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Defining concepts of ecosystem structure and function for UK marine monitoring

Marine Resources Assessment Group (MRAG) &
UNEP-World Conservation Monitoring Centre (UNEP-WCMC)

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For further information please contact:

Joint Nature Conservation Committee
Monkstone House
City Road
Peterborough PE1 1JY

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Executive summary

There are key policy drivers for implementing an ecosystem approach in marine management, including the UK Safeguarding Our Seas Strategy and the EU Marine Strategy Framework Directive. As a result, our monitoring and assessment strategy needs to be amended to give: a picture of the overall state of the ecosystem; information both at local scales and broader ‘ecosystem’ or ‘management area’ scales; and an understanding of important interactions, long-term change and future concerns.

Concepts of ecosystem structure and function may be useful in designing an overall framework for UK marine monitoring, as they are concepts that are inherent within the ecosystem approach and may help us to consider underlying processes rather than monitoring at small spatial scales or of small ecological scope. There are significant challenges in understanding the ecosystem across different sectors and scales, and consideration of processes that link these elements may encourage integration.

A wide range of different concepts of ecosystem structure and function exist and are presented in the discussion document, incorporating many ideas (Annex 1). At one end of the spectrum there are the bottom-up approaches where each element of the ecosystem is described in detail, and due to the level of detail is most often used at the local scale. At the other end of the spectrum, there are a range of top-down approaches that attempt to integrate elements of the ecosystem into a reduced number of parameters, or group attributes under broader headings or categories. A consultation process was undertaken with a broad group of stakeholders and a workshop representing key UK institutions and sectors involved in marine monitoring was conducted to discuss a common approach to structure and function and their use in designing a framework for marine monitoring.

Through this consultation process, it was agreed that structure and function concepts could provide a framework for elements of UK marine monitoring. The approach as to how these concepts are employed however will depend on the stage of the process it is being used for (i.e. from monitoring through to assessment and management). It may therefore be useful to think of the different concepts considered as ‘nested’ with different concepts addressing different components of the management process. There was a general preference for the interpretation of *properties and processes* as it was felt that this was transferable to most sectors. It was recognised that ecosystem structure is already monitored to a high degree, whereas there is less understanding of ecosystem function or processes. The monitoring and assessment system could benefit from a better understanding of function or processes, and how it can be measured through changes in structure.

There are monitoring frameworks under discussion for use within the UK Marine Monitoring and Assessment Strategy (UKMMAS). Incorporation of a holistic understanding of structure and function could help to improve these frameworks and ensure the system leads to an understanding of ecosystem health. Alongside concepts of structure and function, there is also a range of other concepts that may assist in developing a framework for marine monitoring.

Moving forwards, one of the key recommendations emerging from the broad consultation would be to test using practical case studies a series of different frameworks for the UK marine monitoring system (or scenarios), which may be based on different concepts of

structure and function, and evaluate their use against a series of criteria. These case studies could also test different approaches to scale, and linkages between structure and function. Following identification of an appropriate framework, it would be possible to undertake a gap analysis to assess what is missing in our current monitoring system. It is also important that this work fits into ongoing initiatives to develop UKMMAS.

1. Introduction

1.1 Objective of this document

This report documents the current debate on the use of the concepts of ecosystem structure and function to assist development of marine ecosystem monitoring in UK waters and delivery of the UK Marine Monitoring and Assessment Strategy (UKMMAS). It discusses a number of **key questions,** which can be broadly summarised as:

- How are the concepts of ecosystem structure and function currently used in the context of marine monitoring, and what are the different approaches?
- Do the concepts of structure and function provide a useful basis to develop a framework for monitoring marine ecosystems?
- Can consensus be reached on which concepts of ecosystem structure and function are useful in practice to UK marine monitoring and applicable across different scales and sectors?

1.2 Consultation process

The development of this document has followed a consultation process with a series of expected outputs (Figure 1). The initial step was the development of a discussion document (Annex 1) that aimed to stimulate debate; the report was sent out to 190 stakeholders in 50 different institutions for consultation (Annex 2, Section 2). The discussion document consisted of an overview of the current concepts of ecosystem structure and function. It requested feedback on which concepts of ecosystem structure and function would be most practical to apply in the UK context and could be scaled up to larger scales. Responses were received from 12 institutions.

The next step in the consultation process was a stakeholder workshop held on 12th June 2007 with wide representation of institutions, sectors and UK regions (Annex 3, Sections 2 & 3 for a list of the invitees and participants). Following the workshop, the document was revised to incorporate the results of the consultation and outline the next steps. The third step was to send the revised document to the workshop participants for final review. It was expected that the consultation process would lead to selection of final definition options for ecosystem structure and function. In reality, the outcomes of the consultation led to a greater understanding of the concepts and how they fit with other related issues, rather than specific definitions. The outcomes also include a clearer direction on next steps to promote the ecosystem approach within UK marine monitoring.

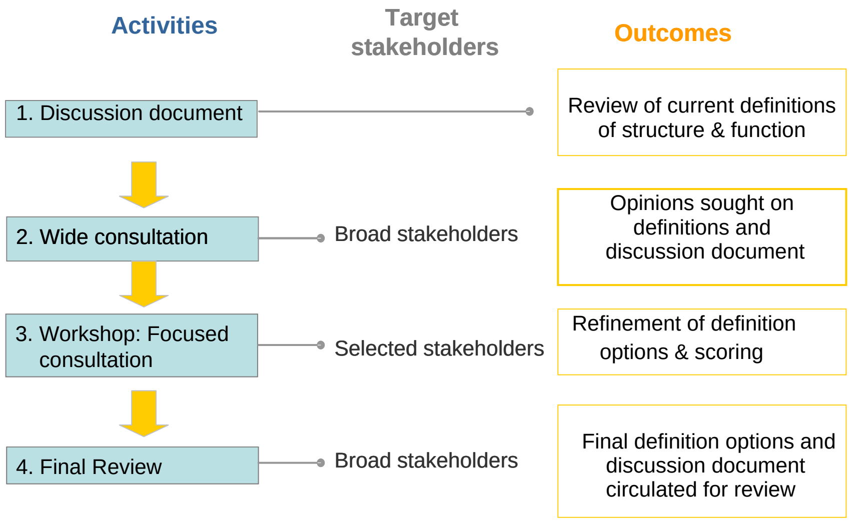


Figure 1. Major steps in the consultation process

1.3 How to read this document

This document provides a summary of the consultation outcomes based on a discussion document and stakeholder workshop on the issue of ecosystem structure and function and the use of this concept in promoting an ecosystem approach to monitoring.

Section 2 provides the background context and describes both the challenges in designing a monitoring system that achieves the ecosystem approach and the potential application of structure and function concepts. Section 3 provides a summary of the consultation outputs and Section 4 concludes with recommendations and next steps in this process. The original discussion document is provided at Annex 1.

The document is therefore structured in the following way:

Section 1	Introduction
Section 2	Background context
Section 3	Consultation outcomes
Section 4	Conclusions
Annex 1	Discussion document
Annex 2	Wider consultation
Annex 3	Workshop outputs
Annex 4	Detailed comparison tables
Annex 5	Comparison of Eco-Regions
Annex 6	References

Please note that the following terms have been used in this report and can be interpreted as:

Regional: Refers to the ‘UNEP Regional Seas’ Level;
Sub-regions: Refers to country or sub-divisions within the UK.

2 Background context

2.1 The ecosystem approach

Our understanding of the marine environment has evolved over time from consideration of individual species or habitats to recognition that the marine environment is characterised by connectivity. Many marine species have distinct phases of their life histories, which may begin as planktonic and end up as sessile, complicating further our ability to delineate the marine environment. Other important ecosystem concepts include productivity, trophic structure and resilience[1].

The new paradigm, known as ‘the ecosystem approach’, has been adopted within a wide range of policy instruments both at the international, regional and national (UK) level (Table 1). Within the UK, the Safeguarding Our Seas Strategy of 2002 sets out a shared vision for clean, healthy, safe, productive and biological diverse oceans and seas, and commits the UK to implementing an ecosystem approach. This is also an obligation within the Bergen Declaration (Fifth International Conference on the Protection of the North Sea, 20-21 March 2002 Bergen, Norway), in which the UK committed to an ecosystem approach. The integrated assessment of UK seas in 2005, ‘Charting Progress’, is a step towards adopting the approach, and the White Paper launched in March 2007 for a Marine Bill recognises the need for ecosystem management to maintain marine biodiversity and ecosystems. These are, in themselves, driving principles in the proposed EU Marine Strategy Framework Directive, and will need to be integrated into the UKMMAS. At the global level, the Convention on Biological Diversity and the World Summit for Sustainable Development encourage the use of the ecosystem approach in marine management. There is hence a strong linkage between the ecosystem approach and the sustainable development agenda, which also calls for an integrated and holistic approach that takes into consideration environmental, economic and social concerns.

A definition of the ecosystem approach provided by ICES and also used within the White Paper for the UK Marine Bill is:

> “*The integrated management of human activities based on knowledge of ecosystem dynamics to achieve sustainable use of ecosystem goods and services, and maintenance of ecosystem integrity”*.

[1] Implementing the Ecosystem Approach Conference May 17th 2001: SOAS, London

Table 1. Policy drivers for the ecosystem approach

Global drivers

Convention on Biological Diversity (CBD, 1992): A strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way.

The World Summit on Sustainable Development (Johannesburg, 2002) set a target for encouraging the application of the ecosystem approach by 2010, noting the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem and the Convention on Biological Diversity.

Regional drivers

ICES defines the ecosystem approach as the integrated management of human activities based on knowledge of ecosystem dynamics to achieve sustainable use of ecosystem goods and services, and maintenance of ecosystem integrity.

Bergen Declaration at the 5th International Conference on the Protection of the North Sea, 2002, agreed to use the ecosystem approach within management of the North Sea.

