23 24
Oxidative Stress		Limited	25
Cumulative Effect of Contamination	Disease prevalance in dab & cod Scope for growth in mussels	Limited Limited	26 27

Notes: 14. Hg, Cd, Organotins, Cu, Ni, Pb & Zn. 15. Pesticides, PCBs, PAHs, & total hydrocarbons. 16. Hg, Cd, Pb, Zn, Cu, Cr, As, Ni & TBT in estuarine sediments. Cd, Cr, Pb and Cu in Irish Sea sediments. 17. PCBs, DDTs, lindane & dieldrin in Dublin Port, Cork Harbour, NE Irish Sea and SE Irish Sea. 18. Hg, Cd, Pb, Zn, Cu & Cr in fish and shellfish. Mercury in seabird eggs & feathers and mammal livers. 19. PCBs, DDTs, dieldrin & toxaphene in fish and shellfish. PCBs, dieldrin & ppDDE in seabird eggs. PCBs, DDE, _-HCH, _-HCH, HCB & dieldrin in Harbour porpoise blubber. 20. Monitoring of oiled birds has not taken place since 1986. 21. RPSI and VDSI at over 70 sites around the coast. 22. Single study to determine exposure to copper in Avoca river estuary in early 1980s. 23. Sampling of several species from Saltee Islands in the 1980s. 24. Single study in Cork Harbour. 25. Oxidative stress in mussels from a study of the impact of leather tannery effluent. 26. Studies in the Irish Sea by UK and Germany. 27. Ten sites around coast tested in 1996/7.

4.2.2 Human Health Hazards

As expected, there was good data available for the compilation of the QSR on the issue of human health hazards. This is due, primarily, to the level of monitoring required under existing EU and national legislation in relation to seafood safety (EEC, 1979; 1991) and bathing water quality (EEC, 1976). Additionally, considerable monitoring is focused on radionuclide inputs, contamination levels and human exposure.

Table 4.2: Indicators of human health hazards used in the Irish QSR (Boelens *et al.*, 1999).
Note: The Indicator Focus numbers refer to Table 3.1.

Indicator	Indicator Focus	Data Availability	Notes
9. Radioactivity			
Radionuclide inputs – discharges from Sellafield		Good	
Radionuclide status	Seawater (Cs-137 and Tc-99)	Good	
	Sediments (Cs-137 & Pu-239,240)	Good	
	Seaweed (Cs-137 & Tc-99)	Good	
	Fish and shellfish (Cs-137 and Tc-99)	Good	
Doses to critical groups – effective annual dose		Good	
10. Seafood Safety			
Classification –	of shellfish production areas under the EU Directive 91/492/EEC.	Good	
Harmful Algal Blooms –	Average duration (as % of year) of closure of selected shellfish growing areas	Good	
Specific contaminants in fish and shellfish for human consumption	– Landed catch – Mariculture produce	Good Good	1
11. Bathing Water Quality			
Bacteriological quality –	Compliance with Bathing Water Directive mandatory and guide levels, and national limit values: – Total coliforms – Faecal coliforms – Faecal streptococci	Good	
Number of blue flag beaches		Good	

Notes: 1. Levels of substances with known human health hazards, e.g. Hg, PCBs, DDTs

4.2.3 Socio–Economic and Aesthetic Values

Impacts on the marine environment, resulting from socio-economic activity, which were considered in the QSR (Table 4.3) include those due to increases in coastal populations, coastal development and levels of shipping activity. Although most of the indicators discussed in this report, in accordance with our brief, fit into the environmental state and impact categories, our proposed core set of indicators (See Chapter 3) includes a small number of pressure indicators (or hazards) specially chosen for their broad implications for marine ecosystems and their management. Group 12 covers shipping traffic, whereas Group 13 covers population pressures and coastal development (including shipping and its infrastructure).

4.2.4 Climate Change

The treatment in the QSR of impacts of climate change was, in general, very much limited to a general discussion of the various topics. For many issues there were insufficient data to allow the use of indicators, even in the broadest sense (Table 4.4). A notable exception to this was the data available from the Continuous Plankton Recorder (CPR). A long-term dataset was analysed to consider changes in primary production and zooplankton abundance.

Note: The Indicator Focus numbers refer to Table 3.1.
Table 4.3: Indicators of socio-economic and aesthetic values used in the Irish QSR (Boelens *et al.*, 1999).

Indicator	Indicator Focus	Data Availability	Notes
12. Extent of Offshore Structures and Activities			
Numbers and location of exploratory wells and production platforms		Good	
13. Coastal Development, Tourism and Recreation			
Coastal Population Trends	changes in population in coastal areas	Good	1
Coastal Development	changes in land use in 10km coastal strip	Adequate	2
Visitor Numbers to:	– coastal areas generally – offshore islands	Poor Adequate	
Coastal Recreation	participation levels in coastal activities	Poor	
14. Litter			
Beach Litter	Type, quantity and distribution	Adequate	

Notes: 1. Based on five-yearly census figures. 2. Satellite imagery used to detect changes on a large spatial scale.

Note: The Indicator Focus numbers refer to Table 3.1.

Table 4.4: Indicators of climate change used in the Irish QSR (Boelens *et al.*, 1999).

Indicator	Indicator Focus	Data Availability	Notes
15. Coastal Erosion			
Rate of Erosion		Poor	
16. Sea Conditions			
Changes in Sea Conditions:	– Temperature – Salinity – Sea level – Storm frequency	Limited Poor Poor Poor	
Changes in Primary Production	Long-term variability – CPR 'Greenness index'	Good	
17. Biological Impact			
Benthos	Long–term changes in community composition	Limited	1
Long term changes in zooplankton	CPR total copepods (Nos/sample)	Good	

Notes: 1. Time-series for two sites – Galway Bay and Kinsale

4.3 Summary of Requirements under the Revised OSPAR Joint Assessment and Monitoring Programme (JAMP)

The OSPAR Convention requires the Contracting Parties, inter alia, to cooperate in carrying out monitoring programmes, develop quality assurance methods and assessment tools, and carry out research that is considered necessary to increase knowledge and understanding of the marine environment.

The Revised OSPAR Joint Assessment and Monitoring Programme (JAMP) sets out the basis on which the OSPAR Contracting Parties should work together in fulfiling these obligations over the period until 2010 (OSPAR Commission, 2002). The main objectives of the JAMP are:

- the preparation of environmental assessments of the status of the marine environment of the maritime area or its regions; and
- the preparation of contributions to overall assessments of the implementation of the OSPAR Strategies.

JAMP activities in support of these objectives include:

- the implementation of collective OSPAR monitoring, including the development of the necessary methodologies;
- the preparation of environmental data and information products needed to implement the OSPAR Strategies.

4.3.1 The JAMP Process and its Aims

The JAMP processes are divided into three groups, according to the products that result from them:

1) The development of tools

   This consists of the development of procedures and techniques that are needed for collecting information, quality assurance, and interpretation and assessment of data.

2) Specification and execution of programmes for information collection

   "Information collection" covers gathering, compiling and processing all kinds of data and information describing human demography and activities and resulting impacts on the marine environment; the distribution of species and their populations; determining temporal trends and/or discrete changes for the purpose of assessing (by the use of suitable indicators) variability in the marine environment; and, establishing links between anthropogenic pressures and observed impacts and changes.

3) The production of assessments

   The JAMP programme sets out to produce both thematic assessments (dealing with one aspect), and general assessments of all aspects of the marine environment, in an integrated series, with the successive thematic assessments providing the basis for a general assessment in 2009 of the quality status of the OSPAR maritime area.

In view of the objectives of the OSPAR Convention, assessments will focus, inter alia, on:

- The occurrence and extent of contamination and other adverse effects due to human activities;
- Whether human health is safeguarded; and
- The conservation of the biological diversity of marine ecosystems, and the sustainable use of components of the marine environment.

4.3.2 JAMP requirements and need for indicators

The JAMP programme is required to focus its attention on five specific strategies established by OSPAPR, as follows:

(i) The strategy on the protection and conservation of the ecosystems and biological diversity of the maritime area:

(ii) The strategy with regard to hazardous substances;

(iii) The strategy to combat eutrophication;

(iv) The strategy on environmental goals and management mechanisms for offshore activities; and

(v) The strategy with regard to radioactive substances.

For each of the five OSPAR strategies, and for assessment of the general status of the OSPAR Maritime region, the JAMP process aims to address a number of 'issues' that in most cases require the adoption/development of indicators. These are outlined below.

For the assessment of the General Status of the OSPAR area the issues to be addressed include:

- How can we distinguish between anthropogenic effects and natural background variations in the marine environment, its biological communities and production?
- What changes, particularly in relation to coastal habitats, can be attributed to long-term climate change?
- How can ecosystem health be assessed in order to determine the extent of human impact?

Under this heading i.e. General Status of the OSPAR area, it is intended that JAMP will make contributions to indicator–based assessments to be produced by the European Environment Agency (EEA) and others, for example in relation to climate change; liquid waste discharges and dumping of dredged material (and other wastes if relevant); introduction of non–indigenous species; changes in marine species and habitats and coastal zones. Over the course of the JAMP, OSPAR intends to develop JAMP Guidelines on pressure, state and impact indicators for the OSPAR maritime area, taking account of the requirements of the EEA.

For each of the other five strategies the JAMP identifies a number of issues (themes or indicators) to be addressed through monitoring, other data-gathering and assessment activities. Each set of indicators is designed to cover practices and activities (driving forces), sources and loads (pressures), changing conditions (state), exposures and effects (impacts), as relevant and appropriate. The JAMP indicator sets applicable to each strategy are summarised in Tables 4.5 to 4.9. Where a JAMP indicator fits within one or more of the groups in our proposed core set of indicators (Table 3.1), this is shown in the table.

Table 4.5: Indicators relevant to the JAMP Strategy to Combat Eutrophication.

JAMP Reference	Assessments	Group
EA-1	Temporal trends and spatial distribution of: • Riverine inputs • Direct discharges • Atmospheric deposition	5
EA-2	Atmospheric Emissions	
EA-6	Eutrophication status of water bodies	5

Table 4.6: Indicators relevant to the JAMP Strategy with regard to Hazardous Substances.

JAMP Reference	Assessments	Group
HA-1	Emissions, discharges and losses of "priority chemicals."	7
HA-2a	Riverine inputs and direct discharges of contaminants. Atmospheric deposition of contaminants.	7
HA-2a	Levels and trends of contaminants in biota, sediments and the water column, and relevant biological effects.	7, 11
HA-2c	Biological effects of hazardous substances in general (i.e. combined effects).	8

N.B. Emphasis is on the so-called "priority chemicals" as outlined in the OSPAR List of Chemicals for Priority Action (See Annex 3).

Table 4.7: Indicators relevant to the JAMP Strategy on the Protection and Conservation of the Ecosystems and Biological Diversity of the Maritime Area.

JAMP Reference	Assessments	Group
BA-2	Status of species and habitats on the OSPAR Priority list of threatened or declining habitats or species1 (and assessment against agreed EcoQOs).	1, 2 & 3
BA-4	A series of assessments of the following human activities, addressing specific questions, as follows2: Sand and gravel extraction • Impacts on communities (particularly benthic communities), coastal habitats and spawning areas.	1
	Dredging and dumping of dredged materials • Impacts on communities (particularly benthic communities), coastal habitats and spawning areas.	1
	Offshore windfarms • Impacts on species and habitats (e.g. birds, mammals, fish and benthic organisms) • Effects on geomorphology and hydrodynamics	1
	Land reclamation and coastal defence activities • Impacts on communities (particularly benthic communities), coastal habitats and spawning areas	1
	Tourism • Impacts on species and habitats • Composition, occurrence and effects on biota of litter	1 14

Table 4.7: Indicators relevant to the JAMP Strategy on the Protection and Conservation of the Ecosystems and Biological Diversity of the Maritime Area.

JAMP Reference	Assessments	Group
	Mariculture • Genetic interaction between cultured and wild fish and shellfish stocks. • Risk of spread of disease from mariculture to wild stocks and introduction of non-indigenous species.	2
	Fisheries • Status of fish stock. • Impacts of fisheries on population size, mortality rate and distribution of commercially exploited target and by-catch species of fish and shellfish; and incidentally caught, damaged or killed benthic organisms, birds and mammals. • Impacts of fisheries on communities, water quality (e.g. oxygen) and habitats.	3,4
	Maritime transportation • Composition, occurrence and effects on biota of litter. • Occurrence and impacts of non-indigenous species.	2
BA-5	Trend analysis of the different human activities and their collective impact on the maritime area.	Various
BA-6	Changes in the distribution and abundance of marine species in relation to changes in hydrodynamics and sea temperature.	2, 16 & 17

Notes: 1. The OSPAR Priority list of threatened or declining habitats or species is presented in Annex 4.
2: In addition to the activities listed here other activities will be assessed. However, specific issues have not been identified for these.
The activities in question are:
Exploration for oil, gas and solid minerals;
Placement of cables, pipelines, and structures for the exploitation of oil and gas;
Construction or placement of artificial islands and reefs; and Coastal development.

Table 4.8: Indicators relevant to the JAMP Strategy on Environmental Goals and Management Mechanisms for Offshore Activities.

JAMP Reference	Assessments	Group
OA-1	Inputs (and trends) to the sea of hydrocarbons and hazardous materials from offshore installations.	
OA-1	Concentrations of hydrocarbons and hazardous materials in environmental compartments – particularly in areas influenced by installations.	7
OA-3	Biological effects (and trends thereof) on the various components of marine biota (benthic communities, demersal and pelagic organisms, mammals and seabirds)?	11

Table 4.9: Indicators relevant to the JAMP Strategy with regard to Radioactive Substances.

JAMP Reference	Assessments	Group
RA-1(i)	Sources of discharge, emissions and losses of radioactive substances to the marine environment.	
RA-1(ii)	Temporal trends and spatial distribution of concentrations of radionuclides, and their fate in the marine environment.	9
RA-1(iii)	Human exposure of humans to radiation from pathways involving the marine environment.	11
RA-1(iv)	Impacts of anthropogenic radioactive substances in the marine environment on marine biota.	

4.4 EU/WFD Indicators

4.4.1 Relevant Features of the Directive

Annex V of the EU Water Framework Directive (WFD) specifies indicators to be used in monitoring and assessing the ecological status of inland, transitional (including estuaries) and coastal waters. It also provides definitions of high, good and moderate ecological status to be used in evaluating the condition of different waterbody types.

The WFD differs from previous approaches to environmental assessment by establishing a mandatory series of interlinked steps from waterbody classification, to standards development, target setting, monitoring, quality ranking, reporting and, where necessary, remedial action. Clearly, the level of effort and investment required in implementing this scheme for any particular indicator will depend on the number of waterbodies to be assessed and the associated sampling strategies. These aspects are under active discussion within a variety of dedicated EU working groups, including representatives from existing and prospective EU states.

4.4.2 WFD Indicators

The marine (transitional and coastal waters) indicators specified in the WFD are summarised in Table 4.10. The directive does not refer to indicators per se; rather, it uses the term 'element' to describe the characteristics of waterbodies that will be used to assess ecological status.

Nevertheless, as the table shows, over half of the WFD elements correspond to one or more of the indicator groups listed in our proposed core set of indicators (Table 3.1) for national application.

Table 4.10: Marine indicators specified under the EU Water Framework Directive.

	Transitional Waters	Coastal Waters	Group No.1
Biological Elements			
Composition, abundance and biomass of phytoplankton & frequency and intensity of blooms.	✓	✓	2
Composition and abundance of macroalgae & angiosperms.	✓	✓	2
Diversity and abundance of benthic invertebrate fauna, & presence of disturbance sensitive taxa.	✓	✓	2
Composition and abundance of fish fauna, especially disturbance sensitive species.	✓		3
Hydromorphological Elements Supporting the Biological Elements			
Depth variation	✓	✓	
Quantity[2] structure and substrate of the bed	✓	✓	
Structure of the intertidal zone	✓	✓	
Freshwater flow	✓		16
Direction of dominant currents		✓	
Wave exposure	✓	✓	15
Chemical and Physico – Chemical Elements Supporting the Biological Elements			
General: Transparency, thermal conditions, oxygenation, salinity & nutrients.	✓	✓	5,6
Priority pollutants & other pollutants discharged in significant quantities.	✓	✓	7

Notes: 1: Corresponding group in Table 3.1. 2: Transitional waters only.

4.4.3 Observations on WFD Indicators

The most significant aspect of the set of WFD indicators is that it focuses largely on biological features. These include physical and chemical features that, directly or indirectly, determine the structure and composition of aquatic communities. In essence, they are features that define the habitat. Thus, the WFD clearly embraces the concept that biological quality reflects water quality. Nevertheless, the directive also aims to achieve good chemical status for all surface waters by requiring compliance with environmental quality standards for specified pollutants based on ecotoxicological properties and the use of appropriate safety factors.

The values of WFD indicators taken to represent 'high ecological status' are to be consistent with 'undisturbed conditions'. Values chosen to represent 'good' ecological status (the target for all surface waters by 2015) may reflect 'slight' changes from undisturbed conditions and must in all cases ensure the maintenance of more sensitive taxa in each of the specified biological groups. Good chemical status i.e. concentrations not exceeding the standards set, must also be achieved for all specified substances.

For each indicator and waterbody type, the Directive requires that 'reference values' be set and used to evaluate the results of monitoring programmes. It is implicit that, wherever possible, reference values should be quantitative so that results can be ranked on numerical scales. This may not be possible in the case of certain hydromorphological features such as structure of the seabed and wave exposure. The derivation of reference values will be based on accumulated scientific knowledge of the areas concerned, taking into account natural variability. Where the extent of natural variability precludes the setting of a reference value for a particular element in a particular area, the element concerned may be excluded from the assessment of ecological status.

Recommended approaches to the monitoring of some WFD indicators are given in Chapter 8. Whereas methodologies exist for most of the biological indicators, there has been little systematic monitoring of these within the OSPAR area and almost none in Ireland. However, it is anticipated that the greatest logistical difficulties in monitoring the WFD biological indicators will relate more to the required spatial and temporal coverage than the methodologies for sampling and analysis. Some of the hydromorphological indicators, such as structure of the intertidal, direction of dominant currents and wave exposure will require methods development. Whereas methods exist for most of the general chemical and physico-chemical indicators, it will still be necessary to evolve standard practices for purposes of WFD compliance. Methodologies do not yet exist for some of the latest chemicals added to the list of priority pollutants (See Section 4.3).

4.5 Indicators identified by the European Environment Agency (EEA)

The European Environment Agency (EEA) is required to keep under surveillance the condition of the terrestrial, water and atmospheric environments across the EU. To this end, in conjunction with its appointed Environment Topic Centres (ETCs), the EEA has devised a scheme of integrated environmental assessment based on sets of indicators covering different environmental sectors, namely:

- Air and Climate Change
- Water including Seas
- Nature and Biodiversity
- Waste
- Terrestrial Environment

and activity sectors, namely:

- Transport
- Tourism
- Fisheries
- Energy
- Agriculture

According to the EEA, indicators have been chosen as the best way to present data from different environmental and sectoral areas in a comparable and structured way (ETC/WTR 2001). The scheme follows the so-called DPSIR assessment framework; this abbreviation stands for Driving Forces, Pressures, State, Impact and Responses. It implicitly recognises the linkages between cause and effect for anthropogenic and climate-related environmental changes (See also Chapter 9).

The EEA environmental indicators are intended to meet the needs of the EU Environment Directorate (DGEnv) in assessing policy effectiveness and in developing assessment procedures for the Water Framework Directive. However, it is recognised that questions to member states related to policy are often poorly framed and this hampers the development of suitable indicators. A priority for the European Topic Centre on Water (ETC-WTR) is to develop comparable assessments and indicators linked to clearly stated policy issues[3].

[3] This could also apply to environmental issues e.g social and scientific concerns (see also sections 2.2 & 2.3)

A system known as EUROWATERNET is to be used to obtain datasets and information and this will be linked to a system for data storage, visualisation and dissemination known as WATERBASE (http://water.eionet.eu.int/Activities). In addition, MARINEBASE has been established as a database for transitional and coastal waters. It contains temporally and spatially aggregated data for 10x10 km areas (eutrophication data) or for reference stations (data on hazardous substances).

It is intended that the EEA integrated assessments (See for example EEA, 2001) should be prepared annually and based on 'available' information from national monitoring programmes, monitoring under the auspices of marine conventions e.g. OSPAR and HELCOM and monitoring carried out for purposes of the Water Framework Directive. The ETC-WTR has indicated that the indicators selected for purposes of EEA assessments should also meet the assessment needs of member states. This seems to suggest that no monitoring programmes will be put in place specifically for purposes of the EEA assessments. However, few of the data obtained from either national or convention monitoring programmes are reported annually and a number of the marine indicators proposed by the EEA have not been routinely monitored by Ireland (and probably many other EU states) to date.

The EEA aims 'to harmonise existing regional sea monitoring and assessment programmes, where comparable data are needed'. The EC is a member of OSPAR. A Memorandum of Understanding between the two organisations specifies the development of 'joint work programmes'. In conjunction with ETC-WTR, the EEA will: 'build upon the results and assessments produced and being produced by the marine Conventions to avoid duplication of efforts'. However, it is far from certain that all of the proposed indicators will be accepted by OSPAR member states for inclusion in OSPAR's Joint Assessment and Monitoring Programme (JAMP). In an attempt to harmonise and integrate the data collection systems of the EEA and marine conventions, the Inter-Regional Forum (IRF), made up of senior representatives of the organisations concerned, has held a series of consultations and workshops. The steps in the harmonisation process are:

1. Identification and development of a core set of marine & coastal indicators;
2. Development and implementation of a strategy on data flow for the core indicators;
3. Implications of data needs for marine Convention monitoring programmes; and
4. Harmonisation of reporting.

Questions being addressed by the IRF include:

- Is the geographical presentation of the indicator/thematic maps acceptable?
- How can the availability and quality of data be improved?
- How can the European wide coverage be improved?
- Does the (data) aggregation method and statistical treatment need improvement?

Although some progress has been made, at the time of writing it appears there remain considerable gaps between the two sides regarding the degree to which their respective programmes can and should be integrated. One obvious difficulty is that EEA data requirements will be integrated with those of the WFD, a legal instrument based on policy elements that differ from those of OSPAR. In this context the ETC-WTR is aware that there are gaps in data produced for the conventions in terms of the numbers of transitional and coastal waters monitored, numbers of stations used to represent each WFD waterbody and determinants measured.

Of those indicators proposed for EEA assessments, only those described as State and Impact indicators are of direct relevance to the present study. To date, the numbers of proposed State and Impact indicators for marine and coastal environments are as follows:

EEA Marine & Coastal Indicators

	Chemical	Biological	Physical/Other
Core set	6	7	
Climate change		3	5
Biodiversity		13	12

The draft set of EEA Impact/State indicators for marine and coastal areas is summarised in Table 4.11. For each indicator, the table also shows the corresponding indicator group number from our proposed core set of indicators presented in Chapter 3 (Table 3.1). It can be seen that all of the EEA 'core set' of indicators are represented in the set developed for purposes of this report, even though they have been developed in an entirely independent manner. A similar situation exists for indicators of climate change. On the other hand the EEA places far greater emphasis on indicators of biodiversity than is the case in this report, presumably reflecting a European response to the 1992 Convention on Biological Diversity (CBD).

However, we feel that important questions remain regarding the definition of marine biodiversity and that methodologies for the monitoring and assessment of marine biodiversity are not yet sufficiently developed for us to suggest specific indicators.

At the time of writing it is by no means certain that all of the marine indicators proposed by the EEA will be applied or that member states will agree that all are suitable for the purposes intended. There are difficulties regarding methodologies for measuring certain indicators and in a number of cases doubts exist concerning the environmental relevance of the indicators and how they might be interpreted for purposes of management and/or policy formulation.

4.6 Are Regional Indicators Represented in the Proposed Core Set?

It is useful to compare the wide range of indicators identified in Sections 4.1 to 4.4 with the proposed core set of indicators for national application (Table 3.1). For example, to gain a better appreciation of the suitability of the core set for management purposes, it is appropriate to compare the scope of the core set with the range of indicators employed by the latest national Quality Status Report (Boelens *et al.*, 1999) and those applied and proposed by OSPAR and the EU.

Such a comparison is presented in Chapter 10 (Table 10.1).

Table 4.11: Proposed EEA marine and coastal State/Impact indicators

Indicator	Description	Scope*	Group**
Core set	State		
	Concentrations of nitrate and phosphate and N:P ratios (by regional sea and waterbody type).	T/C	5
	Concentrations of hazardous substances in water.	T/C/M	
	Concentrations of hazardous substances in marine organisms.	T/C/M	7
	Concentrations of hazardous substances in sediment.	T/C/M	7
	Summer average & peak concentrations of chlorophyll a in surface water.	T/C/M	5
	Occurrence of nuisance algae; species composition and diversity of plankton.	T/C	6
	Status of commercial fish stocks.	C/M	3

* T=Transitional; C=Coastal; M=Marine; CZ=Coastal Zone **Corresponding indicator in Table 3.1.
NCI=No Comparable Indicator; (x)=Comparable to a limited extent. 1: The rationable for the inclusion of organic carbon carbon in this indicator is unclear.

Table 4.11: (continued) Proposed EEA marine and coastal State/Impact indicators

Indicator	Description	Scope*	Group**
Core set	State		
	Species, diversity, structure and function of benthic invertebrate communities and organic carbon of the sediment surface.[1]		
	Composition and abundance of aquatic flora as defined by the WFD i.e. macroalgae & angiosperms.	T/C	NCI
	Habitats: Surface versus potential surface	T/C	1
	Impact of fishing on non-target fish, marine mammals and birds (e.g. nos. of threatened species).	M/C	4
	Natural variability – NAO index		
	Trophic index		
	Fishing effort - e.g. fleet HP per fishing day		
	Impact		
	WFD waterbodies: biol/phys_chem. quality less than 'good'	T/C	NCI
	Nos. bathing waters failing bathing water standards	T/C	10
	Frequency of low oxygen in bottom water	T/C/M	6
	Nos. of introduced species	T/C/M	2
	Biological effects of hazardous substances	T/C/M	8
Climate Change			
	Sea surface temperature	M/CZ	16
	Changes in storm surges	M/CZ	16
	Changes in density (temperature and salinity)	M/CZ	16
	Sea level rise	M/CZ	16
	Rate of coastal erosion	M/CZ	16
	Marine biota	M/CZ	17
	Fish (cod stocks) relative to climate	M/CZ	17
	Plankton relative to climate (CPR)	M/CZ	17

* T=Transitional; C=Coastal; M=Marine; CZ=Coastal Zone **Corresponding indicator in Table 3.1.
NCI=No Comparable Indicator; (x)=Comparable to a limited extent. 1: The rationable for the inclusion of organic carbon carbon in this indicator is unclear.

Table 4.11: (continued) Proposed EEA marine and coastal State/Impact indicators

Indicator	Description	Scope*	Group**
Biodiversity	Species		
	No. of species per 'main' taxonomic group	C/M	NCI
	No. of endemic species	C/M	NCI
	Distribution of endemic species	C/M	NCI
	No. of threatened species	C/M	4
	No. of protected species	C/M	NCI
	Change in status of protected species	C/M	NCI
	Habitats		
	No. of protected habitats	C/M	(1)
	No. of red-listed habitats	C/M	(1)
	Surface area of main habitat type	C/M	1
	Distribution of main habitat type	C/M	1
	Change in distribution of main habitat type	C/M	1
	Conversion of habitat type	C/M	1
	Areas		
	Area and change in area of protected 'land'	C/M	1
	Important bird/plant etc. areas	C	1
	Habitat diversity index; Habitat patterns/corridors. ; Fragmentation	C	NCI NCI

* T=Transitional; C=Coastal; M=Marine; CZ=Coastal Zone **Corresponding indicator in Table 3.1.
NCI=No Comparable Indicator; (x)=Comparable to a limited extent. 1: The rationable for the inclusion of organic carbon carbon in this indicator is unclear.

5.0 A Global Survey of Marine Environmental Indicators

5.1 Approach

This chapter reviews approaches to the use of indicators in marine monitoring and assessment outside the EU and OSPAR communities. It is by no means inclusive and is based largely on information available from the more developed English-speaking countries.

The review spans three different information sources, as follows:

Regional Seas Programmes

At present, international programmes for protection of the marine environment cover 15 of the world's sea areas. A concise summary of the international agreements on which these programmes are based can be found as an Annex in GESAMP (2001). The Regional Seas Programme of UNEP (United Nations Environment Programme) comprises 12 regions with over 140 coastal states and territories participating. Separate programmes exist for the NE Atlantic (OSPAR), the Baltic (HELCOM) and the Arctic (AMAP). All these programmes focus on specific environmental problems and conditions and have dedicated monitoring programmes.

National Programmes

Relatively few states have national monitoring programmes not dictated by regional arrangements. Notable exceptions are Canada and the United States, both of which undertake a range of monitoring programmes at national, regional and sub-regional (e.g. major gulfs, bays and estuaries) levels. Other states such as New Zealand, which are parties to regional agreements, may operate national programmes pending the implementation of planned regional monitoring arrangements.

Assessments by Scientific Institutions

A number of reputable scientific institutions periodically conduct assessments of marine environmental conditions at national, regional, or even global, levels. It is very useful to examine the indicators they employ for this purpose since they are not dictated by governmental programmes and are often tuned to topics that are of widespread public interest or concern.

Indicator sets reviewed are summarised in a series of tables which also show the core set Group Number (# - see Chapter 3, Table 3.1) corresponding most closely to the indicator described. This provides a basis for the analysis in Section 5.5.

5.2 Indicators Used in Regional Seas Programmes

The Arctic Assessment and Monitoring Programme (AMAP)

This programme has been included because it is widely regarded as one of the best in terms of its design, scientific quality and clarity of presentation. The most recent assessment (AMAP, 2002) focuses on pollution of the Arctic, including its inhabitants and wildlife.

The indicators used in the Arctic monitoring programme are selected according to the particular hazards and impacts that are most likely to occur in this region. They fall predominantly into Groups 6-9 as described in Table 3.1 (Chapter 3). Although the human population and range of activities are small in contrast to those of lower latitudes, assessments clearly show that the Arctic is closely connected to the rest of the world and receives contaminants from sources far outside the Arctic region.

The AMAP pollution indicators are summarised in Table 5.1.

Table 5.1: AMAP pollution indicators (adapted from AMAP, 2002).

Focus	Indicator	Group#
Persistent Organic Pollutants (POPs) incl. Alpa & beta-HCH, PCDDs, PCDFs, PCBs, toxaphene, chlordane, dieldrin, mirex,endosulphan, PBDEs, PCNs	Levels in Arctic air, snow & rain. Levels (alpha-HCH, DDT, PCB) in seawater. Levels in the marine food chain, mammals (blubber, lipid) & predaceous birds (lipid & eggs). Levels in traditional seafood items. Immunological responses in mammals (e.g. polar bears, northern fur seals).	7 7 7 11 8
Heavy Metals incl. Hg, Pb and Cd	Mercury, lead and cadmium in atmospheric deposition and the tissues of marine birds and mammals. Pilot-scale studies on levels of platinum, palladium and rhodium (probably originating from automobile catalytic converters) in snow and ice.	7 7
Man-made radionuclides incl. Technetium-99, iodine-129, cesium-137, plutonium	Doses to humans via seafood and other routes of exposure.	9
Human Health	Risk assessments for fetal and neo-natal development in humans, focusing on mercury and PCBs.	11
Contaminant pathways	Climate related variability in pathways of POPs, heavy metals and radionuclides, including changes within food webs and effects on biota.	NCI

#Groups as defined in Chapter 3, Table 3.1; NCI = No directly Comparable Indicator

Proposed Plan Bleu (Blue Plan) Indicators for the Mediterranean

International action to protect the marine environment of the Mediterranean Region is coordinated under the Barcelona Convention (1976) and, in particular, the Mediterranean Action Plan (MAP). The Blue Plan (Mediterranean Action Plan, 2000) is funded by MAP, France, the EU and World Bank to promote national data collection and recording, the use of indicators for the environment and sustainable development and the strengthening of capacities in the field of environmental statistics.

In 2000, the Contracting Parties to the Barcelona Convention adopted 130 indicators of sustainable development in the Mediterranean Region based on recommendations developed under the Blue Plan. The indicators are sub-divided into Pressure, State and Impact indicators, following the model proposed by the EEA and Eurostat (see Chapter 9). Whereas the present study deals mainly with indicators of the state (i.e. condition) of the marine environment, here we present the complete set of marine indicators (Table 5.2) to illustrate the difficulties than can be encountered in trying to distinguish between pressure, state and impact. For example, it is by no means clear why the percentage of 'artificial' coastline should be regarded as a pressure indicator when the real pressures in this context are wave energy and sea level, or why increases in coastal populations should be a state rather than a pressure. Also, a number of the so-called impact indicators listed could, in our view, be better described as response indicators, again in accordance with the EEA's DPSIR (Driving Force-Pressure-State-Impact-Response) system.

Despite such apparent anomalies, the proposed set of marine indicators for the Mediterranean clearly identifies conditions that are important from the standpoint of environmental health and sustainability i.e. extent of habitats, contaminant levels, marine debris, status of fish stocks (inferred from catches), species threatened etc. On the other hand there is a shortage of indicators of biological impact with regard to both communities (e.g. benthic invertebrates) and populations of particular species such as birds and mammals.

Casazza *et al.* (2002) have summarised the indicators being evaluated under the Mediterranean Blue Plan, as well as additional indicators of benthic community structure, and have urged the development of a common suite of biological indicators and associated methodologies for application by the 20 countries surrounding the Mediterranean.

Table 5.2: Proposed 'sustainable development' indicators for the Mediterranean (adapted from Mediterranean Action Plan, 2000).

Theme	Pressure	State	Impact
Littoral and 'littoralisation'	% of coastline with 100m+ sections modified or artificial.	Average annual rate of change (%) in population of coastal admin. regions.	Hectares of protected marine & coastal (whole or part) ecosystems (*1)
	Number of tourists per km of coastline per day	Population per km^2 in coastal admin. regions	
	Number of moorings in yachting harbours per yr.	% of coastline subject to erosion (*16).	
Sea	% of oil tankers amongst cargo vessels entering ports & tonnes of oil product unloaded per yr.	Global quality of coastal waters (1)	Number & area of protected (incl. sensitive) marine areas (*1)
		No. of debris items per km^2 of seabed (*14)	No. of national 'pollutant' monitoring programmes
		No. of coastal pollution 'hot spots' by class, identified under MAP(2) (*7)	% wastewater treated discharge from coastal towns with over 100,000 inhabitants.
		% coastal waters with seagrass beds (e.g. Posidonia spp.) (*2)	Proportion of commercial harbours equipped with deballasting facilities.
Fisheries	Total annual value of sea fish catch at fixed $ rate	Annual tonnages of demersal & pelagic fish caught in Med. per yr. (*4)	Public expenditures on fish stock monitoring
	Number and average H.P. of fishing boats per yr.	Total tonnes of aquaculture products per country / yr.	
Mines, Industry	Tonnes/day discharges of metals, P & N, BOD, COD to sea (*5)		
Biological Diversity; Ecosystems	Coastal wetland area km^2	% threatened species by class (*4)	Total US$ spent on managing protected areas
	No. turtles caught per yr. (*4)		
	H.P. ratio – trawlers: total fishing fleet		

Notes: (*) Indicators ascribable to Groups (#) defined in Chapter 3, Table 3.1
(1) **Definition:** This indicator describes the quality of coastal waters in accordance with three variables:
i) The bacteriological quality of seawater; ii) The concentrations of pollutants in seawater and sediment, and
iii) The concentrations of pollutants in living matter. **Methodological Description:** The suggested approach is based on the Eurostat/OECD questionnaire on the Environment. The bacteriological quality of seawater relates to concentrations of fecal coliforms. The pollutants measured in the sediments and sea water are heavy metals, organochlorine compounds (PCB, DDT, etc), and hydrocarbons. Some mineral parameters are also followed (total Phosphorus, Nitrogen total) as well as chlorophyll a. The pollutants measured in living organisms are heavy metals, the organochlorinated compounds (PCB, DDT, etc), and hydrocarbons. Five animal taxa are concerned: molluscs, fish, arthropods (crustacean), birds and mammals. (2) Mediterranean Action Plan

5.3 Indicators used in National (or Sub – Regional Programmes)

Australia's Key Indicators for Estuaries and the Sea

A key set of 61 environmental indicators for estuaries and the sea has been recommended for Australian state of the environment reporting at the national scale. A detailed report on these indicators (Ward *et al.*, 1998) includes a discussion of monitoring strategies and approaches to interpreting and analysing each of the indicators. The main state/impact indicators are summarised in Table 5.3.

Table 5.3: Australian state/impact indicators for estuaries and the sea (adapted from Ward *et al.*, 1998.)
(#) Indicators ascribable to Groups (#) defined in Chapter 3, Table 3.1

Theme	Indicator	Group#
Cited species/taxa	Part of the Biodiversity theme. Covers marine mammals, reptiles, birds, fish, invertebrates and plants (incl. relevant species of seagrasses or algae). No. of named species or similar-level taxa in each of the relevant IUCN (World Conservation Union) categories and the subject of State, Territory or Commonwealth legislation.	4
Extent of Habitats	Extent (areas) of algal beds, beaches & dunes, coral reefs, intertidal reefs/sands/mudflats, mangroves, saltmarshes, seagrasses.	1
Habitat Quality	Change in dominant species and/or assemblages in each of the habitats listed above; includes fish population indicators and numbers of native & exotic pest species; chlorophyll concentrations. Sampling protocols vary between habitat types.	2
Renewable products	Includes aquaculture production, fish stocks and seafood quality.	4
Water/Sediment Quality	Includes contaminants in sediments, sentinel species (e.g. oysters, mussels, seagrass leaves) & seabird eggs; nutrients in water; turbidity.	5/7
Integrated Management	Includes coastal discharges; coastal protection; marine protected areas; coastal population; coastal tourism.	13/14
Ecosystem Processes	Changes in sea level and sea surface temperature.	16

The Australian set of indicators places considerable emphasis on the status of habitats and their indigenous communities. This would appear to reflect clear national objectives for the maintenance of marine biodiversity and protection of the coastal zone generally.

Almost one-third of the indicators are classified as pressure indicators and these, along with a further 11 response indicators, make up more than half of the 61 indicators covering estuarine and marine areas. There are some unusual assignments to indicator themes and types. For example, fish populations and chlorophyll concentrations are included under 'habitat quality'; algal blooms and all of the water/sediment quality indicators are listed as pressure indicators. This illustrates one of the principal findings of this report, which is that there is no consistent approach internationally in the way indicators are assigned within the Pressure/State/Response System of environmental indicators (See also Chapter 9).

South Africa: Proposed Marine, Coastal & Estuarine Indicators

The South African government has adopted environmental indicators covering the atmosphere and climate, biodiversity and national heritage, inland waters, land use, waste management, and marine, coastal and estuarine areas (Department of Environmental Affairs & Tourism, 2001). The underlying rationale, value and application of each indicator are clearly described. There are 11 marine indicators and these are summarised in Table 5.4.

Table 5.4: Marine indicators to be applied in South Africa (adapted from Department of Environmental Affairs & Tourism, 2001).

Indicator	Measurement	Group#
Catches & Maximum Sustainable Yield (MSY) per Fishery Sector	Tonnes caught and MSY (or TAC(1) per fishery sector (i.e. shellfish, pelagic, demersal, seaweeds, line fishing, beach seining etc.) per year.	3
Distribution & Abundance of Resource Species	Distribution & abundance (as a measure of availability) of specified 'resource' species (seaweeds, fish & shellfish) in the coastal zone.	3
Catch per unit effort per fishery sector	Annual catch (biomass) of major species in each fishery sector (see above) per trawl day or diver hour	3
Commercial fishing rights supporting SMME(2)	4-yearly number of fishing rights issued and % quota size category	NCI
Estuarine Health Index (state of SA estuaries)	Status (ratings) of estuarine fish communities (species richness, assemblages, abundance), water quality (trophic status, suitability for marine life & human contact) & aesthetic conditions (state of development) at 5-10 yr intervals (by region).	2/5/14

Table 5.4: Marine indicators to be applied in South Africa (adapted from Department of Environmental Affairs & Tourism, 2001).

Indicator	Measurement	Group#
Pollutant loading entering the seas from land-based sources	Volumes of municipal & industrial waste discharged daily into identified estuaries, coastal & offshore waters (annual reporting).	7
Blue Flag beaches	% of major SA beaches obtaining Blue Flag status annually.	10
Concentrations of heavy metals (& selected organics) in sediments or biological tissues	Trends in concentrations (measured 2x per yr.) in sediments and/or biota at inter-tidal sites near major SA cities (indicator of chronic pollution).	7
Oil pollution accidents along the coast	Annual number of oil pollution incidents & alerts.	4
Land cover change in the coastal zone	5 – yearly change in area (hectares) of coastal zone (by province) developed for housing, tourism, aquaculture etc.	1
Population density change in the coastal zone	5 – yearly change in pollution density of coastal municipalities.	13

Groups as defined in Chapter 3, Table 3.1; NCI = No directly Comparable Indicator.
(1) TAC = Total Allowable Catch
(2) SMME = Small, Micro & Medium-Sized Enterprises

A majority of the South African indicators are pressure indicators. Only those measuring the distribution and abundance of resources, catch per unit effort, estuarine health, beach (Blue Flag) quality and contaminant concentrations are described as environmental state indicators. However, as is often the case with combinations of environmental indicators, it is not clear how the various indicator types will be related (see Chapter 9).

There is a remarkable degree of transparency in the way the South African indicators are explained and their benefits and limitations described. In cases where existing information is insufficient to allow a particular indicator to be assessed, individual data sheets identify research and development needs as well as responsible agencies.

The set of South African indicators is firmly weighted towards fisheries and coastal land use. There is limited attention to chemical pollution. For example, there are no measurements of specific contaminants in discharges from pipelines or rivers and there is a lack of clarity regarding the determinants to be monitored in sediments and tissues. On the other hand, with the exception of bi-annual measurements of contaminants in sediments and tissues, there is a considerable degree of balance and practicality in the assessment intervals (e.g. 4-5 years) for indicators that tend to change rather slowly.

Of particular interest is the use of an Estuarine Health Index as a form of composite or aggregate indicator. This is based on existing surveys of fish communities, water quality and aesthetic conditions in some 250 estuaries. Each of these conditions was rated as 'good', 'moderate' or 'poor'. A national goal of achieving at least 80% of estuaries in each province with 'good' ratings for all three conditions has been proposed. This indicator will be subject to further development. A means of integrating the three ratings into a single value would seem a worthwhile objective.

The U.S. National Coastal Condition Report

A report on the condition of U.S. coastal waters (USEPA, 2001), based primarily on data from estuaries, employs seven indicators as shown in Table 5.5.

Data available for this assessment were apparently sufficient to rank more than 70% of the estuarine area of the United States i.e. all except New England, the West Coast and Alaska. The report acknowledges that the assessment was based on a limited number of indicators, namely those for which there were consistent data sets to support estimates of ecological condition on regional and national scales. It emphasises that this is merely a starting point for marine environmental assessment in the U.S. Plans to extend the geographical coverage, ecological scope and consistency of both monitoring and assessment are currently being implemented.

There are few surprises in the set of seven indicators chosen for this assessment. Water clarity is possibly one indicator that would be considered relatively unimportant in most areas of the NE Atlantic; it is, however, a major consideration where the welfare of coral reefs is concerned. An interesting approach is the use of spatial criteria (e.g. acreages) to assess condition. Clearly, even with extensive sampling, this approach must rely on a considerable degree of extrapolation.

An important aspect of the assessment is the use of informed, but nevertheless arbitrary, threshold values to rank conditions as good, fair or poor (Note: Only criteria of poor conditions are shown in the table). This provides for natural variability but may also reflect some allowance for minor change due to anthropogenic activities. This is especially significant in the case of contaminant concentrations. The preference within the EU and the NE Atlantic Region is to assess contamination on the basis of 'natural' or 'background' concentrations rather than potential effects, reflecting a more precautionary approach to pollution prevention.

Table 5.5: Indicators in the U.S. coastal condition report (adapted from USEPA, 2001).

Indicator	Interpretation	Group#
Water clarity	Water quality is considered poor if less than 10% of surface light reaches a depth of 1 meter.	NCI
Dissolved oxygen levels	Dissolved oxygen levels are considered poor when concentrations are less than 2 mg/l.	6
Coastal wetland loss	Areas with a greater than 40% decline in wetland acreage from 1780 to 1980 and/or a greater than 10% decline from the mid-1970s to the mid-1980s are considered to be in poor condition.	1
Eutrophic condition	Coastal waters are considered in poor condition if more than 20% of the area (basin, region etc.) (Ed.) show a high level of eutrophy based on six symptoms developed by NOAA.	6
Sediment contamination	Evaluated using Effects Range Medium (ERM: contaminant concentration resulting in ecological effects 50% of the time) and Effects Range Low (ERL: contaminant concentration resulting in ecological effects 10% of the time) criteria. An estuary is considered in poor condition if it exceeds one ERM or five ERL criteria.	7
Benthic index	Coastal waters are considered in a poor condition if more than 20% of the area has a low benthic index score, based on diversity and prevalence of pollution-tolerant or pollution-sensitive species.	2
Fish tissue contaminants	An estuary is considered in poor condition if more than 10% of fish sampled have tissue residues greater than FDA and international criteria or more than 20% have tissue residues (EPA guidance values.	11

#Groups as defined in Chapter 3, Table 3.1; NCI = No Directly Comparable Indicator

Another important component of marine monitoring is the U.S. Mussel Watch Programme which has been operating since 1986. This is part of the National Status and Trends Programme (NS&T) initiated by the National Oceanic and Atmospheric Administration (NOAA) and designed to monitor trends of chemical contamination and assess the effects of human activities on coastal and estuarine areas. Further details of the Mussel Watch Programme are given in Section 7.5.5.

The U.S. Coastal Research and Monitoring Strategy

This valuable report (Coastal Research & Monitoring Strategy Workgroup, 2000) provides a conceptual framework for the development and improvement of marine environmental assessment and management in the United States. It does not propose specific indicators but it does set down a number of criteria to guide indicator selection. The central message of the report is that the ability to effectively manage and protect marine and coastal environments depends on reliable assessments that, in turn, require monitoring and the design of monitoring must be based on research.

The report acknowledges current deficiencies in U.S. programmes of monitoring and assessment (including those identified in the 2001 Coastal Condition Report - See above) and proposes strong inter-agency collaboration to address them, firmly recommending that the initial step should be research in support of indicator selection. In this context the report states:

> *Research plays a vital role in increasing our ability to interpret data from our monitoring programs and enhance our monitoring tools and methods. Research is the foundation underlying all tiers of the monitoring framework and is critical to achieving the objectives of integrated assessments.*

With regard to research on marine environmental indicators, the report suggests that the following specific questions need to be addressed:

- Can the proposed indicator be quantified in a simple manner?
- Does the indicator respond to a broad range of conditions?
- Is the indicator sensitive to problematic conditions or concerns?
- Can the indicator resolve meaningful differences in such environmental conditions?
- Can the measurement provide an integrated view of effects over time and space?
- Are the results from the measurement reproducible?
- Is there reference information by which to judge the results obtained?
- Can the results be compared across differences in time and space?

In chapters 6–8 of the present report, we pose similar questions in discussing various indicator types. It is also important that the significance of the selected indicator properties be understandable and relevant to environmental managers and others, including the general public, who will use the results provided by the monitoring to guide environmental policy and management decisions.

New Zealand: Performance Indicators for the Marine Environment

New Zealand has taken a fully democratic approach to the development and confirmation of marine environmental indicators (NZMFE, 2001). The final set of indicators (Table 5.6), confirmed in 1999, was the result of a continuous cycle of scientific and peer review, which included managers, users, technical workshops and specific input from Maori.

In presenting the set of marine indicators, the New Zealand Ministry for Environment (MFE) notes that the management of issues affecting the oceans is made more complex by the lack of good data and information on which to base decisions. The indicators are aimed at filling these gaps by 'measuring, monitoring and reporting on the marine environment and the effects of human activities'.

The 30 New Zealand indicators will 'operate at a scale sufficient to inform managers and the public about key issues and risks to the marine environment. In many cases, however, they will signal the need for additional survey, monitoring or research at a more detailed level'. It is envisaged that 15 indicators would require further development before they can be implemented nationally.

This set of national indicators is interesting from several points of view. There is a strong focus on biological conditions, especially habitats and fish stocks, and in comparison to Europe and North America relatively little attention to contamination. The influence of suspended particulate materials, and their subsequent sedimentation, on coral reefs is apparent. An important feature is the linkage between sedimentation and eutrophication and land use. The need to consider land use, especially activities and developments that generate or increase run-off of sediments and nutrients, is now widely recognised and has been highlighted in such initiatives as the UNEP Global Programme of Action (UNEP, 1995), the U.S. Coastal Research and Monitoring Strategy (USEPA *et al.*, 2000) and the EU's Water Framework Directive (European Union, 2000).

Table 5.6: Indicators applied in New Zealand (adapted from NZMFE, 2001).