European drivers

Proposed **EU Marine Strategy Framework Directive**: Whereby human activities affecting the marine environment will be managed in an integrated manner promoting conservation and sustainable use in an equitable way of oceans and seas.

National drivers

UK Safeguarding Our Seas Strategy, 2002 Commits the UK in implementing an ecosystem approach to marine management.

Marine Bill (White paper, March 2007) recognises the need to implement the ecosystem approach to management especially to maintain marine biodiversity and ecosystems.

UK Marine Monitoring and Assessment Strategy (UKMMAS): entails taking into consideration all elements that make up the ecosystem (physical, chemical and biological variables) as well as activities taking place there in order to ensure that biodiversity, health and integrity of the marine environment is maintained in the longer term.

2.2 Challenges of implementing the ecosystem approach

There are a number of challenges in implementing the ecosystem approach to marine monitoring (summarised in Box 1). Presently, monitoring and surveillance is limited in its geographical coverage and ecological scope and at times it may not be possible to 'scale-up' the monitoring to give information on the entire ecosystem (i.e. an area that is self-contained and cohesive) or broader management areas that are defined for management or monitoring purposes (Annex 5 for an illustration of the current areas that have been defined or suggested for UK waters). It is also challenging to define areas for monitoring and management that fit with the ecosystem concept and do not split up an ecosystem into separate areas.

Another challenge for marine monitoring and assessment is to provide an overall understanding of the health of the marine environment, its resilience and environmental status. Each of these concepts requires an overview of the ecosystem that sees it as a whole rather than of its constituent parts. Related to this is the need for monitoring and assessment to determine long-term changes and early warning systems for future change. The monitoring system needs to be closely linked to marine management so that decisions can be made based on an understanding of the overall state of the ecosystem, and monitoring indicators and trends. This therefore needs to include both an understanding of society's impact on the environment and the underlying mechanisms that keep the ecosystem functioning and providing ecological goods and services.

Achieving integrated assessments which includes information from different sectors would be a large step in the right direction towards implementing an ecosystem approach. The ICES WGECO[2] recently summarised a typology of assessments ranging from 'single species assessments', through 'ecosystem assessments' (that may include at least two trophic levels and possibly some abiotic features) to 'integrated ecosystem assessments' that represent and link all major trophic levels, incorporate the major abiotic features within dynamic models, and produce estimates of the status and trends of pressures and impacts.

The current development of UKMMAS is responding to the requirement for holistic monitoring. One of the main challenges is designing a monitoring and assessment system that takes into account ongoing reporting obligations, while also enabling an understanding of the system as a whole.

Box 1. Challenges of applying the ecosystem approach to marine monitoring

- Application to different spatial scales
- Defining ecosystems and management areas
- Providing information on ecosystem health, resilience or good environmental status
- Identifying early warning signs for future trends
- Linking marine monitoring to management objectives
- Understanding societal impacts on the environment
- Producing integrated ecosystem assessments
- Achieving a practical monitoring and assessment system which also answers reporting obligations

2.3 Using concepts of structure and function in monitoring

There is potential for the concepts of ecosystem structure and function to be useful in designing an overall framework for the UKMMAS, as they are concepts that are inherent within the ecosystem approach and may help us to consider underlying processes rather than narrow monitoring at small spatial scales or of small ecological scope. As described below, ecosystem structure and function are also concepts that have already been written into related policy instruments, so it is necessary to understand what is meant by them and how they can be applied in practice.

2.3.1 Reference to ecosystem structure and function within policy instruments

As indicated above, concepts of ecosystem structure and function are written in to many of the policy instruments designed to promote an ecosystem approach to marine management. The EU Habitats Directive requires the measurement of ecological structure and function of protected areas, and the Bergen Declaration suggests, "*focused research and information gathering which addresses driving forces of ecosystem variability…which are critical for maintaining ecosystem structure and function*". The proposed EU Marine Strategy Framework Directive refers to the structure and functioning of the marine environment as an integral part of the definition of achieving good environmental status and, at a UK level, the Safeguarding Our Seas Strategy suggests that *an ecosystem-based approach requires a better understanding of the way ecosystems function as a wh*ole.

[2] ICES (2006) ICES ADVISORY COMMITTEE ON ECOSYSTEMS Report of the Working Group on Ecosystem Effects of Fishing Activities (WGECO) 5-12 April 2006, ICES Headquarters, Copenhagen

Maintenance of ecosystem structure and function are also highlighted within the 12 principles of the Convention for Biological Diversity (CBD) for implementing the ecosystem approach (principle 5 in Box 2). Other principles cover issues ranging from the need to consider humans as integral to the ecosystem and the importance of time scales and potential time lags.

Box 2. The 12 principles recommended by the Conference of Parties of the Convention on Biological Diversity (2000) to guide signatory countries in the practical application of the Ecosystem Approach

1. The objectives of management of land, water and living resources are a matter of societal choice.
2. Management should be decentralised to the lowest appropriate level.
3. Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.
4. Recognising potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should: reduce those market distortions that adversely affect biological diversity; align incentives to promote biodiversity conservation and sustainable use; and internalise costs and benefits in the given ecosystem to the extent feasible.
5. **Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the Ecosystem Approach**.
6. Ecosystems must be managed within the limits of their functioning.
7. The Ecosystem Approach should be undertaken at the appropriate spatial and temporal scales.
8. Recognising the varying temporal scales and lag-effects that characterise ecosystem process, objectives for ecosystem management should be set for the long-term.
9. Management must recognise that change is inevitable.
10. The Ecosystem Approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.
11. The Ecosystem Approach should consider all forms of relevant information including scientific and indigenous and local knowledge, innovations and practices.
12. The Ecosystem Approach should involve all relevant sectors of society and scientific disciplines.

These concepts are also being applied more to fisheries management, for example the ecosystem-based approach to fisheries management (EBFM) promoted within the FAO 1995 Code of Conduct for Responsible Fisheries, suggests that key principles include maintaining the characteristic structure, functioning, productivity and biodiversity of ecosystems.

2.3.2 Monitoring and assessment as part of the management cycle

Before we look at how ecosystem structure and function are useful concepts to assist in implementing the ecosystem approach for monitoring and assessment, it is first necessary to consider how monitoring and assessment fit into the management cycle.

The management and monitoring cycle

Figure 2 provides an overview of a generic management, monitoring and assessment cycle, which can be seen as the model the UK is moving towards with the development of UKMMAS and marine management objectives. This model illustrates the setting of marine management objectives. This enables reporting against obligations, but also provides information to determine progress against the objectives and understanding of the ecosystem as a whole. The latter point is important given the UK marine strategy vision of ‘healthy, functioning ecosystems’. Monitoring objectives set the monitoring framework (such as UKMMAS), which should also specify the indicators, trends and indices that need to be measured and enables an assessment of status and trends. This assessment then informs the implementation of ecosystem management and provides feedback on progress against the objectives set within government policy.

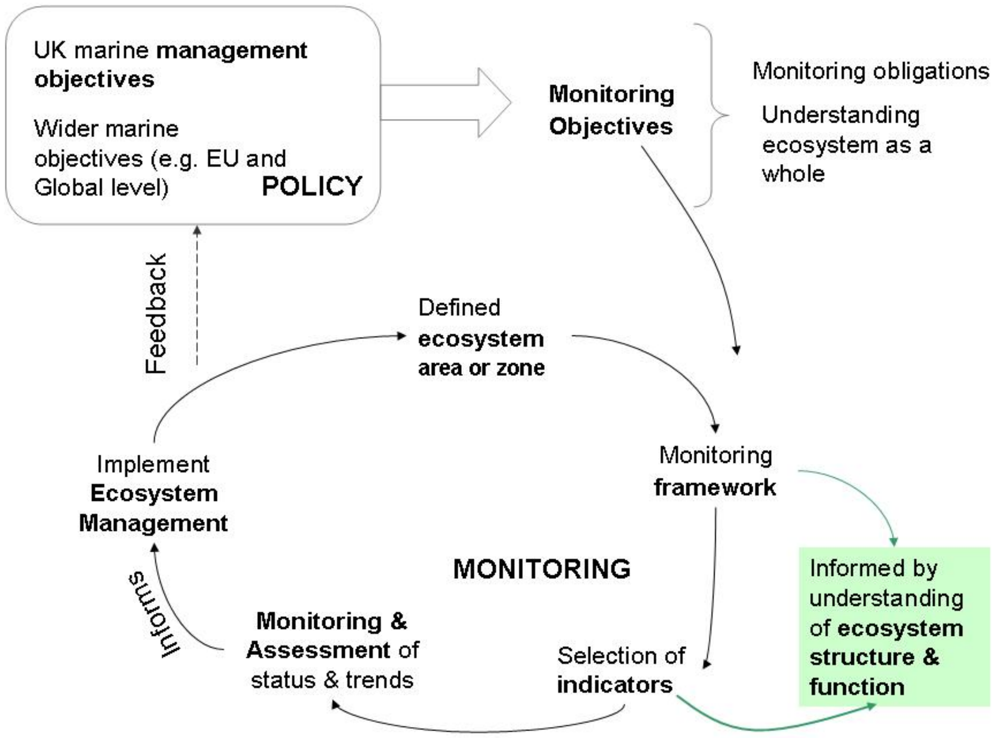


Figure 2. The management, monitoring and assessment cycle

Using ecosystem structure and function within the management, monitoring and assessment cycle

In order to develop a monitoring framework that responds to the needs of ecosystem management, there is a need to ensure that it captures all the required elements of the ecosystem. It is here that the concepts of ecosystem structure and function can be used to assist in developing a holistic monitoring and assessment framework, and in identifying indicators that relate to the underlying state of the ecosystem.

The following section provides a conceptual model of the ecosystem, and where monitoring of the structure and function fits into the different monitoring options available.

2.3.3 Conceptualising the ecosystem in terms of structure and function

It is possible to conceptualise an ecosystem in terms of structure and function, by considering the ecosystem as having inputs, outputs and internal processes. This is illustrated in Figure 3.

Within this model, the ecosystem structure is represented by the ‘black box’. The larger green arrow within the box represents ongoing functions or processes within the ecosystem. There are certain inputs into the ecosystem, such as light and nutrients, illustrated by the green inputs arrow and outputs, such as production or resources, indicated by the green outputs arrow. However if there is a pressure applied to the ecosystem (e.g. additional nutrients through eutrophication) the inputs into the ecosystem change, as illustrated by the red inputs plus pressure ('Input + P') arrow. This may 'distort' the ecosystem processes; the amount by which they are distorted could be considered as an indication of the resilience of the ecosystem. Finally, the outputs from the ecosystem will change ('Outputs + P'), affecting the resulting goods and services.

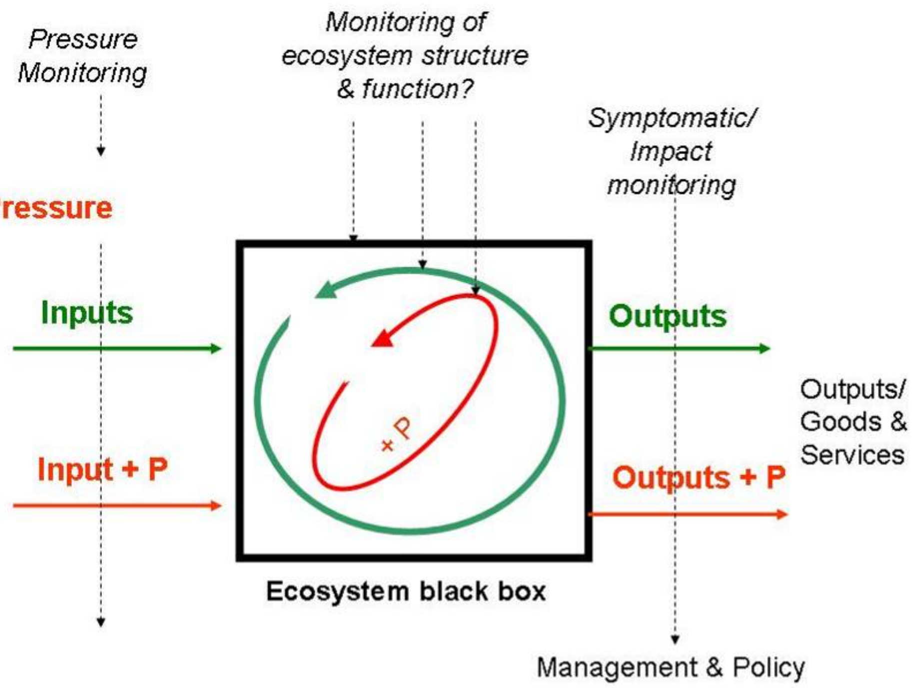


Figure 3. Conceptualising the ecosystem and options for monitoring

This diagram illustrates that there are a number of places within this system where we can undertake monitoring. We can monitor inputs into or pressures on the system, such as by measuring fish catch or measuring pollution; or we can measure the outputs or outcomes, which may be considered symptomatic monitoring and could be related to the implications for ecosystem goods and services. In reality, we probably spend more effort in monitoring the outputs and the pressures on a system.

A **key question** is therefore:

To what degree do we need a monitoring framework and indicators that include monitoring of the inner workings of the system (its structure and function), and how can we link input, process and output indicators together to illustrate causality?

2.3.4 Structure and function within a framework for implementing an ecosystem approach to marine monitoring

There are existing initiatives to provide a framework for marine monitoring that can encapsulate the use of indicators (e.g. data series, trends, metrics and reference points) that reflect current monitoring obligations and provide a more holistic view of the ecosystem. The latter is required to assess the health and state of the ecosystem and also determine long-term trends and potential irreversible threats such as those induced by climate change. These frameworks use ecosystem structure and function to varying degrees, and it may be that these concepts can help formulate a framework that is more closely aligned with the ecosystem approach.

OSPAR framework: Pressure/Component matrix

One of the frameworks currently under development by OSPAR, is known as the '*pressure/component'* matrix (ICES, 2006). This framework uses ecosystem components within a matrix matched against human impacts on the marine environment (Figure 4). The components cover a significant part of ecosystem structure and biotic and abiotic elements. A further breakdown of these ecosystem categories along the top row of the matrix is illustrated provides details on the indicators for *some* of the suggested categories only.

Table 2. Detailed categories within the assessment and monitoring framework for OSPAR's Biodiversity Strategy

Related OSPAR Strategy	Broad monitoring categories	Detailed monitoring categories
Biodiversity strategy	Plankton	Phytoplankton Zooplankton
	Fish-populations	Fish – pelagic Fish – demersal, benthic & coastal Fish – deep sea
	Marine mammals	Cetaceans Seals
	Seabirds	Seabirds
	Reptiles	Turtles
	Habitats	Intertidal rock Intertidal sediment & biogenic reef Coastal subtidal rock Coastal sub-tidal sediment & biogenic reef Shelf seabed (50-200m) Deep seabed
Eutrophication strategy	Water quality	Nutrient levels Oxygen levels
Hazardous substances strategy		Synthetic compound levels
Offshore oil & gas industry strategy		Hydro-carbon levels
Radioactive substances strategy		Radioactivity levels
Not specific OSPAR strategy	Ocean processes	Ocean currents Wave action & storm frequency Temperature regimes Sanity regimes pH Water clarity

Type of impact	Activity causing impact	Plankton	Fish- pelagic	Cetaceans	Habitats	Nutrient levels	Contaminant levels
Eutrophication	Aquaculture						
Eutrophication	Land-based pollution	Chlorophylla Phytoplankton indicator spp.				Winter nutrients (DIN & DIP)	
Habitat transformation	Coastal developments				Littoral chalk Mudflats		
Community structure changes	Aggregate extraction				Density sensitive spp. *Sabellana* reefs		
Community structure changes	Benthic trawling				Density sensitive spp. Maerl beds		
Removal of non-target species	Pelagic trawling		Basking shark	By-catch of harbour porpoise			
Noise disturbance	Seismic survey						

Grey cells - no/low impact
Light blue - possible impact
Dark blue - likely impact

Ecosystem components, linked to EcoQO elements, OSPAR Strategies and MSD Annex II categories

Ecosystem/impact indicators:
Red text - EcoQO
Black text - OSPAR List species or habitat

Figure 4. Outline assessment framework under development by OSPAR

The cells of the matrix (Figure 4) are coloured to indicate the severity of the impact on each of the ecosystem components and are then populated with relevant indicators within the priority cells. These indicators currently cover those under ongoing monitoring obligations, those under development within the OSPAR management objectives system[3] and the current OSPAR list of threatened and declining species. It has been suggested that this framework could be further developed to include additional indicators where there are gaps (e.g. a severe impact but no current indicator in use) and be aligned with the ongoing European Environment Agency's (EEA's) marine indicators and the Scientific, Technical and Economic Committee for Fisheries (STECF) indicators developed by ICES.

The ICES working group on the Ecosystem Effects of Fishing Activities (WGECO) recently reviewed the OSPAR framework (ICES Working Group, 2006). They suggested changes to more effectively reflect the ecosystem as a whole, and a different system of ranking the significance of impacts (based on a measure of acute (A) vs chronic (C) and widespread (W) vs local (L) impact). A number of these suggestions have already been incorporated into the more detailed categories (Table 2).

How far does the 'Pressure/Component' (OSPAR) framework provide details on structure and function, and the causality of impacts?

If we compare this framework to the ecosystem model presented in Figure 3 it becomes clear that it is currently focused on the 'pressure' and 'structure' aspects of the ecosystem model, but does not necessarily say much about the ecosystem functions, or the outputs (i.e. impacts

[3] Ecological Quality Objectives (EcoQOs), associated indicators are tools to implement the ecosystem approach.

on goods and services). For example, the indicator for impacts of aggregate extraction leading to community structure changes is the density of the sensitive species *Sabellaria* reefs. While this provides very useful information on the extent of impacts, it does not tell us how this impact will affect the functions of the ecosystem and the goods and services it provides. It also does not enable us to determine the causality between a reduction in goods and services and the pressure of aggregate extraction, which would be useful in determining management options. Lastly, there are concerns that focusing a monitoring framework on known pressures may not capture unknown, cumulative or future risks.

ICES Suggested: Pressure/Function matrix

The ICES working group, reviewing the OSPAR framework, highlighted a need to adequately assess *functional* as well as structural elements within a monitoring framework. The ICES group referred to ten aspects of ecosystem function (physical and biological processes) discussed by Bremner *et al.*, 2006 (Table 3). It was suggested that to address functional elements, these ten aspects of ecosystem function could be used within a '*pressure/function*' matrix (a simulation is provided in Table 3). However, it is also recognised that ecosystem functions are currently poorly understood and there are therefore constraints and knowledge gaps in developing specific indicators under these headings. If a framework was based on a selection of ecosystem functions, it would also be important to select those that are relevant to all aspects of the ecosystem and all relevant scales.

Table 3. Illustration of a 'pressure/function' matrix

		Ecosystem functions									
Type of impact	Activity causing impact	**Energy & elemental cycling**	**Silicon cycling**	**Calcium carbonate cycling**	**Modification of physical processes**	**Food supply/export**	**Productivity**	**Habitat refuge provision**	**Temporal pattern**	**Propagule supply/export**	**Adult immigration/emigration**
Eutrophication	Aquaculture										
	Land-based pollution										
Habitat transformation	Coastal developments										
Community structure changes	Aggregate extraction										
	Benthic trawling										
Removal of non-target species	Pelagic trawling										
Noise disturbance	Seismic survey										

How far does the 'Pressure/Function (ICES) framework' provide details on structure and function, and the causality of impacts?