Category	Indicator	Group#
Physical/Chemical	Frequency of confirmed marine spills by type, cause & location.	7
	Change in catchment land use in near-shore areas susceptible to sedimentation*.	NCI
	Change in sedimentation for selected near-shore areas*.	NCI
	Change in catchment land-use for estuaries susceptible to eutrophication*.	NCI
	Chl-a concentrations for selected estuaries*.	5
	Toxic & ecotoxic contaminants in shellfish & sediments at selected sites*.	11
Habitats, Communities, Species	Percentage change in extent of selected marine habitats.	1
	Biodiversity condition of selected marine habitats & communities at selected site*.	(2)
	% area of each of NZ's protected marine environments, ecosystems & habitats*.	1
	Number of taxa in IUCN and NZ threat categories*.	4
	Abundance & distribution of adventive (alien/exotic) (Ed.) marine species*.	2
Human Health and Values	% of monitored beaches in beach grades.	(10)
	% of season beaches or coastal areas suitable for bathing or shellfish gathering.	10
	Quantity & category of litter per unit area in the strand zone of beaches.	14
	% of NZ's coastline in public ownership.	NCI
	Frequency, location & species of toxic & non–toxic algal blooms*.	(5)
	Area of NZ coastline with legally, physically or unrestricted public access*.	NCI
	% of coastal environment type in each category of natural character*.	(1, 16)

Table 5.6: (continued) Indicators applied in New Zealand (adapted from NZMFE, 2001).

Category	Indicator	Group#
Fish Stocks	Ratio of current biomass to target biomass for modelled stocks.	3
	% of stocks modelled that are at or above target level	3
	No. of assessed stocks about which stock status is known or unknown	3
	Level of total catch for each species	4
	Ratio of total catch to sustainable yield for modelled stocks.	4
	Current TAC (Total Allowable Catch) (Ed.) for each stock	3/4
	Ratio of TAC to sustainable yield for modelled stocks.	3/4
	% of stocks with current biomass below target where rebuilding plans are in place.	NCI
	No. non-assessed species of high, medium, low or unknown value and % of associated/dependent species that are protected*.	NCI

#Groups as defined in Chapter 3, Table 3.1; NCI = No Directly Comparable Indicator; [x] = Comparable in part
* Second phase of indicator implementation, 2001 – 2006

As indicated in Table 5.6, one-third of the indicators applied in New Zealand have no counterparts in the base set of indicators proposed in Chapter 3 of this report. However, most of these relate to conditions of special relevance to reefs or to ownership of, and access to, the shore; in Ireland such matters are not generally considered within the purview of water management.

Pacific Canada: Potential Indicators for Use in the Georgia Basin[4] Area

The Department of Fisheries and Oceans in Canada has developed a set of environmental objectives and associated indicators for use in the Georgia Basin in western Canada that includes a number of objectives applicable to marine areas. A report (Wilson, 1999) evaluating the objectives in relation to various technical criteria shows the linkages between specific objectives and corresponding indicators. The marine indicator component is summarised in Table 5.7. The table links the Georgia Basin indicators with the comparable indicators in the composite set given in Table 3.1.

[4] The Georgia Basin incorporates the Strait of Georgia (Canada), Puget Sound (U.S.) and Juan de Fuca strait, which separates Vancouver Island (Canada) from the State of Washington (U.S.) The marine areas of the Georgia Basin fall within a joint Canada/U.S. agreement on research and monitoring.

Although the report does not identify the determinants or methodologies to be used in measuring the indicators, the linking of indicators with particular management objectives is useful and constitutes a logical approach to the interpretation of monitoring data. A parallel approach is that used in the Heinz Center report (See Section 5.4), which develops indicators in response to specific questions about the health of the marine environment.

The Georgia basin indicators are characterised by their localised focus - many address aspects of local resources - and their emphasis on biological properties. There are lessons here for countries that are committed to large-scale regional programmes. For example, it may be counter-productive for a country to subscribe to joint monitoring programmes that carry obligations to monitor features and conditions of little or no relevance nationally.

Table 5.7: Georgia Basin (Canada) environmental objectives and corresponding marine indicators (adapted from Wilson, 1999).

Management Objective	Indicator	Group#
Reduce source emissions of substances of global and local concern.	Sea level change as an indicator of climate change effects.	16
	Seasonal and extreme marine climate. Change in sea-surface temperature and salinity.	16
Ensure that aquatic ecosystems are healthy and not affected by toxic substances.	Frequency of phytoplankton blooms.	6
	Area closed to fishing by dioxin and furan contamination.	11
	Temporal and spatial trends in the input of contaminants to sediment.	7
	Organochlorine contaminant trends in seals and killer whales.	7
Re-establish healthy shellfish harvesting areas	PSP and shellfish toxin outbreak incidence and severity.	11
Reduce non-point source pollution	Intertidal flora and fauna on unprotected beaches (exotic or keystone species).	(6)
Reduce pollutant loadings from point sources	Area closed to fishing by dioxin and furan contamination.	11
Protect healthy marine habitats for fauna, flora, and biodiversity	Changes in the abundance and species composition of zooplankton and ichthyoplankton.	2
	Spatial and temporal changes in the locations where herring spawn.	NCI
	Intertidal flora and fauna on unprotected beaches (exotic or keystone species).	2

Table 5.7: (continued) Georgia Basin (Canada) environmental objectives and corresponding marine indicators (adapted from Wilson, 1999).

Management Objective	Indicator	Group#
	Proportion of salmon stocks classified as extinct or at moderate to high risk of extinction. Natural changes in faunal biodiversity on reef habitats.	4 local*
	Trends in spawning biomass of herring (Strait of Georgia/Juan de Fuca).	3/4
	Tonnes of white sturgeon caught in the Fraser River. Natural changes in temperature and salinity outside the Fraser River plume, as an indicator of conditions favourable for salmon.	local local
	Trends in killer whale abundance.	3

#Groups as defined in Chapter 3, Table 3.1; NCI = No directly comparable indicator;
(x) = Comparable in part; *local = local relevance only. Pacific Canada: Pacific & Yukon environmental indicators

The federal government maintains a monitoring programme in western Canada, complementary to that for the Georgia Basin, (Environment Canada, 2003). It applies a small set of indicators selected to address specific priority issues i.e. contamination with synthetic organic chemicals in the region. These are summarised in Table 5.8.

Table 5.8: Priority indicators for the Pacific/Yukon region of western Canada (adapted from Environment Canada, 2003).

Indicator	Measurements	Group#
Status of seabird populations	Numbers of birds or burrows at c. 5-yr intervals	3
Contaminants in seabird eggs	PCBs in cormorant eggs from island colonies	7
Contamination of shellfish & sediments in hot-spots	Dioxins & furans in crab hepatopancreas & sediments adjacent to pulp & paper mill sites	7
Shellfishery closures	Km^2 closed due to dioxin or furan contamination	11

#Groups as defined in Chapter 3, Table 3.1; NCI = No directly comparable indicator

Atlantic Canada/US: Gulf of Maine indicators

In the Gulf of Maine[5] on the Atlantic coast of North America, Canada and the U.S. conduct a wide range of monitoring activities designed to continually assess the condition of the Gulf's ecosystems and living resources. The programme consists of numerous individual surveys carried out by various government agencies and academic institutions. Some of the surveys cover the entire Gulf, while others are confined to particular bays or estuaries in one or other jurisdiction. An inventory (Chandler, 2001) of monitoring in the Gulf region provides descriptions of individual studies and surveys, including sampling design, methodologies and quality assurance procedures. An overview of the principal indicators and related measurements is shown in Table 5.9.

[5] The Gulf Maine region includes Georges Bank as well as the Bay Fundy.

Table 5.9: Principal indicators applied in the Gulf of Maine.

Indicator	Measurements	Group#
Condition/extent of habitats	Includes wetlands, saltmarshes & coastal land use surveys.	1
Extent of seagrass communities	Aerial surveys of eelgrass beds	2
Phytoplankton communities	Monthly CPR surveys. Plankton & nutrient sampling.	2
Harmful algal species	Examination of water samples for presence of 4 potentially toxic species.	6/11
Toxins in shellfish	PSP, ASP (demoic acid) & where indicated diarrhetic SP.	11
Seabird populations	Aerial census.	3
Contaminants in mussels	10 metals, 24 PAHs, 24 PCBs, 17 chlorinated pesticides.	7
Contamination & histopathology of demersal fish	Metals & OCs in liver. Metals & OCs in stomach contents (selected fish). Incidence of specific diseases.	7/8
Contaminants in sediments	Dioxins, furans, PCBs, TBT, PAHs, Pesticides & heavy metals.	7
POPs in seals	Stranded & by-caught animals.	7
Contaminants in seabird eggs	OCs and mercury in eggs of cormorants, storm petrels & puffins.	7
Atmospheric inputs	Mercury deposition and air sampling for a range of chemicals.	7
Bacteria in bathing waters	Enterococci	10

#Groups as defined in Chapter 3, Table 3.1; NCI = No directly comparable indicator

All of the Gulf of Maine indicators, with the possible exception of atmospheric inputs, can be described as indicators of environmental state (i.e. condition). Unfortunately, as presented in Table 5.9 the indicators are not true indicators because only the property or feature to be assessed is described. Although methodologies for measuring the indicators are documented (Chandler, 2001), no information could be found on how the indicators are interpreted or assessed.

Despite such limitations, the Gulf of Maine indicators do focus on the main priority issues from the ecological, human health and management perspectives. There is very thorough coverage of the major chemical pollutants in sediments and tissues, including the tissues of predatory seabirds and mammals. Of the sets of indicators discussed in this review, this set of indicators is most comparable in scope to those currently applied or proposed in Europe and the NE Atlantic.

5.4 Assessments by Scientific Institutions

The Heinz Center Report on US Ecosystems[6]

A major assessment of United States' ecosystems (Heinz Center, 2002), including coasts and oceans, has recently been prepared by the Heinz Center for Science, Economics and the Environment. The report claims to present 'a unique system of indicators that is simultaneously relevant to contemporary policy and decision making, balanced and unbiased in what it chooses to report on, and scientifically credible in the data it presents'. The 23 scientists responsible for the marine assessment were selected from universities, research institutes, national and state agencies (including NOAA, the US Geological Survey and the EPA), private consultancies and environmental organisations.

In marked contrast to current approaches within OSPAR and the EU, the Heinz Center report is highly selective in its choice of indicators and in each case provides a clear description of the indicator and why it is included. It is intended that the 16 indicators selected will also be used in subsequent assessments, with some refinement where this is considered necessary. For the initial assessment the availability and adequacy of data varied widely between indicators. Partial or complete data were available for nine of the indicators; of these, five had sufficient data to analyse trends. For seven indicators, no data could be reported. The 16 indicators are summarised in Table 5.10.

The shortage of information on many of the indicators selected by the Heinz report experts is significant. It shows that after many years involvement in marine monitoring, and substantial investment, the combined state and federal monitoring activities of the U.S. still do not generate the kind of information needed to properly assess the condition of U.S. marine and coastal areas. This is almost certainly a reflection of the situation in other regions and countries, including Ireland.

The right-hand column in Table 5.10 provides a link to the nearest corresponding indicator listed in Table 3.1. Although the coverages are similar, there are some notable absences from the Heinz list e.g. radioactivity, litter, socio-economic indicators, wider effects of climate change.

Table 5.10: Indicators for U.S. marine ecosystems (Heinz Center, 2002).

Focus	Indicator [1]	Group#
System Dimensions		
Coastal habitats	Acreage of habitats composed of, or built by, living organisms (seagrass beds, wetlands, shellfish beds etc.)	1
Shoreline types	Miles of coastline by category i.e. beaches, mud, sand, rock, wetlands, cliffs, armoured etc.	1
Chemical & Physical Conditions		
Areas with depleted oxygen[2]	% area of estuaries & coastal waters (out to 25 nm) whose lowest DO levels fall within certain concentration ranges (0 ppm, 0-2 ppm, 2-4 ppm, >4 ppm) for at least 1 month.	6
Contamination in bottom sediments	% of sediments within 25 nm of the coast exceeding federal guidelines for pesticides, PCBs, PAHs & heavy metals.	7
Coastal erosion[2]	% of shoreline managed to control erosion	15
Sea surface temperature	% deviation from 14-yr average regional temperature in any given year (waters within 25 nm of coast).	16
Biological Components		
Native species at risk[2]	Relative risk of extinction of native marine plants & animals; based on population & territory size, threats etc.	4
Non-native species[2]	% of major estuaries with high, medium or low influence by non-native species (number of species, habitat area affected)	2
Unusual marine moralities	Incidence (numbers of dead animals, locations) of mortalities not typical for the species.	4
Harmful algal blooms[2]	Numbers of harmful blooms, or algae-caused illnesses, within 200 nm of the coast.	6, 11
Condition of bottom–dwelling animals	% area within 25 nm of the coast in which benthic invertebrate communities, are in undegraded, moderate or degraded conditions compared to undisturbed areas.	2
Chlorophyll concentrations	% area of estuaries & waters within 25 nm of the coast (by region) with seasonal averages and max. levels of chlorophyll in ranges (<5, 5-20, >20 ppb).	5
Human Uses		
Commercial fish & shellfish landings	Annual catch tonnages of fish, shellfish & other products for 5 regions out to the 200 nm territorial limit.	4
Status of commercially important fish stocks	Number of fish stocks whose biomass increased or decreased by at least 25%.	3
Selected contaminants in fish & shellfish[2]	Levels of DDT, PCBs and Hg in edible seafood tissue in relation to FDA recommended action levels.	11
Recreational water quality[2]	% of beach-mile days affected by various levels of Enterococcus	10

#Groups as defined in Chapter 3. (1) Technical notes further explaining each indicator, and covering such matters as data sources, methodologies and data manipulation are given in a technical Annex to the report. Relevant points are considered in Chapters 6-8. (2) Insufficient data available so far to report on these seven indicators.

Inter–Governmental Oceanographic Commission (IOC) of UNESCO

Immediately prior to completion of the present study a new report on marine indicators from the International Oceanographic Commission (IOC, 2003) of UNESCO came to the attention of the project team. This very useful report examines concepts and approaches relevant to the use of indicators in integrated coastal management and provides examples of environmental, socio-economic and governance indicators as applied (or proposed) in various countries and organisations. It is based on a background document prepared for an international workshop on the topic held in Ottawa in 2002. The information sources consulted for the present and IOC reports are, to a large extent, similar. All of the environmental state/impact indicators addressed in the IOC report are covered by the recommended core set of indicators presented in Chapter 3 (Table 3.1) of the present report.

5.5 Analysis and Discussion

All but two of the indicator groups contained in the conceptual core set proposed in Chapter 3 are represented in the 10 national and international sets of marine environmental indicators reviewed in this chapter. The two not represented are:

- Group 12: Offshore structures and activities (patterns & trends); and
- Group 17: Biological impacts of climate change.

We consider the inclusion of these two themes to be important because they relate to predicted future developments, one related to the expansion of offshore activities with potential to affect habitats and living resources, the other related to the medium to long-term effects of climate change in altering distributions of species and communities.

The relative frequencies at which the core set groups are represented amongst the national and international indicator sets reviewed are shown in Figure 5.1.

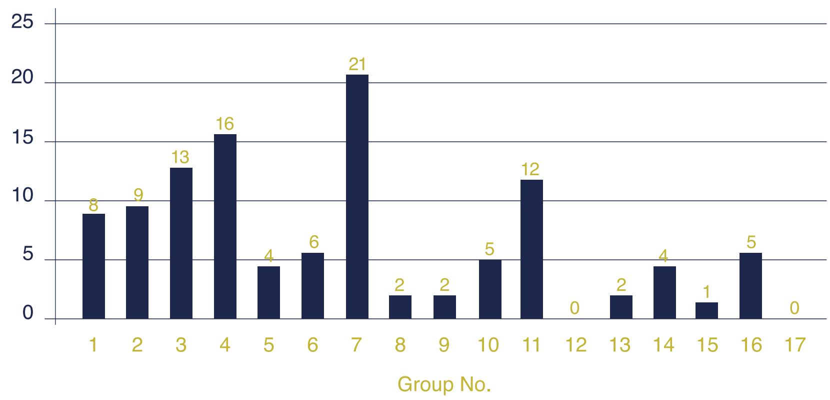


Figure 5.1: Number of indicators in sets reviewed comparable to core set groups (Chapter 3, Table 3.1)

[6] Heinz Centre (2002). This independent assessment report is not confined to the marine environment; it also covers farmlands, forests, fresh waters, grasslands and shrublands, urban and surburban areas.

Almost a third of the indicators fall into two groups, namely Hazards to Populations and Renewable Resources (Group 4) and Chemical Hazards (Group 7). Over two-thirds of the indicators fall into just seven groups, as follows:

1. Status of habitats
2. Status of communities
3. Status of populations and renewable resources
4. Hazards to populations and renewable resources
6. Effects of nutrient enrichment
7. Chemical hazards
11. Seafood safety

As this analysis shows, the classical concerns regarding the health of the marine environment - pollution, eutrophication, habitat loss, status of fisheries and hazards to human health - are still very much evident amongst the indicators used in contemporary assessments of marine and coastal environments around the world.

Further observations worthy of note are that:

- there is a surprising shortage of indicators of biological exposure (e.g. biomarkers) or effect;
- indicators of actual or potential eutrophication are not as prevalent as in the OSPAR and HELCOM (Baltic) regions;
- seafood safety appears to be a more frequent concern than bathing water quality;
- outside Europe, the assessment of radioactivity is mainly in the Arctic; and
- as yet the manifestations and effects of climate change are not a major focus of assessment.

Indicators not represented in the Core Group

The national and international indicator sets reviewed included 11 indicators[7] for which there are no directly comparable entries in the core set proposed in this report (Table 3.1). We feel it is important to examine any apparent omissions from the core set to determine if these would constitute significant weaknesses in the overall scheme.

[7] Shown in the tables as NCI: No Comparable Indicator.

Contaminant Pathways

In the context of the Arctic Monitoring and Assessment Programme (AMAP), an important research topic concerns the pathways by which chemical contaminants are transported to the Arctic from sources far to the south. This is not, strictly speaking, an environmental indicator although changes in contaminant pathways might represent significant reductions or increases in the potential for residues in humans and wildlife.

Catchment and Coastal Land Use

Several indicators focus on patterns of land use that may affect estuaries and coastal waters through the discharge of nutrients and silt. These is no doubt that these pressure indicators are of significance to marine environmental conditions and we would strongly urge that they be included in monitoring programmes in areas and habitats known, or likely to be, affected by enrichment or turbidity. However, we are reluctant to include in our core set of indicators activities and practices that may be carried out well inland from the coasts; there are many such practices and activities and their significance for estuarine and coastal waters is likely to be highly variable. Two other indicators not covered by our core set were related to land ownership and public access in the coastal zone; these issues are of special relevance in countries where the rights of Indigenous Peoples must be protected but they may also be an important ingredient in coastal zone management. We feel they would warrant inclusion only in an expanded set of indicators that addressed compliance with defined objectives for coastal land-use management

Water Clarity / Change in Sedimentation

These indicators are closely related to the problem of silt discharge referred to above. Turbidity due to suspended silt is, of course, a particular problem in tropical waters where it can be extremely harmful to coral reefs that support important local fisheries. Sedimentation is problematic mainly in areas of weak circulation where it can interfere with certain forms of aquaculture such as oyster production. However, this is not a widespread problem in Irish waters and we do not consider that specific indicators for turbidity or sedimentation are warranted in the core set. Associated biological effects should be readily identifiable from surveys to establish the Status of Communities (Table 3.1, Group 2).

Criteria for Fish Stock Assessment

Several indicators were clearly designed to assess progress in implementing fisheries policies and associated measures peculiar to the country concerned. One focused on stock biomass in relation to management plans and the other on the status of 'non-assessed' but protected fish species. These do not appear relevant in the current Irish context. Another national indicator recorded the number of 'fishing rights' issued to small and medium-sized enterprises and their percentage of available quotas.

A similar pressure indicator may have relevance for the status of salmonid netting in Irish estuaries and could be included in Group 4 of our core set of indicators if suitable catch data were unavailable.

Changes in Fish Spawning Grounds

One of the indicators listed for the Georgia Basin on the U.S./Canadian Pacific coast relates to the locations and times at which herring spawn. It is unclear whether this is directed at natural shifts in stock distribution, direct human interference with spawning grounds (e.g. aggregate extraction), or the possible effects of climate change. Clearly, changes in spawning patterns of commercial species may have major implications for fisheries. Insofar as this may be a manifestation of climate change, Group 17 of our core set of indicators covers it. Group 1 covers the direct effects on habitats, including spawning grounds.

5.6 Conclusion

This review of marine environmental indicators used or proposed outside Europe has not revealed any new or especially innovative indicators that would significantly improve the monitoring or assessment of Ireland's marine and coastal areas. The core set of indicators proposed in Chapter 3 stands up well in comparison to those used internationally. The review increases confidence in the applicability of the core set for use in Ireland and similar developed temperate regions.

6.0 Population, Community and Ecosystem Responses as Bio-Indicators in Marine Environmental Monitoring

6.1 Introduction

This section reviews biological responses to pollution at the population, community and ecosystem levels. Indicators of biological change due to natural and anthropogenic influences are essential tools for marine monitoring but there is often confusion regarding the levels of biological organisation that should be investigated. In Chapter 7 we examine a range of biomarkers, many of which respond to particular stressors (e.g. contaminants or contaminant types). Here, we look at less definitive approaches for detecting change for use where there is limited prior knowledge concerning the types and levels of contamination present. Such methods can provide a measure of net impact on marine life that may not be detected by more specific indicators or deduced by extrapolation from ecotoxicological data.

This topic warrants special treatment in this report as there has to date been limited biological monitoring in Ireland's marine monitoring programmes and this situation will need to be reviewed in the light of impending EU (e.g. Water Framework Directive) requirements. Furthermore, monitoring of benthic communities is likely to be an important tool in any future monitoring of offshore activities, such as the exploitation of oil and gas reserves off Ireland's west coast.

Perhaps the first question to ask is what responses are shown by biological systems to stressors such as nutrients, metals, persistent organics, suspended solids and oil, and physical effects due to sedimentation. The concept of stress, however, remains highly controversial and there seems no reason why the term should be used in a marine context. Indeed, the medical literature on stress confuses cause and effect and it is by no means clear that stress is necessarily harmful to human health. Grime (1989) defined stress as "external constraints limiting the rates of resource acquisition, growth or reproduction of organisms". He justified the continued usage of the term stress by arguing that ecologists are being asked to predict and analyse stress responses at all levels from individual organisms to whole ecosystems for management purposes, which is precisely the purpose of this review. However, Grime's definition also includes disturbance, a term widely used in ecology. Harper (in Grime 1989) objects to the lack of precision of what the term disturbance means, for exactly the same reason that it confuses cause and effect.

No attempt is made here to define disturbance or to distinguish between stress and disturbance. Furthermore, there seems no valid reason to continue to use the term stress response. Instead the approach is more pragmatic, examining how changes in populations, communities and ecosystems are measured in response to nutrients, metals, toxic organics, suspended solids and oil. However, there is a fundamental difference between responses measured at the individual level and at the population, assemblage and ecosystem levels. Whereas it is possible to use biomarkers that respond to specific contaminants (e.g. metallothioneins to metals and cytochrome P-450 to PAHs) the responses at the population and higher levels are general ones and do not indicate a specific contaminant source.

6.2 Population Level

It is widely believed by biologists that it is only at the population level and above that effects of pollutants are significant. The reason for this is that although biomarkers may show signs of effects on individuals it is only if these effects lead to a reduction in the number of eggs produced, or survival or increased mortality (called fitness), and many individuals in the population are affected, that effects are regarded as significant. In other words, if the survival of the population is not threatened, the damage to the community or to other ecosystem components or processes will be limited and unlikely to have widespread or long-term consequences. Of course, this approach is not always accepted by the general public, particularly when applied to certain marine birds and mammals that are of special appeal due either to their appearance or behaviour. In this context, it is important to emphasise that significance in scientific terms is not the same as acceptability to society as a whole.

The classical approach is to census the population over time and record changes in the number of individuals and the distribution of age-classes. From such data it is possible to derive survivorship (l_x) and mortality (m_x) curves.

Typical data from such surveys are shown in Table 6.1.

Table 6.1: Example of calculation of population survival rate (l_x) and mortality rate (m_x)

Age in years ($_x$)	Observed numbers of animals alive (n_x)	Proportion surviving at start of age interval (l_x)	Number dying within age interval age interval (d_x)	Rate of mortality (m_x)
0	115	1.0	90	0.78
1	25	0.217	6	0.24
2	19	0.165	7	0.37
3	12	0.104	10	0.83
4	2	0.017	1	0.50
5	1	0.009	1	1.0
6	0	0	–	–

In the above:

$n_x+_1 = n_x – d_x$

$l_x = n_x / n_o$

$m_x = d_x / n_x$

In order to make survivorship and mortality curves one must be able to age the plants or animals under study. This is often not an easy task and one has to assume that size-classes are equivalent to age classes. This is not the place to give details of the methodology needed but they were described by Crisp (1984) as part of the IGBP (International Geosphere-Biosphere Programme) and are still valid today.

From such data one can compare the populations of a given species at a site subjected to a contaminant with a control site not affected to see if there is higher mortality at the contaminated site.

However, there are many problems with such studies. The definition of a population is a group of individuals at a particular site that are capable of interbreeding with each other. Most marine species occur in open systems with no clear boundaries between individuals and many have larvae that are dispersed great distances. Thus, defining what is a population in a marine context is exceedingly difficult. In practice the population is usually defined by samples taken at a given locality where not all the individuals are sampled.

Perhaps surprising to those not working in this field, very few of the many published papers on the effects of pollutants on marine organisms show effects at population level. The most obvious effects on populations occur in response to nutrient enrichment. Whereas there is much literature showing that metals and organic chemicals accumulate to high levels in many marine organisms, these do not lead to effects on populations except in a few cases.

6.3. Community Level

It is generally believed that monitoring of effects of pollutants is best done at the level of the community. The reasons for this are that marine communities are species rich and the species cover a wide range of feeding and reproductive types. Contaminants will often affect some of the species and by use of modern statistical analyses it is straightforward to determine the type and scale of change in community structure. Whilst it is possible to measure changes in planktonic communities the problem is that, by definition, plankton moves with tides and currents and thus it is often extremely difficult to relate changes found to a specific contaminant or discharge. Benthic monitoring is the preferred option. For example, a recent USEPA report (USEPA, 2000) states, "Benthic macroinvertebrates are an appropriate assemblage for all biological assessments of water bodies because they respond to water, sediment, and habitat qualities, are not very mobile, and consequently, integrate long-term changes in these ecosystem components."

The reason for this is that most contaminants adsorb to particles in the water column and are deposited on the sediment. Thus, effects are more likely to be detectable in the benthos than the water column. Most of the species are non-motile or at best able to move short distances. Chemical contaminants will affect a proportion of the species that must either adapt to the contaminant or die. As species have widely different tolerances to different chemicals, many respond and changes in population densities of suites of species is the general rule. Furthermore, some of the species are suspension feeders in the water column, some deposit feeders and some predators. Reproductive patterns also vary from species that have long-lived planktonic larvae to direct developers and brooders. For these reasons benthic systems have become the most widely used method of monitoring effects of pollutants.

The US EPA has prepared a document designed to assess which stressors are important in a given system (http://www.epa.gov/ost/biocriteria/technical/). There are a large number of ways of measuring effects of contaminants on communities. These range from simple indices to graphical methods and to sophisticated multivariate statistical analyses.

Diversity indices as indicators of effects of contaminants

Engineers and managers are often overwhelmed by the complexity of biological data. With typical benthic data one single grab sample (0.1 m2) of seabed from 50 m (below the picno- and thermoclines) sieved on a 1 mm sieve will usually obtain 40-50 species. Take 10 replicate samples and one obtains on average around 300 species and perhaps 10,000 individuals. Since sampling is blind and the animals are usually buried beneath the sediment surface one is unable to select visually a few species as would be the case with population monitoring. In a typical monitoring survey, 25 or more sites (often called stations) may be sampled and thus it is difficult to interpret the data and to obtain a simple overview. Presenting this wealth of data can be confusing, so summarising, or so-called diversity, indices were developed in the 1950s (Shannon & Weaver, 1949), which attempt to measure the 'well-being' of a community. Diversity indices integrate the number of individuals per species, and total number of species, into a single number that is usually large in undisturbed assemblages and low in highly disturbed assemblages (see Gray 1989 for an example).

There is a wide variety of diversity indices - reviewed by Magurran (1988) and Gray (2000) - that seem to have an appeal to managers, as they are believed to incorporate a variety of complex biological data into a single figure. Although their use is widespread it is naïve to believe that complex biological data can in fact be reduced to a single index (Gray,1976) and it is not an approach that we recommend. Diversity of sediment-living communities alters with a wide variety of natural changes in the environment, such as depth, environmental heterogeneity, competition between species, varying predation pressures and environmental variability. Thus, effects of contaminants have to be measured against these naturally varying factors. This is seldom done. Yet, since indices are widely used and are simple to calculate, we see no reason why they should not be calculated.

Hill (1973) showed that of the commonly used diversity indices, total species richness and Simpson's index between them characterise the partitioning of abundance between species; with Shannon's index intermediate. These three indices are those recommended for characterising species diversity.

Whittaker (1972) proposed as the first index of species diversity an index which Gray called Heterogeneity Diversity HD1:

HD1 = exp(H'), where

$$H' = -\sum_{i=1}^{S} p_i \log_2 p_i$$

H' (is the commonly used Shannon–Wiener index: where S = total number of species, and $p_i = n_i / N$ where n_i = number of individuals of the ith species and N = total number of individuals.

Whittaker (1972) also first suggested using the reciprocal of Simpson's index (called HD_2):

$HD_2 = 1/(p_1^2 + p^2_2 + p_n^2)$

where p_1 is the proportional abundance of the first species compared to the total number of individuals in the n samples. Hill (1973) also used this notation. Whittaker (1972) argued that the Simpson index is primarily a measure of dominance, especially of the first 2-3 species whereas the Shannon index is more strongly affected by species in the middle of the species rank sequence. Thus the two indices measure different aspects of species diversity.

An additional aspect is how the abundances are partitioned among the species. This aspect has been called evenness. The most commonly used form is that of Pielou (1976):

$J = H'/H_{max}$

where H' is the Shannon-Wiener diversity index and H_{max} is maximal diversity i.e. log (H).

Whittaker (1972) argued convincingly that J is not, in fact, a good measure of evenness since log S is greatly influenced by sample size, whereas H' is not. Hill (1973) suggested a new index to overcome this problem:

$J' = H' - H_{max}$ or $\ln (HD_1 / SR_S)$.

A major criticism of the use of diversity indices to measure effects of stress is their insensitivity. This has been stated many times but is most clearly demonstrated by Gray *et al.* (1990) and Warwick and Clarke (1991). Figure 6.1 shows typical data from the Statfjord oil field, (Kaarstad *et al.*, 1993). Abundance increases only within 500m of the discharge point; the number of species changes at 1000m distance as does the Shannon-Wiener index. From practical experience, a statistically significant reduction in the Shannon-Wiener index occurs only when approximately half the species have been lost; one does not need an index to show such a change. This is shown clearly in Figure 6.1b the number of species drops from 84 at 2500m to 55 at 1000m from the point of discharge, whereas the Shannon-Wiener index decreases from 5,17 to 4,05 (Figure 6.1c). Yet the surprising fact is that there has been a resurgence of interest in diversity indices and these are still widely used to indicate effects of stress, (e.g. Estacio *et al.*, 1997; McLusky & Martins, 1998). However, there are alternative multivariate methods that are able to detect changes in similar data from oilfields out to 3,000m distance from the source of contamination (Gray *et al.*, 1990).

A diversity index measures the total number of species (species richness) and the distribution of individuals among species (the evenness component). There are many studies (see Gray 1981; Magurran, 1988) that show that the most used index, the Shannon-Wiener, varies more with evenness (which is the inverse of dominance) than it does with species richness. Thus, it is change in dominance patterns that is the key to understanding changes in the Shannon-Wiener index. A common trend with severe stress caused by contaminants is that some opportunistic species increase in abundance since many of their competitors are eliminated. This is most clearly shown with organic enrichment (see Pearson and Rosenberg's 1978 review), which is the most widespread source of pollution in coastal waters worldwide (GESAMP, 1990). Yet, do all effects of stress result in the same pattern of effect? Gray (1982) argued that physical disturbances leading to a reduction of numbers of individuals of many species would lead to increases in abundance of opportunists and thereby changes (an increase in this case) in dominance. In relation to organic enrichment, increased sedimentation of organic material (a physical disturbance) leads to such an effect. Chemical contaminants on the other hand do not lead to such effects since often the dominance pattern does not change and thus the Shannon-Wiener index does not alter (Olsgard, 1993). Thus, there are differences in responses dependent on the type of stress imposed on the system.

Figure 6.1: Changes in abundance, number of species and Shannon–Wiener diversity index along a gradient of contamination as distances (in m) from the oil installation at the Statfjord field (data from Kaarstad *et al.*, 1993, unpubl.).

Species–abundance patterns as indicators of effects of contaminants

A wide variety of different methods of plotting species-abundance patterns have been suggested (see Magurran, 1988 and Begon *et al.*, 1996). Marine benthic ecologists have derived their own methods. For example, Pearson and Rosenberg (1978), in their review of effects of organic matter on benthic systems, proposed SAB curves (Species, Abundance, Biomass) that showed changes along organic enrichment gradients. Pearson and Rosenberg's (1978) review shows clearly that, as a general rule, as organic matter increases slightly there is an increase in number of species. Then, as organic matter increases further, first total biomass increases and then numbers of individuals increase, until S, A and B decrease sharply - a point they term the "ecotone point" (Figure 6.2).

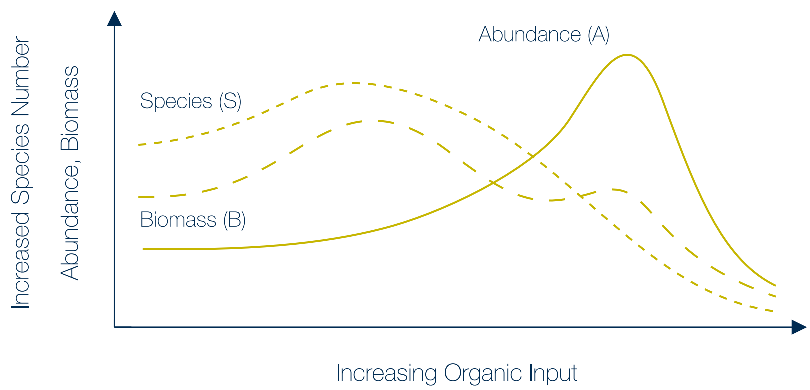


Figure 6.2: Pearson and Rosenberg's model of organic enrichment, the Species, Abundance and Biomass (SAB) curves (from Pearson and Rosenberg, 1978).

This pattern has been found almost universally with organic enrichment. One of the major problems, however, is that the pattern is not predictive in the sense that the organic matter axis is simply described as "increasing organic matter". What is needed is an understanding of the quantitative relationships between nutrient inputs, organic enrichment and the effects on organisms. Environmental managers want to know by how much they need to decrease inputs to return the system to within normal limits of variability.

Based on the Pearson-Rosenberg model, Gray (1993) attempted to analyse what were the predicted effects of organic enrichment. Organic enrichment encompasses increased sedimentation of particles, a purely physical process, increased amounts of carbon and increased amounts of nutrient (nitrogen compounds and phosphate) and decreases in oxygen. Whilst most attention has been given to carbon loading, carbon is seldom limiting for processes that occur in sediment whereas nitrogen is often limiting (Valderhaug and Gray, 1984). If we are to develop models that can be used by managers, we need to separate effects caused by increasing nitrogen from decreasing oxygen and from the purely physical effects of particle sedimentation.

Table 6.2 shows the suggested influence of increased nitrate in pore water on the benthic fauna. The data on which the table is based are in fact correlative rather than cause and effect, so there is a need for experimentation to check whether or not the hypothesis is tenable or not.

Increased aerobic bacterial activity will lead to reductions in oxygen saturation. Figure 6.3 shows known effects of reduced oxygen saturation. As saturation decreases the initial responses, when saturation falls below 40%, is that fish leave the area. With the absence of fish, predator pressure is probably reduced on the benthos and this will lead to changes in abundances and species composition. Opportunists are no longer predated and increase in abundance; some rare species are out-competed and become locally extinct. Below 25% saturation mortalities begin to occur, notably with bivalves, and some polychaete species die. Those species that tolerate low oxygen increase in abundance (e.g. the Capitella complex of species, a number of species of Polydora and Chaetozone setosa). The result is dominance by polychaetes. Under extreme conditions only a few species of nematode survive.

Table 6.2: Suggested changes in benthos of boreal fjordic assemblages associated with changes in Nitrogen in pore water, (from Gray 1993).

Nitrate in Pore Water

Normal 40-50 µmol cm^{-3}	X2 60-70 µmol cm^{-3}	X4 70-80 µmol cm^{-3}	X6 80-90 µmol cm^{-3}	X10 >100 µmol cm^{-3}
Normal community Low dominance <20%	**Increased:** Abundance	**Increased:** Abundance **Decreased:** Abundance	Few species survive	H_2S
Rich in Phyla and Families	Abra Goniada Ophiura Nephtys Chaetozone	Chaetozone Pholoe Ophiura Capitella Jassa Hippomedon Montacuta Abra A.filiformis Scoloplos	Capitella Chaetozone	Beggiatoa mats. Few nematodes only.

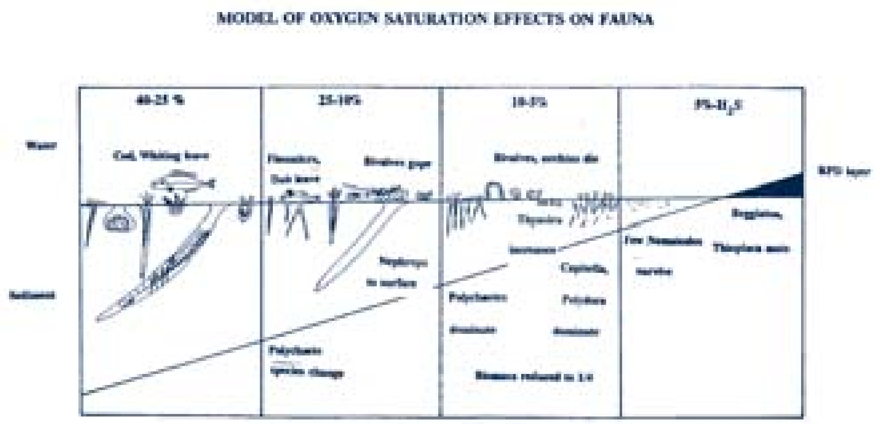


Figure 6.3: Changes occurring with organic enrichment (from Gray 1993, based on Pihl, 1989)

Gray (1982) has suggested that the response to organic enrichment from sewage outfalls may not in fact be to either increases of carbon or nitrogen nor to reductions in oxygen but simply be a physical effect of sedimentation from the water column. High particle sedimentation rate leads to smothering of the sediment surface and of course smothering of the organisms within the sediment. Species that cannot tolerate high sedimentation rates, such as burrowing polychaetes and suspension feeding bivalves, die. The new surface is available for colonisation and the species that colonise are those with larvae available in the water column such as Capitella capitata and species of Polydora. A terrestrial model developed by Grime (1989) suggests that there are two primary adaptive strategies, tolerance and ruderal. In relation to organic enrichment tolerant species are those that tolerate low concentrations of oxygen. The ruderal strategy ensures rapid colonisation of disturbed habitats, shown here by species of the genera Capitella and Polydora, which are typically opportunistic species.

One other characteristic of the species that occur at the end-points of high disturbance is that they are often complexes of sibling species (Gray, 1982; 1989). Knowlton (1993) has reviewed the occurrence of sibling species in the marine environment but has overlooked Gray's earlier suggestion (1982) that this may be a characteristic of species occurring in stressed environments.

Methods

Log-normal distribution as an indicator of effects of contaminants

Gray & Mirza, (1979) proposed a method for detecting effects of pollution on benthic assemblages. The idea was based on an earlier paper of Patrick (1972) who had examined the distribution of individuals among species in diatom assemblages attached to slides in freshwater. She plotted her data as log-normal curves of abundance. Gray & Mirza's (1979) proposal was that in unstressed marine benthic assemblages a log-normal distribution of individuals among species was the usual pattern. Under stress the distribution changed to give two or more log-normal distributions. The idea was widely tested and led to considerable controversy with opponents claiming that other distributions such as the log-series were more appropriate models (Lambshead *et al.*, 1983, 1985). Ugland and Gray (1983) developed a theoretical model of the changes that were occurring in species-rich assemblages under stress. In an unstressed assemblage, 70% of the species are rare occurring at densities of 1-2 per sampling unit and few species are common. They suggested that in response to a disturbance some rare species become locally extinct, some rare species become moderately common and some species become extremely common. The result is that a single log-normal curve splits into 2 or more curves (Figure 6.4).

The pattern described above occurs with many different types of assemblage and so is a predictable one. Yet the failing of Gray and Mirza (1979) and Ugland and Gray (1983) was to call this a log-normal distribution. It does not matter whether the data exactly fit a log-series, log-normal or negative-binomial distribution; it is the change in the pattern of the distribution of individuals among species that is of interest. It is precisely these complex changes that are the key to the success of the multivariate methods described below.

In the undisturbed situation most species occur as single individuals or at low abundances e.g. 2-3 individuals per species and there are few common species with high abundances. A slight stress leads to a number of fundamental changes: 1) the number of rare species is reduced, 2) some moderately common species increase in abundance and others decrease, and c) some species increase greatly in abundance. The overall species number may increase. The single unstressed "log-normal" curve splits up into two overlapping curves. At severe levels of stress, 1) the number of rare species decreases greatly and many species become less abundant, 2) some species become extremely common and 3) some moderately common species increase in abundance. Here the original unstressed "log-normal" curve becomes three or more overlapping curves.

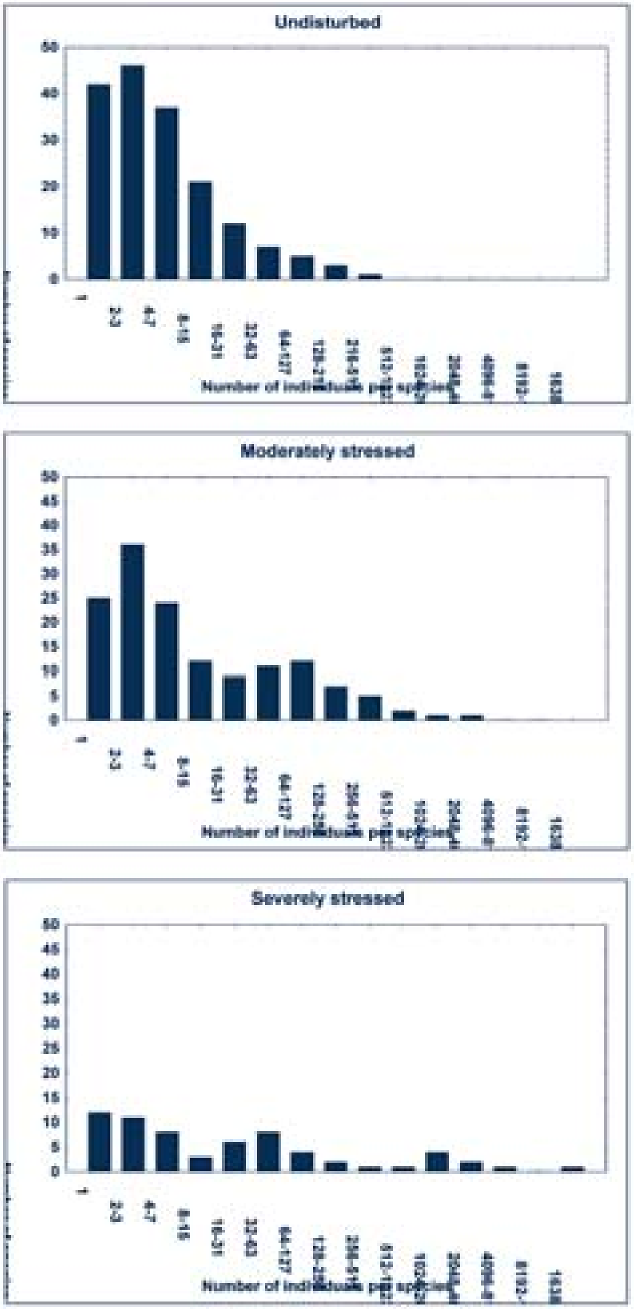


Figure 6.4: Theoretical effects of stress on the distribution of individuals among species in x2 geometric classes, (log-normal distribution), against number of species per class (from Ugland and Gray, 1983). For explanation see text.

Plots of this type have been used for many years in recording changes caused by discharges of drilling cuttings in the Norwegian sector of the North Sea. The patterns above are repeatable and predictable. Figure 6.5 shows a plot from a field data set.

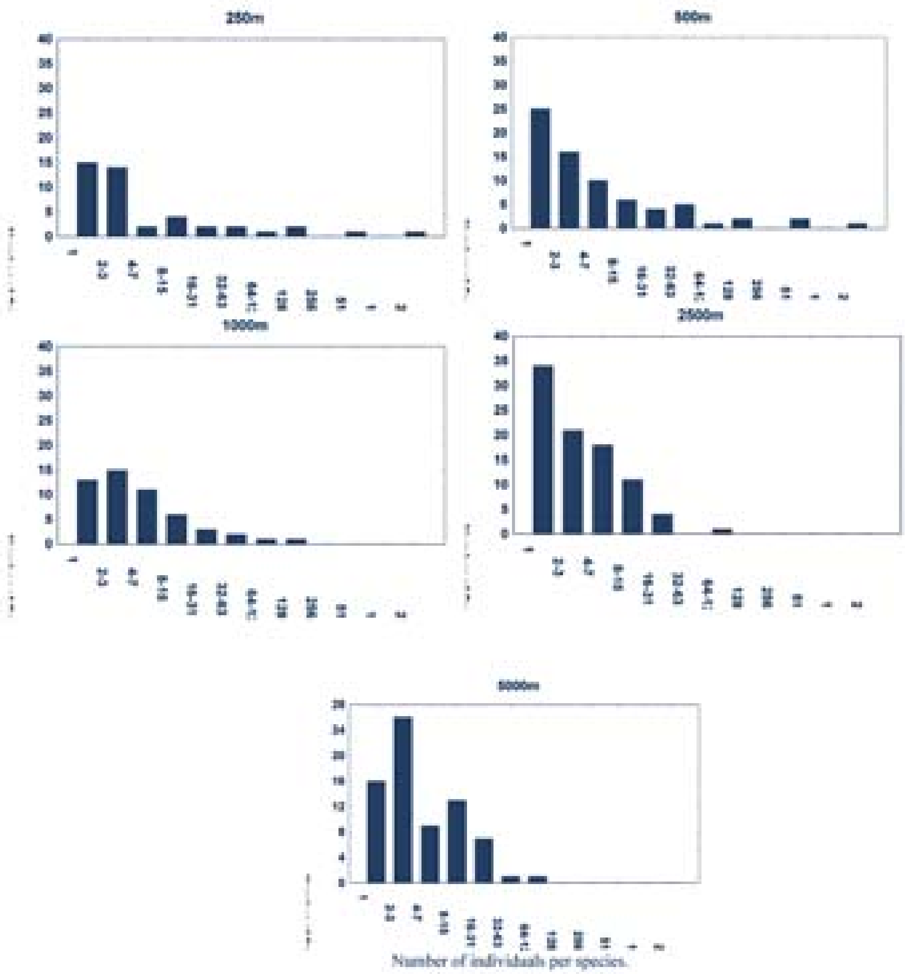


Figure 6.5: Plots of species-abundance curves for the Statfjord oilfield, 1992 (Data from Kaarstad *et al.*, 1992).

Figure 6.5 shows that many rare species become locally extinct, some species become very common and there are large changes in abundance of the moderately common species as predicted. The data show good agreement to the theoretical model (Figure 6.4).

Figure 6.6 shows that at a dumping site for sewage sludge in the Firth of Clyde there is a highly impacted faunal community, as shown for Station 7. Stations 1,2 and 10,11,12 are unaffected and the intermediate ones (3,4,5,8,9) are slightly affected.

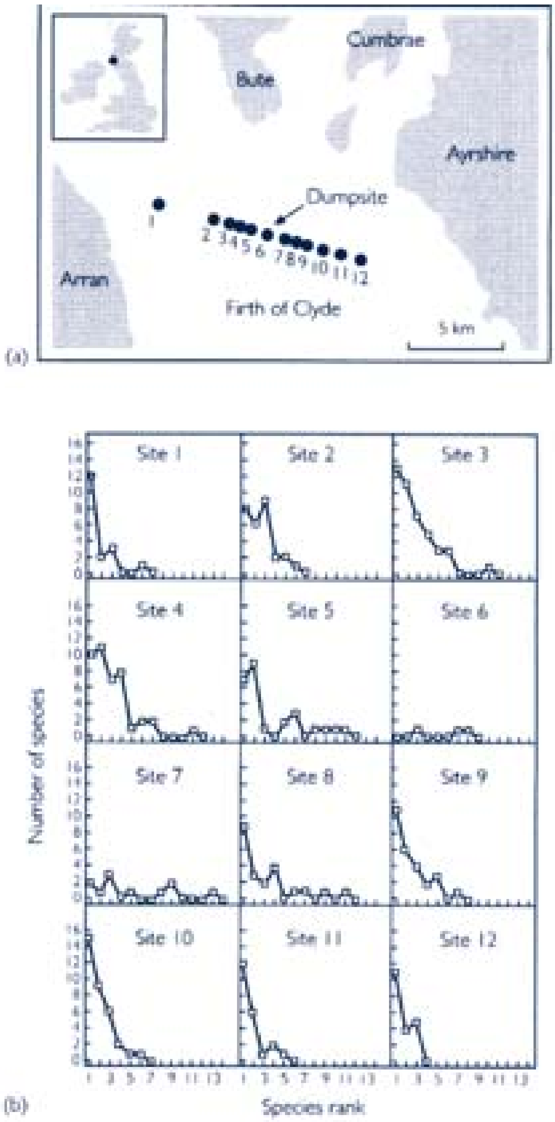


Figure 6.6: Benthic macrofauna at the sewage dumping site in the Firth of Clyde, Scotland, UK: a) sites, b) log-normal plots (from Gray & Pearson, 1982).