Comparing the pressure/function framework with the ecosystem model presented in Figure 3, the missing elements include the structure of the ecosystem and the outputs, as well as the ability to determine causality. As with the pressure/component framework, there is also no indication on whether monitoring at the required spatial scales will be achieved.

Wildfowl and Wetlands Trust Pilot: Goods and Services Framework

At the other end of the scale, a framework suggested by the Wildfowl and Wetlands Trust has taken ecosystem goods and services as the starting point, and linked these to ecosystem functions and underlying processes. This starts with the outcomes of the system and works backwards to determine how ecosystem goods and services are determined by internal processes.

This 'goods and services framework' applies the principals of the Millennium Ecosystem Assessment to the local scale and is being piloted within a monitoring project (supported by Defra) of selected wetlands in Oxfordshire. Each service is broken down into constituent functions and each of these into individual processes, which in theory can be measured.

Figure 5 illustrates this breakdown for one of the ecosystem services: *Regulation services* and illustrates the functions associated with pollution control and detoxification, and processes associated with removal and retention of nutrients. There would in reality be a series of these diagrams to illustrate the breakdown for each service and function.

How far does the 'Goods and Services framework' provide details on structure and function, and the causality of impacts?

This framework allows managers to understand the impacts of pressures on key services, and is directly related to management actions. However, there are also limitations to this approach:

- The risk that important functions of the ecosystem are overlooked, as we do not yet know all the services that an ecosystem provides.

- The risk of prioritising the wrong 'service'. In other words, it is likely that some of these services are trade-offs from each other, e.g. provision of snipe habitat versus nutrient cycling in bogs.

- Whilst this framework provides information on the outcomes and the internal processes of the ecosystem, it does not link this to inputs so that again it would be difficult to determine the causal link with pressures.

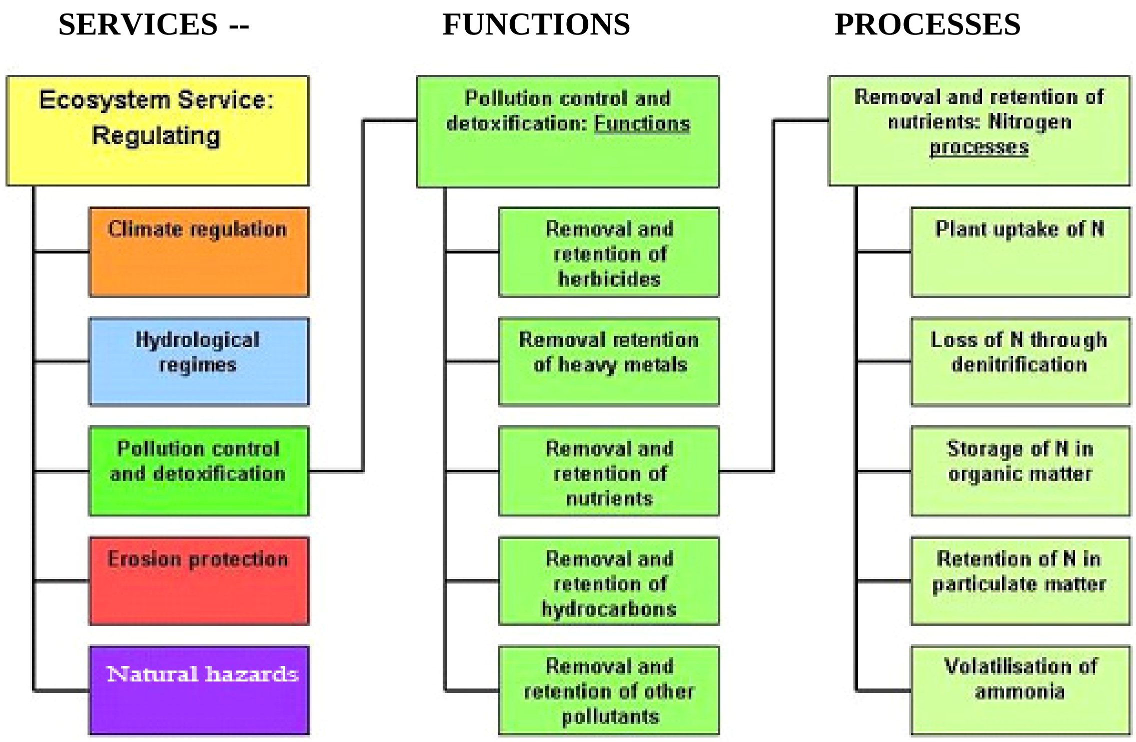


Figure 5 . Illustration of the framework designed by WWT[4]

Further to this, a potential framework for monitoring was also put forward based on elements of ecosystem structure and function (Annex 2, Section 3).

2.3.5 Discussion document on definitions of ecosystem structure and function

Despite the growing interest in the use of the concepts of ecosystem structure and function within a framework for marine monitoring, there are differences in how people have interpreted these concepts.

A **discussion document** was prepared to facilitate consultation with the aim to reach a consensus on the utility of the concepts to underpin a framework for marine monitoring in the UK. The document is presented in the form that it was sent out for consultation as Annex 1 to this report. The objective was for the document to provide a synthesis of recent publications to stimulate debate. Three key questions were put to its audience:

- Do the concepts of structure and function provide a useful basis to develop a framework for monitoring marine ecosystems?
- How are these concepts currently used in the context of marine monitoring, and what are the different approaches?
- Can consensus be reached on definitions that allow the concepts to be useful in practice across different scales and sectors?

[4] Diagram provided with thanks from Rob McInnes, Head of Wetland Conservation, Wildfowl & Wetlands Trust as presented at the conference on Implementing the Ecosystem Approach May 17 2001: SOAS, London

The discussion document provided the reader with an introduction to the literature and political context of the debate and went on to present an overview of the conceptual ideas and definitions for use of ecosystem structure and function as described in thirteen publications. It considers how and where the approaches differ, in particular:

- **Definitions of the concepts:** ecosystem structure and function were considered separately in the document. Detailed summaries of how the concepts were defined and then applied to a monitoring context were provided.
- **Comparing definitions for structure and function to scale:** The different definitions were discussed comparing the range of approaches and suggesting how these may be integrated.
- **Scale of marine monitoring:** monitoring takes place at a range of scales from the individual water-body to the ocean wide level. The discussion document considered how the reviewed approaches to ecosystem structure and function addressed this issue of scale, the challenges that were identified and asking if these concepts could be used to define ecosystem boundaries.

In providing this overview, information was drawn from a range of recent reports undertaken by sub-regional institutions and national institutions (e.g. CCW, SEPA, FRS, CEFAS, Natural England and Defra).

Opportunities were provided for a broad range of stakeholders to provide feedback on the discussion document through email or telephone as well as during the consultative workshop held on the 12th June 2007. Feedback and outcomes from the consultation process are presented in Section 3.

3 Consultation outcomes

This section provides an overview of the feedback from the consultation process and the outcomes of the stakeholder workshop.

3.1 Written feedback

As described in the introduction of this report, the original discussion document was sent out for broad consultation to over 190 stakeholders representing 50 institutions (Annex 2, Section 2) and written feedback was received by email from 12 institutions. Following the written feedback, the workshop took the discussion topics forward, and this revised report was also sent out for final comments from stakeholders.

3.2 Workshop format

The stakeholder workshop was held on 12 June 2007. A list of the stakeholders invited and those that participated is presented at Annex 3. The workshop covered an overview of the discussion document and plenary discussions to discuss the potential use of structure and function as a framework for monitoring. Participants divided into working groups and addressed four main issues concerning the concepts of structure and function:

- Using ecosystem structure and function as a framework
- Using ecosystem structure and function to inform the selection of monitoring indicators
- Scalability issues
- Linkages between ecosystem structure and function

The detailed workshop agenda is provided at Annex 3.

3.3 Main points of discussion

The following section describes both the written and workshop feedback under specific themes and therefore provides a description of the evolution of the debate. Concluding points are provided in boxes throughout the text and summarised in Section 4.

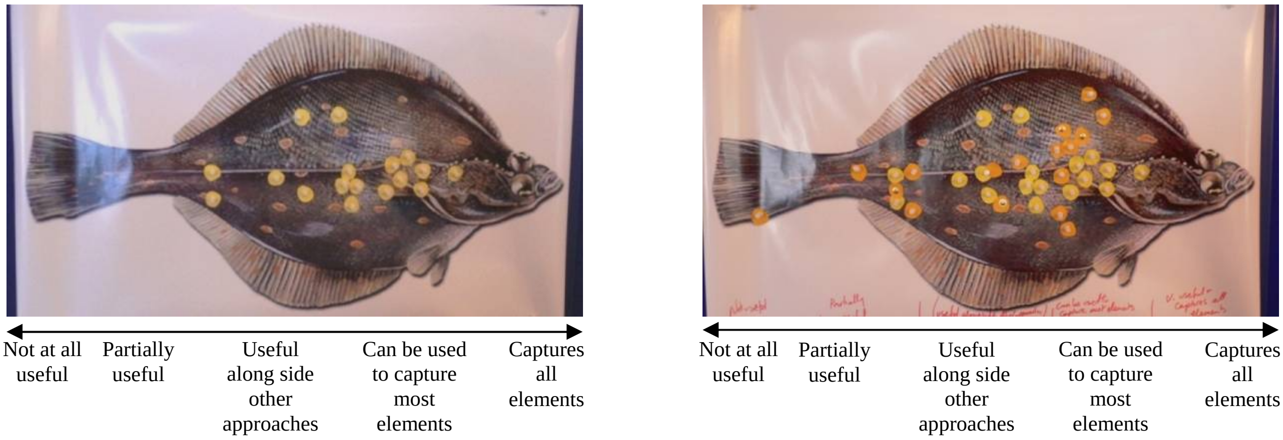
3.3.1 Usefulness of concepts of structure and function

The written feedback received indicated that ecosystem structure and function were useful concepts to break down monitoring systems into sensible components, and thus spot any gaps. It was also recognised that there are global, regional and national obligations that require an understanding of the ecosystem in terms of their structure and function. It was also considered that the concepts could be useful as indications of good 'ecosystem health', as required in the UK, Safeguarding Our Seas Strategy (Defra, 2002)[5], or 'good environmental status', as required in the EU Marine Strategy Framework Directive.

[5] The vision of the UK marine Strategy is of clean, healthy, safe, productive and biologically diverse oceans and seas.

Concerns were raised in the written responses that there are ranges of different concepts for ecosystem structure and function and definitions depending on perspectives or the spatial and temporal scales under consideration. The workshop also raised concerns that limits to our knowledge on the links between ecosystem structure and function may limit their usefulness as a basis for monitoring ecosystems.

The consultation workshop included an exercise to review people's opinions on how useful they found the concepts for UK marine monitoring. Participants were asked to indicate their opinion along a scale, starting at 'not at all useful', finishing with 'very useful and captures all elements'. Participants' views were indicated by pinning a spot on a scale (illustrated by a plaice) at the beginning and again at the end of the workshop to indicate any shift in opinion, as shown in Figure 6 below.



(a) At the beginning of the workshop **b) At the end of the workshop**

Note: yellow spots were pinned on at the beginning of the workshop; orange spots were added at the end of the workshop

Figure 6 'Pin the spot on the Plaice'

The majority of participants considered the concept of structure and function as 'useful alongside other concepts'. There was one change in opinion towards the 'not at all useful' end of the spectrum. This reflected the lack of clear definitions for structure and function and its unfamiliar terminology to some non-biological sectors of the monitoring constituency. However, it was agreed that if the concepts were explained in terms of properties and processes they would be more useful (also see Section 3.3.4). It also became clear during the workshop discussions that we were not talking about rigid **definitions**, but considering different **concepts** of structure and function.

The workshop reached a consensus that before elaborating the concepts, it was necessary to determine *what* the concepts would be used for. This may depend, for example, upon whether they are to be used to define indicators at habitat and species the level of a special conservation area, or to capture the entire monitoring and assessment system.

Concluding points

- The terms ‘ecosystem structure and function’ can be difficult to understand and are unfamiliar to non-biological sectors.
- There is a need to understand the concepts in the context of how they will be used (e.g. to define a monitoring framework or to define indicators).
- The concepts will be useful in developing a framework for UK marine monitoring, along side other concepts.

3.3.2 Application of concepts of structure and function

Current monitoring

One of the important points that came from the written feedback and the workshop is that the concepts of structure and function, although perhaps not explicit, are inherent in much of the monitoring already undertaken.

It was agreed that monitoring currently focuses on ecosystem structure, which is in some instances used as a proxy for ecosystem functioning (Section 3.3.3). There was no discussion about what ecosystem structure included but one participant gave the example of sea mammal structure being measured as the number of individuals and their distribution, rather than according to functional elements such as their influence on the food web. There was general agreement that ‘structure’ is probably reasonably comprehensively assessed, although a gap analysis is still required. However, the current understanding of ecosystem function is much less advanced.

How can concepts of structure and function be used to improve marine monitoring?

The workshop clarified the different uses of concepts of structure and function related to marine monitoring in order to achieve an understanding the state of the marine ecosystem:

1. By designing a monitoring framework and assisting a gap analysis;
2. Informing the design and selection of indicators;
3. Developing composite indices which link detailed processes and broader-scale functions;
4. Encouraging a multi-disciplinary approach to monitoring and assessment.

1) Designing a monitoring framework and assisting a gap analysis

Both the written feedback and the workshop participants felt that one potential use of the concepts of structure and function would be to provide a framework for the UKMMAS. Current monitoring activities could be mapped against this framework and assessed for any significant gaps. Monitoring of ecosystem processes would be one of the major gaps to emerge.

Section 2.3.4 describes several different frameworks that are currently being discussed elsewhere. It was felt that these could be developed to incorporate concepts of structure and function for use as a framework for UKMMAS. It was further recognised that the emerging framework would need to reflect marine policy objectives, whilst, at the same time, providing some understanding of the prevailing state of the ecosystem, irrespective of specific policies.

2) Informing the design and selection of indicators

Another potential use of concepts of structure and function is in the selection of indicators. Once an ecosystem framework has been established and the most important elements identified, it is necessary to populate the framework with indicators. A number of indicators are already in use, have been developed or the criteria for their selection proposed (Laffoley *et al*., 2006), but consideration of structure and function may help us to determine indicators that measure the 'inner workings' of the ecosystem as well as the inputs and outputs and the pressures they experience. If we refer back to Figure 3, this means determining how many of these indicators describe the structure and function of the 'black box' compared to others that may monitor inputs or outputs from the ecosystem and their causal linkages (i.e. the impacts of different pressures on the ecosystem).

3) Designing composite indices

The concepts of structure and function were also highlighted in their use for determination of composite indices, which can be used to give information on the overall state of the ecosystem. A participant brought attention to a Natural England report (Laffoley *et al*., 2006)[6], which concluded that while we may have some information on detailed processes and broader scale functions we may be missing links between these. These will be necessary to ensure the completeness of composite indices, so that they contain all aspects of ecosystem structure and function.

Workshop participants felt that indices could be very useful for communicating pressures and trends, and reporting on obligations. They do have limitations, however, in that they may be several steps removed from the point of change and that there may be dangers in having 'headline' numbers without understanding what is causing the changes. It is therefore important that indices reflect both ecosystem structure and function, and there is sufficient knowledge to understand a change in score (e.g. if the index measure falls, what is causing this, what effect is this having on the ecosystem structure and function and do we need to know this?).

4) Encouraging multi-disciplinary approaches

Finally, it was suggested that consideration of ecosystem function may encourage multi-disciplinary approaches since ecosystem functions or processes are likely to cross sectoral boundaries. For example, the processes involved in successful recruitment of fish stocks include an understanding of water currents, temperatures, plankton availability and status of habitat, amongst others. Similarly, effective nutrient cycling (such as carbon cycling) requires an understanding of primary productivity and interactions in the food chain, as well as knowledge of the decomposition processes. Microscopic organisms such as bacteria play a key role in decomposition but are presently only monitored routinely in the context of bathing water safety.

[6] Laffoley *et al*, 2006 'Developing the concepts of good environmental status and marine ecosystem objectives'

Concluding points

- The concepts of ecosystem structure and function are already used within our current monitoring system, but not explicitly.
- There are some gaps in the ecosystem structure that we measure, but there are more significant gaps in measures - or proxies - for ecosystem function. (This is described in more detail in the next section).
- The concepts of ecosystem structure and function have four potential uses: 1) To design a monitoring framework and assist a gap analysis of what our current marine monitoring does not cover; 2) To inform the design and selection of indicators; 3) To develop composite indicators and 4) To encourage a multi-disciplinary approach to monitoring and assessment.

3.3.3 Linkages between concepts of structure and function

Another key issue raised by the stakeholder consultation was the linkages between ecosystem structure and function. The written feedback highlighted that structure and function cannot be considered separately as they are intricately linked. Furthermore, the links between structure and function need to be better understood. Structure is easier to define and monitor than function, and our understanding of ecosystem structure is more developed than of ecosystem function.

An important acknowledgement during the workshop was the difficulty and expense in measuring ecosystem function directly. It is more practical to measure changes in structure that imply changes in ecosystem function. However, research is needed to determine the links between structure and function where they are not known. The question here is whether we can select structural components that imply the functioning of an ecosystem. For example, how much of a seagrass bed can be removed before the system stops functioning effectively?

Another example, developed by participants in the workshop, is the importance of understanding underlying processes within fisheries production. This requires understanding what processes support successful recruitment which determines the health of the stock in the future. These processes are multiple and can occur at the time of spawning (e.g. the current size of the population and the age and size of spawning fish); during the larval stages (e.g. environmental conditions such as currents and temperature); or the temporal availability of plankton food for the larvae; or during or following larvae survival (e.g. suitable habitat). It has been found with herring, for example, that recent poor year-classes were related to mortality during a critical state in its life cycle between the end of the larval phase and adulthood (rather than factors affecting the larval stage) and that this recruitment failure was having a large impact on the size of the resulting adult population. Understanding causality of the final observed condition of the stock (i.e. underlying processes) would enable us to identify critical indicators that may give us predictive power of future stock conditions.

As indicated above, workshop participants recognised that attempting to understand ecosystem functions may also encourage cross-disciplinary information exchange and the integration of data sets across different scales, for example, the large amounts of remote sensing data on phytoplankton distribution that is available could be used to provide contextual information to fisheries management. However, it is necessary first to understand the functional relationships between primary productivity and other trophic levels. At worst, such information without an understanding of causality could end up giving mixed messages i.e. due to a range of other factors that determine whether high primary productivity leads to high fisheries productivity. There may also be more effective and practical indicators to measure fisheries productivity.

Another example given was of the links between the structure of phytoplankton communities and their functional aspects e.g. uptake of nutrients, growth or the resultant productivity. For example, a current research project at the Fisheries Research Services laboratory in Aberdeen is measuring phytoplankton community structure alongside chemical nutrient uptake rates and phytoplankton production, at their monitoring site 3km offshore of the town of Stonehaven. Regular Continuous Plankton Recording (CPR) routes pass this site and the project will go on to attempt to link the patterns of community structure seen at the Stonehaven site with those of the wider CPR survey. If the seasonal patterns of locally measured phytoplankton production can be functionally related to the local community structure, then it may be possible to build and validate mathematical models that allow estimation and possibly prediction of phytoplankton production based on data across the wider North Sea areas covered by the CPR community structure surveys.