The interest in plotting the curves is to demonstrate that changes are occurring but also that these changes are complex and cannot be presented as a change in a single univariate index, such as a diversity index. The main focus should be to examine which species are changing. Why are some rare species disappearing? Are the species of intermediate abundance those that are most sensitive to change both as increases and as decreases? Gray and Pearson (1982) suggested that by concentrating on these species one is in a better position to monitor changes in space and time caused by stress. The argument being that these 7-10 species were highly sensitive to environmental change and use of many species rather than a single indicator species is preferable; in addition these species occurred in abundances that were amenable to statistical analyses. Recently, Harvey *et al.* (1998) have applied these ideas to changes in faunal composition at a dredged site in

Canada and found that the low and intermediate abundance species were indeed those that best showed responses. Explaining why species are rare, and why they are eliminated, is much more difficult since there are many reasons why species are naturally rare. One approach is to construct models that mimic stress situations and make predictions of the probability that individual species will become locally extinct.

'k' dominance and ABC plots

Another method of expressing response to 'stress' is to plot the rank of abundance and rank of biomass per species and compare the two curves. Here Abundance and Biomass are used in a Comparison, the ABC method of Warwick (1986). In such plots the rank abundance of species against abundance and biomass (so-called 'k' dominance curves) are plotted. In an unstressed environment the biomass curve is always above the abundance curve, whereas in severely stressed environments the abundance curve is above the biomass curve. Where the two curves cross is regarded as an intermediate situation (Figure 6.7).

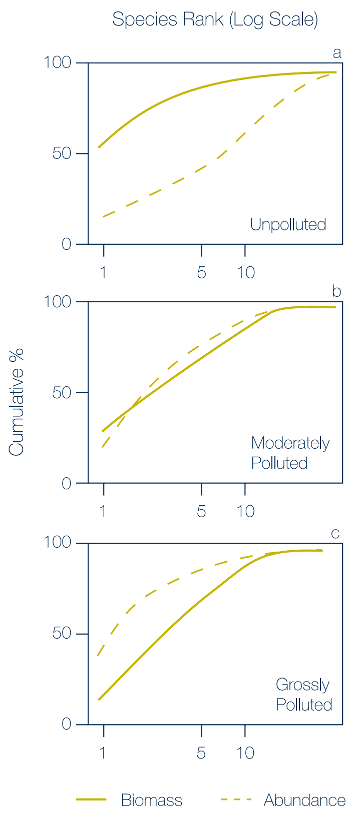


Figure 6.7: The ABC comparison using `k´ dominance curves, showing changes with degrees of pollution (from Warwick, 1986). See text for explanation.

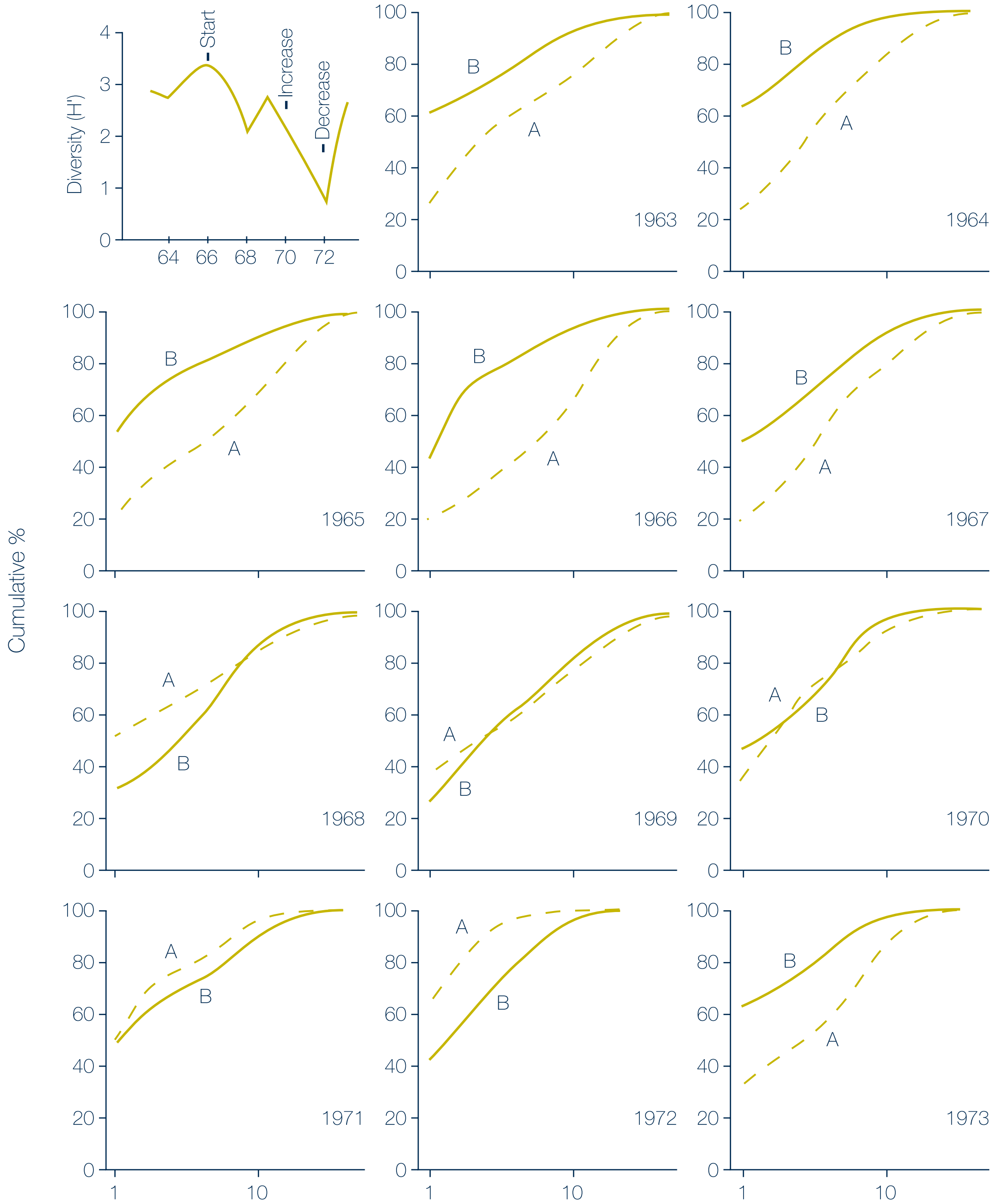


Figure 6.8: Changes in benthic fauna in Loch Linnhe Scotland, UK subjected to organic enrichment from a paper mill that began discharge in late 1966 and stopped in 1971.
(From: Gray, J.S. – co-author of this report – personal files)

Figure 6.8 shows changes over time assessed by the ABC method with data from discharge of a paper mill to a Scottish fjord.

Warwick originally suggested that these curves could be used to interpret whether a given environment was polluted or unpolluted, but Beukema (1988) found that at high levels of intertidal beaches in the Netherlands the "polluted" curves were found. Since the high intertidal can be regarded as a physically disturbed habitat, it is perhaps better to interpret these curves as indicating responses to disturbed habitats, rather than to effects of pollution.

Multivariate Statistics

Perhaps the most striking success of the past two decades has been the application of multivariate statistics to analysis of effects of stress on marine benthic assemblages. With the development of easy to use packages (notably PRIMER, Clarke and Warwick, 1994) multivariate statistics are now widely applied. These methods are able to detect effects at much greater distances from a point source discharge than other methods such as diversity indices (see Gray *et al.*, 1990; Warwick & Clarke, 1993). Not only is their sensitivity superior to univariate methods but also when used in a consistent manner with the same procedures (e.g. dissimilarity index, clustering method, transformation method and species exclusion) the techniques are objective. Newly developed methods of linking species groupings to environmental variables such as BIOENV in PRIMER and forward selection in CANOCO (Jongman *et al.*, 1987) have greatly facilitated the interpretation of the species patterns found, (Olsgard & Gray, 1995; Olsgard *et al.*, 1998). Yet the major problem is that the results of the multivariate analyses are merely correlative and are not necessarily cause and effect relationships. Too often studies stop at the multivariate analysis rather than this resulting in the posing of hypotheses that can, by use of experimental methods, be tested further.

To give a practical example, data are shown in Figure 6.9 from a survey of benthos around the Ekofisk oil field, North Sea (Gray *et al.*, 1990).

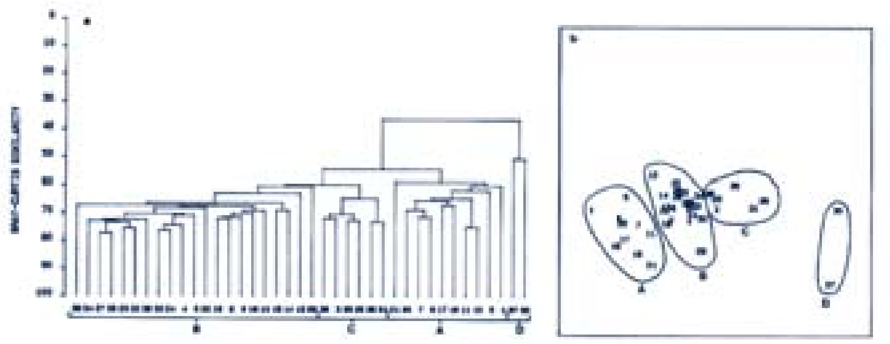


Figure 6.9: A classification and ordination analysis of the benthos around the Ekofisk oilfield showing groups of stations from unpolluted (A) to grossly polluted (D) (from Gray et al., 1990).

Multivariate analysis shows the 40 samples can be split into groups. The groups on the MDS[8] (r.h. figure) are from the classification analysis and show how well the two analysis methods agree. Clearly there is a gradient in the fauna from A-D or D-A. Plotting the groups on the sample map is shown in the next figure. Gray *et al.* (1990) show clearly that the effects are found out to 3000m, much further than could be revealed by use of univariate methods. Figure 6.10 shows the results.

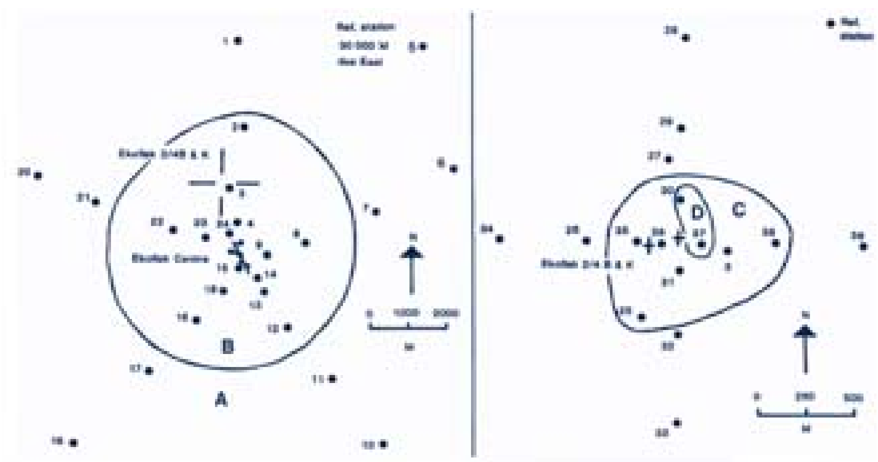


Figure 6.10: Plotting the groups of stations from the multivariate statistical analyses on a map of the area. This shows that effects are found to a 3,000 m radius (the split between A and B) (from Gray et al., 1990).

Another example illustrates the effectiveness of multivariate compared with univariate methods. These data are taken from the polluted Norwegian Frierfjord that has discharges from the chemical industry (Gray *et al.*, 1988). Site A is unpolluted at the mouth of the fjord and the sites thereafter move into the fjord, with Site G innermost.

[8] Multi–Dimensional Scaling (See also Annex 2).

In Figure 6.11 the Shannon-Wiener index shows clearly that site A is unpolluted but there is little difference between sites B-G as the 95% confidence intervals overlap. Yet multivariate analyses (Figure 6.12) show clear separation between sites and high similarity between grabs within sites.

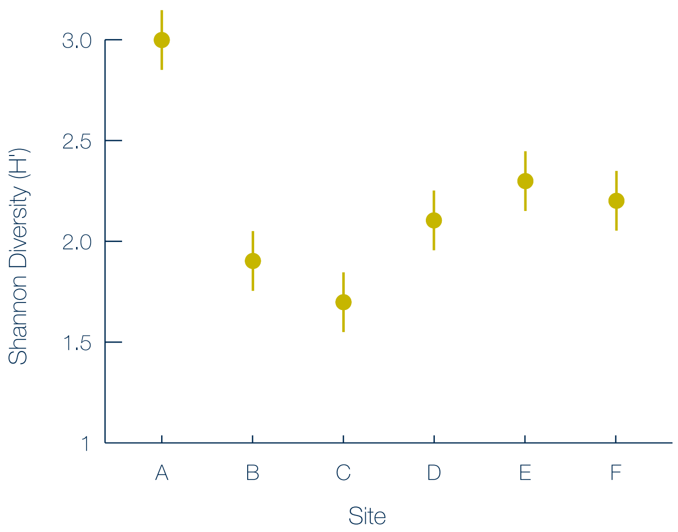


Figure 6.11: The Shannon-Wiener index for benthic samples from Frierfjord, Norway (from Gray *et al.*, 1988).

The classification analysis (Figure 6.12a) shows the similarity between replicate samples from each site (4 similar letters). The data show high degrees of similarity between replicates and that Sites G and E are different from all the other sites with Site A being different from B, C and D. We cannot, however, interpret a gradient from these results. For that we need a MDS analysis.

In the MDS plot (Figure 6.12b), the stations are depicted in two-dimensional space in relation to each other and show that the clean site A is separated from the others, but it is not clear whether Sites E and G and Sites B, C and D can be separated. For this we have to employ more complicated analyses methods. These will not be discussed here but interested readers should consult Clarke & Warwick, 1994. The results are described in Gray *et al.* (1988).

Whilst the approach suggested by Field *et al.* (1982) and encapsulated in the PRIMER programme (Clarke and Warwick, 1994) and in CANOCO (Jongman *et al.*, 1987) has been adopted almost universally, such programmes have been largely ignored in the United States. Instead, in the U.S. a Triad approach has been adopted (Long, 1989; Long & Chapman, 1985; Chapman, 1992). The Triad involves analysing the grain size and chemistry of sediments, the species: site matrices and conducting toxicity tests based on extracted pore-water. Most recent analyses using PRIMER and CANOCO also relate the sediment physico-chemical properties to faunal distribution patterns (Olsgard & Gray, 1995). Yet the Triad approach does not use the species:site matrix but instead uses surrogates by first calculating diversity indices and other faunal indices before using a Principal Components Analysis to relate these surrogates to the physico-chemical data.

For that we need to do a MDS analysis.

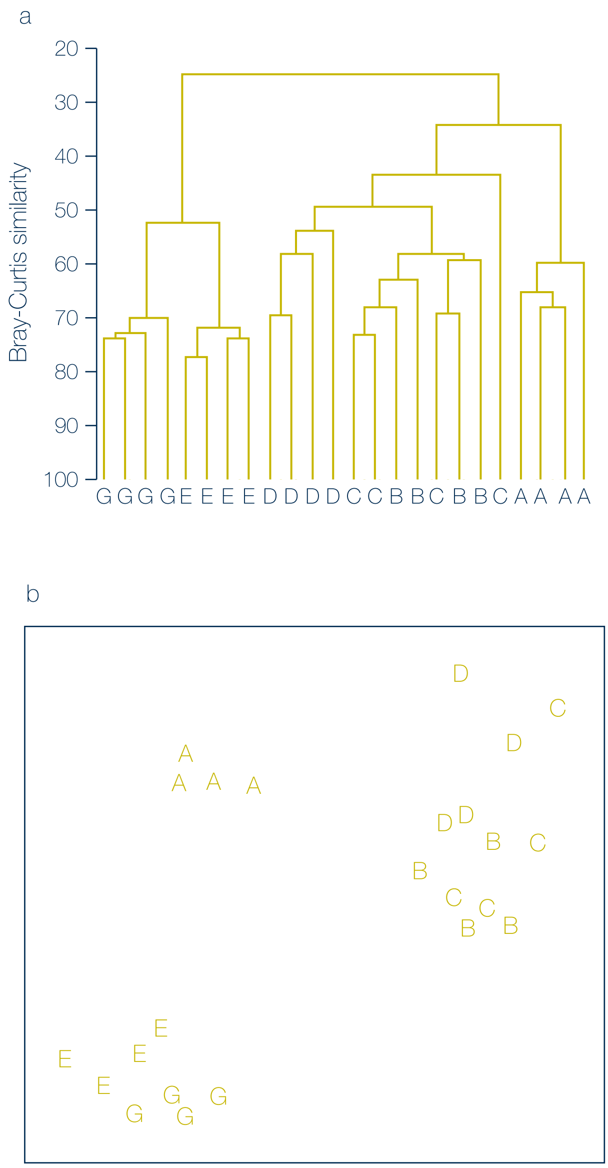


Figure 6.12: a) Classification of benthic data from Frierfjord, Norway, data as in Figure 6.11; b) MDS plots, (from Gray *et al.*, 1988). Symbols as in Figure 6.11.

As demonstrated clearly above, diversity indices are much less sensitive than, for example, MDS analyses in detecting effects of stress. Thus, it is not surprising that the Triad approach does not detect subtle effects, such as that found at Ekofisk by Gray *et al.* (1990). Use of a Principal Coordinates Analysis (PCA) for analysing complex data with many variables is also regarded generally as statistically less sound than use of, for example, MDS.

The third part of the Triad is an interesting aspect and is based on the argument that relating faunal patterns to physico-chemical properties merely indicates correlation and does not help in unravelling cause and effect relationships. By testing the toxicity of the sediments, it is hoped that such relationships can be established. Yet the problems of establishing highly sensitive sediment-toxicity tests are immense. One test is based on burrowing activities of an amphipod Rheopoxynius abronius. Yet most sediment-living species have distinct preferences for limited ranges of sediment grain size (Gray, 1974) and thus do not burrow into unattractive sediments. Interpreting burrowing behaviour is difficult and one cannot simply assume that it is a chemical factor that gives a certain response. Such sediment-toxicity tests were carried out on three species of amphipod at the Bremerhaven workshop (Chapman, 1992) and in general showed lack of sensitivity, whereas other tests, such as hepatic MFO induction, showed clear trends (Renton & Addison, 1992). Extraction of pore water in order to make a representative test is also exceedingly difficult. It is still not agreed on how best to extract pore water, by suction, or centrifugation or other method' and whether or not to use acids to extract organically bound chemicals. In muddy sediments, acid-volatile sulphide was once thought to be a useful measure of sediment-toxicity; it is no longer believed that this provides useful information and the idea has been abandoned.

Thus, whilst there are urgent needs to develop reliable methods for assessing hazards of contaminants in sediments, especially in relation to the development of sediment quality criteria for management purposes, much more research is needed. The Triad idea is elegant in concept but falls far short of its goals when applied in practice. The European-developed multivariate statistical programmes have been shown to be far more sensitive and reliable for detection of stress effects amongst the fauna of coastal benthic sediments.

Higher Taxa

Multivariate analyses are usually done at the species level, with the data inserted into a species: site matrix. Yet it is a surprising fact that many of the patterns that are found at the level of species can be found by using genera, families and even phyla. The loss of precision at the family level is slight (Warwick, 1988; Olsgard *et al.*, 1998).

Figure 6.13 shows data on higher taxa from the Frierfjord study shown in Figures 6.11 & 6.12 above. Here the data are shown for different taxonomic levels up to phyla and show that, as in other studies, there is little or no loss in precision at the family level. This finding is extremely important for monitoring. The effort and time needed to identify to the species level compared with the family level is very much greater and furthermore requires less taxonomical expertise. It is likely that costs for identification to the family level will be around 30% of those required for identification at the species level.

Figure 6.13 also shows the effects of different transformations before statistical analysis. It is clear that tighter clusters are achieved with double-root transformations, which down-weight the importance of abundant species. The double-root transformation (See Annex 2) has been shown to be the soundest choice.

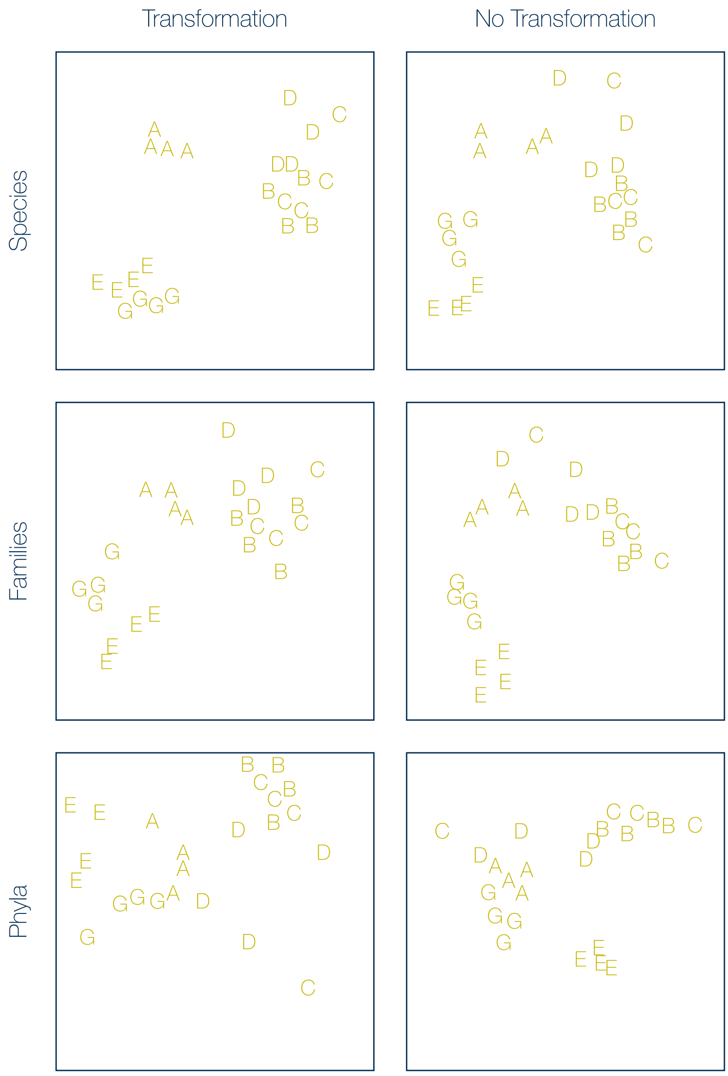


Figure 6.13: Data from Frierfjord analysed at different taxonomical levels (from Warwick, 1988).

Linking responses to cause.

As mentioned in the introduction to the community section, although changes in community structure can be measured easily, linking to the cause is difficult. One of the simplest methods is to superimpose environmental variables on the MDS plots.

Figure 6.14 shows clearly that the faunal groupings can be attributed to both natural environmental variables such as depth and grain size but at the polluted sites E and G there are high metal and PAH concentrations.

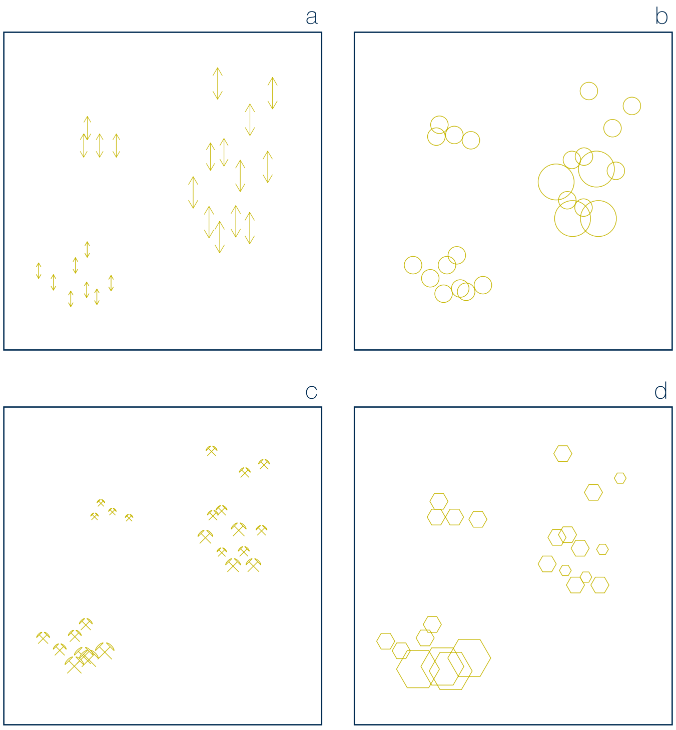


Figure 6.14: MDS ordination of sites with superimposed environmental variables a) depth, b) median particle diameter, c) metal concentration, and d) total PAH (from Warwick, 1988).

This approach can be progressed further by combining analyses of the fauna and measured environmental variables (including contaminants). The procedure is described by Clarke & Ainsworth (1993) and is a routine called BIOENV in the PRIMER package. What the procedure does is to take the two data matrices (samples-species and samples-environmental variables) and calculate the similarity matrices for the fauna, and Euclidean distance for the environmental variables, and then compare the ranks using a non-parametric rank correlation. In this case a weighted Spearman Rank Correlation coefficient is calculated, π_w.

Figure 6.15 shows an analysis of the effects of oil on the benthos of the North Sea at the Gyda field (Olsgard & Gray, 1995). In 1987 a baseline survey was carried out where there were no discharges. Three years later the effects are clearly seen and in 1993, after 6 years of discharge, the area of benthic fauna that is affected covers ca. 30 km[2].

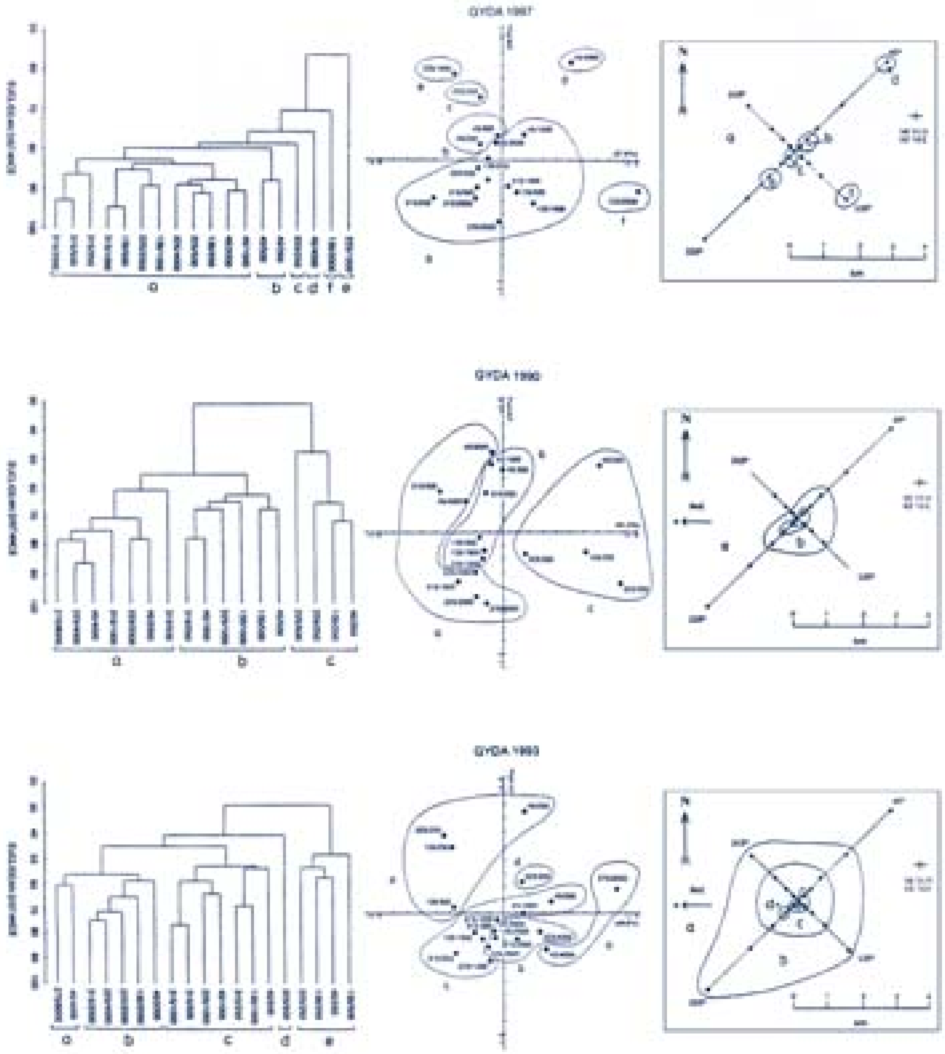


Figure 6.15: Multivariate statistical analyses showing effects of oil discharges on the benthic fauna at the Gyda oilfield, North Sea (from Olsgard & Gray, 1995). Linkage of the effects to the patterns in the fauna are shown below in Table 6.3.

Table 6.3: Linking site groupings from the multivariate analyses to possible causes (from: Olsgard & Gray, 1995).

Gyda					
1987	1990	1993	1987	1990	1993
Cu 14.7%**	Cu 38.1%**	THC 39.7%**	Cu r=0.312	Ba r=0.583	Ba r=0.679
Sr 9.4%**	THC 37.7%**	Ba 39.2%**	MdØ r=0.039	THC r=0.535	THC r=0.677
Zn 8.4%**	Zn 37.2%**	Sr 39.2%**	Sr r=0.014	Cu r=0.531	Sr r=0.599
MdØ 7.3%ns	Sorting 34.5%**	Zn 37.5%**	Sorting r=-0.075	Zn r=0.395	Kurtosis r=0.485
TOC 6.3%ns	Ba 33.6%*	Cu 37.0%**	Pb r=-0.011	Sorting r=0.341	Cu r=0.443
			Max. corr.: Cu	Max. corr.:	Max. corr.:
			Cu	Ba, Cu	Ba, THC, Kurtosis
			rs = 0.312	rs = 0.687	rs = 0.773

Here, two methods are shown from the CANOCO programme (Jongman *et al.*, 1987) to the left and from BIOENV in Primer to the right. The methods give slightly different results for 1990 and 1993 but both show clearly that Ba and THC (total hydrocarbons) are correlated with changes in faunal patterns and must in fact be the causal agents of these patterns.

6.4 Ecosystem Level

The ecosystem level of monitoring is difficult. Just as it is difficult to define populations in a classical sense in the coastal areas of the sea, so is the definition of an ecosystem. In fact a recent and much used textbook of ecology (Begon et al., 1996) does not accept that such a level of organisation exists and states that the community or assemblage level covers all aspects of the ecosystem.

The classical approach to ecosystem monitoring in a marine context is to consider the primary producers, the herbivores, carnivores and the detritus and micro-organisms that regenerate nutrients needed to fuel the system. Satellite monitoring of primary production is one of the ways that whole systems can be monitored, (Falkowski & Newman, 1998). Chlorophyll concentration of the surface waters is estimated by spectral reflectance and production can be followed on large scales. In the sea it is light and nitrogen that limit primary production. Monitoring from satellites will give a good picture of changes over time and can be included in coastal monitoring programmes. However, in areas where there is marked salinity stratification, primary production maxima are often well below the surface and cannot be observed from satellites. Good examples are fjords and polar areas where production begins under the ice. So caution is needed in regard to expectations that satellite imagery will give good coverage of coastal productivity.

Although there are methods for monitoring of zooplankton over large spatial scales, such as the Continuous Plankton Recorder (Reid *et al.*, 1998), analysis of the data is extremely time-consuming and expensive and is not recommended for routine pollution monitoring. However, datasets and interpretations from defined areas and time periods covered by the CPR may be commissioned from SAHFOS in Plymouth. Acoustic methods are widely used to estimate fish stocks and abundance patterns, but again this is a highly specialised field of research and is inappropriate for routine monitoring in relation to pollution effects.

A widely used method for assessing aquatic ecosystems is to use indicators of gross metabolism. This idea was pioneered by Odum (1956) who suggested that for freshwater streams the ratio of total primary production (P) to total community respiration (R) could be used to classify communities into whether they were autotrophic systems where the P/R >1 or heterotrophic where P/R<1. Gattuso *et al.* (1998) have given an extensive review of P/R ratios in marine systems. They suggest that there are three key components of community metabolism: Gross Primary Production (Pg), Net Primary Production (Pn) and Ecosystem Respiration (R). Net Ecosystem Production (NEP) is the difference between Pg and R. The P/R ratio is defined as Pg /R. NEP shows considerable variation and is far more sensitive as an index of gross community change than Pg /R.

Disturbances often do lead to changes in NEP or Pg /R for a given system, such as sediment on coral reefs (Riegl & Branch, 1995). However, the Pg /R ratio has very little discriminatory power. In fact data on production and respiration are not usually obtained for the purposes of monitoring effects of pollutants on ecosystems, but rather to examine aspects of the global carbon cycle. Considering the complexity and lack of sensitivity of the methods, and the immense logistical tasks of making measurements at appropriate scales in space and time, we do not recommend gross production and respiration measurements for routine monitoring of marine ecosystems. There are, however, initiatives to investigate further how in future such measurements might be used to assess the effects of pollutants at the ecosystem level and it is recommended that a watching brief be held on these initiatives.

Assessing ecosystem health

A final aspect of ecosystem monitoring that has been extensively publicised is monitoring "ecosystem health" (Rapport *et al.*, 1998). Yet it is extremely unclear what this term refers to. For example, the US EPA states, (http://www.epa.gov/aed/ecoint.html), 'Although we know that the condition of any ecosystem is the result of the cumulative effects of natural and anthropogenic influences, terms like "health" and "integrity" are not well-defined, scientifically measurable attributes of marine systems. An ecosystem, by definition, is an intricate combination of organisms interacting with their physical and chemical environments, functioning together as an ecological unit.' Thus the EPA has undertaken a programme to try and define what criteria can be used.

Rapport has been a leading protagonist for use of the term "ecosystem health" and its measurement. In a recent editorial, Rapport *et al.* (1999) state 'the starting point is to define ecosystem health in terms of properties that are amenable to regional scale assessment; properties such as: "vigour", "resilience", "organisation," and the absence of Ecosystem Distress Syndrome'. He suggests that vigour can be measured in terms of primary and secondary production and degraded systems "invariably exhibit failures in their capacity to sustain primary and secondary production". In a longer review, Rapport *et al.* (1998) gave the following as indicators of changed ecosystem structure: decreased biodiversity, decreased resilience, increased disease, changed community structure with shifts to r-selected species, eutrophication. Yet there are vociferous critics of such an approach such as Calow (1992, 2000) and Wilkins (1999), who argue that neither ecosystems nor health can be properly defined. We tend to support the critics, as we believe the indicators proposed by Rapport *et al.* (1998) do not indicate negative changes in biological systems. Many of the indicators in fact decrease quite naturally without being subjected to any human induced change. Biodiversity, resilience, community structure are not reliable indices and cannot be used in such a context.

Thus, whilst it is a laudable goal to provide managers with indicators of ecosystem change, much research needs to be done and better indicators proposed before such methods can be recommended for practical use.

6.5 Summary of Effects at Population, Community and Ecosystem Levels of Organisation

Population level monitoring has been successful (e.g. effects of tributyltin) when there is a known and quantifiable effect that can be routinely monitored. With most contaminants, we do not have such clear ideas about the responses to be found nor which populations of which species should be monitored. Although general population monitoring techniques are developed they are time-consuming and expensive to use.

Community level monitoring, particularly of soft-sediment living benthos, is the most widely and probably most sensitive way of monitoring for effects of contaminants and nutrients on coastal systems. Yet diversity indices are insensitive and even simpler methods such as simply plotting numbers of species, total biomass and total abundance give more insight into the biological responses than do diversity indices.

As 'stress' increases, benthic assemblages respond in a consistent manner. Some rare species become locally extinct and some species of intermediate abundance show decreases in abundance. At this stage some species of intermediate abundance increase and a few species become much more abundant. These changes can be illustrated by species-abundance plots (Gray and Pearson, 1982; Harvey *et al.*, 1998), and by ABC curves (Warwick, 1986). Yet the most consistent and more or less objective analyses of these changes can be done by application of multivariate statistical analyses (Clarke and Warwick, 1994; Jongman *et al.*, 1987. Recently developed techniques link changes in assemblages to environmental variables.

The most cost-effective monitoring method is probably identification to family level and then applying multivariate analyses (see Annex 2).

Although there are movements internationally to develop indicators of ecosystem health, these are not yet developed to a stage where they can be applied in a consistent manner. At their present stage of development they cannot be recommended for application.

7.0 Biomarkers

7.1 What is a Biomarker?

Various indicators are increasingly promoted as early warning signals. These include an expanding array of biomarkers of which there are many different types at various stages of development.

Biomarkers

The term biomarkers refers to a biological response that can be specified in terms of a molecular or cellular event, which may be measured with precision and which then yields information on either the degree of exposure to a stimulus (e.g. chemical, physical or even biological – as with exposure to pathogens),its effect on the organism, or both. Biomakers may fall into several categories depending upon their diagnostic value:

- biomarkers of exposure only;
- biomarkers of exposure with uncertain eventual consequence;
- biomarkers of known deleterious consequence based on mechanistic understanding.

(Adapted from GESAMP 1995)

The methodologies involved vary widely in complexity, and whereas some are suitable for routine use, others require equipment and expertise not yet widely available (e.g. Scope for Growth). Thus, while some biomarkers may be used in investigative monitoring, such as in areas where impacts are suspected but not detectable by more routine methodologies, others require further research before their real potential can be properly assessed.

As well as their use as early warning signals, in conjunction with chemical measurements, biomarkers may assist in determination of cause-effect relationships. Some biomarkers may indicate a response to a combination of pressures that, by themselves, may not exert an impact but do in concert.

In this chapter, we describe a broad selection of biomarkers and conclude with a tabulated summary (Table 7.1) identifying those that are sufficiently well tested for routine application as well as those that show potential but nevertheless require additional research and development. A selection of biomarkers suited to routine application is described in more detail in Chapter 8.

7.2 Molecular Biomarkers

Molecular markers are relatively new and untried yet offer great potential. This field is expanding rapidly and probably will, in time, become routine in monitoring the health of the ocean. Here we briefly review techniques presently available.

Differential Display

One method the RFDD-PCR technique permits the isolation and identification of gene products whose expression is altered by exposure to chemicals and other stressors. Organisms are compared between control sites and sites subjected to expected contaminant loads (Semizarov *et al.*, 1998). Hsiu-Chuan & Freedman (1998) exposed nematodes to cadmium and showed clear gene expression alteration. However, the technique is time-consuming and at present only semi-quantitative.

Gene Chip Technology

This technique is related to the foregoing and allows for the measurement of the expression of thousands of genes in a single experiment, but only for those that are homologous to those on the chip. Usually two cell culture lines are used - a vertebrate and an invertebrate - for which the response to a given stressor is known e.g. the induction of CYP450 in response to PAHs. Then, taking a species from the area to be studied, one might expect the same response in this species. It is necessary to develop a DNA probe for this response in this species by first developing PCR primers and cDNA probes are constructed for the CYP 450. Once a probe is developed it can be used routinely as a biomarker of exposure. Whilst these are powerful techniques a great deal of work is needed to cover all likely contaminants and the probe simply gives a yes or no response to exposure.

Microarray

DNA microarrays allow the analyses of expression to hundreds of thousands of genes simultaneously. The technique would be to select say a fish, an invertebrate and an alga. Then, selection of genes to be included on the microarray is made, based on the likely stressors in the environment. Commercially produced microarrays are available and sometimes these can be modified for the species and stressors of interest. The technique involves preparing cDNA from organisms from control and exposed sites, labelling them fluorescently and exposure to the microarray. The relative expression of the genes in control and exposed sites are compared. Again, this offers potential but is not ready for general field application.

DNA Adduct

This technique has been widely used in field assays. In the detoxification of genotoxicants, reactive chemical intermediates are produced which bind to the bases of DNA forming what are called adducts. The presence of an adduct is an indication of exposure to genotoxicants (Shugart, 1999). Recently, this technique has been used in the green-lipped mussel in Hong Kong and it was shown that there was a positive correlation between DNA adducts and benz[a] pyrene and total polycyclic aromatic hydrocarbons (PAHs) (Xu *et al.*, 1999). However, little is know about seasonal variations in adducts, how they vary with reproductive cycles or whether the response is stable or not. Thus, again, they cannot be recommended for routine monitoring.

DNA Strand Breakage

Genotoxicants also can lead to breaks in strands of DNA and have been advocated as a general and non-specific indicator of exposure to a wide variety of genotoxicants. Different methods have been developed (Everaarts *et al.*, 1998, Kanter & Schwartz, 1982 and Mitchelmore *et al.*, 1998). Again however, field studies (Ching *et al.*, 2001) show that strand breaks can be repaired so the incidence of breaks is not necessarily a reliable quantitative indicator of exposure. Again much more work is needed before these techniques can be recommended for routine monitoring.

7.3 Biochemical Biomarkers

Biochemical biomarkers have been used extensively in monitoring whether or not an organism has been exposed to a given contaminant (biomarkers of exposure) or whether there are effects of that contaminant, (biomarkers of effect). A wide variety of methods have been proposed. Here we give a short review.

RNA/DNA Ratio, a Biomarker for growth

RNA is involved in the synthesis of proteins and its cellular concentration is highly dependent on growth rate. Tissue RNA is a function of the rate of protein synthesis of the cells and the total number of cells. Variations resulting from the differences in numbers of cells per unit weight of tissue can be corrected by expressing RNA as the ratio of RNA to DNA as the amount of DNA per cell is constant (Haines, 1980). The use of RNA/DNA ratios is especially suitable for young stages since a high percentage of the synthesised proteins are used for growth and not tissue maintenance. RNA/DNA ratios have been used in the oyster Crassostrea virginica (Wright & Hetzel, 1985), the gastropod Nassarius obsoletus (Wo *et al.*, 1999), Atlantic cod (Gadus morrhua) larvae (Buckely, 1980), Daphnia magna (Knowles & McKee, 1987) and many other freshwater species. Much effort has been expanded on improving the sensitivity and application of the method (Reid, 1997). Yet it has not become part of routine monitoring programmes since it is highly variable. Much of the variability is thought due to the fact that growth is the result of anabolic and catabolic processes, yet the method only measures synthesis. If anabolic and catabolic processes are uncoupled then the RNA/DNA ratio is not a useful biomarker of growth.

Adenylate Energy Charge

ATP is required for all biological functions within the organism. The availability of ATP should provide an indication of the potential energy available for growth and metabolism. ATP is continuously consumed and regenerated from ADP and AMP, thus it was suggested that the availability of ATP could be measured as the adenylate energy charge (AEC) (Ivanovicic, 1980):

$$AEC = \frac{ATP}{\frac{1}{2} ADP + AMP}$$

The idea is that unstressed organisms have values between 0.8 and 0.9 whereas stressed organisms have values of 0.5-0.7 (Vetter & Hobson, 1982). It has been tested during the Oslo workshop (Bayne *et al.*, 1988) and was found to be highly variable and thus not a reliable biomarker of effect. It is not routinely used for monitoring stress of organisms.

Mixed Function Oxidases (MFOs)

Many contaminants are lipid soluble and such chemicals are readily bioaccumulated within organisms. Accumulation of such chemicals may be prevented by detoxification through enzyme-catalysed reactions (mainly in the liver) and subsequent excretion via the kidneys or in bile (Stegeman, 1989). Both vertebrates and invertebrates have the ability to metabolise chlorinated pesticides, dioxins, furans and specific polycyclic aromatic hydrocarbons (PAHs) which results in induction of a specific form of an enzyme called Phase 1 cytochrome P-450 mediated mixed function oxidase, the P4501A (or CYP 1A1) (Stegeman, 1989, Stegeman *et al.*, 1988). CYP 1A1 is normally measured by EROD (ethoxyresofurin-O-deethylase) activity, for example in fish liver. The method has been extensively tested and is widely utilised in ecological assessments of the health of populations (e.g. OSPAR, in Canada and Australia) (See Livingstone, 1993; Holdway *et al.*, 1995). It is used to identify areas that are significantly impacted by effluents from pulp and paper and oil discharges. A useful feature, for example where dioxin contamination is of concern, is that studies of MFOs in fish can be undertaken for between one tenth and one fifth of the cost of a single dioxin analysis. Where there is no evidence of MFO induction it is highly unlikely that concentrations of dioxin would be of significance.

Bile Metabolite

Rainbow trout (*Onchorhynchus mykiss*) exposed to paper and pulp mill wastes have been shown to excrete in the bile conjugates of chlorinated phenolics and resin acids. Thus, it is suggested that measurements in bile will give a means to detect sublethal effects of highly complex effluents (Oikari *et al.*, 1984, 1985). It has been shown, also, that analyses of PAH metabolites in fish bile are a sensitive means of testing for exposure (Krahn *et al.*, 1986). Whilst this seems a promising biomarker of exposure it has not been used in routine monitoring programmes. It is of particular interest as PAHs are not routinely measured in fish tissue due to their relative instability.

Metallothioneins

When organisms are exposed to metals, both essential and non-essential, regulation is a critical aspect of the maintenance of homeostasis. At the cellular level metal-binding ligands such as metallothionein (MT) and phytochelatin bind metals and can sequester them in mineral concretions, inclusion bodies or membrane-bound vesicles (Schlenk & Brouwer, 1993). They have been used as biomarkers for metal exposure in Mytilus edulis (Livingstone, 1993). However, as with many other biomarkers there is considerable seasonal variability associated with reproductive cycles and MT can be induced by stressors other than metals.

Heat Shock Proteins

When organisms are stressed, by whatever cause, a family of proteins called heat shock proteins are synthesised. These proteins prevent stress-induced damage by assisting in the removal of denatured proteins from the cell and limit and prevent damage by the stressor (Ryan & Hightower, 1996). Heat shock proteins have been induced by exposure to a variety of stressors in the flounder, Platichthys flesus. (Sanders *et al.*, 1992; Koban *et al.*, 1991). Yet again, seasonal differences in expression of heat shock proteins were found in mussels, *Mytilus californianus* (Roberts *et al.*, 1997) and *M. edulis* (Veldhuzen-Tsoerkan *et al.*, 1991). In *M. edulis*, Brown *et al.* (1995) showed that one group of mussels with high HSP expression had higher tolerance to cadmium than a group with lower HSP expression. Thus, whilst HSP may provide a general indication of exposure to stressors, it is first necessary to determine the seasonal variability and effects of reproductive cycles on HSP so that monitoring can be designed in a way that yields results that can be interpreted reliably.

Acetylcholinesterase (AChE) Activity

AChE production is inhibited in the presence of organophosphorus pesticides and carbamates. Acetylcholine (Ach) is the primary neurotransmitter in the sensory and neuromuscular system and the enzyme AChE finely regulates its levels. Inhibition of the enzyme causes continuous stimulation of nerve/muscle fibres and may result in tetany and death. Measurement of AChE activity has been used successfully in flounders (*Platichthys flesus*) measuring a gradient from the Elbe estuary across the N. Sea (Galgani *et al.*, 1992) and more recently in dab and plaice at sites around the UK (MPMMG, 2001). Data from the latter surveys discriminated well between more contaminated near-shore and clean offshore areas and the technique is to be included in regular monitoring of biological effects around UK coasts.

Citrate Synthetase

Citrate synthetase is a mitochondrial enzyme involved in aerobic metabolism and is used as a measure of the aerobic capacity of tissues. It has been shown to increase in the mussel, *M. edulis*, under stress (Widdows *et al.*, 1982). Yet other studies have found that different organisms may show decreases in citrate synthetase under stress (Bhagyalakshmi *et al.*, 1984) or there is no change at all (Gould & Greig, 1983). The best use of this biomarker is probably to ascertain whether or not aerobic or anaerobic metabolism occurs in mussels, *M edulis*, as it has been shown that mussels shifted from aerobic to anaerobic metabolism under stress (Wang & Zou, 1992). It is not a suitable indicator for routine use.

Lactate Dehydrogenase (LDH)

LDH is used when animal tissues do not have sufficient oxygen to support aerobic metabolism and is a biomarker of anaerobic capacity (Wu & Lam, 1997). It has been used as a biomarker for exposure to hypoxia in the green-lipped mussel, Perna viridis, by Wu & Lam (1997) who transplanted organisms to various sites in Hong Kong. *M. edulis* exposed to cadmium also increased LDH activity (de Zwaan *et al.*, 1995). Apart from the fact that LDH is relatively untested, it seems a sensitive biomarker for exposure to low oxygen concentrations.

Octopine Dehydrogenase

In certain molluscs (bivalves and cephalopods) another group of enzymes, octopine dehydrogenase, are used together with LDH. It has been suggested that these may also be used as a biomarker of anaerobic stress (Fields & Hochachka, 1975).