In all of these considerations, however, whilst there is always the urge to know more, some relationship to cost effectiveness must always be borne in mind. There must always be some balance between the minimum indications required for effective monitoring and management with the research grade information required to satisfy scientific curiosity and the need to explain the whole system. As well as monitoring aspects of pressures, inputs and outputs (net effects/responses) the information required to determine causality, which is particularly important where there are several pressures being exerted, lies at some point within this range. Within a monitoring system, however, the collection of such ‘causality’ data should require adequate justification.

It was agreed that the key here is the link between monitoring and research. It is the role of research to understand causality, and it is therefore at this level that structural indicators for key ecosystem functions or processes can be identified and then used in monitoring. The important ecosystem functions will need to be identified and related structural indicators selected that are practical and affordable. However, there is a challenge in achieving coherence between research and monitoring, especially when funding for research is provided on an ad-hoc basis. One participant referred to lessons drawn from implementation of the Water Framework Directive (WFD), which illustrated that a monitoring system can suffer if there are not clear and sufficient linkages between research and monitoring. Overall principles need to be developed that cross-cut both areas and funding needs to encourage prioritised research that investigates the linkages and uses multi-disciplinary approaches to make the most of information or data that is already being collected.

Concluding points

- Ecosystem structure and function are intrinsically linked and can therefore not be treated separately.

- It is very difficult to measure functions or underlying processes directly, but it is possible to infer changes in function through changes in structure.

- Attempting to understand ecosystem function encourages cross-disciplinary information exchange and integration of data sets across different scales.

- Beyond basic monitoring of indicators of pressures, inputs and outputs (responses), cost effective collection of some more fundamental information on linkages between ecosystem structure and function may be worthwhile, particularly to help determine causality as an adjunct to effective management.

- In order to know how changes in function affect those in structure and shape the response to pressures, it may be necessary to carry out reviews or targeted research to help determine such linkages and their implications.

- Funding for research is often piece-meal and is not focused on helping to determine indicators that can be used in monitoring.

3.3.4 Feedback on different concepts of ecosystem structure and function

Both in the written feedback and the workshop, stakeholders were asked on their opinions on the different concepts of structure and function.

Written feedback

In general, the written feedback suggested that:

- **Ecosystem structure** has to be considered in terms of both biotic and abiotic elements; and
- **Ecosystem function** is related to processes with some linking it strongly to goods and services.

As well as describing ecosystem structure to abiotic and biotic elements, suggestions were also put forward on breaking down structure in terms of:

- Community structure (number, type and pattern of biotic interactions);
- Abiotic structure (heterogeneity and pattern in light, dissolved oxygen, temperature or other physical or chemical properties, over space or time); and
- Ecosystem structure (heterogeneity of ecosystem function over space and time).

Those that linked function and goods and services argued that it is important for effective management to link ecosystem processes with social and economic deliverables. Others suggested that a focus on goods and services can be too anthropocentric, thereby limiting monitoring to aspects of the ecosystem. The workshop participants felt that this difference could be resolved if goods and services could be defined more broadly than purely in human or economic terms, and there was an allowance for ecosystem processes that may provide future or unknown benefits.

There is a general feeling that everyone has a good idea of what the ecosystem is and that, according to any definition, it contains both the abiotic and biotic elements. However, the problem in the fluid marine system is really where to draw the boundaries. The benthic habitats and communities are static (except for highly mobile planktonic dispersal phases) whilst the overlying bathing environment and suspended pelagic communities can move over them. The linking factor, however, is that anything that affects the aquatic medium (e.g. dissolved pollutants, temperature increases) is transmitted to all communities, benthic or pelagic. Therefore, a marine ecosystem is most adequately defined or characterised by the prevailing water body within which the organisms find themselves. This is easiest to visualise in enclosed seas like the Baltic and the Black seas or, to a lesser extent, in semi-enclosed seas such as the North Sea. In more open waters, it may be considered that the nature of the shelf also plays a role in defining the limits as employed in the determination of the Large Marine Ecosystems.

However, whilst it is important to have some consensus on the approximate definition and limits to each marine ecosystem, with respect to monitoring and management a more important factor is what sub-divisions of the ecosystem we should use. This appears to be the main core of the discussions here. Should we use geographical, structural or functional sub-divisions of the ecosystem as our monitoring unit? Different components of an ecosystem may respond differently to a particular pressure. For example, an increase in suspended organic material from a sewage outfall may be less welcome to the suspended phytoplankton than to the filter feeding clams on the seabed. Consequently, the validity of a sub-division as a monitoring/management unit may be best characterised by nature of their response to prevailing pressures. Furthermore, sub-divisions which respond differently to the prevailing pressures may require different management actions. The issue appears to be, therefore, to decide which ecosystem sub-divisions have the most integrity and validity as a management, and therefore monitoring, unit. Again, this may have criteria which can be geographical, structural or functional – for example, returning to our sewage-fed clams, is the most important feature that they are benthic clams or that they are filter feeders? From a pragmatic management viewpoint however, the most important criteria is the similarity of response from which we can derive appropriate management measures. It is this unity of response that underlines the validity of a seagrass bed as both a habitat and community and a useful subdivision from the management point of view, within a marine ecosystem.

It may therefore be helpful to define the ecosystem and monitoring and management areas along these lines, to provide a unit in which to assess components of structure and function in more detail. There are further schemes for ‘scaling’ the ecosystem as discuss in section 3.3.6 (below).

Workshop feedback

The workshop participants were asked to rank their preference for the different models (Table 4). However, it needs to be borne in mind that most participants felt that it was only possible to understand concepts of structure and function once you had decided how you were going to use the concept. Others felt that detailing the concept in this way was over-simplistic. Bearing in mind these caveats, Table 4 illustrates some consistency in results.

Table 4. Ranking of approaches to implementing the published concepts of structure and function reviewed for the discussion paper.

	Link to ecosystem approach		Practicality		Scalability		Relevance to all sectors	
	Rank	Score	Rank	Score	Rank	Score	Rank	Score
STRUCTURE								
Biotic	3	2.00	2	2.13	2	1.56	3	1.88
Biotic & Abiotic	**1**	2.72	**1**	2.61	**1**	2.06	**1**	2.47
Trophic Structure	2	2.39	3	1.82	3	2	2	1.59
FUNCTION								
Biological Traits	4	1.83	2	1.89	4	1.29	4	1.33
Properties & Processes	**1**	2.67	**1**	2.17	**1**	2.12	**1**	2.39
Energy flow	2	2.39	4	1.56	2	1.71	3	1.65
Goods & Services	3	2.00	3	1.67	3	1.47	2	2.22

Note: Scoring was from 1-4. The scores indicated are the average score of the workshop participants.

Concepts of Ecosystem Structure

Overall, there was support for a concept of ecosystem structure that included both abiotic and biotic features. Trophic structure was only considered to be important in the concept of ecosystem structure by some of the participants, and only consideration of biotic factors was considered too narrow by many of the workshop stakeholders.

Concepts of Ecosystem Function (also relating to ecosystem structure)

- *Properties and Processes (Ranked 1st)*

In general, there was most support for a concept of ecosystem function that equated to ecosystem processes, while ecosystem structure could be understood in terms of ecosystem properties. The concept of ‘properties and processes’ was therefore considered the most useful way of understanding ‘structure and function’, because it:

- encompasses structure;
- is applicable across scales;
- brings in both abiotic and biotic elements/biodiversity;
- can be useful in identifying indicators;

- can help in forming indices; and
- assists in considering linkages between structures and functions.

It was agreed that further work could be undertaken to determine which ecosystem properties and processes are important at different scales, to inform the development of an informative monitoring framework.

- *Energy Flow (Ranked 2nd)*

There was a difference in opinion on the importance of energy flow within the concept of ecosystem function, with some participants ranking it highly and others giving it low importance. It may be that this is not sufficient a concept to explain ecosystem function but could form an important part of ecosystem processes.

- *Goods and services as a focus? (Ranked 3rd)*

The consensus of the workshop was that the approach of goods and services is one that has great utility for delivery and framing the outputs of monitoring, but not as the monitoring framework as the focus would be too constrained. This approach does however provide information that is more easily linked to management or policy objectives. For example, giving information on the ability of the marine environment to break down pollutants is more tangible to policy makers than specific information on the distribution of species responsible for decomposition. It was also agreed that it was important to think of goods and services in terms of ecological goods and services as defined in the Millennium Ecosystem Report, rather than only considering the economic value.

- *Use of Biological traits approach (Ranked 4th):*

Workshop participants considered that an ecosystem structure and function framework based on using ‘Biological traits’ alone would not be appropriate. This approach was considered useful but too narrow to employ on its own as it omitted some fundamental aspects of the marine environment such as physical structure, and physical-chemical processes. It could form an essential element of a monitoring programme, but on its own would not be sufficient to understand the processes or functions of the ecosystem. Written feedback consistently regarded both biotic and abiotic elements as essential.

Concluding points

- Both written and workshop feedback suggested that the concept of ecosystem structure needs to include both abiotic and biotic features.
- Many participants of the workshop felt it was artificial to agree on concepts for ecosystem structure and function without first specifying the context they would be used in, e.g. to define a framework, to design indicators or indices.
- With these caveats in mind, most participants felt that the terms ecosystem properties and processes were most useful in describing ecosystem structure and function for use in a monitoring framework, and were terms more easily understood across the spectrum of stakeholders in the marine monitoring sector.
- A useful next step would be to elaborate which aspects of ecosystem properties and processes are important at different scales, with the most appropriate subdivisions and management units for inclusion within a monitoring framework.
- Other concepts of ecosystem structure and function (including trophic structure, energy flow, biological traits and goods and services) were still considered useful but in different contexts (this is described further in Section 3.3.5).