Sorbitol Dehydrogenase (s-SDH)

Normally sorbitol dehydrogenase concentration is low in the bloodstream. Its presence indicates hepatocellular damage. SDH activity has been used as an indicator of liver damage in salmon (*Salmo salar*) exposed to crude oil (Gagnon & Holdway, 1999). Once more, there are too few studies for this to be recommended for routine monitoring.

Glycogen Storage

In fish, glycogen is the major form of energy storage, so it is suggested that glycogen levels and glycolitic enzyme activity could be used as a biomarker of environmental stress (Lagadic *et al.*, 1994). This has been tested in the dog-whelk *Nassarius lapillus* where glycogen in the foot muscle and digestive gland was reduced on exposure to sublethal concentrations of cadmium, (Zhou *et al.* 2000). However, it is well known that many factors also influence the glycogen content e.g. food availability, activity, reproductive cycle, temperature etc. Thus, it is probably a too general response to be of use in monitoring health or organisms.

Immune Fraction

It has been suggested that immune biomarkers in fish should be able to detect the presence of immunotoxins in a water body. The immune biomarkers include macrophage responses, leucocyte volume, blood differential counts, lysozyme levels, mitogenic response, natural cytotoxic activity and humoral antibody responses to toxic contaminants (Weeks *et al.*, 1992). However, research in this area is at a very early stage and no biomarkers can be recommended.

7.4 Physiological Biomarkers

Photosynthesis and Respiration

It has been demonstrated that photosynthesis and respiration in many species of phytoplankton, macroalgae, seagrasses and cyanobacteria are affected by a wide variety of contaminants including organochlorines and metals (Cid *et al.*, 1995; Fargasova, 1998; Prange & Denison, 2000; Suresh-babu *et al.*, 2001). However, there are many other factors that also alter rates of photosynthesis such as light, temperature and oxygen concentration (Wu & Woo, 1985). Thus, photosynthesis and respiration rates of plants are not used routinely in monitoring the health of the marine environment.

With animals, respiration rates are easy to measure but changes are difficult to interpret due to the wide variety of factors that cause changes in these rates. Thus, they are perhaps best used as part of the scope-for-growth method (See below).

Growth and Condition Factor

Growth represents the integration of feeding assimilation and energy expenditure over periods of time, whereas poor growth leads to less energy being available for reproduction that may lead to a decline in population numbers over time (Giesy & Graney, 1989; Widdows et al, 1982; Page & Widdows, 1991). There are many studies of effects on growth rates using a wide variety of both organisms and contaminants; metals and shrimp larvae (Santos *et al.*, 2000); metals and seaweed (Coelho *et al.*, 2000); barnacles and mussels to pulp mill effluent (Wu & Levings, 1980), oysters (*Saccostrea commercialis*) and sewage (Avery *et al.*, 1996). Daily growth rates can be measured accurately in mussels (Richardson *et al.*, 1990) and in cockles (Lønne & Gray, 1988) and thus can be used for effective monitoring.

In fish, a simple index of weight / body length has been termed condition factor (CF) (Donaldson *et al.*, 1979). This has also been applied to molluscs with good effect in contaminated, compared with clean, sites in Hong Kong (Nicholson, 1999a, b), with PAHs and mussels (Granby & Spliid, 1995). In a study in England, Kirby *et al.* (1999) related CF to EROD activity in flounders.

Scope for Growth (SfG)

Scope for growth is defined as the amount of food consumed minus the combined effects of egestion, respiration and excretion. It was first determined in fish but has been widely applied and used in mussels (mainly *M. edulis*) by Widdows and co-workers (Widdows *et al.*, 1995). However, SfG is time-consuming and difficult to determine. For example measuring food consumption in a mussel is not easy as much seston is sorted on the gills and only a small fraction of food entering the gills may be consumed. Yet the method has been widely used and highly refined and has been shown to give reliable responses to a variety of contaminants in field situations (Widdows *et al.*, 1995). Scope for growth is used routinely in health monitoring around the North Sea under the OSPAR protocol.

Mobility

Whilst behavioural response to contaminants have been shown in gastropods and in fish (Walsh *et al.*, 1993) the responses are difficult to measure, especially under field conditions, and so no general method is used for health monitoring.

Hepatosomatic Index

The ratio of the liver weight to body weight has been suggested as a simple index of condition of the energy reserves of an organism (Arndt, 2000). Although it has been used in freshwater situations it has not been tested on marine organisms, and thus it is too early to say whether or not this will be an appropriate indicator.

Reproduction and Gonadosomatic Index (GSI)

If the reproductive ability of an organism is affected then it is likely that the population will be affected. A simple index, the weight of the gonad x 100 / body weight, has been suggested as a GSI. Although Wu & Levings (1980) showed that barnacles transferred to a polluted site showed lower GSI compared with controls, Liu & Morton (1998) found that the limpet *Patelloidea* saccharina had higher GSI at polluted sites in Hong Kong, which they suggested was an adaptation to polluted conditions. So one is unsure what the GSI is expected to give in a polluted site. Again, a simple index but interpretation of results is not straightforward.

7.5 Population Condition Biomarkers

It has been suggested that the frequency of diseases increases as contaminant loads increase. Data from the Pacific North-West (Malins *et al.*, 1988) and the US North East (Johnson *et al.*, 1992a,b) provide convincing evidence of this. Yet not all disease can be related to contaminant loads and many diseases occur naturally (ICES, 1996). The following are widely used in monitoring surveys:

7.5.1 External Fish Diseases

Fin Erosion

Fin erosion is easy to observe and samples of a given population can estimate frequencies, which can then be compared with frequencies for control areas. The US National Benthic Surveillance project in Puget Sound showed clearly that fin erosion was higher in urban areas in starry flounder, English sole, rock sole, Dover sole, rex sole, barred sand bass (Malins *et al.*, 1986). Winter flounders from heavily contaminated areas on the US Northeast coast had high levels of fin erosion and high levels of PAHs, PCBs and DDT and its derivatives (Johnson, *et al.*, 1992a,b). Data on fin erosion are required in the monitoring programmes of ICES (1996,1997), Virginia (Strobel *et al.*, 1999) and the Gulf of Mexico (USEPA, 2000).

Skeletal Malformation

Skeletal malformations include upward or downward curvature of the vertebral column, shortened upper or lower jaw and fin ray damage. Whilst the symptoms are easy to recognise, the diagnosis of cause and effect is difficult. The etiology of skeletal malformations has not been established, although metals, parasitic infestation, genetic background and vitamin deficiencies have been implicated (ICES, 1996). Skeletal deformation data are easy to obtain and routinely collected in monitoring programmes of ICES (1989, 1996, 1997) and the Gulf of Mexico (USEPA, 2000).

Epidermal Hyperplasia/Papilloma

Epidermal hyperplasia and papilloma frequencies in dab, Limanda limanda, were correlated with titanium dioxide dumping in Germany (Dethlefsen, 1980, 1984) and it has been claimed that extensive hypoxia off the Danish coast led to increases in these abnormalities (Dethefsen, 1990; Vethaak, 1993). Again, these symptoms are easy to recognise and have been employed by ICES for routine monitoring (ICES 1989, 1996, 1997). More research is, however, needed to relate frequencies to possible causal factors.

Operculum Abnormalities

Abnormalities of the freshwater fish perch have been observed in response to pulp and paper mill effluents, (Lindesjöö *et al.*, 1994). Whilst similar data on marine fish are not available in the primary literature, in the Gulf of Mexico operculum abnormalities are also included in routine monitoring (USEPA, 2000).

Gill Histopathology

Histopathological changes in the gills of Atlantic cod (*Gadus morrhua*) have been shown in response to exposure to oil (Khan & Kiceniuk, 1984). Data on freshwater fish suggest that gills are damaged by a wide variety of chemicals. Yet gill damage is not used routinely in any monitoring programme and more research both in the laboratory and field is needed before such methods can be included in a future programme.

Lymphocystis

Lymphocystis is a common disease of both wild and aquarium fish and is caused by an iridovirus; it is not necessarily linked to chemical pollution. Infected cells become greatly hypertrophied forming nodules on the epidermis (Bucke *et al.*, 1983). It has a low mortality rate but infected individuals become disfigured, may have difficulty feeding and are more likely to become targets of aggression. In addition, lymphocystis may be complicated by secondary bacterial or mycotic infections. It is widely investigated as part of fish disease surveys (See for example, MPMMG, 1998)

Ulcerations

Skin ulcers are also commonly included in fish disease surveys (See for example, MPMMG, 1998). They most likely originate from wounds that are attacked by opportunistic pathogens and there is no clear association with chemical pollution. In a number of US Atlantic estuaries, the most common disease affecting fish is ulcerative necrosis in which an oomycete causes severe inflammation producing lesions. Various kinds of fungi have been isolated from ulcerative mycosis lesions, as have bacteria and protozoa. However, none are strong enough to open wounds that must be present for infection to occur (Noga, 2000).

7.5.2 Internal Fish Diseases

Liver Histopathology

Extensive studies of liver histopathology have been done on English Sole (*Parophrys vetulus*) in Puget Sound, Washington State, USA, (Malins *et al*, 1984, 1986) and showed high correlations between the concentrations of polycyclic aromatic hydrocarbons (PAHs) in sediments and a wide variety of symptoms, especially neoplasmic lesions. Landahl *et al.* (1990) analysed data from eight different studies encompassing 49 sites and confirmed the relationship between sediment PAH content and liver neoplasms. Johnson *et al.* (1992a,b) showed similar effects on the winter flounder (*Pleuronectes americanus*) in polluted areas of the Northeast coast of USA. Recent data, however, suggest that the types of liver lesions are species specific (Johnson *et al.*, 1993) although Myers *et al.*, (1993) confirm the generality correlation between high levels of PAHs in sediment and liver neoplasms. In Europe, dab (Limanda limanda) sampled along contaminant gradients showed similar findings (Simpson & Hutchinson, 1992). Yet flounder (*Platichthys flesus*) in the contaminated Elbe estuary from 1985-1989 showed low prevalence of liver neoplasms (Vethaak, 1993). It needs to be remembered that tumor development takes a long time and often has low observable frequencies, which requires that many lesions need to be examined histopathologically and also the migratory pattern of the fish species studied needs to be considered. Although liver histopathology is used in ICES (1989, 1996, 1997) and USEPA (2000) monitoring programmes, this health indicator requires considerable skills in interpretation of results obtained.

Macrophage Aggregates (MAs)

Macrophage aggregates occur naturally in fish livers and contain varying amounts of the pigments melanin and lipofuchsin. Either the frequency of occurrence of aggregates increases with exposure to contaminants (Khan & Payne, 1997) or the size and structure of the aggregates changes (Biagianti-Risboug, 1993). Whilst MAs have been recommended for incorporation in NOAA monitoring programmes (Wolfe, 1992), they are only used in the Virginia monitoring programme (Strobel *et al.*, 1999) and thus the method is not widely accepted.

Kidney Histopathology

Kidney lesions in fish have been extensively studied in winter flounder collected at 22 sites on the Northeast coast of the US (Johnson *et al.*, 1992b). No relationships were established between kidney damage and contaminant loads. Thus, kidney histopathology is not used in routine monitoring programmes.

Ovarian Growth

The US National Benthic Surveillance project has studied ovarian damage in two fish species from contaminated estuaries (Johnson *et al.*, 1992a). Although winter flounder showed no depression of ovarian growth or lowering of estradiol concentrations, English sole from PAH contaminated areas showed impaired gonadal development. The difference is likely to be due to the migratory behaviour of the flounder compared with the stationary sole. Again, the method is not sufficiently well studied to be recommended for routine monitoring.

Embryonic Defects

High frequencies of defects were found in dab larvae caught in the contaminated areas of the German Bight compared with those caught in unpolluted control areas (Cameron & Berg, 1992). Likewise similar findings were found with larvae of winter flounder sampled near an oil spill in the US (Hughes, 1999). Although these findings suggest a possible health indicator, sampling larval fish is a difficult task and obtaining representative samples that have been exposed to contaminants is far from easy. Again, this method cannot be recommended for routine monitoring.

7.5.3 Histopathology of Molluscs

A number of studies have shown that marine molluscs show similar histopatholgical responses to contaminant loads as fish, e.g. *Mya truncata* (Wolfe, 1992; Neff *et al.*, 1987), American oyster *Crassostrea virginica* (Gold-Bouchot *et al.*, 1995) and *M. edulis* (Wedderburn *et al.*, 2000). Yet the methods have not been developed as far as those in fish and are thus not used in routine monitoring programmes.

7.5.4 Cytopathology

Lysosome Integrity

Lysosomes are organelles bounded by membranes containing hydrolytic enzymes for breaking down substances within cells (autophagy) or substances taken in from outside the cell (heterophagy). In bivalve molluscs, lysosomes are especially rich in digestive diverticula and are much larger than in mammals. A wide variety of chemicals (PAHs, PCBs and oil derived hydrocarbons) lead to destabilisation of the lysosomal membranes (Lowe *et al.*, 1981; Moore, 1990; Wedderburn *et al.*, 2000). Similar cytological effects have been found in fish (Köhler *et al.*, 1992; Lowe *et al.*, 1992). Lysosomal destabilisation is employed as a cellular biomarker of general stress by ICES (1997), the North Sea monitoring programme (Broeg *et al.*, 1999) and MEDPOL (UNEP, 1997; Cajaraville *et al.*, 2000). This is a sensitive and well-tried biomarker that can be generally adopted.

Lipopigments Content

Related to lysosome studies is the accumulation of lipopigments in lysosomes. The lipopigments, lipofucscin and ceroid, are the end products of lipid peroxidation, which occurs when polyunsaturated fatty acids are damaged by free radicals or reactive oxygen species (Wolke *et al.*, 1985). Accumulation of lipopigment in mammals is a pathological symptom known as ceroid-lipofucscinosis or Batten's disease. In M. edulis, Lowe *et al.* (1981) have shown that lipopigments accumulate in lysosomal compartments as residual bodies. The same has also been demonstrated in flounders sampled in the contaminated Elbe estuary (Köhler, et el., 1992). Yet, although this seems a promising approach, there are problems in that there is no standardised method for lipopigment detection, nor is there sufficient information on possible confounding factors.

Peroxisome Proliferation

Peroxisomes are single membrane-limited organelles that increase in abundance in digestive cells of mussels exposed to PAHs (Cajaraville et al., 1992, 1997). Field studies have been carried out in the Iberian peninsular (Porte *et al.*, 1998) and the Pacific coast of the US (Krishnkumar *et al.*, 1995) and showed that peroxisomes also changed with season, site and reproductive cycle. Thus, again, much more work is required before this method can be used in routine monitoring programmes.

Imposex and Intersex

Imposex is a condition that occurs in gastropods and bivalves exposed to organotin compounds, and especially tributyl tin, that have been widely used in antifouling paints applied to the hulls of vessels. A similar condition known as intersex occurs in the periwinkle, *Littorina littorea*. Imposex is a form of endocrine disruption in which female shellfish take on male characteristics, including a small penis and vas deferens, when exposed to TBT concentrations from <1 ng/l upwards. The use of TBT antifouling paints is now heavily restricted but environmental residues are slow to decline particularly in ports and harbours. Boelens *et al.* (1999) summarised imposex data from Irish coastal waters up to 1998. Sensitive and reliable procedures for quantifying the degree of imposex in the dogwhelk, *Nucellus lapidus*, and periwinkle are available and applied internationally (OSPAR, 1997). The utility of the procedures has been demonstrated in field studies (Harding and Davies, 2000) and results from most laboratories participating in inter-laboratory comparisons have shown good agreement (Davies and Minchin, 2002). These are well-tried and practical contaminant-specific techniques.

Vitellogenesis

The imposition of male characteristics in female gastropods as a result of tributyltin (TBT) exposure is the best known example of endocrine disruption in the marine environment resulting from chemical contamination. Other estrogenic effects have been recorded in wildlife from various parts of the world in response to a diverse range of organic chemicals and some metals. In a review of the issue, Colborn *et al.* (1993) identified a wide range of pesticides and industrial chemicals in common use that have shown evidence of endocrine disruption. Disruption can result from processes such as binding of the chemical to a specific estrogen receptor, the inhibition of steroid biosynthesis etc. A common manifestation of these processes is the induction of yolk protein synthesis in male fish (vitellogenesis). In the worst cases the fish may be feminised to the extent that they are no longer capable of normal sperm production. The best example of this was demonstrated in rainbow trout exposed to sewage effluent in UK rivers (e.g. White *et al.*, 1994). The causative agent in these cases was considered to be synthetic contraceptive pill residues in sewage (i.e. ethynyl estradiol). A methodology for the measurement of vitellogenins in fish has been prepared by ICES (Scott and Hylland, 2002). To date, most effects have been recorded in freshwater systems, although there is mounting evidence of impacts in marine areas also (e.g. Pereira *et al.*, 1992; Lang *et al.*, 1996).

7.5.5 Organismal Indicators

The tissues of certain filter-feeding molluscs are useful indicators of contamination levels in the marine environment. Such 'sentinel' species are now widely employed as part of marine monitoring programmes.

Professor Ed Goldberg (University of California, Berkeley) first suggested that since concentrations of many contaminants in the water column were at or below the limit of detection, monitoring concentrations in mussels was to be preferred. Mussels bioconcentrate contaminants, in the case of some substances many hundreds of times, and so provide useful data on the contaminant status of coastal waters.

Mussel Watch

Following development of suitable procedures, mussel watch programmes have been set up in many countries, the most comprehensive and longest running being the Mussel Watch project administered by the US National Oceanic and Atmospheric Administration (NOAA). This is part of the National Status and Trends (NS&T) programme (http://ccmaserver.nos.noaa.gov/NSandT/New_NSandT.html) initiated in 1984 to monitor chemical contamination and assess the effects of human activities on coastal and estuarine areas.

The NS&T programme makes chemical measurements on surface sediments and whole soft-parts of mussels and oysters collected from about 200 coastal and estuarine sites representative of large areas rather than small-scale patches of contamination. The results are used to describe the spatial distribution of coastal contamination and temporal trends, and to help differentiate between the effects of human activity and those of natural influences. A specimen bank of samples taken each year at about 10 percent of the sites is maintained at the National Institute of Standards and Technology (NIST) for future, retrospective, analyses. A related programme of directed research is examining the relationships between contaminant exposures and indicators of biological responses (i.e. bioeffects) in fish and shellfish from areas shown by the NS&T to have elevated levels of chemicals of relatively high toxicity.

The Mussel Watch Project is designed to monitor the status of, and temporal changes in, metal and organic contaminants in Great Lakes, estuarine and coastal waters. Target bivalve species include the mussel Mytilus edulis and the oyster *Crassostrea virginica* on the East coast, *C. virginica* on the Gulf coast, *C. rhizophorae* in the Caribbean, *M. edulis* and *M. californianus* on the West coast and in Alaska, and the zebra mussel *Dreissena polymorpha* in the Great Lakes. In all, over 160 sites are sampled once yearly, during the winter months. Sampling sites are located away from point source waste discharges. Measured contaminants include a suite of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides and trace elements. Mussel Watch also monitors the health of these bivalve populations through the measurement of a variety of biological indices such as:

- condition index;
- size frequency;
- stage of reproductive development; and
- prevalence and intensity of diseases, parasites and pathologies.

That latter index includes a full histopathological analysis designed to enumerate the prevalence and intensity of a variety of diseases such as MSX and Dermo disease in oysters, pathologies such as digestive gland atrophy, tumors and inflammatory processes, and parasites such as cestodes, trematodes, nematodes and ciliates. Mussel Watch is the first large-scale monitoring program to use a quantitative approach to histopathological analysis including the direct enumeration of parasites and the development of semi-quantitative scales for disease intensity and extent of pathological condition.

Methods of chemical analysis developed during the Mussel Watch Project are now accepted as state-of-the-art. In addition, Mussel Watch has established a nationally recognised laboratory inter-calibration program to assure the comparability of contaminant analyses among different analytical laboratories. All data collected by the Mussel Watch monitoring program are stored on-line in the NOAA S&T office in Silver Springs, MD. The data from the status and trends program are available for downloading on line at: http://ccmaserver.nos.noaa.gov/data.html.

Status of the US Mussel Watch project

The Mussel Watch Project is currently in its 16th year. During this time, Mussel Watch has documented significant changes in contaminant body burdens and population health on all three coasts of the United States. As examples, significant declines in tributyl tin and certain chlorinated pesticides have been documented following regulations limiting their use in the environment. Disease and condition index of oysters have been shown to follow the El Nino cycle in the Gulf of Mexico with declines in health associated with El Nino-associated changes in climate, particularly rainfall. Latitudinal gradients in contaminant body burden in oysters have been identified and correlated with latitudinal changes in reproductive activity, size, and condition. Mussel Watch is one of the largest, longest running monitoring programs ever conducted and will have produced an unparalleled time series relating bivalve population health and contaminant body burden to changes in climate and human activities in every significant coastal, Great Lakes, and estuarine water body in the U.S.

Results show that concentrations of most of the monitored man-made chemicals (e.g. DDT, PCBs) are decreasing. The concentration of cadmium is decreasing as well but concentrations of other trace metals have stayed more or less constant. Many chemicals, particularly those that are man-made, have high concentration levels near cities. Except in the case of lead, however, there is no apparent association between high concentrations of other trace elements (e.g. mercury, copper, zinc) and urban areas.

The data from NOAA's Mussel Watch Project are significantly lower than in two other monitoring programmes, those of the EPA and US Navy, because NOAA's sites are designed to be representative of an entire estuary. The sites monitored by the EPA and the US Navy are much closer to sources of TBT (e.g., marinas and shipyards). The EPA's data show declines in TBT from 1992 to 1997 in surface water and tissue concentrations in Galveston Bay, Texas, Narrangansett Bay, Rhode Island, Puget Sound, Washington and Lake Erie, Ontario. To see the EPA data check: http://www.epa.gov/owow/monitoring/ databases.html.

Monitoring for contaminants in mussel (*Mytilus edulis*) also forms an important component of marine monitoring programmes in Europe, including Ireland. Spatial and trend monitoring of contaminants in mussels is a key element of the OSPAR Co-ordinated Environmental Monitoring Programme (CEMP).

7.6 Summary

Of the more than 40 categories of biomarker described in this report, less than half are considered to be at a stage of development that would justify their use routinely in marine monitoring programmes. Nevertheless, when the requisite methodologies are performed correctly, certain biomarkers will detect exposures to particular types of contaminant and thereby may constitute valuable supplements to chemical analyses and/or monitoring the status of communities. It needs to be stressed, however, that biomarkers generally cannot be used to infer risks to populations of the organisms concerned. With few exceptions (e.g. imposex) biomarkers are non-definitive and causative agents must be determined by other means (e.g. chemical analysis, bioassays).

The biochemical biomarkers suitable for routine application are Mixed Function Oxidase (MFO), particularly EROD activity, which detects exposures to POPs[9] such as PCBs and PAHs, AChE production which is inhibited in the presence of organophosphorus and carbamate pesticides, metallothioneins which detect exposures to metals, and heat shock proteins which provide a measure of general environmental stress. Methodologies for these biomarkers are readily available, well tested and no special problems should be encountered with their application.

Growth and Condition factors, and Scope for Growth, are physiological biomarkers that in conjunction with chemical measurements have been used successfully to measure contamination gradients. Whilst the former involves simple methodologies, Scope for Growth requires special expertise and facilities.

The prevalence of fish diseases such as fin erosion, skeletal malformation and epidermal hyperplasia/papilloma can be used effectively as biomarkers of the condition of particular fish populations. For populations of known geographical range and distribution, these diseases may be correlated with the degree of sediment contamination in the areas concerned. However, it is important to stress that the frequency of fish diseases must be assessed against control populations since, as with humans, diseases are prevalent in all populations.

[9] Persistant Organic Pollutants.

Two valuable **cytopathological** biomarkers, for which methodologies are readily available, are lysosome integrity in bi-valve molluscs and imposex/intersex in gastropods. Lysosome integrity can be affected by exposures to a range of POPs and imposex/intersex is now the standard indicator of exposures to tributyltin.

Mussel Watch: The soft tissues of filter-feeding molluscs, such a mussels, can be used to measure ambient concentrations of contaminants where the corresponding levels in seawater are extremely low and difficult to quantify accurately. Furthermore, this provides a 'time-integrated' sample, as opposed to the more transient nature of concentrations in water where co-variables such as tidal cycles and hydrodynamics are critical to data interpretation. Remote from contaminant 'hot-spots' (e.g. point sources), and in conjunction with histopathological examination, such **sentinel species** can be used as combined indicators of exposure and stress on relatively large spatial and temporal scales.

Finally, biomarkers of benthic **community status**, involving the use of multivariate statistics to compare biological conditions between survey and reference areas, provide a very efficient means of evaluating the degree and spatial extent of biological change (See Chapter 6).

Table 7.1: Summary and overall evaluation of the biomarkers reviewed.

Type of indicator	Indicator	What is it?	Evaluation
Molecular	Differential display	Measures gene expression as response exposure to metals, pesticides other xenobiotics.	New, offers potential but time–consuming and not used routinely.
	Gene chip technology	Usually expression of mRNA for all genes on chip: exposure to metals, pesticides other xenobiotics	New, offers potential but time–consuming and not used routinely.
	Microarray	DNA microarrays analyses thousands of genes for exposure to metals, pesticides other xenobiotics	New, offers potential but time–consuming and not used routinely.
	DNA adduct	Exposure to carcinogens	Not well enough studied to be used routinely
	DNA strand breakage	Exposure to carcinogens	Not well enough studied to be used routinely
Biochemical	RNA/DNA	Growth of animals (general stress)	Variable, responds to too many variables
	AEC	Bioenergetic status of animal (general stress)	Unreliable as a stress indicator
	MFO	Exposure to PAHs and organochlorines	Well tested method giving indicator of exposure to PAHs & organochlorines
	Bile metabolite	Exposure to PAHs and organochlorines	
	Metallothionein	Exposure to metals	Works well in many species as indicator of exposure to metals
	Heat Shock Protein	General stress response to heat, osmotic shock, etc	General stress response that occurs in many species. A useful general stress biomarker
	AchE	Exposure to organophosphates	Worked well in flounders in one test
	Citrate synthase	Aerobic respiration (and indirectly oxygen)	General response but not thoroughly tested
	Lactate dehydrogenase	Anaerobic respiration (and indirectly oxygen)	General response but not thoroughly tested
	Octopine dehydrogenase	Anaerobic respiration (and indirectly oxygen)	General response but not thoroughly tested
	Sorbitol dehydrogenase	Liver damage (and indirectly exposure to xenobiotics)	Few tests done in field
	Glycogen storage	Energy reserve (and general stress)	Variable response to many factors, too imprecise for regular monitoring
	Immune fraction	Exposure to immunotoxins	Not sufficiently tested yet.
Physiological	Respiration and Photosynthesis	General sub-lethal stress	Too general a response, affected by many factors
	Scope for Growth	Energy potentially available for growth and reproduction (and indirectly general stress)	Widely tested and used in routine monitoring in Europe
	Growth & Condition Factor	General condition of animal and stress	Good sensitive methods available
	Mobility	General condition of animal and stress	Cannot be done reliably in field
	Hepatosomatic Index	General stress	Relatively untested, more work needed
	Reproduction and Gonadosomatic index	Reproductive conditions of animals (and indirectly general stress)	Relatively untested, more work needed

Table 7.1: (continued) Summary and overall evaluation of the biomarkers reviewed.

Type of indicator	Indicator	What is it?	Evaluation
Population	Fin erosion	General health condition of fish, indirectly to toxicants	Good index, widely employed in routine monitoring.
	Skeletal malformation	General health condition of fish, indirectly to toxicants	Good index, widely employed in routine monitoring.
	Epidermal hyperplasia /papilloma	General health condition of fish, indirectly to toxicants	Less often used than fin erosion
	Operculum abnormalities	General health condition of fish, indirectly to toxicants and especially pulp mill effluents	Tested in freshwater but not with marine species
	Liver histopathology	General health condition of fish, indirectly to toxicants and carcinogens	Much used index but requires skill to interpret
	Macrophage aggregates	General stress	Used only in Virginia routinely
	Gill histopathology	General stress, but responds to algal blooms, metals, pulp mill effluents and toxicants in general	Not used in routine monitoring
	Kidney histopathology	General health condition of fish, indirectly to toxicants	Not used in routine monitoring
	Ovarian growth	General health condition of fish, indirectly to (oil and metals)	Needs more research
	Embryonic defects	Organic contaminants	Too difficult to sample reliably
	Histopathology of molluscs	Organic contaminants, pesticides, oil	Good index but not used routinely
	Lysosome integrity	General stress in living cells, wide variety of contaminants.	Good well proven index that I used routinely
	Lipopigments content	Oxidative stress caused by PAHs and oil	Can be added to lysosome monitoring
	Peroxisome proliferation	Oxidative stress caused by PAHs and oil	Not tested enough to recommend
	Organismal indicators	Levels of bioavailable fractions of metals and trace organics	
	Population changes	General health response of population	See text
	Imposex	Response to TBT and DBT	Has been shown to be extremely useful
Organismal indicators	Mussel watch	Filter-feeding molluscs as indicators of contamination status	Widely used and efficient procedure.
Assemblage (See Chapter 8)	Diversity indices	General health response of community	Not sensitive
	SAB curves Log-normal distribution	General health response of community, but usually organic enrichment General health response of community	Shows changes graphically and is well-tested Well-tested and shows effects graphically
	ABC plots	General health response of community	Well-tested and shows effects graphically
	Multivariate statistics	Compares affected sites with controls and indirectly measures condition of communities	Highly effective and extremely well tested. Used globally
Ecosystem (See Chapter 8)	Production:respiration ratio Ecosystem health	Overall energy balance of ecosystem General health of system	Too general to be useful Ill-defined terms and too diffuse a concept

8.0 New and Improved Indicators for National Application

8.1 Introduction

In this chapter we identify certain indicators that are either not yet included in Ireland's monitoring and assessment programme or focus on topics that, although partially addressed in the last QSR[10], were not well defined or supported by adequate data.

The indicators selected cover a broad range of environmental conditions. Nevertheless, the selection process has been biased towards filling two particular gaps in the information base needed to assess Ireland's marine and coastal areas, namely biological responses to human activities and conditions in the coastal zone.

The conclusions of the 1999 QSR drew attention to the 'very limited information on biological responses to anthropogenic pressures' and also to the 'distinct shortage of information on the effects of current activities and developments on the coastal environment'. If implemented, the indicators described in this chapter will go some way towards resolving these deficiencies.

The importance of these categories of information should not be under-estimated. Most chemical measurements included in monitoring programmes are surrogates for biological measurements. This is appropriate where the relationship of concentration to effect is known and/or where the cost and feasibility of multiple biological measurements is prohibitive. In general, chemical measurements are less costly and sampling is relatively quick and simple. They may also provide an early warning of pollution in areas subject to continuing inputs of potentially harmful substances. Because of this, chemical measurements will always tend to be applied more broadly than biological measurements and, at certain locations, will provide evidence of contamination that triggers some form of biological investigation. Thus, an efficient monitoring programme will apply a combination of chemical and biological techniques. However, extrapolating biological responses from chemical measurements is seldom straightforward and chemical monitoring can never cover all substances to which marine organisms are exposed. In some cases responses may occur at concentrations below the analytical detection limits. Accordingly, the incorporation of biological measurements into marine environmental monitoring programmes will increase confidence in the power of the programme to identify harmful conditions.

[10] Quality Status Report (Boelens *et al.*, 1999)

The state of the coastal zone is highly relevant to marine environmental assessment. Contemporary policies and measures for environmental protection stress that the coastal zone should be seen as an integral part of the marine environment. Much of the degradation that affects marine areas around the world is directly associated with land-based activities, especially activities on and around the coasts. This is the primary concern of the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (UNEP, 1995). It is also the focus of a recent report by GESAMP (2001). Consequently, it is essential to keep under continuous review the changes on land that affect coastal waters and vice versa. The proposed indicator of coastal development is one of the few pressure indicators included in this report.

8.2 Selected Indicators

Each of the indicators is presented in the following pages in the form of a data-sheet, occupying no more than two pages, for ease of reference. At the head of each information sheet the relevant core group number (from Table 3.1) is shown together with an indication of current usage of the indicator in OSPAR, EU/WFD, EEA and other national/global programmes. The data-sheets provide a description of the indicator and give concise notes on relevant measurements, data acquisition, interpretation and value for money. Selected references are also provided. The indicators are numbered for ease of identification; the order in which they are presented does not imply any degree of priority.

1. Name of Indicator: Seabird Numbers and Breeding Success

Group	3	OSPAR		EU/WFD		EEA		Global	✓

Description:

Monitoring of seabirds (other than terns) at selected or 'key' sites around the coast of Ireland to provide data on population numbers and breeding success. Ideally, key sites should be counted annually to provide detailed information on population changes. However, counts every 2-3 years can still provide useful information on trends. Monitoring should focus on key sites within already identified JNCC regions of SE, SW and NW Ireland. The collection of data at these sites will enable long-term trends in seabird populations to be established and for some species, notably the kittiwake, short-term impacts may be detectable through changes in breeding success.

Measurement Units:

Number of breeding birds – to monitor population trends.

Number of fledged young – to monitor breeding success.

For some species these data are collected through counts of apparently occupied nests or burrows, for others through counts of number of adult birds. For some species a single well-timed count will be sufficient, for others a number of counts will be required. Where repeated counts are necessary whole colony counts may not be possible and sample plots can be used.

Data Availability/Acquisition:

To date, seabird monitoring has focused on a few island colonies on the east (Rockabill, Lambay, Ireland's Eye), south-east (Saltees) and south-west coasts (Skelligs and Beginish). Long-term data for mainland Kittiwake colonies on the south-east are also available. For some of these sites annual monitoring of all or part of the seabird colony has been completed, for other sites the monitoring interval is four to five years. However, for these sites good baseline data have already been established. Finally, a recent national census (1998-2002) will provide population data on other important seabird colonies. Historical data are also available from the 1985/87 and 1969/70 censuses of important seabird colonies.

Selection of key sites within each of JNCC identified Irish coastal regions will provide good geographical coverage of Irish seabird populations. Monitoring of population numbers and breeding success at these sites should take place as part of co-ordinated national monitoring programme with linked database. Invaluable long-term data from established monitoring sites could contribute to such a programme.

Interpretation & Usefulness:

The collection of seabird monitoring data from key regional sites will allow trends in population numbers to be established. Any adverse trends within a geographical area can then be identified and the reasons investigated. Long-term data sets are also essential for the provision of 'before and after' impact assessment, such as the impact of a major oil spill on breeding seabird populations. For small surface feeding species (e.g. Kittiwake), data on breeding success can indicate adverse trends over the short term. In the case of Kittiwake, poor chick survival in one year may be linked to food shortages, highlighting potential issues with fisheries. It is important to establish that factors such as predation, weather and/or disturbance are not responsible where low productivity has been recorded, limiting the reasons to those of the wider marine environment. In the future, the benefits of seabird monitoring data will increase as more research into seabird diet is completed. Population data can then be more directly linked to prey abundance and fisheries interactions.

The results of the Seabird 2000 census have highlighted the importance of Ireland's west coast for Storm Petrel, a nocturnal species that feeds on plankton. Further research into this species and suitable monitoring methods are required; however, in the future the monitoring of key west coast colonies will provide a useful link to plankton abundance.

Reliability (e.g. QA Requirements):

In Ireland, and more so the UK, annual monitoring of key seabird colonies has taken place since the 1980s. Seabirds are generally easy to count and their identification is well established. Monitoring methods for seabirds have been tested and improved and standard methods are now used. Given the history of seabird monitoring and the availability of standard methods data reliability should not be a problem, providing sites are properly selected and methods properly implemented. Between expertise available in Ireland and the UK, experienced personnel should be available to implement a national seabird-monitoring programme.

Ancillary Requirements:

Weather data will allow for useful interpretation of seabird monitoring results. Data on fisheries around breeding colonies will provide information on potential food sources of breeding seabirds and other pressures on this food source. For island colonies boat access will be required. A national database for data storage and analysis will be required.

Overall Evaluation & Value for Money:

A regionally targeted, nationally coordinated monitoring programme for seabird colonies is already well established in the UK. This programme has proven its worth in relation to, for example, assessing the effects of oil spills on seabird populations and highlighting poor breeding success among some species, which has been attributable to fisheries impacts. Likewise, a nationally coordinated seabird-monitoring programme for Ireland should provide similar benefits. As many seabird colonies in Ireland are of international importance, and are designated as SPAs under the EU Birds Directive, monitoring requirements under the EU Birds Directive will also be met. To reduce costs mainland colonies can be targeted where possible and sample plots can be used.

References:

Mavor, R.A., Pickerell, G., Heubeck, M. & Mitchell, P.I., 2002. Seabird numbers and breeding success in Britain and Ireland, 2001. UK Nature Conservation Series No. 26. JNCC

Merne, O.J.M. & Madden, B., 2000. Breeding seabirds of Ireland's Eye, County Dublin. Irish Birds, 6: 495-506.

Merne, O.J.M. & Madden, B., 1999. Breeding seabirds of Lambay, County Dublin. Irish Birds, 6: 345-358.

Tasker, M.L., 2000. The UK and Ireland seabird monitoring programme - A history and introduction. Atlantic Seabirds, 2(3/4).

Walsh, P.M., Halley, D.J., Harris, M.P., del Nevo, A., Sim, I.M.W. & Tasker, M.L., 1995. Seabird Monitoring Handbook for Britain and Ireland. JNCC/RSPB/ITE/Seabird Group, Peterborough.

2. Name of Indicator: Trends in Tern Populations

Group	3	OSPAR		EU/WFD		EEA		Global	

Description:

Monitoring a number of important tern colonies located around the Irish coast to determine population trends and breeding success. Terns are highly sensitive to changes in the marine environment and low fish availability in the vicinity of breeding colonies can reduce breeding success to low or zero. Impacts such as this over several years can diminish population size. Five species of tern breed in Ireland and colony monitoring so far has largely been restricted to east coast sites. Monitoring of important colonies in other coastal regions will provide important data on regional trends in tern populations. All five species of tern are listed under Annex I of the EU Birds Directive. Ireland is particularly important for Roseate Terns, with 70% of the NW European breeding population, Little and Sandwich Tern - and also supports important numbers of Common and Arctic Tern.

Measurement units:

While detailed monitoring programmes are necessary for tern species as part of a conservation management programme, monitoring of population numbers and breeding success is sufficient for indicator purposes. Numbers of apparently occupied nests or apparently incubating adults are recorded to estimate breeding population size. Numbers of fledged chicks per nest site are recorded to indicate breeding success/colony productivity. Whole colony counts should be completed and counts should take place annually or at a minimum of 2-3 year intervals. Monitoring should be targeted at a number of key sites covering each of the three geographical regions currently used in JNCC counts (NW, SW and SE).

Data Availability/Acquisition:

To date monitoring of tern colonies has focussed largely on three east coast sites (Rockabill, Kilcoole and Lady's Island Lake). These sites are especially important for Roseate Tern and Little Tern and detailed population monitoring of these species has been undertaken. These programmes are well established and should continue, given the threatened status of the species concerned. Elsewhere, tern colony monitoring has been limited to a handful of sites in the north-west (Lough Swilly and Mulroy Bay), south (Cork Harbour), south-west (Beginish Island) and east (Dublin Port) - with no sites being monitored in the west. The 1995 all-Ireland tern census identified 14 important tern sites, located around the Irish coast. Monitoring efforts should be focused on these sites, using established methods. Populations of breeding terns can be very mobile. Visits to a number of sites within an area may be required to establish the location of the selected colony.

Interpretation & Usefulness:

Monitoring data will provide sufficient information to determine the health of tern population and long-term population trends. Short-term impact on the tern populations due to food shortages for example, should be determined through monitoring of breeding success. This low-input monitoring programme would benefit from the more detailed population monitoring which has taken place at key east coast sites. An expansion of tern monitoring to other important sites around Ireland will provide a better picture of regional influences and potential impacts on tern populations, which may, in turn, reflect wider pressures on the marine environment in these areas.

Reliability (e.g. QA requirements):

Standard methods for tern colony monitoring have been established and are well practised in Ireland, particularly at east coast colonies. A considerable level of expertise is available to advise a tern-monitoring programme. Long-term datasets from the east coast, and other tern colonies, will provide important baseline and historical data. The all-Ireland tern census of 1995 and previous census of 1984 will also provide good historical data for comparison and trend analysis.

Ancillary Requirements:

Boat access, database and data processing facilities. Fisheries and climate data.

Overall Evaluation & Value for Money:

Given the sensitivity of terns to changes in the marine environment, monitoring of this species should provide clear signals of changes in prey abundance due to fisheries or other factors. Studies into the diet of terns have been completed and the link between impacts on tern populations due to food shortages should be easily established. Ireland is important for all five species and a monitoring programme that covers key colonies within all coastal regions will meet obligations under the EU Birds Directive. As top predators within the marine environment, tern populations will reflect changes in this environment.

References:

Hannon, C., Berrow, S.D. & Newton, S.F., 1998. The status and distribution of breeding Sandwich Sterna sandvicensis, Roseate S. dougallii, Common S. hirundo, Arctic S. paradisaea and Little Tern S. albifrons in Ireland in 1995. Irish Birds 6, (1): 1-22.

Newton, S. and Crowe, O., 2000. Roseate Terns - The Natural Connection. Maritime Ireland/Wales INTERREG Report No.2.

Suddaby, D. & Ratcliffe, N., 1997. The effect of food availability on breeding Arctic terns. Auk, 114: 524-530.

3. Name of Indicator: Cetacean Abundance and Distribution

Group	3	OSPAR		EU/WFD		EEA	✓	Global	✓

Description:

Irish waters are important for cetaceans - both in terms of numbers and species diversity. While data on cetacean populations around Ireland remains limited, they are sufficient to provide, at least, an initial framework for monitoring. Cetacean monitoring is made difficult due to a number of practical difficulties. For example, cetaceans are generally wide-ranging species and are long-lived with low reproductive rates. These factors mean that any intensive monitoring programmes for cetaceans is only worthwhile where a resident, geographically defined, population is known to exist - and even then monitoring over a long number of years is required to detect changes in population status. To gain maximum benefit, monitoring programmes should therefore consist of frequent small-scale surveys over a long period of time. Such survey effort will be limited to monitoring cetacean abundance and distribution only, rather than measuring any change in actual population size. A selected number of sites around the coast should be monitored from land using standardised repeatable methods. Monitoring of cetacean distribution and abundance at offshore sites is also necessary.

Measurement Units:

Relative abundance and distribution. The number of each cetacean species recorded within a defined area should be recorded. A standard methodology for monitoring numbers of cetaceans within selected survey squares is being developed. These squares will be monitored over quantifiable time periods so that abundance can be measured relative to survey area and effort. Where ship based surveys take place, the same principle must apply and abundance relative to survey area and effort only, can be measured.

Data Availability/Acquisition:

Considerable data has been collated over the years recording the occurrence of different cetaceans in Irish waters, either through dedicated land and sea surveys or through incidental sightings. Strandings records are also used to measure species occurrence. However, there are few studies providing accurate estimates of cetacean abundance in Irish waters. The SCANS survey in 1994 provided estimates of small cetacean abundance in the Celtic Sea and the recent SIAR survey (2000) derived cetacean abundance estimates for offshore waters at the Atlantic Margin. Intensive survey work has also just been completed (2001-2002) in Broadhaven Bay as part of an impact assessment process. Accurate baseline data on cetacean abundance and distribution is therefore incomplete.

Selected sites representing different habitat and coast types should be monitored from land using standardised repeatable methods. Regular monitoring should take place over a defined area and for a defined period of time. Methods to support such a monitoring scheme are currently being developed by the Irish Whale and Dolphin Group with funding from Dúchas, the Heritage Council and the Northern Ireland Environment and Heritage Service.

Monitoring of cetacean abundance and distribution at offshore sites is also necessary. While baseline data is limited, the recent SIAR survey identified key regions of significance for cetacean abundance and species richness where monitoring efforts could initially be focused. In this case, ships of opportunity can be used. Over time the need for offshore monitoring in other areas is likely to become established.

Interpretation & Usefulness:

Cetaceans are top predators with a distribution linked to prey availability. Monitoring of these species will provide important information on changes in the wider marine environment.

A co-ordinated sightings scheme will provide an essential basic tool for monitoring the relative abundance and distribution of cetacean species in Irish coastal waters. Such a programme will provide at least the start of a standardised and repeatable monitoring programme which should continue over the long term to enable trends in abundance and distribution to be measured.

The use of ship-based monitoring on an opportunistic basis will give some indication of the situation in offshore waters. While gaps in baseline data are acknowledged, so too is the importance of Irish coastal waters for cetaceans.

Methods for cetacean monitoring are under development and over time the use of aerial and acoustic monitoring may also prove to be practical and cost effective.

Reliability (e.g. QA requirements):

Variability in year-to-year abundance estimates may arise due to the use of different observers. Thus, frequent surveys carried out by trained personnel using standardised methods will help to ensure the comparability of data and reduce uncertainty. Issues relating to the methodology will arise over time and changes to the scheme may be required.

Ancillary Requirements:

National co-ordination with database and reporting facilities. May usefully be linked to seabird monitoring co-ordination.

Overall Evaluation & Value for Money:

To be of any value this programme will require funding over a long period of time. Initial set-up costs will be greatest, such as establishing methodology, sites, surveyors and co-ordination. There will be ongoing costs in terms of survey personnel, co-ordination, data handling and management and reporting.

References:

Berrow, S.D. & Rogan, E., 1997. Review of cetaceans stranded on the Irish Coast, 1901 - '95. Mammal Review 27(1): 51-76.

Wilson, B., Hammond, P.S. & Thompson, P.M., 1999. Estimating size and assessing trends in a coastal bottlenose dolphin population. Ecological Applications, 9(1): 288-300.

Ó Cadhla, O., Borchers, D.L., Burt, M.L. & Rogan, E., 2001. Summer distribution and abundance of cetaceans in western Irish waters and the Rockall Trough. Int. Whal. Commn. Scientific Committee paper SC/53/O15.

Pollock, C.M., Reid, J.B. Webb, A. & Tasker, M.L., 1997. The distribution of seabirds and cetaceans in the waters around Ireland. JNCC Report No. 267. Joint Nature Conservancy Council, Peterborough, UK.

Thompson, P., Tufft, L., Spencer, N., Grellier, K., & Durban, J., 2000. Evaluation of techniques for monitoring the abundance and distribution of Bottlenose Dolphins - The Kessock Channel as a case study. Scottish Natural Heritage Commissioned Report F99LE01.

4. Name of Indicator: Trends in Seal Populations

Group	3	OSPAR		EU/WFD		EEA		Global	

Description:

Both the harbour, or common, seal (*Phoca vitulina vitulina*) and the grey seal (*Halichoerus grypus*) are found around the Irish coast. Due to habitat and behaviour differences population monitoring methods differ for harbour and grey seals. For grey seals, population monitoring is based on counts completed at breeding sites. This gives only an estimated population size based on pup production, as counts at breeding sites do not include non-breeding adults or those in the water. Pup counts provide an estimate of birth rate, while counts of pup mortality give an indication of breeding success and therefore the health of the population. For harbour seals, population monitoring is based on counts completed at haul-out sites during the moulting season, a time when the maximum number of seals is likely to be out of the water for the longest period of time. Again, this only gives a minimum estimate of population size. Pup production for harbour seals cannot easily be monitored as pups frequently swim within hours of birth.

Measurement units:

Grey seals - the number of adults and young at breeding sites as an estimate of minimum population size. Number of pups as an estimate of birth rate and pup mortality as an estimate of breeding success. Population estimates of grey seals based on counts at moult sites should also be considered, pending development of this methodology.

Harbour seals - the number of adults and young hauled out during the moulting period as a minimum estimate of population size.

Data Availability/Acquisition

National population estimates for grey and harbour seals are derived from surveys completed during the late 1970s and early 1980s. There has been no co-ordinated national monitoring of seal populations since then. Some recent grey seal surveys provide more recent population estimates for this species at a number of west coast sites, especially the Inishkea Islands (Co. Mayo) and Blasket Islands (Co. Kerry). Grey seal surveys completed between 1996 - 1998 in the western Irish Sea and eastern Celtic Sea provide the first reliable minimum estimate for this breeding population. Data on harbour seals has not been updated since the 1980s. However, a national population census, using thermal imaging techniques developed in Scotland, is planned for 2003. Some seal monitoring work is carried out by Dúchas conservation rangers, and expertise is available at University College Cork.

Using current data on grey seal populations and forthcoming data for harbour seal populations, the principal colonies around the coast should be selected as monitoring sites.

Surveys should be completed from the shore or boat. Aerial surveys using aerial photography may be required at some locations and for harbour seals, which can be camouflaged against the shore, it may be necessary to use thermal imaging photography. Key grey and harbour seal sites around the coast should be selected for annual monitoring. For grey seal colonies 2-3 visits per year will be required to record pup production and survival.

Interpretation & Usefulness:

Seals are top predators in the marine environment and changes in their population status are likely to reflect those within the wider marine environment. Regular monitoring of seal populations at key sites around the Irish coast will provide data on long-term population trends. Data on pup mortality and breeding success will give some indication of the health of the population over the short-term. Such a monitoring programme will provide essential data to inform concerns regarding seal/fisheries interactions; the impact of environmental disasters such as oil spills; and the impact of any infectious diseases such as the phocine distemper virus. There is also a clear need for reliable and recent data on population trends to inform data derived from strandings and bycatch records. Any investigations into the effects of pollution and contaminant levels on the health of seal populations will also usefully be informed by long-term data on the population status of these species.