3.3.5 Other useful concepts

As illustrated above, it was recognised by the workshop participants that concepts of structure and function are not the only aspects that need to be considered within a monitoring framework. There are a range of other related concepts that will need to be used in conjunction with structure and function to enable an improved understanding of the ecosystem. It is also necessary to understand how these different concepts relate to each other within a hierarchy of concepts.

In the written feedback, several respondents highlighted the concept of **ecosystem health** as being important in relation to the UK Marine Strategy. Another important concept brought up by workshop participants was that of monitoring **impacts or pressures**, given that these are elements that we can actively manage. For example, the Water Framework Directive (WFD) uses a ‘pressure-based’ risk assessment to classify the state of water bodies. However, it was also commented that this does not exclude the need to understand the underlying processes that are affected by these pressures.

The concept of **criteria** to **select indicators** was also raised, and how these criteria can be designed to ensure that indicators are ‘ecosystem-based’. For example, Laffoley *et al.,* 2006 gives considerable thought to the design of headline indicators, indices, target reference points, limits and trend analysis; and provides a set of principles to guide development of indicators, so that they:

- provide a comprehensive coverage;
- give representative information;
- use the precautionary approach;
- are threat-focused; and

- are user-orientated.

Another key concept inherent within European policy for environmental monitoring and assessment is the **DPSIR approach** (Drivers, Pressures, State, Impact and Responses). The meanings of each of these terms are indicated below (Box 3). Structure and function could be considered as nested concepts within the ‘State’ of the environment.

Box 3. Concepts within the DPSIR approach

Drivers:	Driving forces of environmental change (i.e. human activities)
Pressures:	on the environment (pressures that follow from human activities and cause impacts)
State:	of the environment
Impacts:	adverse consequences on the environment (or the population & economy)
Responses:	responses of society (i.e. management actions)

Lastly, there are other concepts that are used within the context of the ‘ecosystem approach’ such as that of **ecosystem connectivity** which reminds us of the importance of integrated monitoring and assessment and **ecosystem resilience**, which related to the capacity to resist pressures.

Table 5 illustrates the ways in which concepts of structure and function (alongside other concepts) can assist in answering key challenges of applying the ecosystem approach to marine monitoring, which were raised in Section 2.2.

Table 5. Answering key challenges of applying the ecosystem approach to marine monitoring

Challenges of applying the ecosystem approach to marine monitoring (Section 2.2)	**Concepts that may assist in meeting these challenges**	
	Structure/Function	**Other concepts or approaches**
Defining ecosystems and management areas	Incorporating abiotic and biotic elements of structure, and its physical form assists in defining ecosystem areas	Connectivity
Scaling up		*Criteria for indicators:* Representation Comprehensive coverage Connectivity
Providing information on ecosystem state, ecosystem health, resilience or good environmental status	Understanding ecosystem function (underlying processes) can inform on the health, resilience and status of an ecosystem Understanding ecosystem structure in terms of trophic index	
Linking marine monitoring to management objectives	Structure and function indicators can be directly linked to management and monitoring objectives	Goods and Services DPSIR approach Indicators that are: threat-focussed and user-orientated
Identifying early warning signs for future trends	Information in changes in processes or structure could indicate long-term change	Indicators that make use of the precautionary approach
Understanding societal impacts on the environment	Impacts can be understood in changes to structure or function	DPSIR approach Impacts or Pressures
Producing integrated ecosystem assessments	Understanding the linkages between structure and function promotes cross-sectoral integration	Cross-sectoral integration Hierarchy of indicators

Concluding points

- While ecosystem structure and function (or alternatively ecosystem properties and processes) were considered useful concepts in UK marine monitoring, it was also recognised that there are a range of other related concepts that assist this process.

- It is important to understand how these different concepts relate, and how they help address different challenges faced in marine monitoring.

3.3.6 Applying concepts to different scales

Issues of scale were considered within one of the working groups during the workshop. It was felt by some that it is not possible to 'scale' an ecosystem, which by definition should be self-contained and cohesive. For example, the North Sea is possibly made up of four 'ecosystems' that can be defined by depth, stratification, mixing, productivity, fronts and biology. However, it may still be useful to define ecosystems and then divide them into areas for management and monitoring purposes.

Out of all the schemes illustrated in the discussion document (Annex 1) one of the most useful for defining scales was considered to be the Australian model which divides ecosystems into provinces, biomes, geomorphic units, 1^o biotopes, 2^o biotopes and biological species. Of the other schemes presented, the Elliot *et al*., 2006 model was thought to be useful at the habitat level but did not assist scaling to the ecosystem level. By contrast, the Netherlands model was detailed in linking smaller scales with larger scales but specified areas and was considered too rigid. It was agreed that it would be a useful step forward to test this model within a UK scenario, and determine what the different terms (provinces, biomes, geomorphic units, 1^o biotopes, 2^o biotopes and biological species) would mean in practice. As discussed earlier in Section 3.3.2, there is the potential to define these monitoring and management areas in terms of 'unity of response to particular pressures'.

Concluding points

- Theoretically, it should not be possible to 'scale' an ecosystem, as in essence it should be self-contained and cohesive. Therefore dividing it up would produce areas that could no longer be considered 'ecosystems'.
- However, it was considered useful to introduce a 'scaling system' that divided the ecosystem into manageable areas so that monitoring at any of these different scales could be related to the level of the ecosystem.
- Of all the different models presented in the discussion document, the Australian model was considered the most useful.
- To be of practical use, it would be necessary to work up an example of using this model in practice.

3.3.7 Practicality issues

An important point put forward throughout the workshop, was the need to avoid developing a 'list' of things that it would be desirable to monitor but would be impossible to achieve in practice. Some element of cost effective justification and prioritisation will always be needed. Nevertheless, a framework that helps with a gap analysis against ecosystem 'structure and function' would enable monitoring to be rationalised and prioritised not only against existing obligations but also according to the ecosystem approach. There is also the opportunity that assessing our current monitoring against a framework would identify ways of increasing the analytical power of the information that is already being gathered.

The written feedback also highlighted the importance of affordability, practicality, relevance, repeatability and synthetic capability for any monitoring system. Statistical power, data quality and availability (including historical, current and future data) and the commitment of financial resources should all be considerations in developing a system for monitoring the marine environment.

Concluding points

- Alongside the desire to develop a monitoring and assessment system that is holistic and covers all the elements needed to implement an ecosystem approach, is the need to keep the process practical and within the means and financial resources of the UK.
- However, it was considered necessary undertake a gap analysis against a relevant framework, which highlighted where there are current gaps in our monitoring, but also how it would be possible to increase the analytical power of the information already being gathered.

4. Conclusions

4.1 Concluding points

If we consider the ecosystem as an input-output model, we can understand ecosystem structure and function as describing the internal workings of the ecosystem (Figure 7). This also relates closely to the DPSIR model, which describes drivers, pressures, state of the environment, impacts and responses. Traditionally, marine monitoring in the UK has focused on monitoring inputs and pressures, and to some degree monitoring the outputs or impacts, such as the effects on ecosystem goods and services. However, more recently we have started to monitor the 'status' of habitat and species (e.g. Habitats Directive).

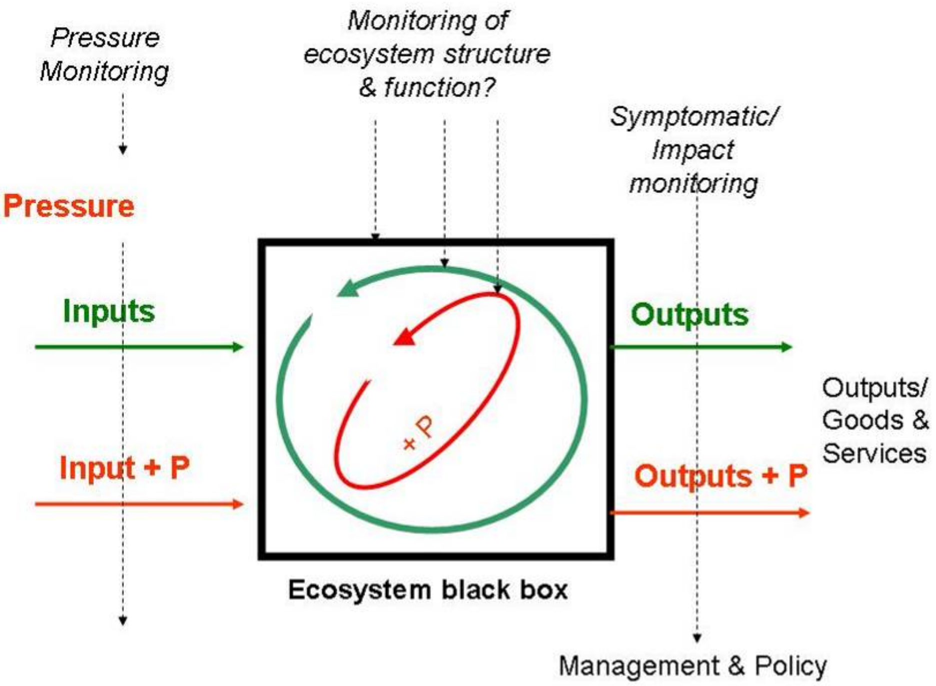


Figure 7. Conceptualising the ecosystem and options for monitoring

A key question is therefore:

- To what degree do we need a monitoring framework and indicators that include monitoring of the inner workings of the system (its structure and function), and how can we link input, process and output indicators together to illustrate causality?