Reliability (e.g. QA requirements):

Techniques for seal survey and monitoring work have been developed at the Sea Mammal Research Unit in Scotland. Considerable expertise is also available in Ireland. Standard monitoring methods and principles are well established. Surveys conducted within this context should provide reliable data derived from repeatable methodologies.

Ancillary Requirements:

Boat and small aircraft use, depending on locations of key sites. Thermal imaging equipment - again depending on key sites selected and level of difficulty in completing accurate counts. National coordination, data collation and reporting facilities.

Overall Evaluation & Value for Money:

A carefully designed monitoring programme to reduce higher costs associated with boat and aerial surveys should ensure costs remain reasonable. Accurate and recent data on seal populations is essential for many reasons, not least to inform debate regarding fisheries interactions. Both the harbour and grey seal are Annex I species under the EU Habitats Directive and monitoring requirements in this context may also be fulfilled.

References:

Davies, J., Baxter, J., Bradley, M., Connor, D., Khan, J., Murray, E., Sanderson, W., Turnbull, C., & Vincent, M., 2001. Marine Monitoring Handbook: UK Marine SACs Poject. Joint Nature Conservation Committee.

Kiely, O., Lidgard, D., McKibben, M., Connolly, N., & Barines, M., 2000. Grey Seals: Status and Monitoring in the Irish and Celtic Seas. Maritime Ireland/Wales INTERREG Report No. 3.

Kiely, O. & Myers, A.A., 1998. Grey Seal (Halichoerus grypus) pup production at the Inishkea island group Co. Mayo and the Blasket Islands, Co. Kerry. Biology and Environmen, 98B(2): 113-122.

Summers, C.F., Warner, P., Nairn, R.G.W., Curry, M.G. & Flynn, J., 1980. An assessment of the status of the common seal Phoca vitulina vitulina in Ireland. Biology and Conservation, 17: 115-123.

5. Name of Indicator: Phytoplankton Biomass, Composition and Abundance in 'Offshore' Waters

Group	2,18	OSPAR	✓	EU/WFD		EEA		Global	✓

Description:

Phytoplankton are of fundamental importance in marine ecosystems as they form the base of marine food chains. They also play an important role in global climate through their draw-down of carbon dioxide into the oceans for photosynthesis. The abundance of phytoplankton in the water column follows predictable, geographically based seasonal patterns related to nutrients, light intensity, temperature and grazing (predation) pressures. However, water quality conditions will influence the composition and abundance of phytoplankton. In waters further offshore such changes are likely to be less pronounced than in coastal and estuarine waters. Nevertheless, clear evidence exists for long-term variability in abundance and composition of phytoplankton. Both natural (e.g. sea surface temperature oscillations and Gulf Stream position) and anthropogenic factors (climate change) have been implicated in these changes.

Chlorophyll-a is generally measured as a surrogate for algal biomass to measure the annual maximum planktonic algal biomass and the duration and magnitude of seasonal (spring and autumn) phytoplankton blooms. Monitoring of the phytoplankton community may highlight changes in composition in major taxonomic groups and possibly at a species level.

N.B. Within the context of the implementation of the WFD, phytoplankton classification and monitoring 'tools' for transitional and coastal water bodies are being developed by a joint UK/Ireland plant classification sub-group. These include indicators of composition and abundance of phytoplankton taxa, biomass (chlorophyll mean, max. and min.) and bloom characteristics (frequency and intensity). The monitoring programme is due to be in place by 2006. Consequently, phytoplankton indicators for transitional and coastal waters are not considered here. Rather, this group of indicators focuses on phytoplankton in waters further offshore.

Measurement Units:

Planktonic algal biomass - the annual maximum planktonic algal biomass (expressed as mg/m3 of chlorophyll-a) is the ideal measurement. The Continuous Plankton Recorder (CPR) Ocean Colour index provides a representative measure of chlorophyll-a concentrations.

Algal bloom characteristics - temporal trends in chlorophyll-a to provide chlorophyll-a maxima and duration of seasonal blooms (in days).

Species composition and abundance - composition and abundance of phytoplanktonic taxa and presence/absence of key species (e.g. nuisance species). The use of a phytoplankton trophic index, such as that currently being developed in the UK, should be considered.

Data Availability/Acquisition:

The availability of data on phytoplankton biomass, primary production, community structure and spatial and temporal trends in Irish waters is reviewed in detail in the QSR (Boelens *et al.*, 1999). Coverage varies considerably, with the best information available being for the northwest Irish Sea and off the southwest coast. There is however, no ongoing annual monitoring. The national research vessels (RV Celtic Voyager and RV Celtic Explorer) collect underway data, include fluorescence, via a flow-through system. CPR sampling, undertaken by volunteer 'ships of opportunity' towing a recorder at about 10m depth along regular routes at monthly intervals, provides data on the patterns and trends in community structure and distribution and abundance of upper layer plankton at oceanic scales. It has been carried out in Irish waters since 1948 and allows the identification of seasonal and long-term trends in the seas around Ireland. Due to the opportunistic nature of the survey, the shelf area (<200m) between Donegal and Kerry is poorly covered by the CPR network.

Algal Biomass and Bloom Characteristics

As repeated sampling to determine the annual maximum phytoplankton biomass in offshore waters is not feasible, remote automated semi-continuous monitoring of phytoplankton at a small number of sites is the ideal means. Automated fluorometers can be used for chlorophyll-a monitoring to determine algal biomass and bloom characteristics. Flow cytometry, an optically based technique that simultaneously measures multiple light scatter and fluorescence properties of individual particles at high speed, is currently being used and developed to accurately discriminate and quantify phytoplankton. The national data buoy network offers the possibility for the installation of in-situ fluorometers for the measurement of the required parameters. Data buoys are now in place off the east, southwest, west and northwest coasts, providing good geographical coverage - a further deployment is planned for the south coast.

Ireland contributes financially to the Sir Alistair Hardy Foundation for Ocean Science (SAHFOS) giving access to all CPR data. Furthermore, the possibility of installing CPR equipment on, for example, the Celtic Explorer has been considered. If implemented this will allow for extension of CPR coverage in the shelf waters to the west of Ireland that are currently poorly represented. Due to the opportunistic nature of CPR surveys the CPR colour index does not represent a substitute for semi-continuous in-situ monitoring.

Satellite sensors (e.g. SeaWiFS) are increasingly used to measure oceanic 'colour' and an index of chlorophyll concentrations to indicate the distribution and abundance of phytoplankton.

Species Composition and Abundance

Boat based surveying is the most feasible means for data collection to determine phytoplankton composition and abundance. Dedicated spring sampling runs along set transects should be established, e.g. Irish Sea, south coast, southwest and west coast. Remote collection of water samples from buoy or sub-surface mooring deployments offers a further possibility but such techniques require further development. The CPR data can provide additional information on to phytoplankton composition and abundance.

Interpretation & Usefulness

The concentration of the chlorophyll-a in marine waters is a proven indicator of the biomass of microphytoplankton. The CPR colour index is a semi-quantitative index of the concentration of microphytoplankton. Phytoplankton composition is a sensitive indicator of perturbation in the expected balance of organisms.

Phytoplankton monitoring in waters beyond the extent of waters covered by the WFD could provide "reference" levels of phytoplankton biomass for coastal waters. This should be used as part of a suite of indicators (e.g. along with water quality indicators); some are already in existence, such as winter nutrient concentrations in the western Irish Sea.

Reliability (e.g. QA requirements):

It is important to emphasise that satellite and aerial monitoring of primary production only measures the first 10cm of the water column. The primary production maximum can, in certain cases, be well below the surface. In such cases satellite monitoring gives false results. In-situ measurements from moored buoys may be used to provide 'sea-truth' data for the verification of satellite data relating to chlorophyll, other phytoplankton pigments and particle loading.

Reference values and acceptance thresholds for all parameters will need to be determined and validated.

Inter-calibration between buoy-based measurements and CPRs with mounted fluorometers may be possible on some CPR routes.

Ancillary Requirements:

The expertise to collect and interpret phytoplankton data exists nationally. Dedicated ship time on one or both of the national research vessels is required for spring sampling runs. There will be special requirements for the storage and handling of large volumes of phytoplankton data; these will need to be considered within the overall context of data acquisition by research vessels. Acquisition of satellite date should be considered and may require expertise in image interpretation.

Overall Evaluation & Value for Money:

Phytoplankton are the base of the marine food chain and, therefore, are a good indicator of the abundance of marine life and overall ecosystem health. Long-term monitoring of phytoplankton biomass and composition can act as an indicator of climate change. Installation of monitoring equipment on the data buoys and acquisition of satellite data will constitute the greatest expense.

References:

Boelens, R.G.V., Walsh, A.R., Parsons, A.P. & Maloney, D.M., 1999. Ireland's Marine and Coastal Areas and Adjacent Seas: an Environmental Review. Marine Institute, Dublin, 381pp + appendices.

Hays, G.C. & Lindley, J.A., 1994. Estimating chlorophyll a abundance from the 'phytoplankton colour' recorded by the Continuous Plankton Recorder survey: validation with simultaneous fluorometry. J. Plankton Res. 16(1), 23-34.

Reid, P.C., Planque, B. & Edwards, M., 1998. Is observed variability in the long-term results of the Continuous Plankton Recorder Survey a response to climate change? Fish. Oceanogr., 7: 282-288.

6. Name of Indicator: Status of Benthic Communities

Group	2	OSPAR	✓	EU/WFD	✓	EEA		Global	

Description:

Soft-sediment benthic invertebrate communities are an important component of marine food chains. They occupy large areas within estuaries and sheltered coastal waters. Their biomass and diversity are functions of sediment texture, depth, food supply, grazing pressure and disturbance by natural events (e.g. storm frequency) as well as the nature and extent of human interferences (e.g. trawling, dredging, contamination).

Substantial changes in biomass and/or diversity of benthic communities over large areas, not explicable by natural variation, may represent a severe loss to marine ecosystems. Thus, the status of benthic communities in selected areas should be kept under surveillance. In addition, benthic communities may serve as useful indicators of environmental changes exerted by specific practices such as offshore resource exploitation, dumping of dredged material, mariculture installations etc. In such cases, sampling at increasing distances from the source or activity (i.e. along gradients) can provide valuable information on the nature of effects and their geographical extent.

Measurement Units:

Numbers of species, total abundance and total biomass. Data should be subject to multi-variate statistical analysis (See Annex 2). Diversity indices are not considered sufficiently sensitive (See Chapter 6).

Data Availability/Acquisition:

To date there have been no regular surveys of marine benthos around the Irish coast. There are few good datasets showing spatial patterns of benthic invertebrate communities. The best available time series are from inner Galway Bay, notably the Margaretta Station.

A national programme of benthic community monitoring needs to be established. The programme should meet the needs of the Water Framework Directive and also provide a basis for surveillance of sediments in the vicinity of offshore installations (including offshore wind turbines).

Interpretation & Usefulness:

Changes and abnormalities in benthic communities should be identified and evaluated through comparisons with carefully selected, unperturbed, reference stations of similar sediment structure, depth and latitude and through comparison of communities at points along known or assumed contamination gradients.

As stress increases, benthic communities respond in a consistent manner. Some rare species become locally extinct and some species of intermediate abundance may either decrease in abundance or, in the case of a few species, become much more abundant. These changes can be illustrated using species-abundance plots but more consistent and objective analyses are obtained by use of multivariate statistics and techniques that link changes in assemblages to environmental variables.

Provides valuable management information on conditions at the sea bottom.

Reliability (e.g. QA requirements):

Good sampling design, standardized methodologies and modern statistical treatment of data will provide very reliable results. Periodic field inter-calibration exercises are recommended. A selection of samples from different survey areas should be preserved and retained in a national sample bank where they will be available for specialist verification and further study and comparison.

Ancillary Requirements:

A roster of qualified marine taxonomists that can assure comparability and continuity within and between surveys; a national marine sample bank; co-samples for sediment chemistry (in an integrated programme chemical measurements may assist in providing a better understanding of cause and effect).

Overall Evaluation & Value for Money:

Costs relatively moderate, mainly manpower; technology costs low. In view of the value of the information for assessment and management, resources devoted to this indicator constitute a worthwhile national investment. Strongly recommended.

References:

Gray, J.S., 2003. Chapter 6, this report

Kennedy, R., Solan, M. & Keegan, B., 2001. Alternatives to quantifying macrobenthic diversity at the species level: the utility of estimating diversity from higher taxonomic levels and sediment profile imagery (SPI). In: Nunn, D. (Ed) Marine Biodiversity in Ireland and adjacent waters. MAGNI publication No.008, Ulster Museum, Belfast, pp 67-92.

Gray, J.S. & Pearson, T.H. 1982. Objective selection of sensitive species indicative of pollution-induced disturbance on marine benthic communities. I. Comparative methodology. Mar. Ecol. Progr. Ser., 9: 111-119.

Clarke, K.R. & Warwick, R.M., 1994. Changes in marine communities: an approach to statistical analysis and interpretation. Plymouth Marine Laboratory, Plymouth.

7. Name of Indicator: Distribution, Composition and Health of Seagrass Beds

Group	1,2,6	OSPAR		EU/WFD	✓	EEA		Global	✓

Description:

This indicator is an estimate of the extent of littoral and sublittoral seagrass habitats, their species composition and health.

Seagrasses are marine angiosperms that are rooted to sand, silt or muddy sediments. They require high light levels to grow (15-25%), compared to other aquatic primary producers (<5%) (Dennison *et al.*, 1993). They are, therefore, most commonly found in low nutrient, shallow waters (estuaries and bays) and in intertidal areas. Seagrasses compete with planktonic and benthic algae for nutrients and light. Nutrient enrichment and reduction in water clarity can tip the balance toward algae to the detriment of seagrasses. Nutrient enrichment in seagrass habitats may also trigger the growth of epiphytes on the surface of the seagrass leaves - further reducing light availability.

Measurement Units:

Distribution – areal extent (e.g. km2) and depth of beds.

Species composition (number of species).

Epiphyte cover (%) – (possible).

Data availability/acquisition:

There is little reliable qualitative data available on a national scale on the extent of Zostera beds. The BIOMAR Survey recorded the presence of Zostera spp. at over 50 subtidal sites around the coast but provided no indication on the extent of beds. However, there are records (extent and biomass of beds) extending back over 20 years for some areas, for example sub-tidal areas on the south coast. The subtidal perennial Z. marina is widespread around the Irish coast, with extensive beds found in Tralee, Castlemaine, Roaringwater, Mannin and Blacksod bays. The main beds of Z. noltii are located at Mulroy Bay, Tralee Bay, Cunnigar Sand Spit (Dungarvan) and Tramore Back Strand. Notable beds of the annual intertidal form of Z. marina are found at Tralee Bay, Mornington/Boyne Estuary, Rosslare Backstrand and Dungarvan Harbour.

Field sampling of intertidal and subtidal seagrass beds relies upon methods such as visual/diver inspections, underwater video, Remotely Operated Vehicles and beach transect sampling. The expertise and capacity to undertake field sampling/groundtruthing for seagrass surveys is available nationally. Water quality and seagrass distribution data is increasingly being derived from remote sensing platforms (both aircraft and satellite). Numerous platforms are available with differing instruments and abilities, and cost associated with obtaining images from each. Aerial photography is widely used to map seagrass beds, however it often cannot distinguish between algae and seagrass. More recently, hyperspectral imagery, obtained from aircraft, has been used. It can detect subtle differences in the structure, function and photosynthetic vigour of plants. Satellite imagery derived from the SeaWiFS (Sea Wide Field-of-View) instrument can also be used to detect seagrass cover. Regardless of the choice of remote sensing platform and instrument(s), field sampling will be required for calibration and to obtain information on species composition and epiphyte cover.

Detailed mapping of the distribution and extent of seagrasses on a national scale is a prerequisite to any ongoing use of seagrasses as an indicator of ecosystem health. Ongoing monitoring should focus on a number of bays, particularly those with extensive beds, and areas with a range of human activities that may lead to changes in Zostera beds. Reference sites with relatively little human activity should also be considered.

Interpretation & Usefulness:

Seagrass meadows support a diverse range of flora and fauna and provide a habitat and food source for fish, shellfish and waterfowl. They also affect nutrient cycling, sediment stability and water turbidity. Intertidal Zostera beds are notable as feeding grounds for Brent Geese - an important overwintering species in Ireland. Other pressures on seagrasses include pests, fishing and sea-level change.

Seagrasses are potentially sensitive indicators of declining water quality because of their high light requirements compared to that of other aquatic primary producers. However, seagrass assemblages change only relatively slowly in temperate areas and, as such, large-scale remote mapping of distribution may only be required on a 3-5 year interval - such as is carried out in, for example, Australia and the U.S.

The WFD requires seagrass assemblages to be considered in assessing the ecological status of transitional and coastal water bodies. It also requires the monitoring of seagrasses on a three-yearly basis. Mapping of seagrass beds may also fulfil certain OSPAR habitat mapping commitments, which are intended to focus initially on a list of threatened and/or declining habitats. This list includes Zostera beds.

Reliability (e.g. QA requirements):

The extent of change in the overall cover of any specific seagrass bed that would be considered unacceptable is unknown. This can only be assessed by a time-series of monitoring data. However, international experience has shown that even small changes in coverage of seagrass beds in temperate areas should be considered as significant.

Ancillary Requirements:

Whilst the expertise to carry out field surveys exists in Ireland, additional requirements will depend on the methodology chosen. These requirements may include access to aircraft, for carrying out surveys, and satellite imagery.

As the data collected to fulfil the requirements of this indicator have a large geographic component, data storage and interpretation will require a GIS.

Overall Evaluation & Value for Money:

Changes in the distribution (both depth and areal extent) of seagrass are a good indicator of transparency-reducing water quality parameters and of overall coastal ecosystem health, and can provide feedback regarding the success, or otherwise, of pollution abatement measures.

Although groundtruthing surveys are considered to be relatively low-cost, they require a great deal of manpower. However, field sampling of seagrasses can be incorporated into other field monitoring to minimise logistical costs (e.g. benthic and macroalgal monitoring). The US EPA conducts a National Estuary Programme that utilizes volunteers to carry out groundtruthing of, amongst other things, seagrass beds. The use of trained volunteers may be worth considering for manpower intensive surveying, such as is required for seagrasses.

Aerial imagery (photographic/video/hyperspectral) and, particularly, satellite imagery are potentially quite expensive. However, consideration should be given to their overall value. Aerial photographs and/or satellite imagery collected for remote monitoring of seagrass beds are a valuable data source for many other applications (e.g. water quality).

References:

Dennison, W.C., Orth, R.J., Moore, K.A., Stevenson, J.C., Carter, V., Kollar, S., Bergstrom, P.W. and Batiuk, R.A., 1993. Assessing water quality with submersed aquatic vegetation. BioScience, 43: 86-94.

Fyfe, S., 2002. Hyperspectral Remote Sensing of Seagrasses. http://www.uow.edu.au/science/geosciences/ pgrad/sfyfe.htm.

Guiry, M.D. & Kilty, G.M., 1972. The Zostera beds of Dungarvan, Co. Waterford. Irish Naturalists' Journal, 17: 187-189.

Madden, B., Jennings, E. & Jeffrey, D.W., 1993. Distribution and ecology of Zostera in Co Dublin. Irish Naturalists Journal, 24 (88): 303-315.

Kirkman H., 1996. Baseline and monitoring methods for seagrass meadows. Journal of Environmental Management 47: 191-201.

Zeledon, E. & Hall C., 2001. Remote Sensing of Seagrasses. ASGSB 2001 Annual Meeting Abstracts. http://asgsb.indstate.edu/programs/2001/41.html.

8. Name of Indicator: Extent and Condition of Important Habitats/Communities

Group	1,2,18	OSPAR	✓	EU/WFD	✓	EEA		Global	✓

Description:

This indicator quantifies the extent and condition of important marine and coastal habitats. The habitats to be included in this indicator cannot be chosen at this stage but are likely to be determined by national responses to the relevant international legislation. Monitoring of SACs (and SPAs) under the EU Birds and Habitats Directives will be undertaken as part of the National Marine Monitoring Programme (EPA, 2002). The monitoring protocol for SACs is currently under development. Many of the habitats listed under the Habitats Directive are very broad in nature, e.g. 'estuaries' and 'large shallow inlets and bays', and can contain many different habitats types and communities. It is likely therefore that monitoring will focus on specific sensitive communities (e.g. Maërl beds, Sabellaria reefs and Modiolus beds), taxa (e.g. echinoderms) or species within these habitats. Additionally, in accordance with the OSPAR Strategy on the Protection and Conservation of Ecosystems and Biodiversity, the Joint Assessment and Monitoring Programme requires assessments of priority habitats that are deemed to be under threat and/or in decline. Many of the habitats identified in the OSPAR list of threatened/declining habitats are considered to be under threat or in decline in Irish waters (Annex 4).

Measurement Units:

The habitat parameters to be monitored will depend to a certain extent upon the choice of habitat but are likely to include the areal extent of the habitat (see, for example, the separate factsheet on seagrass beds) and indicators of changes in biodiversity on decadal scales. Indicators of biodiversity of selected communities (most likely on decadal scales) will provide information on the condition of selected habitats or the status of particular species that are protected through habitat conservation measures.

Data Availability/Acquisition:

In the inshore zone (0-50m) there has, up until relatively recently, been little extensive mapping of habitats/ communities. The BIOMAR survey recorded ecological data from 850 sites around Ireland and formed much of the basis for the selection of marine SACs (Picton & Costello, 1998). Extensive mapping of benthic communities has also been carried out in the Irish Sea by two further projects - SensMap (www.ecoserve.ie/projects/sensmap) and SWISS (Wilson, 2001). The National Parks and Wildlife Service has recently completed the mapping of five marine SACs. The Marine Institute (in collaboration with others) plan to carry out extensive habitat mapping in the inshore zone in the future. The priorities for this mapping programme are currently being decided upon but are likely to focus initially on areas of conservation importance and areas with multiple human activities - and consequently those areas with a potential for habitat damage and/or loss. Such surveys will provide a baseline of information on the location and extent of indicator habitats and their communities. The recently completed mapping of Zone 3 (2-4,500m) of the National Seabed Survey and ongoing mapping of Zone 2 (50-200m) will provide similar baseline data for deeper waters. For example, data from Zone 3 of the survey are being used to map the extent and condition of deepwater coral (*Lophelia pertusa*) reefs.

Targeted biodiversity studies of important communities such as that carried out by De Grave *et al.* (2000) on Maërl beds can also provide important baseline information for indicators of habitat condition.

As with the measurement units (above), data requirements will depend greatly on the choice of habitats/communities and the parameters to be determined. N.B. Féral *et al.* (2003) have reviewed European marine biodiversity indicators in an attempt to achieve consensus on internationally agreed and normalised measures and indicators for biodiversity. The results of this review may have some bearing on the choice of appropriate biodiversity indicators for application in Ireland.

Interpretation & Usefulness:

Any major reduction in protected habitats, loss of marine biodiversity or reduced abundance of protected species will bring into question the efficacy of protection measures. Alternative measures or stricter enforcement may be required. Monitoring the extent of protected habitat types would be most useful for those habitats/communities where a change in extent is likely e.g. saltmarsh, seagrass (see separate factsheet), mudflats, horse mussel beds, sponge and bryozoan beds and other communities sensitive to sedimentation and human activities such as bottom fishing methods.

Decadal scale changes in biodiversity of chosen communities may provide indications of climate change as well as impacts of human activities in the target habitats.

Reliability (e.g. QA requirements):

Suitably trained personnel (e.g. marine ecologists) and standardised methodologies (preferably international) should be employed.

Ancillary Requirements:

Baseline information on the location and extent of selected habitats and the biodiversity of selected communities is a prerequisite for this indicator.

Overall Evaluation & Value for Money:

Confirmation that habitat, community and species conservation measures are effective would support the widely held view that state interventions to protect 'natural capital' assets are workable and justified. Such measures are the cornerstone of environmental protection policies.

References:

De Grave, S., Fazakerley, H., Kelly, L., Guiry, M.D., Ryan, M. and Walshe, J., 2000. A study of selected Maërl beds in Irish waters and their potential for sustainable extraction. Marine Resource Series, No. 10. Marine Institute, Dublin.

EPA, 2002. [Draft] National Environmental Monitoring Plan for Transitional, Coastal and Marine Waters: a discussion document, Version 1. Environmental Protection Agency in collaboration with the Marine Institute, Radiological Protection Institute of Ireland, Met Éireann & Duchas, 153pp.

Féral, J.P., Fourt, M., Perez, T., Warwick, R.M., Emblow, C., Hummel, H., van Avesaath, P. and Heip, C., 2003. European Marine Biodiversity Indicators. Report of the European Concerted Action: BIOMARE - Implementation and networking of large scale, long-term Marine Biodiversity research in Europe. Contract number: EVR1-CT2000-20002.

Picton, B. and Costello, M., 1998. BioMar Biotope Viewer: a guide to habitats, fauna and flora of Britain and Ireland. Environmental Sciences Unit, Trinity College, Dublin. (CD-ROM).

Wilson, J. G., Mackie, A. S. Y., O'Connor, B. D. S., Rees, E. I. S. &Darbyshire, T. 2001. Benthic biodiversity in the southern Irish Sea 2: The south-west Irish Sea survey.

9. Name of Indicator: Alien Species

Group	2	OSPAR		EU/WFD	✓	EEA	✓	Global	✓

Description:

This indicator follows trends in invasions of exotic (introduced, alien, non-native) marine organisms including those whose introduction does, or is likely to, cause economic or environmental harm or impact on human health, whether directly or indirectly. A small number of exotic species are invasive. The invasives arrive via specific vectors or combinations of vectors acting in tandem, i.e. aquaculture, shipping, recreational craft etc.

Measurement Units:

Relative abundance needs to be calculated according to the mode of life of the invasive organism, and by using the appropriate practical sampling method(s). Monitoring based on histological preparations is appropriate for many pathogens; for metazoa traps, dredging or transects on shores may be sufficient and planktonic species will require water filtration. Precise measurements of relative abundance are seldom as important as deducing the rate of spread, range and vectors employed in their dispersal.

Data Availability/Acquisition:

Exotic species are normally overlooked until such time as they demonstrate some impact. Thus, the knowledge of exotic species in Ireland is incomplete. Invasive species are better known but only some of these have been investigated. Invasive species normally appear in Britain or northern Europe before arriving in Ireland. Vigilance in regard to species expected to arrive in Ireland is advisable and should take into account likely vectors. Up-to-date assessments are seldom available either because of the time-lag before exotics are recognised or because of delays in data processing. Sampling methodologies vary greatly. Appropriate techniques must be practical and cost effective and should take into account previous studies of invasions by the species concerned. Summer rotational surveys of key entry areas (e.g. major ports) using a forum of taxonomic expertise are recommended. A central data centre for up-to-date information on spread of invasive and exotic species, and their vectors of dissemination, is needed.

Interpretation & Usefulness:

Increases in number and/or abundance of exotic species signify potential hazards to indigenous communities. Advanced knowledge of invasive species enables preparation to reduce the overall cost of their impact and may enable some means of reducing their spread. In the case of parasites, diseases or disease agents that have economic impacts advance warnings will greatly assist management. Species that act as ecosystem engineers (Dreissena, Crepidula, Sargassum) are almost certainly involved in local or extensive impacts on trophic systems.

Reliability (e.g. QA requirements):

Collection of voucher specimens and confirmation of identity requires expertise not always readily available, particularly should unexplained events arise. Surveyors must have appropriate taxonomic training and experience. However, invasive species likely to cause impacts in Ireland are probably well known to investigators covering different disciplines elsewhere in Europe.

Ancillary Requirements:

There is no substitute for up-to-date information on the current status of problem species in Northern Europe and Britain. The International Council for the Exploration of the Sea has an annual Working Group that should be attended by a biologist from Ireland.

Overall Evaluation & Value for Money:

For invasive species the relative abundance and rate of spread is of importance. Surveys are costly and the full taxonomic expertise is not available in Ireland. Observations of unexplained biological sightings and events warrant rapid investigation particularly where parasites and diseases may be implicated. Monitoring of known invasives to provide the correct mitigation advice is recommended.

References:

Carlton, J.T., 2001. Introduced species in U.S. coastal waters: environmental impacts and management priorities. Pew Oceans Commission, Arlington, Virginia, 28 pp

Gollasch, S. & Leppäkoski, E., 1999. Initial Risk Assessment of Alien Species in Nordic Coastal Waters. Nord 1999:8. Nordic Council of Ministers, Copenhagen. 244 pp.

Leppakoski, E., Gollasch, S. & Olenin, S., 2002. Invasive Aquatic Species of Europe: distribution, impacts and management. Kluwer Academic Publishers 513pp.

Minchin, D., 1996a. Desk assessment of discharges of shipping ballast water in Ireland. ICES CM 1996/E11, 13 pp

Minchin, D., 1996b. Management of the introduction and transfer of marine molluscs. Aquatic Conservation: Marine and Freshwater Ecosystems, 6: 229-244.

10. Name of Indicator: Marine Mammal Strandings

Group	4	OSPAR		EU/WFD		EEA		Global	

Description:

Data obtained through an all-Ireland marine mammals stranding programme will provide an important tool for describing general trends in cetacean and pinniped numbers and distribution around Ireland. Such a programme is also important for identifying unusual events, such as a mass stranding, and their causes. Importantly, post mortem examinations of stranded mammals can give information on parasite levels, contaminant loadings and fisheries interactions (i.e. death due to entanglement) and thus provide a health check on marine mammal populations.

Measurement units:

Number, distribution and species of live and dead stranded cetaceans and pinnipeds. Targeted post mortem examinations of recently stranded animals to determine cause of death, contaminant loading, parasite burden, age, sex, reproduction, diet and other parameters - depending on costs and practicalities

Data Availability/Acquisition:

An INTERREG funded marine mammals strandings programme for the Irish Sea has recently been completed. As a result, data on cetacean and pinniped strandings for the Irish Sea, between 1997 and 1999 is now available. Data from a smaller study of stranded animals found on all Irish coastal waters between 1992 and 1996 are also available. There is on-going reporting of strandings through a network of volunteers coordinated by Irish Whale and Dolphin Group. Conservation Rangers (NPWS), the Gardai and the Royal National Lifeboat Institute also report strandings. Until recently University College Cork has received funding for the completion of post mortem examinations on stranded mammals nationally.

The recent INTERREG programme involved improving public awareness of marine mammal strandings on the east and southeast coasts. As a result, the number of reported strandings increased. This suggests that with similar publicity the reporting of stranded marine mammals could be increased for all coastal waters. Increased public awareness together with an effective reporting network is necessary to allow for good data collection. The presence of an established and national network of volunteers reporting strandings will help considerably.

Interpretation & Usefulness:

Data from a strandings programme will only provide gross number and distribution estimates for cetaceans and pinnipeds in Irish waters. While more detailed small cetacean abundance data is available for the Celtic Sea and for offshore waters of the Atlantic margin, a national survey of cetacean abundance and distribution is necessary. Likewise a national census of harbour and grey seal populations is also required. As baseline data on the status of cetacean and pinniped populations improves this will allow more meaningful interpretation of strandings results. However, even without such baseline data a national strandings programme remains an effective and efficient method for the long-term monitoring of cetaceans and pinnipeds. Targeted post mortem examinations, completed as part of this programme, will provide essential biological information on the health of these populations.

Reliability (e.g. QA requirements):

Data from a strandings programme will be limited by the level of reported strandings. With greater public awareness this problem should be overcome to some degree. However, on sparsely populated and inaccessible coastlines gaps in coverage will remain.

Expertise in relation to post mortem examinations is already established within UCC and guidelines on such examinations are provided by the European Cetacean Society. Adherence to such guidelines and use of established expertise will ensure the provision of reliable data.

Ancillary Requirements:

Small cetacean abundance and distribution data from the SCANS survey.
Cetacean abundance and distribution data from the recent SIAR survey.
Training of personnel to aid in the recording of stranded mammals and in the completion of post mortem examinations. Additional personnel for the completion of post mortem examinations may be required.

Overall Evaluation & Value for Money:

Cost will be minimal as this is an opportunistic programme requiring no concentrated survey effort. The main costs will be due to post mortem examinations. Given the information gained from strandings data and the absence of any survey-based monitoring programme for cetaceans and pinnipeds, such a programme is essential. Should survey-based population monitoring begin in the future a strandings programme will remain essential, as the only means - other than capture and/or killing - of assessing the health of the mammal populations. As top predators this also gives an important indication of the health of the marine ecosystem.

References:

Berrow, S.D. & Rogan, E., 1997. Review of cetaceans stranded on the Irish Coast 1901-95. Mammal Review, 27 (1): 51-76

Hammond, P.S., Berggren, P., Benke, H., Borchers D.L., Collet, A., Heide-Jorgensen, M.P., Heimlich, S., Hiby, A.R. Leopold, M.F. & Oin, N., 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology, 39: 361-376.

Rogan, E., Penrose, R., Gassner, I., Mackey, M.J. & Clayton, P., 2001. Marine Mammal Strandings: A collaborative study for the Irish Sea. Maritime Ireland/Wales INTERREG Report No. 8

Kiely, O., Lidgard, D., McKibben, M., Connolly, N., & Barines, M., 2000. Grey Seals: Status and Monitoring in the Irish and Celtic Seas. Maritime Ireland/Wales INTERREG Report No. 3.

11. Name of Indicator: Marine Mammal Bycatch

Group	4	OSPAR		EU/WFD		EEA	✓	Global	✓

Description:

Marine mammal (cetaceans and pinnipeds) mortality due to entanglement in fishing gear is significant for some species. To date studies of bycatch in Irish waters have focused on the Celtic Sea, where concerns regarding harbour porpoise and grey seal mortality, in particular, have been raised. While postmortem examination, as part of a strandings programme, and voluntary bycatch landings by fishermen can give some indication of mortality levels due to entanglement, accurate estimates can only be obtained through independent scientific observation of bycatch on fishing vessels.

Measurement Units:

Type of fishery (gillnet, tangle net, pelagic trawl), type and number of species caught. Where and when bycatch occurs. Bycatch should be linked to data on vessel location when towing nets or trawling, duration and depth of tow or trawl, water depth and tonnage of catch. Bycatch of marine mammals should be estimated as a proportion of the fishery being monitored.

Data Availability/Acquisition:

At present, data on mammal mortality due to entanglement is largely collected through post mortem examinations of stranded marine mammals. A marine mammals strandings programme is coordinated by the Irish Whale and Dolphin Group and until recently University College Cork have received funding for the completion of post mortem examinations. For the Irish Sea specifically, an INTERREG programme to study marine mammal strandings has recently been completed (2001). Bycatch data collated as part of the INTERREG programme was derived both from bycatch information provided voluntarily by fishermen and from strandings.

Bycatch data from independent observer programmes has only been collected for herring and gillnet fisheries within the Celtic sea. Data on bycatch rates derived from observer programmes in other Irish coastal waters is not available, though strandings data has shown that mortality due to entanglement does occur. Development of an effective observer programme for other fisheries and other coastal waters will depend on careful liaison with fishermen to gain access to fishing vessels and to allow bycatch to be landed. Initiation of such a programme is a considerable task and should begin in a targeted manner, selecting specific fisheries and specific coastal waters.

Interpretation & Usefulness:

While bycatch data will provide useful information on the significance of this threat to cetacean and pinniped populations, it is limited by the lack of any recent and comprehensive Irish data on cetacean abundance and distribution; and on the status of the pinniped population (though a harbour seal census is pending and there is some recent data on some key grey seal sites). Such data will allow more accurate interpretation of bycatch results in terms of its impact on these populations. Notwithstanding this weakness, using the limited data on cetacean and pinniped populations available and given the concerns regarding the impact of entanglement, collection of bycatch data will be valuable and useful. Such a programme could also consider the level of discard amongst non-target species other than marine mammals. This would usefully link to issues surrounding fish stocks and concerns regarding overfishing. This, in turn, may link with any potential concerns regarding seal and seabird populations, resulting from other indicator programmes associated with these species groups.

Reliability (e.g. QA requirements):

Independent observer programmes have already taken place in Irish waters, particularly the Celtic Sea. Observer programmes are well established in the, UK where the Sea Mammal Research Unit (SMRU) have been monitoring bycatch associated with the gillnet fishery since 1995. More recently the SMRU have been monitoring dolphin bycatch on pelagic trawls. Use of already established methods should ensure collection of useful and comparable data. However, the use of trained personnel is essential - particularly if examinations of bycatch are to take place on board fishing vessels.

Ancillary Requirements:

Access to fishing vessels, fisheries data, data storage facilities, fisheries expertise. Training of personnel which may entail training in species identification and post mortem examination if bycatch is to be examined on board fishing vessels rather than onshore.

Overall Evaluation & Value for Money:

Given concerns regarding bycatch impacts upon cetacean and pinniped populations, with particular concerns in relation to harbour porpoise, the implementation of an independent observer programme is essential. Initially an observer programme can be targeted to specific fisheries and specific coastal areas where concerns are greatest. For such a programme to be effective good relations with the fishing industry must be harnessed. As there is no requirement for dedicated boat and survey equipment, costs are minimised. Training, personnel, data storage facilities, coordination and post mortem examination costs will be greatest. Finally, the implementation of a bycatch monitoring programme will fulfil requirements under the EU Habitats Directive.

References:

Berrow, S. O'Neill, M. & Brogan, D., 1998. Discarding practices and marine mammal by-catch in the Celtic sea herring fishery. Biology and Environment 98b, 1-8.

Hammond, P.S., Berggren, P., Benke, H., Borchers D.L., Collet, A., Heide-Jorgensen, M.P., Heimlich, S., Hiby, A.R. Leopold, M.F. & Oin, N., 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology 39: 361-376.

Kiely, O., Lidgard, D., McKibben, M., Connolly, N., & Barines, M., 2000. Grey Seals: Status and Monitoring in the Irish and Celtic Seas. Maritime Ireland/Wales INTERREG Report No. 3.

Tregenza, N.J.C., Berrow, S.D., Hammond, P.S. & Leaper, R., 1997. Harbour porpoise (Phocoena phocoena L.) by-catch in set gillnets in the Celtic Sea. ICES J. Mar. Sci. 54, 896-904.

Berrow, S.D., Tregenza, N.J.C. & Hammond, P.S., 1994. Marine Mammal By-catch on the Celtic Shelf. Report to the Commission of the European Communities, DG XIV/C/1. Study Contract 92/3503.

Northridge, P., 1996. A review of marine mammal bycatch observer schemes with recommendations for best practice. JNCC Report No 219 Aberdeen, UK

12. Name of Indicator: Biomarkers of Contaminant Exposure (Definitive and Semi-Definitive)

Group	8	OSPAR	✓	EU/WFD		EEA		Global	

Description:

The three biomarkers described here may be used to indicate exposure to particular types of contaminant either in the water or diet, including those derived from residues in sediment. Positive responses do not necessarily imply that exposures are harmful. The measurements are made on fish, mainly bottom-living fish. The biomarkers are as follows:

- EROD (ethoxyresofurin-O-deethylase) as a marker of PAH/PCB detoxification in dab (*Limanda limanda*) (Stagg *et al.*, 1995);
- AChE (acetylcholinesterase) activity in dab (*Limanda limanda*) and/or plaice (*Pleuronectes platessa*) as a measure of exposure to organophosphorus and carbamate compounds (Bocquené & Galgani, 1998);
- Vitellogenins as a measure of oestrogen exposure in fish e.g. salmonids, flounder (Scott and Hylland, 2002).

The principal use of the EROD and AChE biomarkers is to supplement chemical monitoring in low-energy, near-shore areas adjacent to large urban and/or industrial centres with potential for greater than background concentrations of organic contaminants (e.g. Cork Harbour, Dublin Bay etc.); they provide valuable supporting evidence for interpreting the environmental significance of contaminant data and may also reveal biological stresses not predictable from analyses of the suite of contaminants routinely monitored. The vitellogenin biomarker is mainly applicable to fish inhabiting major estuaries receiving significant discharges of municipal effluent.

Measurement Units:

EROD activity:
Normalized to protein content and expressed as pM resorufin/min/mg protein;

AChE activity:
Normalized to protein and expressed as mU AChE/min/mg protein (1U=1m Optical Density unit);

Vitellogenins:
Concentration in plasma

Data Availability/Acquisition:

To date, apart from Imposex/Intersex and a pilot Scope-for-Growth survey in the Irish Sea (1996/97), biomarkers of contaminant exposure have not been part of Ireland's marine monitoring programme. Thus, to apply these indicators it will be necessary to introduce methodologies and to develop the necessary expertise. These could probably be acquired through collaboration (training, inter-laboratory comparisons) with DANI in Northern Ireland, which is represented on the UK's Marine Pollution Monitoring Management Group (MPMMG); the MPMMG is actively involved in the development of marine bio-effects measurements and the UK National Monitoring Plan (MPMMG 1998).

Interpretation & Usefulness:

These biomarkers of response to sediment contamination are interpreted through comparisons in space and time. Ideally, comparisons will be made between contaminated areas and clean areas with similar environmental characteristics (depth, sediment type & structure, community types) and also between successive surveys. Measurements in both survey and reference/control areas must be consistent (standardized methods) and regular (every 1-2 years) for these biomarkers to be useful for management purposes. Consistently high or low values are indicative of the status of contamination and other stresses.

Reliability (e.g. QA requirements):

All the biomarkers require standardized methods, operator training and inter-comparison exercises. QA procedures are outlined in the methodologies referenced below. The development of national capabilities and related QA requirements in the field of marine biomarkers might be advanced through collaboration with DANI as proposed above.

Ancillary Requirements:

Shipboard sampling and laboratory-based analytical facilities.

Overall Evaluation & Value for Money:

In areas known or likely to have elevated levels of contaminants, and in conjunction with chemical measurements, these biomarkers will increase confidence in the overall findings of environmental assessments. Costs are moderately high, but so is the added value to marine environmental protection.

References:

Bocquené, G. and Galgani, F., 1998. Biological effects of contaminants: Cholinesterase inhibition by organophosphate and carbamate compounds. ICES Techniques in Marine Environmental Sciences No.22, 12pp.

MPMMG, 1998. National Monitoring Programme: Survey of the Quality of UK Coastal Waters. Marine Pollution Monitoring Management Group (MPMMG), Aberdeen, 79pp.

OSPAR, 1998. JAMP Guidelines for contaminant-specific biological effects monitoring (Agreement 1998-3).

Scott, A.P. and Hylland, K., 2002. Biological effects of contaminants: Radioimmunoassay (RIA) and enzyme-linked immunosorbent assay (ELISA) techniques for the measurement of marine fish vitellogenins. ICES Techniques in Marine Science, No.31, 21pp.

13. Name of Indicator: Biomarkers of contaminant exposure (non-definitive)

Group	8	OSPAR	✓	EU/WFD		EEA		Global	

Description:

These indicators involve measurements of biological responses (biomarkers) to mixtures of contaminants in sediments, water and/or the diet of the organisms concerned. Positive responses do not necessarily imply that exposures are harmful either to individuals or populations. The principal use of these biological measurements is to supplement chemical monitoring in areas shown to have greater than background concentrations of contaminants e.g. bays and estuaries moderately or heavily influenced by land-based activities; the main use of the oyster embryo bioassay is for evaluating the quality of seawater in estuaries of more highly developed river catchments. The measurements may reveal biological stresses not predictable from analyses of the suite of contaminants routinely monitored. Measurements of benthic biomarkers, in conjunction with analysis of contaminants in sediment, are most appropriate in low-energy nears-shore areas adjacent to large urban and/or industrial centres (e.g. Cork Harbour, Dublin Bay etc.). The non-definitive contaminant biomarkers suited to routine monitoring are:

- Whole sediment bioassays (Thain & Bifield, 2001; Thain & Roddie, 2001)
- Diseases & Condition Factor (CF) in bottom-living fish (Bucke *et al.*, 1996; Donaldson *et al.*, 1979);
- Oyster embryo bioassay (Thain, 1991).

Measurement Units:

Whole sediment bioassays:Percentage net response

Oyster embryo bioassay: Percentage net response

Fish diseases: Prevalence of lymphocystis, epidermal papilloma, ulcers, hyperpigmentation & liver nodules in dab;

Condition Factor (CF): Index of weight/body length

Data Availability/Acquisition:

Of the biomarkers included here, only periodic surveys of external fish diseases have been undertaken; these were in the Irish Sea (1970s & 1980s) including Dublin Bay and in Cork Harbour and adjacent areas. Thus, to apply these indicators it will be necessary to introduce methodologies and to develop the necessary expertise. These could probably be acquired through collaboration (training, inter-laboratory comparisons) with DANI in Northern Ireland, which is represented on the UK's Marine Pollution Monitoring Management Group (MPMMG); the MPMMG is actively involved in the development of marine bio-effects measurements and the UK National Monitoring Plan (MPMMG 1998).

Interpretation & Usefulness:

The oyster embryo bioassay is one of the few routine procedures for assessing the toxicity of seawater. Its main use is in the estuaries of more developed catchments with relatively high contaminant loads. The sediment bioassay responses are interpreted through comparisons in space and time. Ideally, comparisons will be made between contaminated areas and clean areas with similar environmental characteristics (depth, sediment type & structure, community types) and also between successive surveys. Measurements in both survey and reference/control areas must be consistent (standardized methods) and regular (every 1-2 years) for these biomarkers to be useful for management purposes. Consistently high or low values are indicative of the status of contamination and other stresses.

Reliability (e.g. QA requirements):

All the biomarkers require standardized methods, operator training and inter-comparison exercises. QA procedures are outlined in the methodologies referenced below. The development of national capabilities and related QA requirements in the field of marine biomarkers might be advanced through collaboration with DANI as proposed above.

Ancillary Requirements:

Shipboard sampling and laboratory-based analytical facilities.

Overall Evaluation & Value for Money:

In areas known or likely to have elevated levels of contaminants, and in conjunction with chemical measurements, these biomarkers will increase confidence in the overall findings of environmental assessments. Costs are moderately high, but so is the added value to marine environmental protection.

References:

Donaldson, E.M., Fagerlund, U.H.M., Higgs, D.A. & McBride, J.R., 1979. Hormonal enhancement of growth. In: Hoar, W.S., Randall, D.J. & Brett, J.R., (Eds.) Fish Physiology VIII, Bioenergetics & Growth. Academic Press, NY, 455-597.

OSPAR, 1997. JAMP Guidelines for general biological effects monitoring (Agreement 1997-7).

Thain, J.E., 1991. Biological effects of contaminants: oyster (Crassostrea gigas) embryo bioassay. ICES Techniques in Marine Environmental Sciences, No.11.

Thain, J. and Bifield, S., 2001. Biological effects of contaminants: Sediment bioassay using the polychaete Arenicola marina. ICES Tecniques in Marine Environmental Sciences, No.29, 16pp.

Thain, J. and Roddie, B., 2001. Biological effects of contaminants: Corophium sp. Sediment bioassay and toxicity test. ICES Techniques in Marine Environmental Sciences, No.28, 21pp.

14. Name of Indicator: Disruption of Endocrine Systems in Marine Snails

Group	8	OSPAR	✓	EU/WFD		EEA	✓	Global	

Description:

Biomarker using the dogwhelk Nucella lapillus and the periwinkle Littorina littorea, as indicators of organotin (TBT) contamination.

Female neogastropod snails, in inshore areas exposed to TBT, even at low levels, have superimposed male features and each species responds differently, in Nucella the condition can render females sterile and cause population extinctions, such effects have been recorded in some Irish ports but with declines in contamination populations recover. In Littorina the oviduct becomes split and female features are gradually replaced with male characteristics. Because Littorina is less sensitive and has pelagic larvae, heavily contaminated areas can be evaluated using this species.

Measurement Units:

Androgenic effects of imposex in neogastropods and intesex in Littorina are determined by scales of deformity from 0-6 (imposex) and 0-3 (intersex). In neogastropods the proportion of the male penis on affected females to that of males is used. Forty snails are used for station samples.

Data Availability/Acquisition:

Surveys should take place at the principal source regions (ports) every three years. In the last 10 years attention has focused on port regions as the decline in the usage of organotins in ship hull paints is likely to result in improved water quality in ports with possible consequences for biological invasions. Good temporal records exist for Ireland from 1987-1993-1999 for some aquaculture, small boat and shipping areas. Surveys, now undertaken by the Marine Institute, should continue. Several other data sets have been published. Some chemical analysis has been undertaken for a small number of sites. Data are also generated through assessments of dredged material disposal sites.

Interpretation & Usefulness:

Imposex values relate to TBT levels in water, although this relationship is non-linear with TBT burden. Effects of distortion evolve in juveniles. Nucella is faithful to shores with hard substrata and has no pelagic life history stage. Where females become infertile and expire (imposex value > 5.0) there may be population extinctions. Whereas, Littorina has a pelagic stage enabling annual colonization and evaluation at greater levels of TBT contamination. Both snail species are effective for measurements in Ireland.

Reliability (e.g. QA requirements):

Assessments need to be undertaken by experienced researchers as there has been shown to be a high variability between workers. QUASIMEME (Aberdeen) provides intercalibration exercises from time to time, recognised by OSPAR. Stations need to be accurately revisited, as there are some large local differences. The chemical analysis is highly specialised and intercalibration exercises are required. Examination of biological material also requires an experienced researcher.

Ancillary Requirements:

Field requirements are basic. Binocular vision to 40x is required for laboratory examination. Laboratory equipment and processing techniques are specialised. Samples for chemical analysis are normally required to verify the biological interpretation.

Overall Evaluation & Value for Money:

These bioindicators are cost effective and enable rapid assessments.

References:

Boelens, R.G.V., Walsh, A.R., Parsons, A.P. & Maloney, D.M., 1999. Ireland's Marine and Coastal Areas and Adjacent Seas: an Environmental Review. Marine Institute, Dublin, 381pp + appendices.

Davies, I.M. & Minchin, A., 2002. Quality assurance of imposex and intersex in marine snails. J. Env. Monit., 4: 788-790.

Minchin, D., Bauer, B., Oehlmann, J., Schulte-Oehlmann, U. & Duggan, C.B., 1997. Biological indicators used to map organotin contamination at a fishing port, Killybegs, Ireland. Mar. Poll. Bull., 34(4): 235-243.

Minchin, A. & Minchin, D., 1997. Dispersal of TBT from a fishing port determined using the dogwhelk Nucella lapillus as an indicator. Environmental Technology, 18(12): 1225-1234.

OSPAR, 2002. JAMP Guidelines for Contaminant-specific biological effects monitoring (Agreement 2002-14). Revision of Technical Annex 3 (TBT-specific biological effects monitoring.

Stroben, E., Schulte-Oehlmann, U., Fioroni, P. & Oehlmann, J., 1995. A comparative method for easy assessment of coastal TBT pollution by the degree of imposex in prosobranch species. Haliotis, 24: 1-12

15. Name of Indicator: Litter and Debris on Beaches

Group	15	OSPAR		EU/WFD		EEA		Global	✓

Description:

Certain objects (e.g. plastics, nets, containers, broken glass, medical and personal hygiene products) discarded on beaches or at sea are potentially hazardous to marine life and human health. Litter and marine debris on beaches severely reduce the aesthetic quality of these amenities and thereby may have a significant far-reaching impact on tourism, recreation and the local economy (Hall, 2000).

Identification and quantification of litter and marine debris on selected beaches of varying exposure and fetch, as well as trends over time, can provide information concerning the different sources of these items and thus the adequacy of current preventative measures and enforcement procedures.

Previous voluntary surveys have not been sufficiently well designed or executed to yield the kinds of information needed for management purposes (e.g. reliable temporal and spatial trends). A more scientific approach is required (Boelens *et al.*, 1999).

Measurement Units:

Numbers & weights of items in total and by category (plastic containers, metal containers, netting, medical, personal hygiene items etc.) per 500m beach (splash zone only). Two collections per annum - spring (March) & summer (late Aug/early Sept.).

Beaches should be selected in relation to exposure, fetch, resorts, landfill sites, major towns and rivers. As a guide, four beaches on each of the NW, W, S and E. coasts should provide reasonable national coverage.

Data Availability/Acquisition:

Data suitable for trend analysis does not yet exist. A new survey methodology and implementation plan should be introduced as soon as possible. This could be done efficiently and economically by the appointment of a suitably qualified national co-ordinator to locate, instruct and supervise local voluntary groups to carry out surveys. Continuity of the surveys from year to year is imperative. Liaison with coastal local authorities should be maintained. Costs could be shared by local authorities and central government (DoEHLG, DCMNR).

Interpretation & Usefulness:

Measurements made in accordance with this indicator will enable an analysis of the sources, patterns and trends in litter and debris on beaches. Through careful selection of survey sites and times, and through examination of weather conditions and adjacent offshore activities, a better understanding of the activities responsible for marine debris can be obtained (e.g. mariculture, offshore exploration, fishing, shipping etc.).

The findings will inform management on this important issue and enable reviews of the efficacy of current policies and measures, their implementation and enforcement. The need for modified and/or further measures can be assessed. Successes in reducing the extent of littering can be publicized through the co–ordinator's annual reports that ideally should be issued within the first three months of the year following that in which the surveys are conducted.

Reliability (e.g. QA requirements):

QA requirements should be developed and applied by the national survey Co-ordinator. Volunteers should be trained and should always work in pairs. As a guide, the Co-ordinator might commence each survey by requiring volunteers to record a beach section that he/she had already surveyed. A disparity >10% in any statistic would be unacceptable. A more costly alternative would be to hold centralized training/certification courses for survey volunteers.

Ancillary Requirements:

Transport (e.g. large van) and equipment (gloves, bags, weighing equipment, measuring tapes, record sheets, camera etc.) for the Co-ordinator and volunteers. Data on weather conditions preceding surveys. Data on beach usage. Data on offshore activities and shipping traffic.

Overall Evaluation & Value for Money:

An indicator of considerable public interest and socio-economic importance. Extremely cost-effective.

References:

Boelens, R.G.V., Maloney, D.M., Parsons, A.P. & Walsh, A.R., 1999. Ireland's Marine and Coastal Areas and Adjacent Seas: an Environmental Assessment. Marine Institute, Dublin, 388pp. (Section 4.1.8; fully referenced).

Hall, K., 2000. Impacts of marine debris and oil: economic & social costs to coastal communities. Kommunenes Internasjonale Miljøorganisasjon (KIMO), Shetland, 97pp.

16. Name of Indicator: Patterns & Trends in Offshore Activities

Group	13	OSPAR		EU/WFD		EEA	✓	Global	

Description:

There is increasing interest in the utilization of offshore energy resources (oil, gas, wind, wave) and there is likely to be increasing demand for licenses to extract aggregates from the seabed for use in construction. Shipping traffic is likely to increase and changes in the patterns of vessel movements, size and cargo may occur.

All such activities represent hazards (i.e. pressures) to the marine environment. Their location, extent and implications for habitats should be kept under continuous review. Mapping such information in relation to habitat types (Group 1 indicator), benthic communities (Group 2 indicator) and biomarkers (Group 8 indicator) will provide valuable information for purposes of marine environmental assessment and management.

Measurement Units:

Numbers of installations, licenses, vessels etc. by category, start date or time period, location (long./lat.), licensed boundaries, sea area, habitat type, spawning grounds, designated conservation areas, co-occurring activities, distance from shore, water depth, substrate type etc.

Data Availability/Acquisition:

Much of the data needed for such an inventory exists but is widely dispersed. It needs to be sourced, collated and preferably logged on a suitable GIS. Information on shipping is available commercially and can be obtained annually by subscription.

The main requirement for implementing this indicator is, therefore, a trained data manager with appropriate facilities and authority to request information from national sources such as the Department of Communications, marine and Natural Resources, National Parks and Wildlife Service, GSI etc. Indices of offshore developments and activities will greatly improve environmental management and assessment capabilities.

Interpretation & Usefulness:

A comprehensive and up-to-date set of information on offshore activities will clearly show which areas of the Irish shelf are most exposed to potential hazards and possible impacts from such activities. The relative risks to the environment can be evaluated both for each type of activity and for combinations of different activities within the same area. The scale and/or frequency of offshore operations will be important factors in these evaluations.

Hazard and risk assessments for offshore activities should be central elements in the design of monitoring programmes (e.g. selection of determinants and sampling sites) as well as for contingency planning (e.g. marine accidents, oil spills).

Reliability (e.g. QA requirements):

This is a compound indicator that does not generate raw data. Accordingly, data reliability should be assured by using only data from original sources that employ reliable data verification systems. Any subsequent hazard or risk assessments must be accompanied by clear statements of the uncertainty associated with those assessments.

Ancillary Requirements:

This indicator could be readily implemented by building on progress made in developing management information systems for the Irish Sea (InterReg Project) and through co-ordination with the UK's Joint Nature Conservation Committee (JNCC) - The Irish Sea pilot data collection exercise. It would logically become an extension of the Marine Data Services provided by the Marine Institute.

Overall Evaluation & Value for Money:

One of the most useful, if not essential, indicators and excellent value for money.

References:

Marine Institute, 1998. A marine environmental RTDI Strategy. In: A Marine RTDI Strategy for Ireland; a national team approach. Marine Institute, Dublin, 14-18.

Hyder Consulting, Informatic Management International Ltd., GeoData Institute and Aquafact International Ltd., 1998. Scoping study for an INTERREG Marine Information System for the Southern Irish Sea, Vols. 1-3 Final Report. Eds. Irish Marine Institute, Marine Data Centre and Countryside Council for Wales.

Boelens R.G.V., 1995. An Integrated Science Programme for the Irish Sea: Synthesis & Recommendations. 3rd Report of the Irish Sea Science Co-ordinator, Dept. of Environment, Dublin and Dept. of Environment, London, 36+iiip

Important European website on marine GIS systems and services: www.sea-search.net.

17. Name of Indicator: Trends in Coastal Development

Group	14	OSPAR		EU/WFD		EEA		Global	✓

Description:

The coastal zone, including its natural habitats, harvested species, wildlife, beaches and scenic landscapes is a finite resource that provides essential ecosystem services such as breeding grounds, feeding and nursery areas for birds & fish, protection of hinterlands (dunes) and a variety of leisure experiences of immense socio-economic value to local communities and the nation. Continuous development of coastal areas may constitute a net loss of natural capital. Many of the pressures on marine ecosystems result from developments and activities on and around the coastal margin. The type and extent of human impacts on marine and coastal areas can frequently be traced to factors such as coastal population density, urbanization, waste disposal, infrastructure, tourism/recreation and associated facilities, expansion of facilities for commercial and recreational vessels, mariculture etc.

This indicator is designed around a set of measurements that can be aggregated to form a coastal development index (See Chapter 9). The indicator will chart the trend in human use and development of Ireland's coastal zones, providing essential input to coastal zone management (CZM) and for assessment of environmental conditions in near-shore areas.

Measurement Units:

% change in coastal urban areas; % change in population of coastal towns; visitor bed-nights per year; recreational vessel berth availability & use; commercial vessel visits & tonnage; fishing vessel HP and tonnage; % change in natural coastline features (e.g. dunes, grassland, machair, lagoons, saltmarshes etc.); number and annual tonnage of mariculture operations by installation type; seabed area subject to dredging. Records should be maintained for a series of coastal units such as those established for purposes of the Water Framework Directive i.e. river basin boundaries.

Data Availability/Acquisition:

The need for this indicator, and the current shortage of relevant statistics, were highlighted by the national Quality Status Report (Boelens *et al.*, 1999). Much of the requisite information exists, although not always in a suitable form or readily accessible; various agencies are involved in collecting and storing the information.

Accordingly, for this indicator to be fully developed and applied, co-operation between agencies will be necessary. The key contributors will be the local authorities of coastal counties, the Central Statistics Office, Bord Fáilte, port &

harbour authorities, the 'competent authorities' for purposes of the Water Framework Directive (Article 3), the Departments of Environment & Local Government and Defense, Marine & Natural Resources, the Environmental Protection Agency, the Marine Institute, Duchas, the Heritage Council, aquaculture representative bodies and other relevant sectoral/representative bodies. Co-ordination and the provision of a central data storage facility should be the responsibility of a central body such as the Inter-Departmental Committee on Coastal Zone Management.

Interpretation & Usefulness:

The indicator will allow the type, rate, scale and environmental and economic impacts of coastal development to be kept under review in a structured manner. Measurements may be aggregated into various indices of change and impact. A pre-requisite for this to operate effectively will be to define and agree national and local targets (and/or limits) for conservation and protection of coastal zones; this will aid both construction and interpretation of coastal indices. The extent and rate of physical change should be evaluated in the light of current conservation measures e.g. habitat designations. Progress in achieving targets should be evaluated at intervals of 5 years or less. This could be part of WFD River Basin management plans.

Reliability (e.g. QA requirements):

A harmonized national data recording and reporting system is needed. Accordingly, the co-ordinating body should commission the preparation of a manual to be prepared in conjunction with contributing agencies and organisations and detailing the procedures to be adopted. Only data obtained in accordance with the manual should be entered into the coastal zone database.

Ancillary Requirements:

A central data storage facility with a suitable Geographic Information System and a permanent trained operator. Formal links between the data centre and contributing agencies and organisations to ensure that statistics are provided routinely each year.

Overall Evaluation & Value for Money:

Minor establishment and maintenance costs will provide an invaluable basis for coastal protection and management.

References:

Boelens, R.G.V., Maloney, D.M., Parsons, A.P. & Walsh, A.R., 1999. Ireland's Marine and Coastal Areas and Adjacent Seas: an Environmental Assessment. Marine Institute, Dublin, 388pp. (Section 4.1.8; fully referenced)

18. Name of Indicator: Post-larval Grey Mullet, Chelon Labrosus, as an Indicator of Climate Change

Group	18	OSPAR		EU/WFD		EEA		Global	

Description:

The Grey Mullet is a native fish that moves offshore during the winter and spawns in the spring off the SW coast of Ireland. Irish populations are made up of several year classes that reside in estuaries and shallow bays from May to September. Mullet reproduce on the SW Irish coast in April and arrive in coastal shallows from June appearing inshore at progressively later dates further eastwards along the south coast.

The post-larval stages of Grey Mullet appear inshore from June/July, forming shoals of up to some hundreds. Air temperature is important for the growth of the neustonic post-larval stages. Consequently, trends in post-larval growth can be used to track local climatic conditions.

Measurement Units:

Standard length measurements (mm) of 'O' group grey mullet captured in shallows using a mist net.

Data Availability/Acquisition:

Only one data set published, based on measurements in selected years. The mean air-temperature values for May-August relate well to mullet size (SL) in August for the shallows of one monitoring station, Lough Hyne. Further monitoring stations need to be considered and also related to sea-surface temperatures. The largest modal size of post-larval mullet is used in calculations. Air temperature data close to south and south-west coast stations is required and when available sea-surface temperature data sets.

Interpretation & Usefulness:

As data sets of sea temperature are not widely available for Ireland, the selection of a biological indicator of climatic patterns has benefits. The post-larvae are exposed to the surface region of the sea directly influenced by air temperature.

Reliability (e.g. QA requirements):

Preliminary results using this indicator appear effective. However, differences between cool and warm summers have been noted. A useful index could be generated if undertaken for more than one site during August/September before the 'O'-group move out of the shallows in September/October.

Ancillary Requirements:

Basic capture equipment. Air and sea temperature records.

Overall Evaluation & Value for Money:

The utility of the technique at other coastal locations needs to be established; some minor research required. Annual sampling may be undertaken by one individual (biologist) and confined to about a two-week period. Potentially very good value for money.

References:

Minchin, D., 1993. Possible influence of increases in mean sea temperature on Irish marine fauna and fisheries. In: M.J. Costello & K.S. Kelly (eds) Biogeography of Ireland: past, present and future. Occ. Publ. Ir biogeog. Soc. No. 2. pp 113-126.

19. Name of Indicator: Regional Marine Climate Change

Group	17	OSPAR		EU/WFD		EEA	✓	Global	✓

Description:

Global climate change will force changes in regional weather patterns with corresponding changes in sea temperature, storm frequency, wave height etc. Changes in rainfall may also influence salinity patterns on large areas of the shelf. In general, changes occur slowly and, even on decadal time-scales, may be indistinguishable from natural climatic variation. However, the overriding influence of the North Atlantic Oscillation (NAO) on this region is well established (See Section 2.4). Because marine climatic conditions regulate marine ecosystems, and because shifts in biological and chemical baseline conditions can frustrate many aspects of monitoring, and because regional changes in temperature, storm frequency and wave height are now evident, it is imperative that reliable measures of trends in marine climate are available to guide Ireland's marine science programme.

This indicator comprises a group of measurements that can be made available for global, oceanic and regional analyses of marine climate. Possibilities exist for aggregating the measurements into a marine climate index applicable to Irish waters.

Measurement Units: (Tentative)

Sea surface temperature (bulk): Average monthly degrees C

Salinity: Practical salinity units (PSU)

Wave height: Average monthly significant wave height (H1/3 m)

Storm frequency/intensity: Hours per month wind-speeds > e.g. 20 ms-1 and > 28 ms-1 (linked to wind direction)

Data Availability/Acquisition:

Until recently, information on sea conditions around Ireland was generated by a network of UK Met Office data buoys, by satellite measurements and by observation from ships. Ground truth data from Irish shelf and near-shore areas has been very limited, both in quantity and quality. There is a plethora of global and regional charts, especially of wave heights, but they lack the resolution necessary to track conditions in coastal environments where much of the environmental monitoring takes place.

Since the launching of the first of five Irish data buoys in November 2000 (three now operating), real time data on wind, temperature and other conditions is now fed into the UK Met Office for analysis and forecasting of sea conditions and will form the basis of a valuable record that may be used directly, as ground-truth for satellite data interpretation and for hind-cast modeling to assess spatial and temporal patterns of regional marine climate. It is intended that information from the data buoys can be supplemented by underway / profile data from the 2 Irish research vessels, Celtic Explorer and Celtic Voyager.

Interpretation & Usefulness:

Climate is notoriously variable and it is difficult to distinguish short and medium-term trends from long-term variation. Nevertheless, it is indisputable that recent trends are significant in terms of their potential effects on oceanographic conditions and marine ecosystems. The available data on current patterns of marine climate should be taken into account in the design of monitoring programmes to measure chemical and biological changes over time. Data from Irish buoys and vessels may also contribute to climate research activities such as those at the University of Wales, Bangor (Holsmeer project), Plymouth Marine Laboratory (MarClim), NASA (satellite observations) and Met Éireann's regional Irish wave model (WAM).

Reliability (e.g. QA requirements):

Procedures are available for calibrating instruments and for correcting remote measurements through comparison with ground-truth measurements. Meteorological and oceanographic services apply these procedures as a matter of course and are continuously refining and improving data quality. As a result, the reliability of marine climate data is generally very high.

Ancillary Requirements:

The product required is a regular synthesis of marine climate patterns relevant to Irish waters and adjacent sea areas. A suitable national coordinator (e.g. Met Éireann, Marine Institute Ocean Science Services), with responsibility to liaise with relevant bodies in Ireland and abroad and to oversee the production of such a synthesis, is required.

Overall Evaluation & Value for Money:

An indicator that complements all other marine monitoring activities. All of the data are available from existing sources. A regular synthesis of marine climate patterns in Irish and adjacent waters is indispensable.

References:

POL, 2001. Joint Evaluation of Remote Sensing Information for Coastal Defence and Harbour Organisations. (Jericho project). Plymouth Oceanographic Laboratory: http://www.pol.ac.uk/home/research/jericho.html

NOAA, 2000. Tropical waters in northern hemisphere heating at an accelerated rate. National Oceanographic and Atmospheric Administration: http://www.noaanews.noaa.gov/stories/s468.htm

MBA, 2003. Marine biodiversity and climate change - MarClim. Marine Biological Association: http://www.mba.ac.uk/marclim. Also: http://www.satobsys.co.uk/Jericho/webpages/mainframes/ukframe

9.0 Aggregating and Integrating Indicators

9.1 Preface

In theory, combinations of environmental indicators would have a number of benefits. They might, for example:

- provide more useful management information than single indicators;
- reveal more about cause/effect relationships; and
- shed light on mechanisms underlying indicator variability.

Such possibilities deserve careful consideration. However, there is no consensus in the literature regarding how aggregated or integrated indicators should be constructed or where and how they should be applied. In most discussions about aggregate indicators the term refers merely to the grouping of indicators into sets, either because they represent different facets of the same problem (e.g. pollution) or because they provide a broad overview of a country's performance in relation to a policy field such as Sustainable Development. Integration is a more complicated process in which indicators are assigned numerical ratings for use in calculating a value for a chosen property or characteristic; these values can then be used for purposes of comparison or classification[11]. In practice, aggregation is a prerequisite for integration.

It needs to be stressed that when different types of measurement are linked together with the aim of producing a more useful or relevant index of environmental status or condition, the relationships between them should be well understood or such that they can reasonably be inferred from existing knowledge.

Thus, it is important that all indicators are based firmly on a proper scientific understanding of their ecological, socio-economic and/or human health significance.

In this chapter we examine a number of examples of indicator aggregation and integration in the environmental field and consider their advantages for monitoring and assessment purposes. The starting point is a review of indicator aggregation procedures being developed by international agencies.

[11] Integrated indicators are typically used to generate indices of environmental – economic performance.

9.2 Institutional Approaches to Indicator Aggregation

When the Commission of the European Communities (1996) initiated the system of environmental pressure indicators in the mid-1990s, it made the following observations concerning the aggregation of indicators:

'A complete description of all "unwanted activities" will require a set of 50-100 physical pressure indicators. In order to communicate scientific evidence to a broad audience, structuring by aggregation is necessary.'

And

'Aggregating such indicators to indices would ideally require a scientific consensus about the share of the components of a problem. Such a consensus is currently only available for Climate Change and Ozone Layer Depletion, based on recommendations of the Intergovernmental Panel on Climate Change. To establish weighting coefficients for the other policy areas (including Marine Environment & Coastal Zones), we have chosen an IPCC-like consultation process with panels of experts nominated by.....'

Since that time there have been major developments in the aggregation and 'weighting' of pressure indicators, almost exclusively for purposes of environmental-economic information systems. As far as Eurostat (1999) is concerned, aggregated pressure 'indicators' differ from statistics as they serve different purposes (communication, macro-evaluation). In general their sensitivity need not be as high as that of statistics (but should nevertheless be as high as technically and economically feasible)'.

In its 1999 publication, Eurostat provides no details as to how they will achieve their stated aim of 'aggregating' the six Marine Environment & Coastal indicators (Table 9.1) into a single index; it seems the task of developing the necessary methodologies has been fulfilled mainly by the EC's Joint Research Centre (JRC). Eurostat did, however, provide caveats concerning the current status of the indicators in terms of their accuracy, reliability and comparability over space and time. These were presented in colour-coded boxes - green signifying no major problems, red signifying that there were major reservations about the indicator and yellow as an intermediate rating.

Table 9.1: Eurostat marine 'pressure' indicators - in order of importance based on the frequency at which they were selected by expert advisors (Eurostat, 1999).

Pressure indicator	Determinand
Eutrophication	Riverine and direct inputs of total nitrogen and phosphorous (tonnes/ yr).
Fishing Pressure	Annual fishing mortality for stocks constituting the 'main catch'
Development along shore	% increase in structural hard surfaces in the coastal zone
Discharges of heavy metals	Tonnes/yr. of Hg, Cd, Pb, Cu and Zn from via direct and riverine inputs
Oil pollution at coast & at sea	Total accidental, licensed & illegal disposal of oil to the coastal & marine environment (tonnes/yr.)
Discharges of halogenated organic compounds	mg/capita/yr. of _-HCH (lindane) introduced from rivers and direct inputs

Even the most recent EEA report on indicators (European Environment Agency, 2001), provides no firm evidence that the agency has aggregated or integrated environmental indicators in a way that would increase the value of single indicators. However, the report notes that in recent years 'environmental indicators have expanded from describing changes in the state of the environment to an interrelated family of indicator sets in line with the broadening of environmental policy towards integration of environmental issues in other policy fields'. This seems to suggest that the EEA places considerable emphasis on the use of environmental indicators in policy formulation and assessment, as well as for environmental management.

Given the limitations of much of the data generated by national monitoring programmes, especially where annual loadings of contaminants are extrapolated from relatively few measurements and the carrier fluxes (e.g. sewage flows, river discharges) are massive, the confidence placed in some of Eurostat's pressure indicators is somewhat surprising. Table 9.2 summarises the 1999 ratings.

Table 9.2: Confidence ratings for Eurostat pressure indicators (Eurostat 1999).
XXX No major problems; X Major reservations; XX Intermediate

Pressure Indicator	Relevancy	Accuracy	Spatial Comparability	Temporal Comparability
Eutrophication	XX	XXX	XXX	XXX
Fishing Pressure	XXX	XXX	XXX	XXX
Development along shoreline	XXX	XXX	XX	XXX
Discharges of heavy metals	XX	XX	XX	XX
Oil pollution at coast & sea	XX	XX	X	XX
Discharges of halogenated compounds	XXX	XXX	XX	X

The Pressure, State, Response System

Because of its overriding influence on the development of environmental monitoring within the EU, it is important to examine the 'pressure-state-response' (PSR) framework. Initially developed by the OECD (OECD, 1994), this has become the basis for sets of environmental indicators applied in many national and regional settings.

The PSR framework is based on the concept of causality, is simple, widely accepted and can be applied on any scale. It is a convenient basis for aggregating indicators for purposes of intra-regional comparison. The components of the framework are:

- Pressure Indicators - describe the pressure (stress) on the environment caused by human activities;
- State Indicators - describe the environmental condition. They represent environmental values i.e. qualities & quantities of ecosystems and natural resources;
- Response Indicators - represent the policies and measures introduced in response to environmental problems.

Implicit in this categorisation of indicators is that degraded environmental conditions (i.e. state) tend to be caused by human-induced pressures. Invariably, various, often complex, physical, geo-chemical and biological processes, characteristic of the ecosystems concerned, mediate such relationships. Because of this, it can be difficult to substantiate pressure-state linkages, even in localised situations. Any suggestion that such relationships may apply generically (i.e. in all circumstances) would be open to question.

The second association – the link between environmental conditions and policy responses – is exclusively anthropogenic.

The European Environment Agency (EEA) has extended the OECD system with the addition of Driving Force and Impact indicators; the interrelationships are depicted as follows:

Driving Force → Pressure → State → Impact → Response

Driving Forces are human activities, societal developments and economic sectors (e.g. population growth, fisheries and industry) that lead to the pressures, whereas Impacts represent effects on ecosystems and human health that result from changes in State.

This so-called DPSIR system has been adopted in various forms by numerous countries and organisations. Eurostat (1999) has adopted the DPSIR model '...as the most appropriate way to structure environmental information' for use by the EU and its member states and '...to provide decision-makers and the general public with the information necessary for the design and monitoring of an adequate environmental policy for the European Union'.

According to Eurostat, its main interest is in Driving Forces, Pressures and Responses while responsibility for State and Impact indicators resides with the EEA.

Indicator Selection

Marine Environment and Coastal Zones is one of 10 policy fields derived from 'themes' identified by the EC's Fifth Environmental Action Plan (Commission of the European Communities, 1996). Each policy field is informed by six selected pressure indicators; those for the marine environment are summarised in Table 9.1.

There are serious flaws in this particular set of marine pressure indicators, most of which are well recognised by Eurostat. For example, the coverage, reliability and comparability of data from different parts of the region are known to be deficient and, for at least some determinants, are likely to persist. An even more intractable problem is that the assumed associations, for example between nutrients and eutrophication, are speculative and for some sea areas almost certainly false. Nevertheless, many statistical and policy-making bodies feel that aggregations of pressure indicators are essential for relating environmental and socio-economic conditions at local and regional scales.

Although it is the intention to steadily improve the databases used in environmental policy assessment, ultimately it will be necessary to determine the feasibility of measuring the selected determinants with sufficient accuracy to permit legitimate comparisons across the entire EU area. In this context, feasibility should include cost-effectiveness. It would certainly be helpful if this matter were resolved before planned legal obligations (Künitzer, 2002) for reporting data to the EEA are brought into force.

Pathway Analysis

The derivation of linkages between indicators is even more problematic. So far neither the EEA nor Eurostat has given guidance on the associations between adjacent indicators in the DPSIR scheme or how the scheme will be applied in practice. Indeed, to our knowledge it has not been explicitly stated that such associations will be attempted in any structured or formal manner.

In Table 4.6 (see Chapter 4) we list the state and impact indicators for marine and coastal areas proposed by the EEA. The proposed driving force, pressure and response indicators were not included as in general they are outside the remit of this report. Nevertheless, to explore potential connections between indicators that would have relevance for monitoring and assessment programmes, it is useful to consider some of the more plausible links in the indicator chains that address the EEA's priority 'issues'[12]. In Figure 9.1 we illustrate possible/implied links in the eutrophication chain.

The figure contains most (but not all) of the proposed EEA indicators relevant to nutrient inputs to the sea and associated environmental changes. It also shows one of the various possible pathways (solid lines) between and within indicator categories. Some of the variants (dotted lines) involve pathways that are partially within a single indicator category.

[12] EEA Issues

1. Eutrophication & organic pollution
2. Hazardous substances in water
3. Groundwork quality / quantity
4. Water stress
5. Climate change
6. Drinking water quality
7. Microbiological contamination
8. Impact of fishing
9. Ecological quality
10. Aquatic biodiversity
11. Coastal zone management

This raises questions concerning indicator classification, especially the criteria for deciding whether a particular environmental condition is a 'state' or 'impact'. In some schemes it would appear that such decisions are subjective, if not entirely arbitrary (See, for example, Table 5.2 showing Mediterranean indicators).

The main lesson to be learned from this analysis is that relationships between pairs of indicators, whether in the same or different categories, are sometimes indirect, often unpredictable and therefore unlikely to apply on regional scales. Consequently, the principal use of pathway analysis is at the level of individual catchments and adjacent estuarine and coastal areas i.e. localised. We conclude that pathway analysis is probably not one of the main intended uses of the DPSIR indicator system. Indeed, it seems likely that the value of the system derives mainly from its use in designing and monitoring environmental policy.

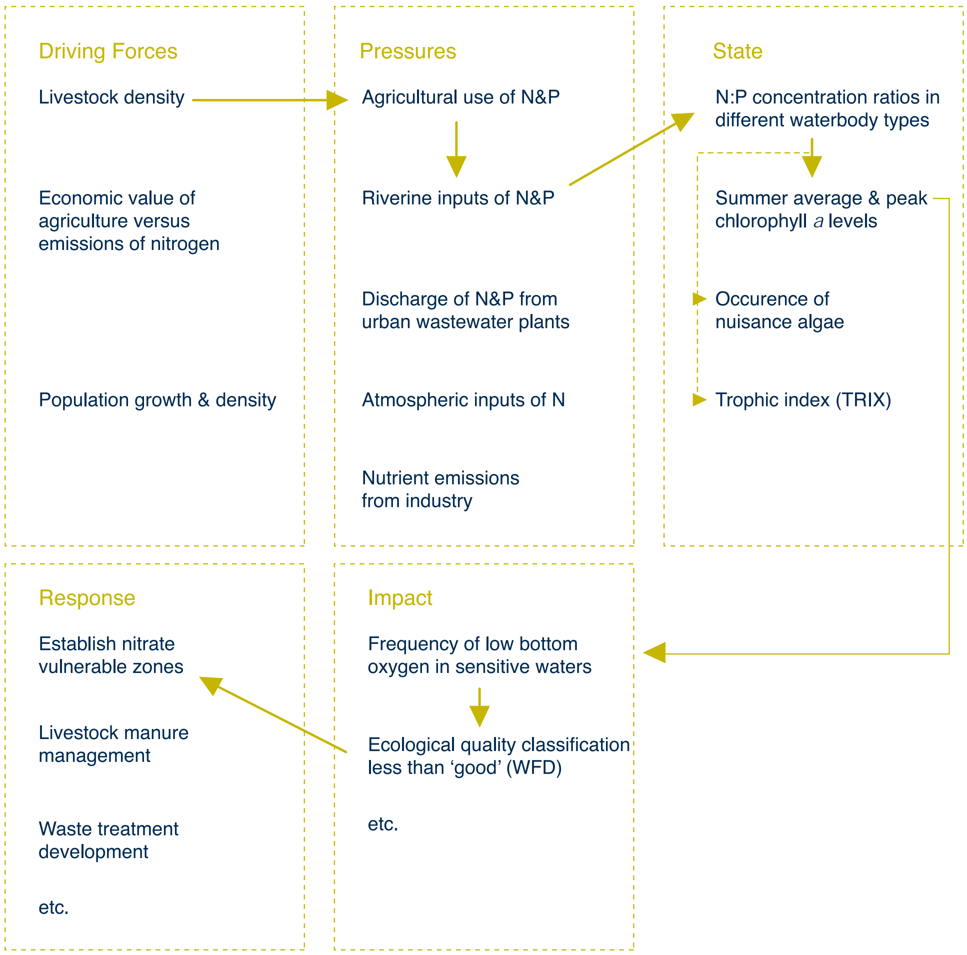


Figure 9.1: One of the many possible (indicator) pathways to marine eutrophication.

9.3 Science-Based Approaches to Indicator Aggregation

So far we have dealt mainly with the somewhat institutionalised DPSIR system of indicators and have shown that this has little relevance for the design and interpretation of marine environmental monitoring. From a scientific perspective, a more profitable approach is to examine similar and/or related indicators, to see how they are connected and whether they can be grouped (aggregated) in some logical way that will provide a better understanding of environmental conditions. This, in essence, is the basis of the thematically grouped indicators shown in Table 3.1 (Chapter 3) of this report.

We now look at examples from the scientific literature and then explore possibilities for aggregating indicators and related variables currently measured in marine monitoring programmes.

Estuarine Health Index

In Chapter 5, we noted that South Africa (Department of Environmental Affairs & Tourism, 2001) has proposed an indicator known as the Estuarine Health Index based on existing surveys of fish communities, water quality and aesthetic conditions in some 250 estuaries. Ratings of fish communities consider species richness, assemblages and abundance; water quality takes into account trophic status, suitability for marine life & human contact; aesthetic conditions are rated in accordance with status of coastal development. This is a form of composite or aggregate indicator. Each of the conditions is rated as 'good', 'moderate' or 'poor'. A national goal of achieving at least 80% of estuaries in each province with 'good' ratings for all three conditions has been proposed.

This form of indicator aggregation is analogous to that of the Blue Flag beach scheme where beaches are judged on a set of conditions, not necessarily related, and are awarded Blue Flags based on overall performance. The main advantage of such schemes is that they are readily understood and supported by the general public. They also encourage improved management to deal with conditions that receive negative ratings. On the other hand the mere aggregation of disparate indicators does little to enhance scientific understanding of environmental processes or conditions.

The EU Water Framework Directive

The EU's Water Framework Directive (European Community, 2000) identifies sets of environmental indicators for application to transitional (e.g. estuaries, salt marshes etc.) and coastal waters. In this Directive the term 'quality element' is used in preference to 'indicator'. The biological quality elements for coastal waters, for example (See Section 4.4 for a complete list), encompass phytoplankton, macroalgae & angiosperms, and benthic invertebrates. Each quality element is to be ranked on a scale of 0-1, where values near zero represent 'bad' ecological quality and values near 1 represent 'high' ecological quality. In accordance with Annex V (1.4.2 (i)) of the Directive, the ecological status for the body of water concerned shall be represented by the lower of the values for the relevant biological (and physico-chemical) quality elements.

Under this strategy, a coastal or transitional water body is judged on the basis of a single indicator. There are anomalies in this approach. As descriptors of marine environments, or even important marine values, the selected quality elements are far from comprehensive. They do not, for example, cover zooplankton, resident seabirds, fish diseases, toxin formation or invasive species. Thus, it is perfectly possible that a water body could show signs of damage or degradation and still be accorded high ecological status under the Directive.

The UK's National Monitoring Plan

In the late 1980s, the United Kingdom initiated a National Monitoring Plan (NMP) designed 'to establish the spatial distribution of contaminants in UK marine waters, and to define their biological status'. Synoptic measurements were made at 16 estuarine, 18 intermediate and 21 offshore sites in 26 coastal areas. The first progress report on the findings of the NMP (MPMMG, 1998) was able to compare chemical and biological conditions in relation to proximity to major catchment inputs and between coastal regions. Biological status was assessed by means of benthic community surveys, oyster embryo bioassays, EROD activity in livers of flatfish, imposex in dogwhelks and incidence of fish diseases. An example of spatial variation assessment, using data on imposex from Northern Ireland, is shown in Table 9.3.

Table 9.3: 1994 Survey of imposex in Northern Ireland (MPMMG, 1998)

NMP Station	Type	No. of replicates	Mean RPSI	Standard error
835	Estuarine	10	36.74	2.66
845	Estuarine	10	34.69	2.43
855	Estuarine	10	40.20	3.75
825	Intermediate	10	2.14	1.01
815	Offshore	15	4.17	0.80
875	Offshore	15	0.85	0.28
865	Offshore	15	0.11	0.03
Control	NA	5	0.01	0.01

Contaminant Pathway Indicators

With regard to contamination by persistent and bio-accumulative substances, it is possible to group indicators and associated datasets from the same locality to obtain insight into the likely sources, pathways and sinks of contaminants as well as ensuing biological exposures. A similar approach can be used to track land-sea fluxes of nutrients and, subject to available hydrographic data, localised variations in production indicators such as chlorophyll a, phytoplankton structure and biomass. Carefully chosen synoptic measurements are a prerequisite to contaminant modeling and risk analysis. The National Research Council (1990) of the U.S. provides very pertinent advice on ways of converting monitoring data into useful management information.

To illustrate some of the possibilities in this regard, Table 9.4 selects related indicators from Table 3.1 and shows how synoptic measurements at selected coastal sites might be linked to investigate processes such as contaminant transfer, partitioning and deposition.

Table 9.4: Aggregated thematic indicators for synoptic local surveys.
As shown in Table 3.1 (Chapter 3)

Eutrophication	Indicator Group and Theme#	Contamination/pollution
Nutrient input loads	Groups 5 & 7	Input loads of metals & POPs
Concentrations in seawater	Hazards associated with inputs	Concentrations in tissues and sediments
Phytoplankton biomass Chlorophyll a Bloom frequency & duration Incidence of toxin–forming algae Hypoxia	Groups 6 & 8 Effects	Biomarkers of exposure Fish diseases Benthic community changes
Shellfishery closures	Group 12 Seafood safety	Compliance with seafood safety standards in commercial species

An obvious requirement for synoptic surveys is that survey areas have a certain integrity (e.g. estuary, basin, coastal sector etc.) and are delineated on the basis of their geographic, hydrographic and geo-chemical characteristics including habitat types and distributions. The internal dynamics and exchanges with adjacent areas should be reasonably well understood. All measurements need to be made within a restricted time frame taking into account temporal variations in salinity, water column structure, currents and circulation, as well as land-based activities that may affect inputs.

9.4 Integrating Indicators

A persistent problem is that, within the environmental indicator literature, it is not uncommon for the terms aggregation and integration to be used synonymously. For example, Olsthoom *et al.* (2000) state that aggregation transforms data into different forms or formats to allow a better understanding or interpretation of the data by different groups or for different purposes. They seem to be describing a process of data integration. Nevertheless, the authors make some important points concerning the transformation of environmental data. They stress the need to maintain transparency and credibility by ensuring that data are normalized and standardized as part of the aggregation/integration process, as illustrated in Figure 9.1. In addition, they note that greater aggregation implies less relevance for local or highly specific issues and therefore suggest that data should be aggregated to the lowest hierarchical level at which decisions can be made appropriately.

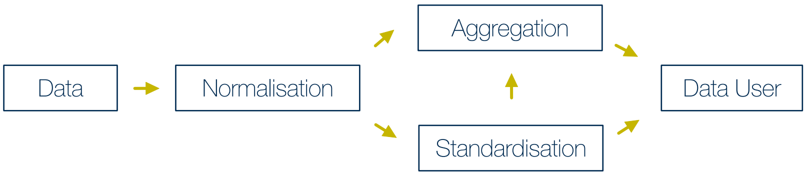


Figure 9.2: Recommended steps in the aggregation/integration of environmental data (after Olsthoom *et al.*, 2000)

Methodologies for integrating environmental information have been slow to evolve due to data limitations and lack of agreement concerning the rating, ranking and weighting systems that should be applied. Data integration is required primarily for purposes of comparisons, both spatial and temporal. To date, the most common use of integration schemes has been in generating performance indices in fields such as energy use, economics and environmental policies and measures.

Environmental Performance Indicators

A widely publicized, and often replicated, system of indicator integration is the Dashboard tool[13], developed by a small group of indicator programme leaders called the "Consultative Group on Sustainable Development Indices" (CGSDI). This is illustrated in Figure 9.3 in which the size of a segment reflects the relative importance of the issue described by the indicator; a colour code signals performance relative to others: green means "good", red means "bad"; and the central circle (PPI, Policy Performance Index) summarizes the information of the component indicators.

[13] Figurative term based on an analogy to the car driver, pilot and ship's captain who have dashboards in front of them with an array of instruments that help them make decisions.

Most of the currently included Dashboard indicator sets describe national performance, often at worldwide scale, sometimes only for Europe. Most indicators come directly from official statistics. According to the EC's Joint Research Centre (http://esl.jrc.it/envind/db_meths.htm), the level 2 segments covering the economy, social care and the environment are calculated 'by multiplying performance points with weighting coefficients' and the policy performance index (PPI) is 'calculated on the basis of the overall points achieved'. Again, in a rather confusing fashion, these procedures are described as 'aggregation' rather than integration.

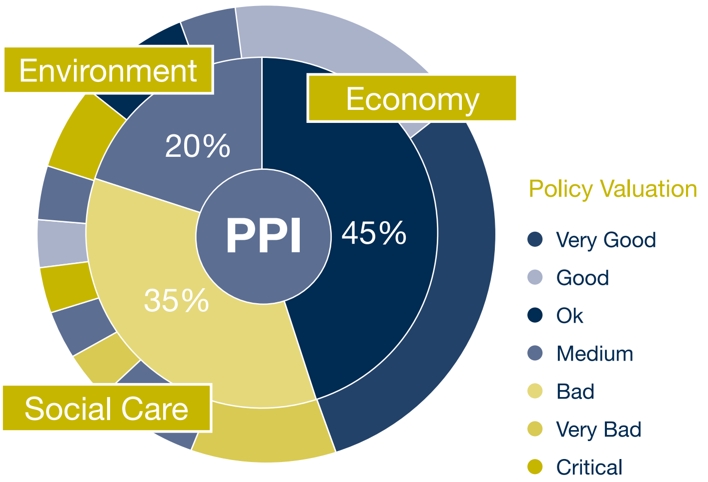


Figure 9.3: The 'Dashboard' approach to indicator integration for policy evaluation. (Source: EU Joint Research Centre (JRC) - http://esl.jrc.it/envin/db_leafl.doc).

In practice, the 1999 versions of the Dashboard used equal weightings for all indicators. While recognizing that not all indicators were of equal importance, experts had not been able to recommend weighting coefficients. Thus, in effect, the Dashboard at that time did not constitute a proper integration mechanism.

Integrated Indicators for Classifying Island Environments (UNEP/Earthwatch)

An example of indicator integration by means of a rating procedure is that developed within the United Nations Environment Programme (UNEP, 1998) for classifying islands on the basis of their environmental, ecological and anthropogenic characteristics.

The process involves a series of numerical indicators combined with weightings for different objective and subjective factors. The aim is to 'make it possible to reduce, or at least to make more consistent and explicit, the subjectivity of judgments as to relative island significance and conservation importance'. Similar approaches can be used to assist and improve the interpretation of data from environmental monitoring.

The indicators of relevance to marine ecosystems are summarised in Table 9.5. To illustrate the aggregation mechanisms that are used to classify islands, we have chosen the one applied in calculating an index of Marine Conservation Importance (MCI). The index, which is adapted to the special characteristics of the island marine environment down to 100 metres depth, consists of:

- the marine Ecosystem Richness (ER) indicator, divided by 3 because of the relative importance of coastal marine ecosystem diversity, and the Species Richness (SR) indicator, both multiplied by 2;
- the Island Endemism (IE) indicator based on the numbers of marine endemic species multiplied by 3 because of the relative rarity of marine endemism;
- one point for each Special Feature (SF);
- the Vulnerability (Vu) indicator (up to 6 points); and
- the Natural Protection indicator (0-4 points).

Thus: MCI = 2(ER/3+SR) + (IE x 3) + SF + Vu + NP

Table 9.5: Indicator rankings for island ecosystems (adapted from UNEP, 1998).

Indicator	Measurement/Rating
Vulnerability	Rating scale 0-6 A measure of the risk of natural or human catastrophes (cyclones, drought, high risk of oil spills etc.) that could endanger endemic species or protected area, thus increasing the importance of conservation action.
Natural Protection	Rating scale 0-3 Natural protection afforded by an island's condition or situation. One point each for: – remoteness ((200 km from other island/land) – not presently inhabited – few or no introductions of predatory or competitor species
Ecosystem richness	Number of ecosystem types or biomes in the coastal zone to 100m depth.
Species richness	Rating scale 1-5 0 = Few or no fish, corals & molluscs (e.g. < 8) 3 = good species richness (e.g. 40-55) 5 = Very rich in species (e.g. (72)
Marine Endemism	Rating scale 0-6 0 = no endemic species; 1 = 1-2 spp.; 2 = 3-6 spp; 3 = 7-12 species; 4 = 13-20 spp; 5 = 21-30 spp; 6 = over 31 endemic species
Special Features	Number of sites or areas of conservation/tourism importance

Table 9.5: (continued) Indicator rankings for island ecosystems (adapted from UNEP, 1998).

Indicator	Measurement/Rating
Invasive species	Rating scale 0-5 0 = Few or no introductions 3 = some problems with invasive species 5 = devastated by invasive species
Human threat	% Of population engaged in agriculture, mining and fishing divided by 30, giving a scale of 1-3
Protected Area Coverage	Rating scale 0-7 0 = <0.5% protected 7 = (85% protected
Reliability of Data	0 = No reliable data 1 = Poor data (partial and out of date) 2 = Partial or out of date 3 = good recent data

It is said the CMI is designed to favour 'rich and complex coastal areas with good prospects for conservation action. It is not a good measure by which to identify simple, undisturbed coastal areas which may be unique in their own way, nor does it include any measure of the importance of marine protected areas for fisheries management.'

There is considerable scope for similar, combined aggregation and ranking, systems in marine environmental assessment. However, there are few yardsticks by which the suitability or reliability of these schemes can be evaluated other than the credentials and expertise of the scientists engaged to design them. On the other hand, compared to individual indices, these multi-factorial indicators are more robust (e.g. less sensitive to errors due to inaccuracies in data), and where uncertainty associated with a particular indicator is known to be high, its significance can be reduced by applying suitable weighting factors. Nevertheless, it is also important to appreciate that uncertainties may be additive and that overall uncertainty associated with a composite indicator could possibly increase as more factors are included.

It is worth noting that the utility and value of ranking systems are well established at international level. A notable example is the GESAMP Hazard Evaluation Procedure for Chemical Substances Carried by Ships (GESAMP, 2002). This is a comprehensive ranking system, based on the intrinsic properties of chemical substances, that is used by the International Maritime organisation (IMO) to determine whether a substance should be classified as a "Marine Pollutant".

Integration of Datasets from Monitoring

Although there are examples of indicator aggregation for use in interpreting monitoring data (See Environmental Health Index, Section 9.3), proper integration using rating and ranking procedures do not appear to be widely used for environmental assessment purposes. This may be because rating systems involve a degree of subjectivity that can be difficult to justify. Nevertheless, rating systems based on aggregations of carefully selected indicators could become valuable tools for assessing complex environmental conditions such as contamination status, coastal development and climate change (Box 2).

Box 2: Groups of indicators that could be individually rated, then integrated, to improve evaluation of particular conditions

Contamination status	Coastal development	Climate change
Sea surface area (hectares)	Length (km) coastline	Sea level increase
Annual loads of priority substances	Coastal population density	Surface temperature increase
Conc'ns in sediments and tissues	Coastal population increase	Storm frequency
Status of benthic communities	Loss per unit area of marine & coastal habitats	Wave height/energy
Condition factor in mussels	Municipal BOC/COD loads	Investment in coastal defences
EROD in fish	Visitor days per annum	Incidents of 'visitor' species
MFO in fish		

Whereas it is not within the scope of this report to design or recommend specific forms of indicator integration, an overview of the basic approach is appropriate.

The purpose of integrating environmental indicators is to produce an index of a particular environmental condition of interest or concern from a management, and ultimately policy, perspective. For example, indices relating to the conditions referred to in Box 2 might be described as:

- Contaminant Impact Index or Pollution Index
- Coastal Zone Pressure Index
- Marine Climate Index

It is clearly much easier for non-scientific administrators to comprehend differences or changes in a single number rather than a set of independent variables. From a technical standpoint, it may also be more appropriate to assess the environmental status of a locality on the basis of a group of variables rather to place too much emphasis on a single variable, for example a chemical concentration.

A requirement in the construction of an index is that each indicator measurement, or more likely the average or median of a set of measurements, be normalised to some reference value. This could be a similar measurement made at a suitable reference site, a measurement made at some historical point in time, a reference value derived from scientific experience (e.g. an ecotoxicological effect threshold) or a standard set by a reputable organisation.

From experience with the variable in question, it will generally be possible to define the upper and lower limits (i.e. range) of values likely to be encountered. Normalization to the reference value will produce another range of values e.g. -1.0 to +1.0, representing the amounts by which the measured and reference values differ. By sub-dividing this range into classes numbered, say 1-5 or 1-10, each measurement, average or mean value, can be rated on a standard scale. Such numbers can then be integrated (weighted, summed, multiplied, divided) in an equation that defines the index.

Thus, for example:

Where: Range (R): $= V_{Low} - V_{High} = 5 - 30$

and: Reference value (V_R) $= 20$

Then: Normalized range (R_N)

$$= \frac{V_L}{V_R} - \frac{V_H}{V_R}$$

$$= \frac{5}{20} - \frac{30}{20}$$

$$= 0.25 - 1.5$$

Accordingly, the normalized range is divisible into 6 x 0.25 intervals, ≈ 8 x 0.2 intervals etc.

If needed, to simplify presentation or interpretation, the class intervals can be grouped into a few categories labelled, for example, High, Medium and Low. The normalised range can also be converted to a standardised 0-1 or 1-10 scale. In essence, this is the procedure to be adopted for the presentation and assessment of ecological data under the EU Water Framework Directive (Annex V (1.4)). In this case the 'ecological quality ratio scale' will be divided into 5 classes between zero and one, ranging from high to bad ecological status; however, classification is based on the worst case quality element.

The island classification scheme (UNEP, 1998) described earlier uses a similar approach in developing rating scales for the indicators it employs to calculate an index. It also shows that an index can be weighted in various ways that gives more or less priority to certain variables. Decisions as to which variables should be weighted, and by how much, may be based on scientific grounds - depending, for example, on whether or not the variable has a controlling influence on the index condition, or is of downstream significance - or on socio-political grounds e.g. the variable is of special concern to the public.

Mathematical models of marine environmental processes, especially those mediated by human activities such as contaminant inputs and resource exploitation, are increasingly used to investigate cause-effect relationships, to predict future trends and to test the likely effects of different options for management intervention (e.g. preventative measures). The construction and testing of indices, based on appropriately rated and weighted indicator variables, may be a useful, and in some cases essential, precursor to model development.

9.5 Summary

It may seem self evident that many aspects of the marine environment, ranging from particular conditions such as eutrophication to the health of entire ecosystems, can be better understood by evaluating a broad set of indicators and related variables rather than single variables. Nevertheless contemporary marine environmental assessments do tend to focus, perhaps excessively, on individual indicators. We therefore conclude that the potential benefits of aggregating indicators warrant greater consideration. Tables 3.1 (Chapter 3) of this report shows groups of indicators that might be used to address particular themes of relevance to management and assessment.

There is considerable confusion in the literature surrounding the meaning of aggregation and integration in the context of environmental indicators. In most cases 'aggregation' is used merely in the sense of grouping.

Although there are many examples of indicator aggregation for purposes of environmental-economic analysis, especially within Europe, there are a surprisingly few published accounts of indicator aggregation, or integration, for assessment of environmental conditions.

Groups of indicators can be used to explore and/or monitor cause-effect relationships; this includes pathway analysis of contaminants from source to sink. They can also be the basis of rating and/or scoring systems for use in broadly based evaluations of environmental quality in estuaries and defined sea areas. However, it needs to be stressed that, where it is proposed to aggregate indicators and related variables for assessment purposes, the design of monitoring (sample type, site selection, frequency etc.) should be tailored specifically for this purpose i.e. retrospective aggregation is not advisable.

A more complex, and arguably the most useful, procedure is where aggregated indicators are fully integrated to provide an environmental index. This involves rating and weighting procedures that are partly subjective and therefore open to criticism. Nevertheless, for purposes of comparing environmental conditions between areas and time periods, and as a means of communicating complex information to non-scientific administrators and policy-makers, such indices have real advantages and merit further consideration both nationally and at regional/European level. It seems likely that they would also have a role to play in the development of mathematical models of marine environmental properties and processes.

In integrating indicators, over-simplification should be avoided. It must be considered at what point the integration process no longer produces useful data for its intended purposes. The target audience and use of the indicator should always be clearly identified. Caution must also be exercised to ensure that individual issues requiring management action do not get overlooked during the integration process.

10.0 Discussion

In the preceding chapters we have established that indicators are the basis of marine environmental assessments and an essential ingredient in the design of monitoring programmes. This being the case, it is surprising that detailed consideration of indicators is an apparently recent activity for many countries and regions. A number of national administrations state that their current sets of indicators are tentative i.e. not officially adopted, even though they have well established monitoring programmes. It could be said that Ireland is in a somewhat similar position.

Ireland's marine monitoring programme has evolved since the early 1970s largely in response to its commitments under regional conventions for protection of the marine environment and later in response to directives of the European Commission in relation to bathing water and shellfish safety, and the discharge of wastewater and nutrients. More recently Ireland has been planning its response to the monitoring requirements of the EU Water Framework Directive as well as the revised Joint Assessment and Monitoring programme of the OSPAR Convention. The Convention is also seeking to harmonise its monitoring with parallel data requirements of the European Environment Agency (EEA).

Significant improvements in the quality and scope of Ireland's marine monitoring activities have been realised in the past decade. Nevertheless, with some notable exceptions (e.g. the monitoring of algal toxins to protect the developing aquaculture industry), monitoring priorities have been dictated externally and there has been little interest in developing an indigenous programme with a clear national identity. It could be argued that, for an island state with many valuable marine resources, national expenditure on marine monitoring has been comparatively modest. Greater appreciation within government of the value of monitoring in evaluating options for the development and management of marine resources would help to generate increased support for the national monitoring programme.

The commissioning of this report is a clear signal that Ireland's Marine Institute recognizes the importance of a monitoring programme that addresses national interests and priorities. A review of marine environmental indicators in use or under active consideration around the world is the logical starting point for adaptation of the national monitoring programme towards such a goal. However, this will not be an easy task.

Since the early 1990s there has been a concerted international effort to strengthen measures for protection of the marine environment, to extend the range of controls, to tighten standards and increase monitoring and enforcement. This is reflected in the decisions and programmes of the OSPAR Convention as well as the activities of the EU in introducing the Water Framework Directive and greatly increasing the range of indicators applicable to marine and coastal areas. As a result, the monitoring capacities of Ireland and other European states are seriously stretched and, without substantial increases in technical and scientific resources, there may be a reluctance to apply and monitor indicators not explicitly required under regional arrangements.

Despite the demands on available monitoring capacities, Ireland's latest marine monitoring plan (EPA, 2002) aims to address most of the data requirements of OSPAR and EU programmes for marine environmental protection. Nevertheless, it is a guiding principle of the Plan (Para. 1.6) that whereas monitoring should be targeted at issues which are relevant at national and regional level, it

> *'should not overly focus on issues of international relevance if of little relevance to Ireland, or on very local problems which are best addressed by local measures'.*

We stress that the national monitoring plan is still in draft form and it is not within the mandate of this project to comment on the document. However, we firmly endorse the above principle. Where it is decided that a particular indicator or sampling programme prescribed under regional arrangements is not warranted in the Irish context, it is always appropriate to document the reasons for this and to inform the body concerned. Any savings in resources thereby achieved could usefully be applied in monitoring some of the very relevant and cost-effective indicators described in Chapter 8.

10.1 A Set of Indicators for National Application

A primary aim of this study has been to develop a practical and affordable set of marine indicators to guide Ireland's monitoring and assessment activities. The approach we have taken is to use our collective knowledge and experience, and to consult publications of relevant national and international bodies, in defining criteria for indicator selection. This was the basis for the 17 groups of indicators contained in our proposed core set (Chapter 3, Table 3.1) for national application. For each group of indicators we have provided examples of field measurements (i.e. variables to be monitored) appropriate to that group. Many of the measurements are already part of the national monitoring and assessment programme. The set of measurements is by no means exhaustive; each measurement provides valuable information in its own right and, just as importantly, contributes to the mosaic of knowledge that is necessary to assess the state of the marine environment as a whole.

In the main, the proposed set of indicators concentrates on the state of the marine environment and the impacts due to various anthropogenic influences and practices. This is in contrast to the approach taken by the EU/EEA (Chapters 4 and 9) that focuses heavily on human pressures that can alter the state of the environment and, in turn, lead to unwanted impacts. We do not contest the importance of pressure indicators but feel that, in general, they do not fit smoothly into a marine monitoring programme designed to measure environmental properties. Nevertheless, we have included in our core set a small number of indicators that in our view represent pressures of special significance such as fish landings, contaminant inputs, coastal population and tourism statistics. Apart from being environmental indicators in their own right, the measurements associated with these indicators generate data (i.e. meta-data) that are essential for interpreting changes and trends determined by other monitoring activities.

We stressed in Chapter 2 that indicators adopted nationally should reflect public interests and concerns. Science can respond to these interests and concerns only if they are expressed as clearly stated questions. The questions implicit in the proposed core set of indicators, for example, include:

- Are the more ecologically significant marine habitats decreasing in area?
- Is the diversity and/or productivity of these habitats reduced by human activities?
- What is the status of marine communities and populations of commercial species, seabirds and mammals?
- What is the extent of contamination by chemicals and nutrients?
- What are the effects of nutrient enrichment?
- What the biological effects of contaminants? How significant are they?
- How safe is our seafood?
- How clean are our beaches?
- What is the impact of human activities on the coastal zone?
- What are the effects of climate change on the sea?

We recognise it is quite possible that certain administrators, sectoral bodies, the public at large and other scientists may have different or additional questions requiring other forms of indicator.

Chapter 3 summarises the indicators and related measurements used in preparing Ireland's first marine Quality Status Report (Boelens *et al.*, 1999) as well as those required or proposed under regional programmes with which Ireland is associated. To test the similarity between our conceptual set of indicators and those applied by these other programmes and approaches, we made a judgement[14] as to whether an indicator fell within one of our core groups and, if so, which one. An overview of the findings is given in Table 10.1 below.

[14] Refer to tables presented in Chapter 4.

Table 10.1: Incidence of indicators corresponding to the proposed core set (this report) in other marine environmental assessment schemes.

Core set[1] Group No.	Indicator Focus[1]	1999 QSR[2]	OSPAR/ JAMP[3]	EU/WFD[4]	EU/EEA[5]
1	Status of habitats	✓	✓		✓
2	Status of communities	✓	✓	✓	✓
3	Status of populations/ renewable resources	✓	✓		✓
4	Hazards to populations/ renewable resources	✓	✓		✓
5	Hazards of nutrient enrichment	✓	✓	✓	✓
6	Effects of nutrient enrichment	✓	✓	✓	✓
7	Chemical hazards	✓	✓	✓	✓
8	Effects of contaminants	✓	✓		✓
9	Radioactivity	✓	✓		
10	Bathing water quality	✓			✓
11	Seafood safety	✓	✓		
12	Extent of offshore structures & activities	✓			
13	Coastal development, tourism & recreation	✓			
14	Litter	✓			
15	Coastal erosion	✓		✓	
16	Sea conditions	✓	✓	✓	✓
17	Biological impact	✓	✓		✓

Notes: 1. From Table 3.1. 2. Boelens *et al.*, 1999. 3. OSPAR Joint Assessment & Monitoring Programme. 4. EU Water Framework Directive, 2000. 5. European Environment Agency indicators

It can be seen that the scope of the 1999 QSR was broad in relation to other schemes and covered all the core set indicator groups. The EU and OSPAR indicators are comparatively narrow in scope; indicators relating to human health (Groups 9-11) and socio-economic and aesthetic values (Groups 12-14) are not as well represented as other categories.

10.2 Indicators used by the International Community

A notable feature of the sets of indicators used both within (Chapter 4) and beyond (Chapter 5) Europe/ NE Atlantic is the apparent tendency to focus more on chemical hazards, and the status of populations and communities (i.e. ecosystem qualities) than on human health and socio-economic or aesthetic values. This may, however, be an artefact related to the separation in many countries of legal and administrative arrangements for marine environmental protection from those relating to health and economic and social development. It may also reflect a tendency to separate issues relating to the offshore environment from those regarded as coastal. The concept of the coastal zone as an integral part of the marine environment may take some time to penetrate the legislative and institutional systems of some riparian states.

The review of indicators used internationally strongly suggests that the core set of marine environmental indicators proposed in Chapter 3 is at least as comprehensive and well balanced as any of those applied, or under consideration, in other countries or regions. Specific indicators of biodiversity have not been included as the concept of biodiversity indicators is relatively new and still under development (Féral *et al.*, 2003; ECNC, 2002). There is clearly a need for practical measurements of marine biodiversity that will generate information of use to managers and legislators. However, indices of biodiversity within defined areas (e.g. protected habitats) and taxa are a normal part of community surveys.

10.3 The Need for Biological Indicators

The national quality status report (Boelens *et al.*, 1999) drew attention to the shortage of information concerning biological responses to contamination and other human interferences. This remains an important limitation of Ireland's marine monitoring programme. The draft national monitoring plan (EPA, 2002) acknowledges the need for research to identify suitable procedures and to develop the necessary technical capabilities. Consequently, two chapters of this report have been devoted to indicators of biological response to changing environmental conditions.

Chapter 6 reviews approaches to monitoring biological conditions and discusses the merits of measurements made at either population, community or ecosystem level. A strong case is made for the monitoring of benthic invertebrate communities involving identification of organisms to family level followed by multi-variate statistical analysis. We believe that the development of such methods and their regular application in selected areas - those most exposed to contamination as well as comparable reference sites - warrant a high degree of priority. Chapter 7 gives an overview of the many different biomarkers that may be used to detect biological responses to contaminant exposures. A number of these are sufficiently well developed and tested to be included in national monitoring programmes. Few biomarkers are definitive i.e. they detect a response to a contaminant or other environmental condition but not necessarily the specific agent concerned. Nevertheless, in conjunction with chemical monitoring in areas that are relatively more exposed to contaminants they can either provide evidence of responses that warrant further investigation or reassurance that contamination is below harmful levels. Some biomarkers are relatively specific while others reflect the combined effects of contaminant mixtures.

Chapter 8 includes information sheets on a number of biomarkers suitable for inclusion in Ireland's marine monitoring programmes. Together, the selected biomarkers cover a diverse range of environmental conditions and responses. We strongly recommend that these indicators be given serious consideration as part of ongoing efforts to improve and extend the national monitoring programme; some are already recommended for inclusion in OSPAR/JAMP. The necessary expertise for applying particular biomarkers could either be obtained through contracts with laboratories employing operators with the necessary experience or by training personnel specifically for this purpose in national laboratories. The continuity and quality control needed for long-term programmes is perhaps more easily provided through developing in-house capabilities in state agency laboratories.

10.4 Monitoring of Hazardous Substances

We have referred previously to the historical emphasis on chemical measurements in marine monitoring programmes. A valuable legacy of this approach has been the experience acquired in the analysis of contaminants at low concentrations in marine media, combined with considerable improvements in sampling, sample preparation and data quality assurance. Lists of priority (hazardous) substances, which include both mandatory and voluntary determinants, are published and continuously updated by both OSPAR and the EU. The 2002 updated OSPAR list (OSPAR, 2002), for example, lists more than 30 substances or groups of substances, of which relatively few warrant widespread or continuous monitoring in Ireland. In our view the technical capabilities in Ireland for monitoring marine contaminants are well developed in comparison to those for biological monitoring and, providing suitable analytical procedures exist for any new priority chemicals to be monitored, and sufficient resources are made available to provide the necessary capacities, there is no reason why requirements for chemical monitoring cannot be met.

10.5 Pre-Requisites to Obtaining Reliable and Useful Environmental Measurements

As noted in Chapter 2, two factors that may seriously impede efforts to quantify temporal and spatial differences in marine environmental conditions, especially contaminant concentrations, are natural variability and failure to take account of this in sampling design. Considering the substantial investments that may be involved in long-term monitoring, these are probably the two most important issues to be addressed by those responsible for monitoring and assessment programmes. In this context, we stress again the links between management questions, the choice of indicators, the understanding of variability inherent in the conditions to be measured and the statistical considerations that will determine sampling design and ease of data interpretation.

Detailed attention to sampling design has not been a prominent feature of Ireland's marine monitoring to date. This will almost certainly have weakened abilities to discriminate between environmental conditions at different places and at different times, and constrained assessment capabilities. To overcome such limitations, it would be helpful to include a trained statistician amongst the team of scientists responsible for the design and implementation of the national marine monitoring programme.

The need for compatibility among similar datasets from different times and locations is obvious. The success of European initiatives (e.g. Water Framework Directive, EEA environmental indicators) to assess patterns and trends in environmental quality at regional level will depend on this. The feasibility of achieving data compatibility on a European scale has yet to be demonstrated but, to a large extent, will be contingent on the performance of national programmes in this regard. From an evaluation of experience in conducting Ireland's first comprehensive marine environmental assessment, on the issue of data comparability the Marine Institute (2000) concluded that:

> *..it is essential that collaborative monitoring programmes are planned meticulously from the design of field surveys to the analysis and reporting of results. This planning must embrace all parameters (i.e. variables and co-variables) to be entered into the data storage system with particular attention to standardising formats used in recording dates, times, locations, quality assurance indexes and units of measurement. As assessment is an on-going process, this aspect of the planning and management of assessment-related marine science warrants the most urgent attention.*

Furthermore, it is essential to provide appropriate facilities and resources for data management (i.e. processing, archiving, storage etc.) and quality assurance.

10.6 Indicator Aggregation

Techniques for combining and/or integrating related indicators, providing more broadly-based indices of environmental conditions, have considerable potential as tools for marine environmental assessment and management (Chapter 9). To date, however, it appears that such techniques have not been widely used either in Europe or elsewhere. The use of aggregated indicators by the EU/EEA and supporting institutions is mainly directed at Europe-wide comparisons of environmental/economic performance, rather than evaluation of environmental quality. However, in such fields as eutrophication, climate change and impacts on coastal systems, groups of indicators combined with simple rating and/or weighting systems could provide more robust and dependable indices of environmental change than single indicators. The provision of research funding to develop such indices, and to test them on a pilot scale in selected areas on and around the Irish coast, would be a worthwhile investment.

10.7 Political and Administrative Significance of Indicators

Perhaps the principal finding of this report is that the choice, development, application and review of marine environmental indicators is an immensely important aspect of environmental protection that, heretofore, has not been sufficiently appreciated or addressed by the relevant Irish agencies. In the past, there may have been a tendency to assume that indicators adopted under regional programmes of marine environmental protection (i.e. OSPAR and EU) are suited to Irish conditions and meet all Ireland's marine data requirements. Experience suggests that this is not invariably the case. In preparing the national marine Quality Status Report (Boelens *et al.*, 1999) much of the information needed for a proper assessment came from sources outside regional monitoring programmes. It was also evident that measurements associated with some indicators (e.g. riverine inputs, temporal trends in sediment contamination) applied within regional monitoring programmes (OSPAR/JAMP) needed further development in order to generate reliable and useful data. Most importantly, it was clear that considerable expenditures had sometimes been incurred in making repeated measurements of conditions at levels well outside the known range of biological relevance.

We stress that there is much at stake in conducting a national programme of marine monitoring and assessment. Both costs and expectations are high. A poor choice of indicator, the repeated use of a measurement before the methodology has been fully developed or inadequate attention to sampling design can be very costly in terms of wasted resources and delays in taking measures for environmental protection due to uncertainty regarding trends. Because the state of the marine environment has very real implications with regard to the economy at both national and local levels, seafood supply and safety and, of course, the sustainability of marine ecosystems (with international dimensions), these matters should be regarded as politically sensitive and worthy of greater involvement by the responsible government agencies.

Accordingly, we firmly recommend that marine environmental indicators and associated methodologies be kept under review by **thematic technical committees**, meeting at least once in every 3 years, to reconfirm the relevance, reliability and accuracy of the measurements, review sampling designs, resolve any problems of data interpretation and update or amend methodologies. Such committees could convene under the auspices of the recently established Marine Monitoring Forum which marks a new era of collaboration between gorvernment departments, state agencies and other bodies engaged in marine monitoring and assessment. Records of these committees, their findings and recommendations should be maintained and could be used to guide Ireland's input to committees and technical negotiations within OSPAR and EU programmes for marine monitoring and assessment. In this context it would appear both sensible and reasonable to apply, as both a guiding principle and policy element, that all indicators applied by Ireland will be relevant to Irish conditions as well as practical and cost-effective in the context of Ireland's overall marine science programme.

In reviewing experience from the 1999 QSR process, the Marine Institute (2000) saw the need for a long term assessment programme that will produce a regular series of authoritative, up-to-date reports on issues and conditions of environmental importance. It concluded that:

> *'a permanent national focal point for marine assessments, collaborating with all relevant data sources and supported by computerised data storage facilities, are prerequisites for an efficient and cost-effective programme of this kind'.*

Responsibilities for collecting information on the marine environment, and capabilities for measuring features related to particular indicators, are distributed among many different Irish agencies and organisations. The 1999 QSR process showed that some highly relevant data, albeit in existence, were difficult to access or extract. Some agencies appear not to understand or accept their role as providers of data for marine environmental assessments. As the range of indicators and measurements is expanded in accordance with OSPAR, EU and national assessment requirements, such difficulties will increase. A more co-ordinated approach to data collection, transfer, processing and storage is urgently required. It is self-evident that an expanded set of marine environmental indicators, and associated requirements for data collection and management, will require significantly more human and operational resources than allocated to date.

11.0 Conclusions and Recommendations

11.1 Conclusions

i) National administrations responsible for marine environmental protection, and those engaged in monitoring the sea and its resources, need to consider carefully the choice of marine environmental indicators. Our understanding of the health of the oceans comes almost entirely from monitoring designed to measure trends in particular marine features, according to the indicators selected. Indicators are also important instruments of marine policy formulation and review.

ii) Environmental indicators are currently receiving unprecedented attention from governments and environmental agencies worldwide because they are recognised as essential tools in meeting mandates to protect and manage the sea, its ecosystems, resources and amenities.

iii) Classical concerns regarding the health of the marine environment - pollution, eutrophication, habitat loss, status of fisheries and hazards to human health - are still very much evident from the indicators used in assessing marine and coastal environments around the world.

iv) Much of the development work on environmental indicators, both by countries and international agencies (including the EU) has been directed at classifying indicators according to the Driving Force/Pressure/State/Impact/Response (DPSIR) scheme. This is most suited to analysing relationships between environmental and socio–economic conditions. However, there is no consistent approach internationally for the way in which indicators are assigned within the DPSIR scheme and considerable anomalies result.

v) An effective indicator will address specific questions about clearly defined aspects of the environment, be readily understood by society as a whole, involve measurements that can detect significant differences between samples and be practicable in terms of the time and resources required.

vi) The indicators that have determined Ireland's marine monitoring programmes to date stem largely from regional and European programmes for marine environmental protection. During the preparation of the national marine Quality Status Report (QSR) published in 1999, it was evident that internationally determined indicators alone were not sufficient for marine environmental assessment purposes. An indigenous and more comprehensive set of indicators is required.

vii) It would appear both sensible and reasonable to adopt an approach, both as guiding principle and policy element, whereby all indicators applied by Ireland will be relevant to Irish conditions. Their practicality and cost-effectiveness should also be evaluated, taking into account all facets of parallel national programmes for marine environmental management, and marine research and development.

viii) The selection of marine environmental indicators has ecological, scientific, technical, social, socio-economic and political dimensions. The process can be made easier by the setting of clearly defined objectives for marine environmental conditions reflecting interests and values within all sectors. Providing the national marine monitoring programme complies with the aims and approaches of agreed regional programmes (JAMP, EU/WFD, EEA), there is no good reason why objectives and indicators for national application should be identical to those applied at regional level.

ix) A core set of marine indicators suitable for national application needs to address ecological conditions, including associated hazards and impacts, threats to human health, environmental changes of potential socio-economic importance and manifestations of climate change.

x) Based on contemporary understanding of these issues, the report finds that a wide-ranging but nevertheless practical set of marine environmental indicators can be constructed around 17 indicator groups. The proposed core set of indicators is shown to be broad in scope, practical, consistent with regional requirements and a good basis on which to build a national programme of marine environmental monitoring and assessment.

xi) The 1999 QSR process revealed serious shortages of information concerning some important features of the marine and coastal environments. For about half of the c.80 specific indicators investigated, available information was either limited or poor. A revised assessment process will need a more comprehensive and better co-ordinated system of data collection.

xii) Whereas the component of Ireland's monitoring programme dealing with measurements of chemical contaminants is comparatively well developed, Ireland has not to date made sufficient use of indicators that determine the status of populations and communities of marine organisms. Indicators of the impacts of human activities on habitats and coastal systems are also required.

xiii) Some knowledge of the variability associated with indicators is essential if sampling is to be designed so that significant differences in time and space can be detected with the necessary degree of reliability. It is still not sufficiently appreciated that, without adequate preliminary research to determine the types and degrees of variability, the chances of designing an efficient and cost-effective sampling programme are considerably reduced.

xiv) Many aspects of the marine environment, ranging from specific conditions such as eutrophication to the health of entire ecosystems, can be better understood by evaluating a broad set of indicator variables rather than single variables. Groups of indicators can be used to explore and/or monitor cause-effect relationships; this includes pathway analysis of contaminants from source to sink. They can also be the basis of rating and/or scoring systems for use in broadly based evaluations of environmental quality in estuaries and defined sea areas.

xv) Groups of indicators may also be fully integrated to provide environmental indices through the use of rating and weighting procedures. For purposes of comparing environmental conditions between areas and time periods, and as a means of communicating complex information to non-scientific administrators and policy-makers, such indices have real advantages and merit further consideration both nationally and at regional/European level. They might also be used in the development of mathematical models of marine systems and processes. Nevertheless, such indices should be transparent in their construction and scientifically credible.

xvi) In view of the changing patterns of climate, both global and regional, it is of utmost importance to Irish marine science, environmental monitoring and assessment that trends in the climate of Ireland's maritime areas be kept under continuous review so that they can be taken into account in planning and designing research and monitoring projects, and in selecting environmental indicators and associated measurements

xvii) Responsibilities for collecting information on the marine environment, and capabilities for measuring features related to particular indicators, are distributed among many different Irish agencies and organisations. The 1999 QSR process showed that some highly relevant data, albeit in existence, were difficult to access or extract. As the range of indicators and measurements is expanded in accordance with OSPAR, EU and national assessment requirements, such difficulties will increase. A more co-ordinated approach to data collection, transfer, processing and storage is urgently required. It is self-evident that an expanded set of marine environmental indicators, and associated requirements for data collection and management, will require significantly more human and operational resources than currently available.

11.2 Recommendations

i) Ireland's marine monitoring programme should be designed around a carefully chosen suite of indicators so that the programme will meet the needs of the state, the EU and relevant international conventions for information on the nature, effects and causes of degradation in marine and coastal areas.

ii) Accordingly, the responsible agencies should develop and adopt a coherent set of marine environmental indicators similar to that presented in Chapter 3 of the report (Table 3.1). This would have major advantages for the design and development of Ireland's marine monitoring programme and contribute significantly to marine environmental assessment, management and policy formulation.

iii) Indicators and associated methodologies should be kept under review by thematic technical committees, meeting at least once in every 3 years, to reconfirm the relevance, reliability and accuracy of the measurements, review sampling designs, resolve any problems of data interpretation and update or amend methodologies. This could be achieved in the context of the Irish Marine Monitoring Forum.

iv) The marine environmental indicators selected or proposed for use in Ireland should be widely publicised, open to public appraisal and comment, and periodically updated in accordance with recommendations from the relevant technical committees. The specific questions for monitoring to address should be clearly identified. The present report might serve as a discussion document in advance of the first report to be issued.

v) In accordance with the findings of the 1999 Quality Status Report that there are deficiencies in information on biological effects, and also on developments in the coastal zone, it is recommended that serious consideration be given to incorporating the select group of indicators described in Chapter 8 into Ireland's monitoring and assessment programmes.

vi) Considering the high levels of variability that characterise features of the marine environment and their measurement, and the strong influence this exerts on the results of monitoring, there is a general need to extend research into both existing and potential indicators to better understand their inherent variability and its significance for the design of sampling strategies.

vii) To bring about necessary improvements in sampling designs applied in monitoring spatial differences and temporal trends in environmental conditions, and to assist with assessments, a trained statistician should be included in the team of scientists responsible for the design and implementation of the national marine monitoring programme.

viii) Combinations of indicators could assist in the assessment of conditions such as eutrophication, chemical pollution, marine climate change and coastal development. A multi-disciplinary group of marine scientists should be established to investigate the potential for aggregating and integrating indicators (and related variables) to provide indices of environmental conditions for both management and modelling purposes.

ix) In such fields as eutrophication, climate change and impacts on coastal systems, groups of indicators combined with simple rating and/or weighting systems could provide more robust and dependable indices of environmental change than single indicators. The provision of research funding to develop such indices, and to test them on a pilot scale in selected areas on and around the Irish coast, would be a worthwhile investment.

x) The European Environment Agency (EEA) in conjunction with its Water Topic Centre (ETC/WTR) are co-operating with OSPAR - through the medium of the Inter-Regional Forum (IRF) - to develop a strategy for handling data relevant to EEA's core set of indicators. Recognizing that ICES and national data centres will play key roles in this process, it would be advisable for the Marine Institute to link into this system thereby facilitating a smooth flow of data from national marine monitoring programmes to the EEA. As data generated for purposes of the Water Framework Directive (WFD) must also be fed into this system, it would be useful to have a central repository for data generated by all marine monitoring activities.

References

Chapter 1.0

Boelens, R.G.V., Maloney, D.M., Parsons, A.P. & Walsh, A.R., 1999. Ireland's Marine and Coastal Areas and Adjacent Seas: an Environmental Assessment. Marine Institute, Dublin, 388pp.

GESAMP, 1991. Global Strategies for Marine Environmental Protection. IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), Reports & Studies 45. IMO London, 36pp.

Chapter 2.0

Anon., 1989. Statistical analysis of the ICES cooperative monitoring programme data on contaminants in fish muscle tissues (1975-1985) for determination of temporal trends. ICES Coop. Res. Rep. No. 162.

Anon., 1991. Statistical analysis of the ICES cooperative monitoring programme data on contaminants in fish liver tissue and Mytilus edulis (1978-1988) for determination of temporal trends. ICES Coop. Res. Rep. No. 189.

Boelens, R.G.V., Maloney, D.M., Parsons, A.P. & Walsh, A.R., 1999. Ireland's Marine and Coastal Areas and Adjacent Seas: an Environmental Assessment. Marine Institute, Dublin, 388pp.

Council of Europe, 1998. The Oceans: State of the Marine Environment and new Trends in International Law if the Sea. Committee on the Environment Regional Planning and Local Authorities. Doc. 8177, 66pp.

Dobson, J., Gardner, M., Miller, B., Jessep, M. and Tait, R., 1999. An approach to the assessment of the quality of environmental monitoring data. J. Environ. Monit., 1: 91-95.

Gray, J.S., Clarke, K.R., Warwick, R.M. & Hobbs, G., 1990. Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, N. Sea. Mar. Ecol. Progr. Ser., 66: 285-299.

Gray, J.S., Bakke, T., Beck, H-J. and Nilssen, I., 1999. Managing the environmental effects of the Norwegian oil and gas industry: from conflict to consensus. Mar. Pollut. Bull., 38: 525-530.

Green, R.H., 1979. Sampling design and statistical methods for environmental biologists. Wiley, Chichester.

ISMARÉ, 1994. Assessing Data Quality: Methods, Experiences and Applications. Abstracts from a MAST Workshop, 20-23 September, 1993. Irish Marine Data Centre (ISMARÉ (Ed.)), 39pp.

MBA, 2003. Marine biodiversity and climate change - Mar Clim. Marine Biological Association: http://www.mba.ac.uk/marclim Also: http://www.satobsys.co.uk/Jericho/webpages/mainframes/ukframe

McGovern, E., E. Monaghan, A. Rowe, C. Duffy, Á. Quinn, B. McHugh, T. McMahon, M. Smyth, M. Naughton, M. McManus and E. Nixon., 2002. Winter Nutrient Monitoring of the Western Irish Sea - 1990 to 2000. Marine Environment and Health Series, No. 4. Marine Insitute, Dublin.

National Research Council, 1990. Managing Troubled Waters: the role of marine environmental monitoring. National Academic Press, Washington, D.C., 125pp.

Nicholson, M.D. & Fryer, R., 2002. Developing effective environmental indicators - does a new dog need old tricks? Mar. Pollut. Bull., 45: 53-61.

Nicholson, M.D., Fryer, R.J. & Ross, C., 1997. Designing monitoring programmes for detecting trends in contaminants in fish and shellfish. Mar. Pollut. Bull., 34: 821-826.

NOAA, 2000. Tropical waters in northern hemisphere heating at an accelerated rate. National Oceanographic and Atmospheric Administration: http://www.noaanews.noaa.gov/stories/s468.htm

O'Connor, S., 2002. Strangers in our seas. Southeastern Fisheries Association, Inc.: http://www.southeasternfish.org/Documents/strangers_in_the_seas.htm

Peterman, R.M., 1990. Statistical power analysis can improve fisheries research and management. Canad. J. Fish Aq. Sci., 47: 2-15.

Phillips, D.J.H. & Segar, D.A., 1986. Use of bioindicators in monitoring conservative contaminants. Mar. Pollut. Bull. 17: 10-17.

POL, 2001. Joint Evaluation of Remote Sensing Information for Coastal Defence and Harbour Organisations. (Jericho project). Plymouth Oceanographic Laboratory: http://www.pol.ac.uk/home/research/jericho.html

Spellerberg, I.F., 1991. Monitoring Ecological Change. Cambridge University Press, xvi + 334pp.

Stewart-Oaten, A., Murdich, W.M. & Parker, K.R. (1986) Environmental impact assessment: "pseudoreplication" in time? Ecology, 67: 1396-1404.

Taylor, J.K., 1985. Principles of quality assurance of chemical measurements. NBSIR 85-3105. National Bureau of Standards, Gaithersburg, Maryland.

Thompson, M., 1999. Sampling: the uncertainty that dares not speak its name. J. Environ. Monit., 1: 19-21.

Underwood. A.J. 1996. Environmental design and analysis in marine environmental sampling. Intergovernmental Oceanographic Commission Manuals and Guides No. 34. UNESCO.

Underwood, A.J., 1997. Experiments in ecology. Cambridge University Press, Cambridge.

USEPA, NOAA, USDA, USGS, 2000. Clean Water Action Plan: Coastal Research and Monitoring Strategy. Environmental Protection Agency, National Oceanic and Atmospheric Administration, U.S. Department of Agriculture & U.S. Geological Survey workgroup, 34pp + appendices.

Ward, T., Butler, E., & Hill, B., 1998. Environmental indicators for national state of the environment reporting - estuaries and the sea. Department of the Environment, Canberra, Australia.

Chapter 4.0

Boelens, R.G.V., Walsh, A.R., Parsons, A.P. and Maloney, D.M., 1999. Ireland's Marine and Coastal Areas and Adjacent Seas: an Environmental Review. Marine Institute, Dublin, 381pp + appendices.

EEA, 2001. Environmental Signals. European Environment Agency regular indicator report. Environmental Assessment Report No.8. European Environment Agency, Copenhagen. 112pp

EEC, 1976. Council Directive of 8 December 1975 Concerning the Quality of Bathing Water (76/160/EEC). Official Journal of the European Communities, No. L 31/1.

EEC, 1979. Council Directive 79/923/EEC of 30 October 1979 on the quality required of shellfish waters. Official Journal L281, 10.11.1979.

EEC, 1991. Council Directive 91/492/EEC of 15 July, 1991 laying down the health conditions for the production and the placing on the market of live bivalve molluscs. Official Journal. L268/1, pp 1-14.

ETC/WTR, 2002. EEA - Marine Conventions joint workshop on indicators: Summary Report. Inter-Regional Forum, Ispra, 25pp.

Environment Canada, 2003. http://www.ecoinfo.org/env_ind/indicators_e.cfm.

European Union, 2000. Directive of the European Parliament and of the Council 2000/60 EC establishing a framework for Community action in the field of water policy. Official Journal of the European Communities 22/12/2000, L 327, 1-70.

OSPAR Commission, 2000a. Quality Status Report 2000, Region III - Celtic Seas. OSPAR Commission, London. 116 + xiii pp.

OSPAR Commission 2000b. Quality Status Report 2000. OSPAR Commission, London. 108 + vii pp.

OSPAR Commission, 2002. The Revision of the Joint Assessment and Monitoring Programme (JAMP). MON 02/2/1.

Chapter 5.0

AMAP, 2002. Assessment of Arctic Pollution Issues. Arctic Monitoring & Assessment Programme (AMAP), Oslo, Norway.

Casazza, G., Silvestri, C. & Spada, E., 2002. The use of bio-indicators for quality assessments of the marine environment: Examples from the Mediterranean. J. Coastal Conservation, 8: 147-156.

Chandler, H., 2001. Marine Monitoring in the Gulf of Maine: an inventory. Prepared for the Maine State Planning Office & the Gulf of Maine Council, Augusta, Maine, 125pp.

Coastal Research & Monitoring Strategy Workgroup, 2000. Clean Water Action Plan: Coastal Research and Monitoring Strategy. Washington, DC. 62 pp.

Department of Environmental Affairs & Tourism, 2001. State of the Environment Indicators. DEAT (South Africa) website: http://www.environment.gov.za/soer/indicator/indicators.htm

European Union, 2000. Directive of the European Parliament and of the Council 2000/60 EC establishing a framework for Community action in the field of water policy. Official Journal 22/12/2000, L 327, 1-70.

GESAMP, 2001. Protecting the Oceans from Land-based Activities. IMO/FAO/UNESCO-IOC/WMO/WHO/ IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, Rep. Stud. No. 71: 162 pp.

Heinz Center, 2002. The State of the Nation's Ecosystems: Measuring the Lands. Waters, and Living Resources of the United States. H. John Heinz III Center for Science, Economics and the Environment. Cambridge University Press. xviii + 270pp.

IOC, 2002. A Reference Guide on the Use of Indicators for Integrated Coastal Management. Intergovernmental Oceanographic Commission (IOC) of the UN Educational, Scientific & Cultural organisation (UNESCO), Manuals & Guides No. 45, 127pp.

Mediterranean Action Plan, 2000. Indicators for the Sustainable Development of the Mediterranean Region: Glossary. Mediterranean Commission on Sustainable Development, Blue Plan, 186pp.

NZMFE, 2001. Environmental Performance Indicators: Confirmed indicators for the marine environment. New Zealand Ministry for Environment, ref. ME 398, x + 65pp.

UNEP, 1995. Global Programme of Action for the Protection of the Marine Environment from Land-based Activities. United Nations Environment Programme, UNEP (OCA)/LBA/IG.2/7, 60pp.

USEPA, 2001. National Coastal Condition Report. Environmental Protection Agency, EPA-620/R-01/005. Office of Research and Development/Office of Water, Washington, DC. 203 pp.

USEPA, NOAA, USDA, USGS, 2000. Clean Water Action Plan: Coastal Research and Monitoring Strategy. Environmental Protection Agency, National Oceanic and Atmospheric Administration, U.S. Department of Agriculture & U.S. Geological Survey workgroup, 34pp + appendices.

Ward, T., Butler, E. and Hill, B., 1998. Environmental indicators for National State of the Environment reporting: estuaries and the sea. Australia: State of the Environment (Environmental Indicator Reports), Department of the Environment, Canberra, 85pp.

Wilson, R., 1999. Ratings for DFO's [Department of Fisheries & Oceans] Potential Indicators of Ecosystem Health. 2WE Associates Consulting Ltd, Victoria, B.C., 13pp. Unpublished report for the Department of Fisheries & Oceans, Pacific Region.

Chapter 6.0

Begon, M., Harper, J.L. & Townsend, C.R., 1996. Ecology: individuals, populations and communities. Blackwell Scientific Publications. 3rd edition, 1068pp.

Beukema, J.J., 1988. An evaluation of the ABC-method (abundance/biomass comparison) as applied to macrozoobenthic communities living on tidal flats in the Dutch Wadden Sea. Marine Biology, 99: 425-433.

Calow, P., 1992. Can ecosystems be healthy? Critical considerations of concepts. J. Aquatic Ecosys. Health, 1: 1-5.

Calow, P., 2000. Critics of ecosystem health misrepresented. Ecosys. Health, 6: 3-4

Chapman, P.M., 1992. Pollution status of North Sea sediments - an international integrative study. Mar. Ecol. Progr. Ser., 91: 313-322.

Clarke, K.R. & Ainsworth, M., 1993. A method for linking multivariate community structure to environmental variables. Mar. Ecol. Progr. Ser., 92: 205-219.

Clarke, K.R. & Warwick, R.M., 1994. Changes in marine communities: an approach to statistical analysis and interpretation. Plymouth Marine Laboratory, Plymouth.

Crisp, D.J., 1984. Energetics. In: Home, N.A. & McIntyre, A.D. (Eds.) Methods for the study of marine benthos. Blackwell Scientific, Oxford.

Estacio, F.J., Garcia-Adiego, E.M., Fa, D.A., Garcia-Gomez, J.C., Daza, J.L. Hortas, F., & Gomez-Ariza, J.L., 1997. Ecological analysis in a polluted area of Algeciras Bay (Southern Spain): External versus internal outfalls and environmental implications. Mar. Pollut. Bull., 34: 780-793.

Falkowski, P. & Newman, W.A., 1998. A pilot study of heavy metal accumulations in a barnacle from the Salton Sea, California. Mar. Pollut. Bull., 36: 138-143.

Field, J.G., Clarke, K.R. Warwick, R.M., 1982. A practical strategy for analysing multispecies distribution patterns. Mar. Ecol. Progr. Ser., 8: 37-52.

Gattuso, J.P., Frankignoulle, M and Smith, S.V., 1999. Measurement of community metabolism and significance in the coral reef CO2 source-sink debate. Proc. Natl. Acad. Sci., 96 (23): 13017-13022.

GESAMP, 1990. The state of the marine environment. United Nations Environment Programme. UNEP Regional Seas Reports and Studies 115, 115pp.

Gray, J.S., 1974. Animal-Sediment Relationships. Oceanography and Marine Biology; an Annual Review (Ed. H. Barnes), 12: 223-261.

Gray, J.S., 1976. Are base-line surveys worthwhile? New Scientist, 70: 219-221.

Gray, J.S., 1981. The Ecology of Marine Sediments: an introduction to the structure and function of marine communities. Cambridge University Press. 187 pp.

Gray, J.S., 1982. Pollution effects on marine ecosystems. Neth. J. Sea Res. 16: 424-443.

Gray, J.S., 1989. Effect of environmental stress in species rich assemblages. Biol. J. Linn. Soc., 37: 19-32.

Gray, J.S., 1993. Eutrophication in the sea. In: Columbo, G. *et al.* (eds.) Marine Eutrophication and Population Dynamics. Proceedings of the 25th EMBS. Olsen & Olsen, Denmark pp. 3-11.

Gray, J.S., 2000. The measurement of species diversity: with an example from the Norwegian continental shelf. J. exp. Mar. Biol. Ecol., 250: 23-49.

Gray, J.S. & Mirza, F.B., 1979. A possible method for the detection of pollution-induced disturbance on marine benthic communities. Mar. Pollut Bull., 10: 142-146.

Gray, J.S. & Pearson, T.H., 1982. Objective selection of sensitive species indicative of pollution-induced disturbance on marine benthic communities. I. Comparative methodology. Mar. Ecol. Progr. Ser., 9: 111-119.

Gray, J.S., Clarke, K.R., Warwick, R.M. & Hobbs, G., 1990. Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, N. Sea. Mar. Ecol. Progr. Ser., 66: 285-299.

Gray, J.S., Aschan, M., Carr, M.R., & Clarke, K.R., 1988. Analysis of community attributes of the benthic macrofauna of Frierfjord/Langesundfjord and in a mesocosm experiment. Mar. Ecol. Progr. Ser., 46: 151-165.

Grime, J.P., 1989. The stress debate: symptom of impending synthesis? Biol. J. Linn. Soc., 37: 3-17.

Harvey, M. Gauthier, D., & Munro, J., 1998. Temporal changes in the composition and abundance of the macrobenthic invertebrate communities at dredged material disposal sites in the Anse à beaufils, Baie des Chaleurs, Eastern Canada. Mar. Poll. Bull., 36: 41-55.

Hill, M.O., 1973. Diversity and evenness: a unifying notation and its consequence. Ecology, 54: 427-432.

Jongman, R.H.G., ter Braak, C.J.F., & van Tongeren, F.R., 1987. Data analysis in community and landscape ecology. Pudoc, Wageningen. 299 pp.

Kaarstad, I., Simnth, J. & Hobbs, G., 1993. Miljøundersøkelse på Statfjordfeltete i 1992. Projekt nr. 22.2094.00/01/92 IKU, Trondheim, Norway.

Knowlton, N., 1993. Sibling species in the sea. Ann. Rev. Ecol. Sys., 24: 189-216.

Lambshead, P.J.D. & Platt, H.M., 1985. Structural patterns of marine benthic assemblages and their relationships with empirical statistical models. In: P.E. Gibbs (ed.) Proceedings of the 19th European Marine Biology Symposium, Plymouth, 1984, Cambridge University Press, Cambridge, pp 371-80.

Lambshead, P.J.D., Platt, H.M. & Shaw, K.M., 1983. Detection of differences among assemblages of benthic species based on an assessment of dominance and diversity. J. Nat. Hist. London, 17: 859-874.

Long, E.R. & Chapman, P.M., 1985. A sediment quality triad: measures of sediment contamination, toxicity and infaunal community structure in Puget Sound. Mar. Pollut. Bull., 16: 405-415.

Long, E.R., 1989. The use of the Sediment Quality Triad in classification of sediment contamination. In: Contaminated marine sediments - assessment and remediation. National Research Council, National Academy Press, Washington, D.C. pp 78-93.

Magurran, A.E., 1988. Ecological diversity and its measurement. Croom Helm, London. 179pp.

McLusky, D.S. & Martins, T., 1998. Long-term study of an estuarine mudflat subjected to petro-chemical discharges. Mar. Pollut. Bull., 36: 791-798.

Noga, E.J., 2000. Skin Ulcers in Fish: Pfiesteria and Other Etiologies. Toxicologic Pathology, 28(6): 807-823.

Odum, E.P., 1963. Ecology. Holt, Reinhart & Winston, New York.

Olsgard, F. & Gray, J.S., 1995. A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. Mar. Ecol. Progr. Ser., 122: 277-306.

Olsgard, F., 1993. Do toxic algal blooms affect subtidal soft-bottom communities? Mar. Ecol. Progr. Ser., 102: 269-286.

Olsgard, F., Somerfield, P.J. & Carr, M.R., 1998. Relationships between taxonomic resolution, macrobenthic community patterns and disturbance. Mar. Ecol. Progr. Ser., 172: 25-36.

Patrick, R., 1972. Benthic communities in streams. Trans. Conn. Acad. Arts. Sci., 44: 271-282.

Pearson, T.H. & Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann. Rev., 16: 229-311.

Pielou, E.C., 1976. Population and Community Ecology. Gordon & Breach, pp 1-424.

Pihl, L., 1989. Effects of oxygen depletion on demersal fish in coastal areas of the south-east Kattegat. In: J.S. Ryland & P.A. Tyler (eds) Reproduction, Genetics and Distribution of Marine Organisms. Olsen & Olsen, Fredensborg. pp 431-439.

Rapport, D.J., Bohm, G., Buckingham, D., Cairns, J. Jr., Costanza, R., Karr, J.R., de Kruif, H.A.M., Levins, R., McMichael, A.J., Nielsen, N.O. & Whitford, W.G., 1999. Ecosystem health: the concept, the ISEH, and the important tasks ahead. Ecosyst. Health, 5: 82-909.

Rapport, D.J., Costanza, R. & McMichael, A.J., 1998. Assessing ecosystem health. Tree, 13: 397-402.

Reid, P.C., Planque, B. & Edwards, M., 1998. Is observed variability in the long-term results of the continuous plankton recorder survey a response to climate change? J. Fish. Res. Bd. Can., 31: 283-292.

Renton, K.W. & Addison, R.F., 1992. Hepatic microsomal mon-oxygenase activity and P450IA mRNA in North Sea dab Limanda limanda from contaminated sites. Mar. Ecol. Progr. Ser., 91: 65-69.

Riegl, B. and Branch, G.M., 1995. Effects of sediment on the energy budgets of 4 scleractinian (Bourne 1900) and 5 alcyonacean (Lamouroux 1816) corals. J. Exp. Mar. Biol. Ecol., 186: 259-275.

Shannon, C.E. & Weaver, W., 1949. The mathematical theory of communication. Urbana, University of Illinois Press.

Ugland, K.I. & Gray, J.S., 1983. Reanalysis of Caswell´s neutral models. Ecology, 64: 603-605.

USEPA, 2000. Estuarine and coastal marine waters bioassessment and biocriteria technical guidance. EPA-822-B-00-024. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

USEPA, 2000. A framework for an integrated and comprehensive monitoring plan for the estuaries of the Gulf of Mexico. Washington; EPA. pp. 1-87

Valderhaug, V. & Gray, J.S., 1984. Constant structure of a macrofaunal community despite a fluctuating food supply in subtidal sediments of Oslofjord, Norway. Mar. Biol., 82: 307-322.

Warwick, R.M., 1986. A new method for detecting pollution effects on marine macrobenthic communities. Mar. Biol., 92: 557-562.

Warwick, R.M., 1988. Analysis of community attributes of the macrobenthos of Freierfjord/Langesundfjord at taxonomic levels higher than the species. Mar. Ecol. Progr Ser., 46: 167-170.

Warwick, R.M. & Clarke, K.R., 1991. A comparison of some methods for analysing changes in benthic community structure. J. mar. biol. Ass. UK., 71: 225-244.

Warwick, R.M. & Clarke, K.R., 1993. Comparing the severity of disturbance: a meta-analysis of marine macrobenthic community data. Mar. Ecol. Progr. Ser., 92: 221-231.

Whittaker, R.H., 1972. Evolution and measurement of species diversity. Taxon, 21: 213-251.

Wilkins, D.A., 1999. Assessing ecosystem health. Tree, 14: 69.

Chapter 7.0

Arndt, S.K., 2000. Influence of sexual maturity on feeding, growth and energy stores of wild salmon parr. J. Fish. Biol., 57: 589-596.

Avery, E.L., Dunstan, R.H. & Neil, J.A., 1996. The detection of pollutant impact in marine environments: condition index, oxidative DNA damage, and their associations with metal bioaccumulation in the Sydney rock oyster Saccostrea commercialis. Arch. Environ. Contam. Toxicol., 31: 192-198.

Bayne, B.L., Clarke, K.R. & Gray, J.S., 1988. Biological effects of pollutants. Results of a practical workshop. Mar. Ecol. Progr. Ser., 46: 1-278.

Bhagyalakshmi A., Reddy, R. & Ramamurthi, R., 1984. Subacute stress induced by sumithion on certain biochemical parameters in Oziotelphusa senex, the freshwater rice field crab. Toxicol. Lett., 21: 127-134.

Biagianti-Risboug, S., 1993. Les cellules immunitaires hepatiques de muges juveniles (Liza sp: Mugilidae; Teleostei): Approche ultrastructurale. J. Appl. Icthyol., 9: 97-109.

Boelens, R.G.V., Maloney, D.M., Parsons, A.P. and Walsh, A.R., 1999. Ireland's marine and coastal areas and adjacent seas: an environmental review. Marine Institute, Dublin, 388pp.

Broeg, K., Zander, S. Diamant, A., Korting, W., Kruner. G., Papena, I. & Westernhagen, H.V., 1999. The use of fish metabolic, pathological and parasitological indices in pollution monitoring in the North Sea. Hegol. Mar. Res., 53: 171-194.

Brown, D.C., Bradley, B.P. & Tedengren, M., 1995. Genetic and environmental regulation of HSP70 expression. Mar. Environ. Res., 39: 181-184.

Bucke, D., Feist, S.W., Norton, M.G. and Rolfe, M.S., 1983. A histopathological report of some epidermal anomalies of Dover sole *Solea solea* L., and other flatfish species, in coastal waters off south-east England. J. Fish Biol., 23: 565-578.

Buckely, L.J., 1980. Changes in ribonucleic acid, deoxyribonucleic acid, and protein content during ontogenesis in winter flounder, Pseudopleuronectes americanus, and the effect of starvation. Fish. Bull., 703-708.

Cajaraville, M.P., Uranga, J.A. & Angulo, E., 1992. Comparative effects of the water accommodated fraction of three oils on mussels. 3. Quantitative histochemistry of enzymes related to the detoxification metabolism. Comp. Biochem. Physiol., 103C: 3669-377.

Cajaraville, M.P., Orbea, A., Marigomez, I. & Cancio, I., 1997. Peroxisome proliferation in digestive epithelium of mussels exposed to the water accommodated fraction of three oils. Comp. Biochem. Physiol., 117C: 233-242.

Cajaraville, M.P., Bebianno, M.J., Blasco, J., Porte, C., Sarasquete, C. & Viarengo, A., 2000. The use of biomarkers to assess the impact of pollution in coastal environments of the Iberian peninsular: a practical approach. Sci. Total Environ., 247: 295-311.

Cameron, P. & Berg, J. 1992. Mophological and chromosomal aberrations during embryonic development in dab Limanda limanda. Mar. Ecol. Progr. Ser., 91: 163-169.

Ching, E.W.K., Siu, W.H.L., Lam, P.K.S., Xu, L., Zhang, Y., Richardson, B.J. & Wu, R.S.S., 2001. DNA adduct formation and DNA strand breaks in green-lipped mussels (*Perna viridis*) exposed to benzo[a]pyrene: dose and time dependent relationships. Mar. Pollut. Bull., 42: 603-610.

Cid, A., Herrero, C., Torres, E. & Abalde, J., 1995. Copper toxicity on the marine alga Phaeodactylum tricornutum: Effects on photosynthesis and related parameters. Aquat. Toxicol., 31: 165-174.

Coelho, S.M., Rijstenbil, J.W. & Brown, M.T., 2000. Impacts of anthropogenic stresses on the early development stages of seaweeds. J. Aquat. Ecosyst. Stess Recovery. 7: 317-333.

Colborn, T., vom Saal, F.S. & Soto, A.M., 1993. Development effects of endocrine-disrupting chemicals in wildlife and humans. Environ. Health Pers. 101 (5), 378-384.

Davies, I.M. and Minchin, A., 2002. Quality assurance of imposex and intersex measurements in marine snails. J. Environ. Monit., 4: 788-790.

Dethlefsen, V., 1980. Observations on fish diseases in the German Bight and their possible relation to pollution. Rapp. P.-v. Reun. Cons. Perm. Int. Explor. Mer., 179: 110-117.

Dethlefsen, V., 1984. Diseases of North Sea fishes. Helgolander Wiss. Meeresunter., 37: 353-374.

Dethefsen, V., 1990. Ten years of fish disease studies of the Federal Research Board of Fisheries Hamburg. Arch. Fish. Wiss., 40: 119-132.

De Zwaan, A., Cortsei, P. & Cattani, O., 1995. Resistance of bivalves to anoxia as a response to pollution-induced environmental stress. Sci. Total Environ., 171: 121-125.

Donaldson, E.M., Fagerlund, U.H.M., Higgs, D.A. & McBride, J.R., 1979. Hormonal enhancement of growth. In: Hoar, W.S., Randall, D.J. & Brett, J.R. (eds.) Fish Physiology VIII, Bioenergetics and Growth, Academic Press, New York. pp 455-597.

Everaarts, J.M., Den Besten, P.J., Hillebrand, M.T.J., Halbrook, R.S. & Shugart, L.R., 1998. DNA strand breaks, cytochrome P-450-dependent monoxygenase system activity and levels of chlorinatedbiphenyl congeners in the pyloric caeca of the seastar (*Asterias rubens*) from the North Sea. Ecotoxicology, 7: 69-79.

Fargasova, A., 1998. Comparison of tributyltin compound effects on the alga Scendesmus quadricauda and the benthic organisms Tubifex tubifex and Chironomus plumosus. Ecotoxicol. Environ. Saf., 41: 222-230.

Fields, J.H.A. & Hochachka, P.W., 1975. Octopine dehydrogenase in squid mantle. Comp. Biochem. Phsyiol., 52B: 158-165.

Gagnon, M.M. & Holdway, D.A., 1999. Metabolic enzyme activities in fish gills as biomarkers of exposure to petroleum hydrocarbon. Ecotoxicol. Environ. Safety, 44: 92-99.

Galgani, F., Bocquené, G. & Cadiou, Y., 1992. Evidence of variation in cholinesterase activity in fish along a pollution gradient in the North Sea. Mar. Ecol. Progr. Ser., 91: 77-82.

GESAMP, 1995. Biological indicators and their use in the measurement of the condition of the marine environment. Group of Experts on the Scientific Aspects of Marine Protection (GESAMP), Reports and Studies No. 55: 56pp.

Giesy, P.G. & Graney, R.L., 1989. Recent developments in and intercomparisons of acute and chronic bioassays and bioindicators. Hydrobiologia, 188/189: 21-60.

Gold-Bouchot, G., Sima-Alvarez, R., Zapeta-Perez, O. & Guemez-Ricalde, J., 1995. Histopathological effects of petroleum hydrocarbons and heavy metals on the American oyster (*Crassostrea virgnica*) from Tabasco, Mexico. Mar. Pollut. Bull., 31: 439-445.

Gould, W. & Greig, T., 1983. Short-term low salinity response in lead-exposed lobsters Homarus americanus (Milne Edwards). J. Exp. Mar. Biol. Ecol., 69: 283-295.

Granby, K. & Spliid, N.H., 1995. Hydrocarbons and organochlorines in common mussels from the Kattegat and the Belts and their relation to condition indices. Mar. Pollut. Bull., 30: 74-82.

Haines, T.A., 1980. Seasonal patterns of muscle RNA-DNA ratio and growth in the black crappie, Promoxis nigromaculatus. Environ. Biol. Fishes, 5: 67-70.

Harding, M.J.C. and Davies, I.M., 2000. A field evaluation of international monitoring guidelines for the biological effects of tributyltin. J. Environ. Monit., 2: 404-409.

Holdway, D.A., Brennan, S.E. & Ahokas, J.T., 1995. Short review of selected fish biomarkers of xenobiotic exposure with an example using hepatic MFO. Audt. J. Ecol., 20: 34-44.

Hsiu-Chuan, V. & Freedman, J.H., 1998. Cadmium-regulated genes from the nematode Caenorhabditis elegans. Identification and cloning of new cadmium-responsive genes by differential display. J. Biol. Chem., 273: 31962-31970.

Hughes, J.B., 1999. Cytological-cytogenetic analyses of winter flounder embryos collected from the benthos of the large North Cape oil spill. Mar. Pollut. Bull., 38: 30-35.

ICES, 1989. Methodology of fish diseases surveys. ICES Coop. Res. Rep., No. 166: 1-43.

ICES, 1996. Common diseases and parasites of fish in the North Atlantic: Training guide for identification. ICES Coop. Res. Rep., No. 191: 1-27.

ICES, 1997. ICES review of the status of biological effects techniques relative to their potential application. ICES Coop. Res. Rep., No. 222: 1-20.

Ivanovicic, A.M., 1980. The adenylate energy charge in the estuarine mollusc, Pyrazus ebenius. Laboratory studies f responses to salinity and temperature. Comp. Biochem. Physiol., 66A: 43-55.

Johnson, L.L., Stehr, C.M., Olson, O.P., Myers, M.S., Pierce, S.M., McCain, B.B. & Varanasi, U., 1992a. National benthic surveillance project: Northeast coast - fish pathology and relationships between lesions and chemical contaminants (1987-1989). U.S. National Technical Information Service, pp. 1-96.

Johnson, L.L., Stein, J.E., Collier, T.K., Casilas, E., McCain, B. & Varanasi, U., 1992b. Bioindicators of contaminant exposure. Liver pathology, and reproductive development in prespawning female winter flounder (*Pleuronectes americanus*) from urban and non-urban estuaries on the northeast Atlantic coast, U.S. National Technical Information Service, pp. 1-71.

Johnson, L.L., Stehr, C.M., Olson, O.P., Myers, M.S., Pierce, S.M., Wigren, C.A., McCain, B.B. & Varanasi, U., 1993. Chemical contaminants and hepatic lesions in winter flounder (*Pleuronectes americanus*) from the northeast coast of the United States. Environ. Sci. Tech., 27: 2759-2771.

Kanter, P.M. & Shwartz, H.S., 1982. A fluorescent enhancement assay for cellular DNA damage. Mol. Pharmacol., 22: 145-151.

Khan, R.A. & Kiceniuk, J., 1984. Histopathological effects of crude oil on Atlantic cod following chronic exposure. Marine Sciences Research Laboratory Contribution No. 478. 62: 2038-2043.

Khan, R.A. & Payne, J.F., 1997. A multidisciplinary approach using several biomarkers, including a parasite, as indicators of pollution: a case history from a paper mill in Newfoundland. Parasitologia, 39: 183-188.

Kirby, M.F., Matiessen, P., Neall, P., Tylor, T., Allchin, C.R., Kelly, C.A., Maxwell, D.L. & Thain, J.E., 1999. Hepatic EROD activity in flounder (*Platichthys flesus*) as an indicator of contaminant exposure in English estuaries. Mar. Pollut. Bull., 38: 676-686.

Knowles, C.O. & McKee, M.J., 1987. Protein and nucleic acid content in Daphnia magna during chronic exposure to cadmium. Ecotoxicol. Environ. Safety, 13: 290-300.

Koban, M., Yup, A.A., Agellon, L.B. & Powers, D.A., 1991. Molecular adaptation to environmental temperature; heat shock response of the eurythermal teleost Fundulus heteroclitus. Mol. Mar. Biol. Biotech. 1: 1-17.

Köhler, A., Deisemann, H. & Lauritzen, B., 1992. Histopathological and cytochemical indices of toxic injury in the liver of dab *Limanda limanda*. Mar. Ecol. Progr. Ser., 91: 141-153.

Krahn, M.M., Rhodes, L.D., Myers, M.S., Moore, L.K., MacLeod, Jr. W.D. & Malins, D.C., 1986. Associations between metabolites of aromatic compounds in bile and the occurrence of hepatic lesions in English sole (*Parophrys vetulus*) from Puget Sound, Washington. Arch. Environ. Contam. Toxicol., 15: 61-67.

Krishnkumar, P.K., Casillas, E. & Varanesi, U., 1995. Effects of chemical contaminants on the health of Mytilus edulis from Puget Sound, Washington. II. Cytochemical detection of subcellular changes in digestive cells. Mar. Biol., 124: 251-259.

Lagadic, L., Caquet, T. & Ramade, F., 1994. The role of biomarkers in environmental assessment (5). Invertebrate populations and communities. Ecotoxicol., 3: 193-208.

Landahl, J.T., McCain, B.B., Myers, M.S., Rhodes, L.D. & Brown, D.W., 1990. Consistent associations between hepatic lesions in English sole (*Parophyrs vetlus*) and polycyclic aromatic hydrocarbons in bottom sediment. Environ. Health Persp., 89: 195-203.

Lang, T. and Dethlefsen, V., 1996. Fish disease monitoring - a valuable tool for pollution assessment? ICES Marine Environmental Quality Committee. ICES CM 1996/E:17, 18pp.

Lindesjöö, E. & Thulin, J., 1994. Histopathology of skin and gill of fish in pulp mill effluents. Dis. Aquat. Organ., 18: 81-93.

Liu, J.H. & Morton, B., 1998. The impacts of pollution on the growth, reproduction and population structure of Hong Kong limpets. Mar. Pollut. Bull., 36: 152-158.

Livingstone, D.R., 1993. Biotechnology and pollution monitoring: use of molecular biomarkers in the aquatic environment. J. Chem. Technol. Biotechnol., 57: 195-211.

Lowe, D.M., Moore, M.N., & Clarke, K.R., 1981. Effects of oil on digestive cells in mussels: quantitative alterations in cellular and lysosomal structure. Aquat. Toxicol., 1: 213-226.

Lowe, D.M., Moore, M.N. & Evans, B.M., 1992. Contaminant impact on interactions of molecular probes with lysosomes in living hepatocytes from dab Limanda limanda. Mar. Ecol. Progr. Ser., 91: 135-140.

Lønne, O.J. & Gray, J.S., 1988. Influence of tides on microgrowth bands in Cerastoderma edule from Norway. Mar. Ecol. Progr. Ser., 42: 1-17.

Malins, D.C., McCain, B.B., Brown, D.W., Chan, S.L., Myers, M.S., Landahl, J.T., Prohaska, P.G., Friedman, A.J., Rhodes, L.D., Burrows, D.G., Gronlund, W.D. & Hodgkins, H.O., 1984. Chemical pollutants in sediments and diseases in bottom-living fish in Puget Sound, Washington. Environ. Sci. Technol., 18: 705-713.

Malins, D.C., Schiewe, M.H., McCain, B.B., Brown, D.W., Varanasi, U., Roubal, W.T. & Chan, S.L., 1986. Etiology of tumors in bottom living marine fish. Annual Report to the Natl. Cancer Inst, 1-38.

Mitchelmore, C.L. & Chipman, J.K., 1998. Detection of DNA strand breaks in brown trout (*Salmo trutta*) hepatocytes and blood cell using the single cell gel electrophoresis (comet) assay. Aquat. Toxicol., 41: 161-182.

Moore, M.N., 1990. Lysosomal cytochemistry in marine environmental monitoring. Histochem. J., 22: 187-191.

MPMMG, 1998. National Monitoring Programme: Survey of the Quality of UK Coastal Waters. Marine Pollution Monitoring Management Group (MPMMG), Aberdeen, 79pp.

MPMMG, 2001. Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1998. Marine Pollution Monitoring Management Group (MPMMG), Aquatic Monitoring Report No. 53, Centre for Environment, Fisheries & Aquatic Sciences (CEFAS), Lowestoft, 75pp.

Myers, M.S., Stehr, C.M., Olson, O.P., Johnson, L.L., McCain, B.B., Chan, S.L. & Varanasi, U., 1993. National benthic surveillance project: Pacific coast - fish histopathology and relationships between toxicopathic lesions and exposure to chemical contaminants for cycles I to V (1984-1988). U.S. National Technical Information Service. pp 1-147.

Neff, J.M., Hillman, R.E., Scott Carr, R., Buhl, R.L. & Lahey, J.I., 1987. Histopathological and biochemical responses in Arctic marine bivalve molluscs exposed to experimentally spilled oil. The Arctic Institute of North America 40: 220-229.

Nicholson, S., 1999a. Cytological and physiological biomarkers in *Perna viridis* (L.), (Bivalvia; Myilidae). Ph.D. Thesis, University of Hong Kong, Hong Kong.

Nicholson, S., 1999b. Cytological and physiological biomarkers from green-lipped mussels, *Perna viridis* (L.) transplanted to contaminated sites in Hong Kong coastal waters. Mar. Pollut. Bull., 39: 261-268.

Oikari , A., Ånäs, E., Kruzynski, G. & Holmbom, B., 1984. Free and conjugated resin acid in the bile of rainbow trout, *Salmo gairdneri*. Environ. Contam. Toxicol., 33: 233-240.

Oikari, A., Holmbom, B., Ånäs, E., Milunpalo, M., Kruzynski, G. & Catsren, M., 1985. Ecotoxicological aspects of pulp and paper mill effluents discharged to an inland water system: distribution in water, and toxicant residues and physiological effects in caged fish, *Salmo gairdneri*. Aquat Toxicol., 6: 219-239.

OSPAR, 1997. Guidelines for contaminant-specific biological effects monitoring. Oslo and Paris Commissions, London.

Page, D.S. & Widdows, J., 1991. Temporal and spatial variation in levels of alkyltins in mussel tissue: A toxicological interpretation of field data. Mar. Environ. Res., 32: 113-129.

Pereira, J.J., Ziskowski, J., Mercaldo-Allen, R., Kuropat, C., Luedke, D. & Gould, E., 1992. Vitellogenin in winter flounder (*Pleuronectes americanus*) from Long Island Sound and Boston Harbour. Estuar., 15, 289-297.

Porte, C., Sole, M., Borghi, V., Ortiz., M., Orbea, A. & Cajaraville, M.P., 1998. Application of a battery of biochemical and cellular markers in mussels to assess environmental pollution along the Mediterranean coast. 8th Annual Meeting SETAC-Europe. Abstract Book 52.

Prange, J.A. & Denison, W.C., 2000. Physiological responses of seagrass to five trace metals. Mar. Pollut. Bull., 42: 327-336.

Reid, H.P., 1997. Examination of biomarkers in the crimson-spotted rainbowfish (*Melanotaenia fluviatilis*). Ph.D. Thesis, Royal Melbourne Institute of Technology, June 1997. Melbourne, Victoria, Australia, pp 287.

Richardson, C.A., Seed, R. & Naylor, E., 1990. Use of internal growth bands for measuring individual and population growth rates in *Mytilus edulis* from offshore production platforms. Mar. Ecol. Progr. Ser., 66: 259-265.

Roberts, D.A., Hofmann, G.E. & Somero, G.N., 1997. Heat-shock protein expression in *Mytilus californianus*: acclimatization (seasonal and tidal-height comparison) and acclimation effects. Biol. Bull., 192: 309-320.

Ryan, J.A. & Hightower, L.E., 1996. Stress proteins as molecular biomarkers for environmental toxicology. In: Feige, U., Morimota, R.I., Yahara, I. & Polla, B. (eds), Stress-inducible cellular responses. Berkhauser Verlag, Basel, Switzerland. pp. 411-424.

Sanders, B.M., Pascoe, V.M., Nakagawa, P.A. & Martin, L.S., 1992. Persistence of the heat-shock response over time in a common mussel *Mytilus edulis*. Mol. Mar. Biol. Biotechnol., 1: 147-154.

Santos, M.H.S., Da Vunha, N.T. & Bianchini, A., 2000. Effects of copper and zinc on growth, feeding and oxygen consumption of Farfantepenaues *pauliensis postlarvae* (Decapoda: Penaidae). J. Exp. Mar. Biol. Ecol., 247: 233-242.

Schlenk, D. & Brouwer, M., 1993. Induction of metallothionein mRNA in the blue crab (Callinectes sapidus) after treatment with cadmium. Comp. Biochem. Phsyiol., 104C: 317-321.

Scott, A.P., and Hylland, K., 2002. Biological effects of contaminants: Radioimmunoassay (RIA) and enzyme-linked immunosorbent assay (ELISA) techniques for the measurement of marine fish vitellogenins. ICES Techniques in Marine Environmental Sciences. 21pp.

Semizarov, D., Glesne, D., Laouar, A., Schiebel, K. & Hunerman, E., 1998. A lineage-specific protein kinase crucial for myeloid maturation. Proc. Natl. Acad. Sci., 95: 15412-15417.

Shugart, L.R., 1999. Structural damage to DNA in response to toxicant exposure. In: Forbes, V.E. (ed.) Genetics and Ecotoxicology. Taylor & Francis, U.S.A. pp. 151-168.

Simpson, M.G. & Hutchinson, T.H., 1992. Toxicological pathology of dab Limanda limanda along pollution gradients in the southern North Sea. Mar. Ecol. Progr. Ser., 91: 155-161.

Stegeman, J.J., 1989. Cytochrome P-450 forms in fish: catalytic immunological and sequence similarities. Xenobiotica, 19: 1093-1110.

Stegeman, J.J., Woodin, B.R. & Goksøyr, A., 1988. Apparent cytochrome P-450 induction as an indication of exposure to environmental chemicals in the flounder Platichthys flesus. Mar. Ecol. Progr. Ser., 46: 55-60.

Strobel, C.J., Buffum, H.W., Benyi, S.J. & Paul, J.F., 1999. Environmental monitoring and assessment program: current status of Virginian province (U.S.) estuaries. Environ. Monit. Assess., 56(1): 1-25.

Suresh-babu, G., Hans, R.K., Singh, J., Viswanathan, P.N. & Jishi, P.C., 2001. Effect of lindane on the growth and metabolic activities of cyanobacteria. Ecotooxicol. Environ. Safety, 48: 219-221.

UNEP, 1997. Report of the meeting of experts to review the MED POL biomonitoring programme. Athens, Greece: UNEP (OCA) /MED/WG. 132/7.

USEPA, 2000. A framework for an integrated and comprehensive monitoring plan for the estuaries of the Gulf of Mexico. Washington; EPA. pp. 1-87

Veldhuzen-Tsoerkan, M.B., Holwerda, D.A., van der Mast, C.A. & Zandee, D.I., 1991. Synthesis of stress proteins under normal and heat shock conditions in fill tissue of sea mussels (*Mytilus edulis*) after chronic exposure to cadmium. Comp. Biochem. Physiol., 100C: 699-706.

Vethaak, D., 1993. Fish disease and marine pollution: A case study of the flounder (*Platicthys flesus*) in Dutch coastal and estuarine waters. Harlem, Netherlands Ministry of Transport, Public Works and Water.

Vetter, R.D. & Hobson, R.E., 1982. Use of adenylate concentrations and adenylate energy charge as indicators of hypoxic stress in estuarine fish. Can. J. Fish. Aquat. Sci., 39: 535-541.

Walsh, P.J., Bergman, H.L., Narhara, A., Wood, C.M., Wright, P.A., Randall, D.J., Maina, J.N. & Laurent, P., 1993. Effects of ammonia on survival, swimming and activities of enzymes of nitrogen metabolism in Lake Magadi Tilapia, Oreochromis alcalicus grahami. J. Exp. Biol., 180: 323-327.

White, R., Jobling, S., Hoare, S.A., Sumpter, J.P. & Parker, M.G., 1994. Environmentally persistent alkylphenolic compounds are estrogenic. Endocrinol., 135 (1), 175-182.

Wang, Z.H. & Zou, R.L., 1992. A fuzzy clustering analysis of the Genus Favia (Anthozoa, Scleractinia) at How Ha Wan. In: Morton, B. (ed.), Proceedings of the 4th International Marine Biological Workshop: The marine flora and fauna of Hong Kong and southern China, Hong Kong 1989. Hong Kong University Press, Hong Kong. pp. 883-889.

Wedderburn, J., Mc Fadzen, I., Sanger, R.C., Beesley, A., Heath, C., Hornsby, M. & Lowe, D., 2000. The field application of cellular and physiological biomarkers in the mussel *Mytilus edulis*, in comparison with early life stage bioassays and adult histopathology. Mar. Pollut. Bull., 40: 257-267.

Weeks, B.A., Anderson, D.P. & Dufour, A., 1992. Immunological biomarkers to assess environmental stress. In: Huggett, R.J., Kimerle, R.A., Mehrle Jr., P.M. & Bergman, H.L. (eds.) Biomarkers – biochemical, physiological and histological markers of anthropogenic stress. Lewis Publishers, USA. pp 211-2334.

Widdows, J., Bakke, T., Bayne, B., Donkin, P., Livingstone, D., Lowe, D., Morre, M., Evans, S. & Morre, S., 1982. Responses of *Mytilus edulis* on exposure to water-accommodated fraction of North Sea oil. Mar. Biol., 67: 15-31

Widdows, J., Donkin, P., Brinsley, M.D. & Evans, S.V., 1995. Scope for growth and contaminant levels in North Sea mussels *Mytlius edulis*. Mar. Ecol. Progr. Ser., 127: 131-148.

Wo, K.T., Lam, P.K.S. & Wu, R.R.S., 1999. A comparison of growth biomarkers for assessing sublethal effects of cadmium on a marine gastropod, *Nassarius festivus*. Mar. Pollut. Bull., 39: 165-173.

Wolfe, D.A., 1992. Selection of bioindicators of pollution for marine monitoring programmes. Chem. Ecol., 6: 149-167.

Wolke, R.E., Murchelano, R.A., Dickstein, C.D. & George, C.J., 1985. Preliminary evaluation of the use of macrophage aggregates (MA) as fish health monitors. Bull. Environ. Contam. Toxicol., 35: 222-227.

Wright, D.A. & Hetzel, E.W., 1985. Uses of RNA/DNA ratios as an indicator of nutritional stress in the American oyster *Crassostrea virginica*. Mar. Ecol., 25: 199-206.

Wu, R.R.S. & Lam, P.K.S., 1997. Glucose-6-phosphate dehydrogenase and lactate dehydrogenase in the green-lipped mussel (*Perna viridis*): possible biomarkers for hypoxia in the marine environment. Wat. Res., 31: 2797-2801.

Wu, R.R.S. & Levings, C.D., 1980. Mortality, growth and fecundity of transplanted mussel and barnacle populations near a pulp mill outfall. Mar. Pollut. Bull., 11: 11-15.

Wu, R.R.S. & Woo, N.Y.S., 1985. Respiratory responses and tolerance to hypoxia in two marine teleosts, *Epinephelus akaaara* (Temmick & Schlegal) and *Mylio macrocephalus* (Basilewsky). Hydrobiologia, 119: 209-217.

Xu, L., Lam., P.K.S. & Richardson, B., 1999. Relationships between tissue concentrations of polycylic aromatic hydrocarbons and DNA adducts in green-lipped mussels (*Perna viridis*). Ecotoxicol., 8: 73-82.

Zhou, B.S., Wu, R.R.S., Randall, D.J. Lam, P.K.S., Ip, Y.K. & Chew, S.F., 2000. Metabolic adjustments in the common carp (*Cyrpinus carpio L.*) during prolonged exposure to aquatic hypoxia. J. Fish. Biol., 57: 1160-1171.

Chapter 8.0

Boelens, R.G.V., Maloney, D.M., Parsons, A.P. & Walsh, A.R., 1999. Ireland's Marine and Coastal Areas and Adjacent Seas: an Environmental Assessment. Marine Institute, Dublin, 388pp.

GESAMP, 2001. Protecting the Oceans from Land-Based Activities. IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), Reports & Studies No.71, 162pp.

UNEP, 1995. Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities. United Nations Environment Programme, UNEP (OCA) /LBA/IG.2/7, 60pp.

Chapter 9.0

Commission of the European Communities, 1996. Environmental indicators and green accounting. DG XI, DG XII & Eurostat, COM(94) 670 final, 14pp.

Department of Environmental Affairs & Tourism, 2001. State of the Environment Indicators. DEAT (South Africa) website: http://www.environment.gov.za/soer/indicator/indicators.htm.

European Community, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal of the European Communities, L327, 72pp.

European Environment Agency, 2001. Environmental Signals. Environment Assessment Report No.8, EEA Copenhagen, 112pp.

Eurostat, 1999. Towards environmental pressure indicators for the EU. Eurostat, Theme 8: Environment & Energy, First Edition, 178pp.

GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint group of Experts on the Scientific Aspects of Marine Protection), 2002. Revised GESAMP Hazard Evaluation Procedure for Chemical Substances Carried by Ships. Re. Stud. GESAMP No. 64, 126pp.

Künitzer, A., 2002. Role of regional marine conventions in EEA indicator based reporting on the marine and coastal environment. OSPAR Commission, ASMO 02/9/6, 13pp.

MPMMG, 1998. National Monitoring Programme: survey of the quality of UK coastal waters. Aberdeen, 79pp.

National Research Council, 1990. Managing Troubled Waters: the role of marine environmental monitoring. National Academy Press, Washington, D.C., 125pp.

OECD, 1994. Environmental indicators: OECD core set OECD, Paris

Olsthoom, X., Tyteca, D., Wehrmeyer, W. & Wagner, M., 2000. Environmental indicators for business: a review of the literature and standardisation methods. Manuscript for the Journal of Cleaner Production, Ref. CpDH/2000/000311, 27pp.

UNEP, 1998. Explanation of island indicators: www.unep.ch/earthw/indicat.htm.

Chapter 10.0

Boelens, R.G.V., Maloney, D.M., Parsons, A.P. & Walsh, A.R., 1999. Ireland's Marine and Coastal Areas and Adjacent Seas: an Environmental Assessment. Marine Institute, Dublin, 388pp.

ECNC, 2002. An Inventory Of Biodiversity Indicators In Europe. Final Draft prepared by the European Centre for Nature Conservation for the European Environment Agency (European Topic Centre on Nature Protection and Biodiversity).

EPA, 2002. [Draft] National Environmental Monitoring Plan for Transitional, Coastal and Marine Waters: a discussion document, Version 1. Environmental Protection Agency in collaboration with the Marine Institute, Radiological Protection Institute of Ireland, Met Éireann & Duchas, 153pp.

Féral, J.P., Fourt, M., Perez, T., Warwick, R.M., Emblow, C., Hummel, H., van Avesaath, P. and Heip, C., 2003. European Marine Biodiversity Indicators. Report of the European Concerted Action: BIOMARE - Implementation and networking of large scale, long-term Marine Biodiversity research in Europe. Funded under the Energy, Environment and Sustainable Development Programme (Support to Infrastructures) of the European Union. Contract number: EVR1-CT2000-20002.

Marine Institute, 2000. Quality Status Report 1999: Experience gained – lessons learned. 7pp.

OSPAR, 2002. OSPAR List of Chemicals for Priority Action (Update 2002). Summary Record of OSPAR Commission Meeting (24-28 June 2002), Annex 5, 4pp.

List of Abbreviations

AMAP	Arctic Monitoring and Assessment Programme
CPR	Continuous Plankton Recorder
DNA	Deoxyribonucleic acid
DoEHLG	Department of the Environment, Heritage and Local Government
DCMNR	Department of Communications, Marine and Natural Resources
DPSIR	Driving Force/Pressure/State/Impact/Response system of environmental indicators
EC	European Commission
EEA	European Environment Agency
EPA	Environmental Protection Agency
EROD	7-ethoxyresorufin *O*-deethylase
ETC	Environment Topic Centre (EU-EEA)
EU	European Union
HELCOM	Helsinki Commission (for Baltic Marine Environment Protection)
ICES	International Council for Exploration of the Sea
IGBP	International Geosphere-Biosphere Programme
IMO	International Maritime organisation
JAMP	Joint Assessment and Monitoring Programme
JRC	Joint Research Centre (EU)
MPMMG	Marine Pollution Monitoring Management Group (UK)
NMP	National Monitoring Plan (UK)
OECD	organisation for Economic Co-operation and Development
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
QUASIMEME	Quality Assurance of Information in Marine Environmental Monitoring (scheme)
QSR	Quality Status Report
UNEP	United Nations Environment Programme
WFD	Water Framework Directive

Annex 1

Objectives, related instructions and considerations for Marine RTDI Desk Study Ref: DK/01/006: Review and Evaluation of Marine Environmental State/Impact Indicators and their Application in Ireland

Objectives/Deliverables:

1. Identify and prepare a comprehensive review of marine environmental indicators and their application, both nationally and internationally, in the assessment and monitoring of environmental impact/change;
2. Identify a suite of key marine environmental indicators that may be used in the measurement and monitoring of environmental change in an Irish context;
3. Identify related issues such as data availability and requirements, methodology, quality assurance etc.

The Marine Institute instructed that the study should take into account:

a) Current and future international requirements and developments of relevance to Ireland, e.g. OSPAR Convention, EU Water Framework Directive, EEA, Marine Topic Centre, etc.;

b) International practices and developments in this field;

c) Current environmental impact indicator work being carried out in Ireland (e.g. EPA, Marine Institute);

and consider the following issues:

d) Marine environmental data currently available nationally that could be utilised as an indicator or combined with other data to construct a composite environmental indicator. Other data requirements for key indicators and identification of necessary tools (e.g. methodologies, databases) and resources for data acquisition;

e) Issues of methodology - e.g. comparability of data and confounding factors; statistical aspects such as power of trend detection, aggregation of data and spatial coverage, frequency of data acquisition, quality assurance, data storage and analysis;

f) Potential problems with this approach and how these might be best addressed.

Annex 2

Multivariate Statistical Analysis of Benthos Data

Preface

Chapter 6 of this report discusses different approaches to the monitoring of biological responses to environmental change at community level, as well as responses of populations and ecosystems. At community level, a strong case is made for the use of multivariate analyses in the processing of taxonomic data obtained from field samples. This Annex gives a concise account of the procedures involved.

Procedure

An overview of the procedure is shown schematically in Figure 1.

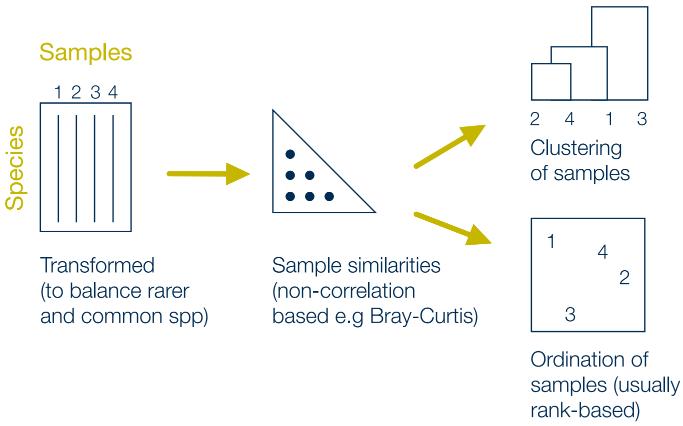


Figure 1: Stages in multivariate statistical analyses: 1. The sample:species matrix of raw data is first transformed, usually by a double-root transformation then the similarity between samples is calculated and finally the samples are clustered or ordinated.

The data are placed in a matrix of samples against species. From this the similarity between sample 1 and sample 2, 1 and 3, 1 and 4, 2 and 3, 3 and 4 etc are calculated. This gives us a similarity half matrix (middle figure). From this matrix we derive the classification (or clusters) of samples and a spatial ordination of samples. These latter two plots are usually based on ranks rather than quantitative data.

Equation 1 (below) shows the Bray-Curtis similarity index, which is one of the most used in multivariate statistical analyses.

Equation 1

$$S_{jk} = 100 \left(1 - \frac{\sum_{i=1}^{p} | y_{ij} - y_{ik} |}{\sum_{i=1}^{p} (y_{ij} - y_{ik})}\right)$$

$$= 100 \frac{\sum_{i=1}^{p} 2 \min (y_{ij}, y_{ik})}{\sum_{i=1}^{p} (y_{ij} + y_{ik})}$$

Table 1 shows data from a survey of benthic macrofauna in a Scottish fjord, for only a few sites to illustrate the method. Here the Bray-Curtis Index is calculated for untransformed data.

Table 1: Loch Linnhe macrofauna subset. a) Abundance (untransformed) for some selected species and years; b) The resulting Bray-Curtis similarities between every pair of samples.

(a) Year: (Sample:	64 1	68 2	71 3	73 4)	(b) Sample:	1	2	3	4
Species									
Echinoca.	9	0	0	0	1.	–			
Myrioche.	19	0	0	3	2.	8	–		
Libidopl.	9	37	0	10	3.	0	42	–	
Amaeana	0	12	144	9	4.	39	21	4	–
Capitella	0	128	344	2					
Mytilus	0	0	0	0					

Part a of Table 1 shows the data matrix of counts and part b the resulting lower triangular matrix of Bray-Curtis similarity coefficients. For example, using the first form of Equation 1, the similarity between samples 1 and 4 (years 1964 and 1973) is:

$$S_{14} = 100 \{1 - \frac{9 + 16 + 1 + 9 + 2 + 0}{9 + 22 + 19 + 9 + 2 + 0}\} = 39.3$$

The second form of Equation 1 can be seen to give the same result:

$$S_{14} = 100 \{1 - \frac{2 (0 + 3 + 9 + 0 + 0)}{9 + 22 + 19 + 9 + 2 + 0}\} = 39.3$$

Table 2 shows the same calculations for transformed data showing the differences in the Similarity Indices.

Table 2: Loch Linnhe macrofauna (L.) subset. a) √√-transformed abundance for the four years and six species of Table 1; b) Resulting Bray-Curtis similarity matrix.

a) Year:	64	68	71	73	(b)				
(Sample:	1	2	3	4)	Sample:	1	2	3	4
Species									
Echinoca.	1.7	0	0	0	1.	–			
Myrioche.	2.1	0	0	1.3	2.	26	–		
Libidopl.	1.7	2.5	0	1.8	3.	0	68	–	
Amaeana	0	1.9	3.5	1.7	4.	52	68	42	–
Capitella	0	3.4	4.3	1.2					
Mytilus	0	0	0	0					

The reasons for using transformations are that if we use the raw data, following the log-normal distribution there will be a few common species and very many rare species found with only 1 individual per species. We need to weight the data so that we are not overwhelmed by the dominant species, but give more weight to the moderately common and rare species. Experience shows us that a double square root transformation is effective and this is used in a standardised way. Here the original data from Loch Linnhe is **transformed** using the double root. The similarity index is recalculated using the transformed data.

Once the similarity matrix is available then the samples can be clustered and ordinated. Table 3 shows the clustering.

Table 3: Loch Linnhe macrofauna (L.) subset. Abundance array after √√ - transform, the resulting Bray-Curtis similarity matrix and the successively fused similarity matrices from a hierarchical clustering, using group average linking.

Year:	64	68	71	73												
(Sample:	1	2	3	4)	Sample:	1	2	3	4	Sample:	1	2 & 4	3	Sample:	1	2 & 3 & 4
Species																
Echinoca.	1.7	0	0	0	▶ 1.	–				▶ 1.	–			▶ 1.	–	
Myrioche.	2.1	0	0	1.3	2.	25.6	–			2&4.	38.9	–		2&3&4	25.9	–
Libidopl.	1.7	2.5	0	1.8	3.	0.0	67.9	–		3.	0.0	55.0	–			
Amaeana	0	1.9	3.5	1.7	4.	52.2	68.1	42.0	–							
Capitella	0	3.4	4.3	1.2												
Mytilus	0	0	0	0												

In order to calculate clusters we first take the samples that show the highest similarity and fuse them to a pair (here samples 2 and 4 at a similarity of 68.1%). Then we must recalculate the similarity matrix but now using samples 2 and 4 fused together. This gives us the second matrix where the largest value is 55% for 3 with 2&4. Repeat using the fused 2, 3 & 4 and the final cluster is 25.9 for sample 1.

The clusters formed are shown in Figure 2, with the similarity going from 100 at the bottom upwards.

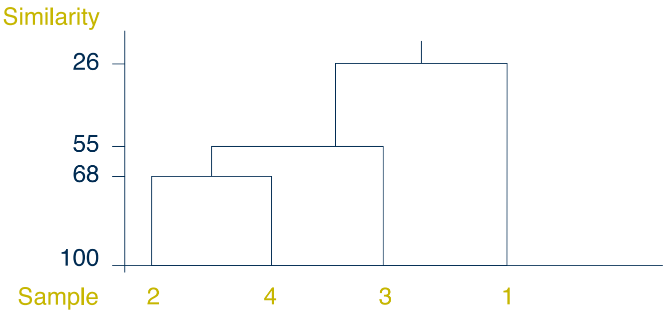


Figure 2: The resulting dendrogram of similarity between samples.

For the Multi Dimensional Scaling (MDS) analysis we use the same similarity matrix. Then we prepare a rank-similarity matrix (Table 4). This is simply the highest value gets rank 1 (here 68.1), the second highest rank 2 (67.9) and so on.

(a) Year:	64	68	71	73		(b)														
(Sample:	1	2	3	4)		Sample:	1	2	3	4		Sample:	1	2	3	4				
Species																				
Echinoa	1.7	0	0	0	▸	1.	–				▸	1.	–				▸			3
Myrioche	2.1	0	0	1.3		2.	25.6	–				2.	5	–					2	
Libidopl	1.7	2.5	0	1.8		3.	0.0	67.9	–			3.	6	2	–			1	4	
Amaeana	0	1.9	3.5	1.7		4.	52.2	68.1	42.0	–		4.	3	1	4	–				
Capitella	0	3.4	4.3	1.2																
Mytilus	0	0	0	0																

Table 4: Loch Linnhe macrofauna (L) subset. Abundance array after √√ -transform, the Bray-Curtis similarities (as in Table 3), the rank similarity matrix and the resulting 2-dimensional MDS estimation.

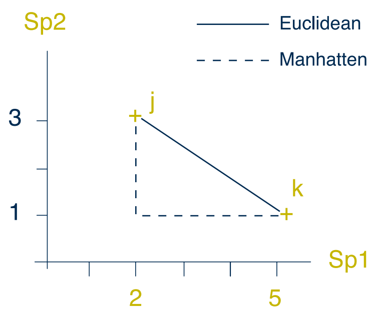
Once the rank matrix has been obtained the data are plotted in Euclidean space.

Equation 2

$$d_{jk} = \sqrt{\left[\sum_{i=1}^{p} (y_{ij} - y_{ik})^2 \right]}$$

This can best be understood, geometrically, by taking the special case where there are only two species so that samples can be represented by points in 2-dimensional space, namely their position on the two axes of Species 1 and Species 2 counts. This is illustrated in below for a specific two samples by two species abundance matrix.

Sample:	j	k
Sp1	2	5
Sp2	3	1



The co-ordinate points (2, 3) and (5, 1) on the (Sp.1, Sp. 2) axes are the two samples j and k. The direct distance d_{jk} between them of $\sqrt{[(2-5)^2 + (3-1)^2]}$ (Pythagoras) clearly corresponds to Equation 2.

The MDS method is based on non-metric data as ranks are used. But the method is extremely robust as the plot below illustrates (Figure 3). It is based simply on the half matrix of distances between towns by road in the UK. The towns are placed in the correct location.

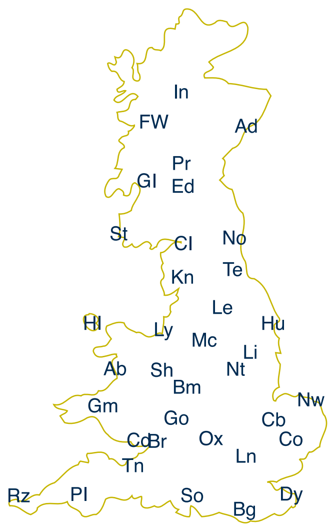


Figure 3: Illustration of the success of the non-parametric MDS analysis in placing towns correctly based solely on the distance matrix between towns.

Figure 4 shows the procedure for linking the multivariate analyses to measured variables that might be causes of the patterns recorded.

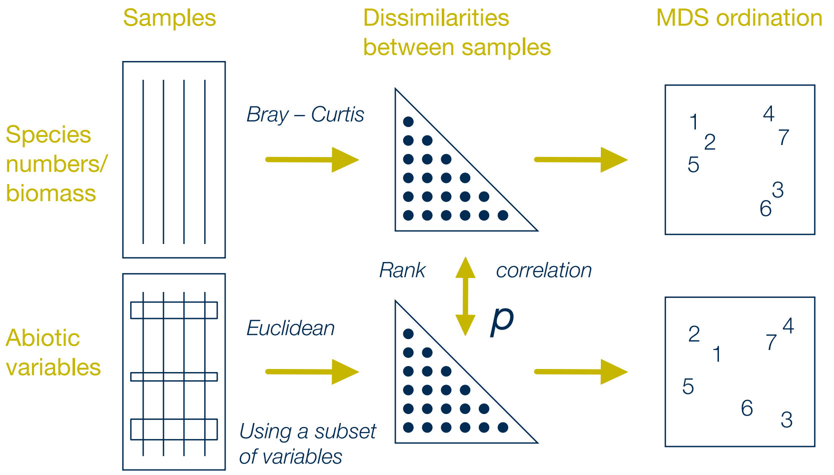


Figure 4: Procedures for linking faunal data to environmental data: BIOENV in the Primer package.

The two plots are slightly different, thus the correlation coefficient is less than 1.0. If perfect the correlation would be 1.0 or -1.0. The procedure involves using all the environmental variables separately and in combination to determine which combination gives the highest correlation.

Annex 3

OSPAR List of Chemicals for Priority Action

Type	Group of substances / substances
Aromatic hydrocarbon	4-tert-butyltoluene
Metallic compound	cadmium
Metal/organometallic compounds	lead and organic lead compounds mercury and organic mercury compounds
Organometallic compounds	organic tin compounds
Organic ester	neodecanoic acid, ethenyl ester
Organohalogens	tetrabromobisphenol A (TBBP-A) hexachlorocyclopentadiene (HCCP) 1,2,3-trichlorobenzene 1,2,4-trichlorobenzene 1,3,5-trichlorobenzene brominated flame retardants polychlorinated biphenyls (PCBs) polychlorinated dibenzodioxins (PCDDs) polychlorinated dibenzofurans (PCDFs) short chained chlorinated paraffins (SCCP)
Organic nitrogen compound	4-(dimethylbutylamino)diphenylamin (6PPD)
Organophosphate	triphenyl phosphine
Organosilicane	hexamethyldisiloxane (HMDS)
Pesticides/Biocides/Organohalogens	dicofol endosulphan hexachlorocyclohexane isomers (HCH) methoxychlor pentachlorophenol (PCP) trifluralin
Pharmaceutical	clotrimazole
Phenols	2,4,6-tri-tert-butylphenol nonylphenol/ethoxylates (NP/NPEs) and related substances octylphenol
Phthalate esters	certain phthalates: dibutylphthalate, diethylhexylphthalate
Polycyclic aromatic compounds	polyaromatic hydrocarbons (PAHs)
Synthetic musk	musk xylene
Aliphatic hydrocarbons	1,5,9 cyclododecatriene cyclododecane

Type	Group of substances / substances
Organohalogens	2,4,6-bromophenyl 1-2 (2,3-dibromo-2-methylpropyl) pentabromoethylbenzene heptachloronorbornene pentachloroanisole polychlorinated naphthalenes trichloronaphthalene tetrachloronaphthalene pentachloronaphthalene hexachloronaphthalene heptachloronaphthalene octachloronaphthalene naphthalene, chloro derivs.
Organic nitrogen compound	3,3'-(ureylenedimethylene)bis (3,5,5-trimethylcyclohexyl) diisocyanate
Pesticides/Biocides	ethyl O-(p-nitrophenyl) phenyl phosphonothionate (EPN) flucythrinate isodrin tetrasul
Pharmaceutical	diosgenin

Source: OSPAR, 2002. OSPAR List of Chemicals for Priority Action (Update 2002). Summary Record of OSPAR Commission Meeting (24-28 June 2002), Annex 5, 4pp.

Annex 4

OSPAR List of Species and Habitats found in Regions III and V (Irish Waters) Considered to be Under Threat and/or in Decline

Species	
Invertebrates	
Dog Whelk	(Nucella lapillus)
Fish	
Allis Shad	(Alosa alosa)
Basking Shark	(Cetorhinus maximus)
Common Skate	(Dipturus batis - synonym Raja batis)
Spotted Ray	(Dipturus montagui - synonym Raja montagui)
Cod	(Gadus morhua)
Couch's Goby	(Gobius couchi)
Snouted Seahorse	(Hippocampus hippocampus)
Long-snouted Seahorse	(Hippocampus guttulatus - synonym Hippocampus ramulosus)
Orange Roughy	Hoplostethus atlanticus)
Sea Lamprey	Petromyzon marinus
Salmon	(Salmo salar)
Bluefin tuna	(Thunnus thynnus)
Birds	
Roseate Tern	Sterna dougallii)
Mammals	
Blue Whale	(Balaenoptera musculus)
Northern Right Whale	(Eubalaena glacialis)
Harbour Porpoise	(Phocoena phocoena)
Habitats	
Carbonate mounds	
Deep-sea sponge aggregations	
Oceanic ridges with hydrothermal vents/fields	
Intertidal mudflats	
Littoral chalk communities	
Lophelia pertusa reefs	
Ostrea edulis beds	
Seamounts	
Seapen and burrowing megafauna communities	
Zostera beds	

N.B. This list will continue to evolve as contracting parties add or remove species and habitats according to the so-called Texel-Faial criteria.

Marine Institute
Foras na Mara

Marine Institute Galway Technology Park
Parkmore Galway Ireland

telephone 353 91 730 400
facsimile 353 91 730 470
e-mail institute.mail@marine.ie
website www.marine.ie