A consensus was reached that the concepts of ecosystem structure and function would be useful to elaborate a framework for UK marine monitoring, along side other concepts. It was therefore considered important to understand the internal workings of the ecosystem, and how these link to inputs and outputs. These concepts are also important in defining indicators and indices, and promoting a cross-sectoral approach to monitoring and assessment.

It was recognised that we already monitor the structure of the ecosystem to some degree, but that our understanding of ecosystem function is more limited. It is difficult to measure ecosystem function directly, and it is therefore necessary to measure changes in ecosystem structure that infer changes in function. To be able to do this, we need the research to determine the correct indicators of change. We also need research that establishes causality i.e. how the ecosystem will respond to pressures.

In order to use the concepts of structure and function more effectively, it was considered important to establish what we mean by these concepts. Of the concepts considered, it was agreed that the terms 'properties and processes' (Hiscock *et al.*, 2006) were the most useful for establishing a monitoring framework. However, the other concepts of ecosystem structure and function are also useful but at different points of the monitoring, assessment and management cycle.

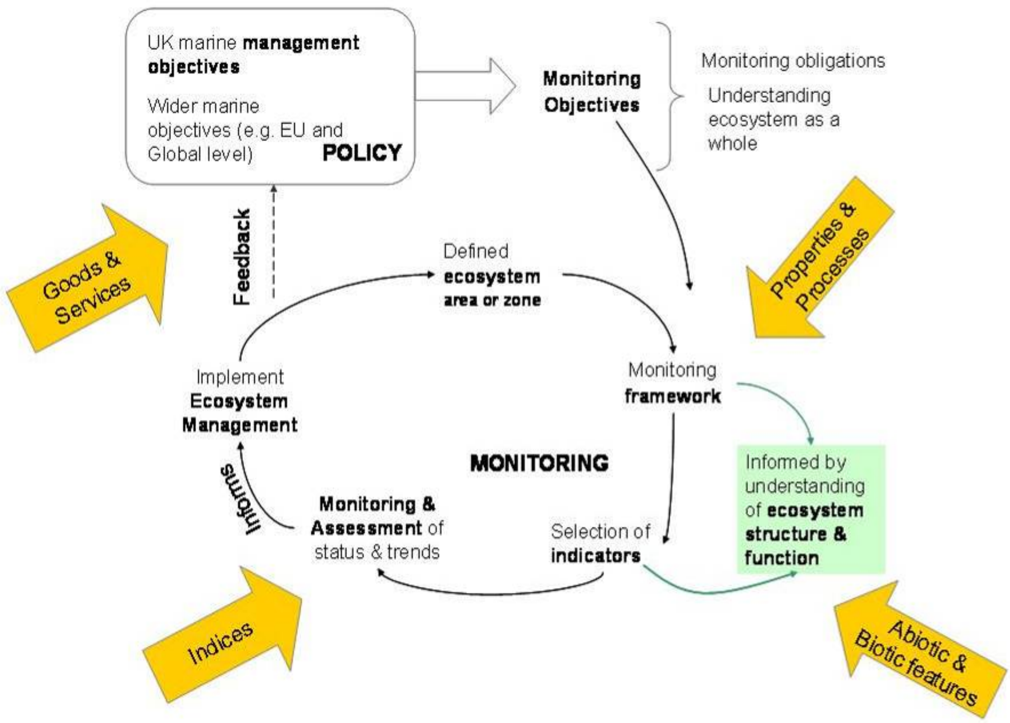


Figure 8. Indication of where different concepts may be useful in different stages of the monitoring, assessment and management cycle.

Figure 8 illustrates the different points where these concepts can be used:

- **Ecosystem properties and processes:** to help define a monitoring framework that can be used to undertake a gap analysis;
- **Considering both abiotic and biotic features of the ecosystem:** to define indicators that are fully representative of the ecosystem;
- **Use of indices that represent ecosystem structure and function:** when integrating information or data for ecosystem assessments;
- **Description of goods and services:** when communicating the results of assessments to managers and policy makers.

In addition to the different ways of understanding the concepts of ecosystem structure and function, there are also other related concepts and approaches (such as ‘ecosystem connectivity’ and the DPSIR approach). It is important to determine how these concepts fit together as it is not a case of only using just one of the concepts, as together they can help us overcome the challenges faced by marine monitoring (Table 5).

There are a number of suggested monitoring frameworks that have been put forward (Section 2.3.4), which use the concepts of ecosystem structure and function to different degrees. It would be a useful step forward to further develop these frameworks ensuring that:

1. Both ecosystem structure and function are well represented;

2. The framework enables linkages to be made between the impacts on the ecosystem and pressures (by understanding how pressures affect the ecosystem structure and function).

In order to develop these frameworks further, it will be necessary to determine which ecosystem properties and processes are considered important at different scales. In the discussions on how to develop a monitoring system that addresses the issue of scale, the Australian model (which describes provinces, biomes, geomorphic units, 1^{o} biotopes, 2^{o} biotopes and biological species) was considered useful and could be tested in this context.

Development of such a framework would assist a gap analysis, which could be undertaken to determine whether current monitoring addresses our reporting obligations and enables an overall assessment of ecological or environmental status. In undertaking this gap analysis, it would be necessary to keep practical and resource limitations in mind. However, a gap analysis may also shed light on ways to improve the analytical power of the data and information that is already calculated.

4.2 Recommendations and next steps

Emerging questions

A series of questions have emerged from this process:

- Given that the current marine monitoring in the UK is biased toward the monitoring of impacts or goods and services (and to some extent pressures), to what extent do we need to monitor and understand ecosystem structure and function to determine the degree of causality between pressures and impacts?

- What are we using as our ecosystem units, and how can we design a hierarchy of indicators to match this understanding of scale?

Suggested Actions

In order to answer these questions and take the debate forward, a number of suggested actions have been identified or recommended by stakeholders. All these actions are complementary, but there are some that would naturally flow on from each other. Highly related actions have been grouped to illustrate the steps involved:

A) Develop a monitoring framework based on an understanding of ecosystem structure and function:

- **Elaborate how different concepts of structure and function (and related concepts) fit together:** This would build on Figure 8 (above) and outline how the concepts feed into different stages of the monitoring and assessment processes. This process would also draw on other concepts such as ecosystem connectivity, DPSIR approach and ecosystem goods and services. In addition to this, provide a worked example based on ongoing monitoring (e.g. Irish Sea pilot).

- **Detail concepts of properties and processes:** Determine which ecosystem properties and processes are important at different scales to include within a monitoring framework. As part of this process, look at previous experience of where there have been significant or long-term changes in the ecosystem and whether these could be analysed to see what information (on ecosystem structure and function) was of use in detecting this change, and what information was required and was lacking.

- **Engage with the development of other frameworks:** Engage with groups developing monitoring frameworks to see how they can be improved with consideration of ecosystem structure and function, and the need to establish causality between inputs and outputs. Related to this, feed the structure and function debate into ongoing policy initiatives such as drafting the marine objectives.

- **Develop a series of monitoring frameworks:** This requires development of different frameworks making use of the concepts of ecosystem structure and function (i.e. properties and processes). As part of this process, draw on other concepts such as ecosystem connectivity, DPSIR approach and ecosystem goods and services and determine how they are related to each other within the frameworks.

- **Test the monitoring frameworks**: This can be done through worked examples, for example elaborating a number of monitoring frameworks for North Sea or Irish Sea monitoring. These could then be used to determine the advantages, disadvantages, analytical power, cost and practicalities of the different frameworks.

- **Undertake a gap analysis:** Carry out a gap analysis of UK marine monitoring with the favoured framework. This would involve assessing what is monitored now and why; what aspect of the ecosystem it refers to; what this tells us; and how it related to management; and: determine where effort needs to be focused or where current data collection is either not of analytical use or could be made of more use through multi-disciplinary integration.

B) Test a model for monitoring at different scales:

- **Develop a worked example for using a scaling model:** Assess how we currently divide up monitoring units and the reasons for this. Elaborate worked examples of monitoring based on other models of defining units/scaling, such as the Australian model presented in the discussion document. This would need to take place in parallel with actions A) above so that the approach can be incorporated within an overall monitoring framework.

C) Apply the concepts of ecosystem structure and function to the development and identification of indicators:

- **Feed into the elaboration of indicators:** Determine what aspects of ecosystem structure and function (or properties and processes) could be used within criteria for selecting indicators and indices, building on previous work to establish criteria and principles (sections 3.3.2 & 3.3.5). The selection of indicators and indices also needs to make use of the ecosystem model and consider the relative importance of input indicators, indicators of structure and function and indicators of outputs or impacts.

D) Determine research questions:

- **Develop proposals and recommendations for research**: for understanding the links between ecosystem structure and function, so that indicators of function can be developed. This should feed into UK research strategies, including biodiversity.

Asking questions about function encourages us to understand the underlying processes within an ecosystem, rather than only understanding the individual components that are present in certain habitats. For instance if we concentrate on monitoring the existence of sea fans and sponges, how do we know if the ecosystem is still functioning correctly, and are we missing critical information on the fish, plankton and water temperature and all the interactions between these components?

Some of the research questions that may be asked include:

- What are the links between structure and function?
- How much can you lose before function changes?
- How much fragmentation can happen before loss of function?
- How is the resilience of an ecosystem affected by changes in structure?

This work could also draw on lessons from other monitoring experiences (such as the Water Framework Directive).

E) Continue stakeholder engagement of a wide range of stakeholders, and expand particularly to non-biological disciplines.

JNCC is planning to discuss these suggested actions with institutional partners to determine what the most appropriate next steps will be.

Annex 1: Discussion document

This section provides a record of the discussion document as it was sent out for consultation. This therefore provides the base on which the debate evolved both through written feedback and discussions during the stakeholder workshop. Feedback and outcomes from the consultation process are provided in Section 3.

1. Definitions of ecosystem structure

This section summarises the current definitions that are being used to describe the structure of marine ecosystems. Some definitions focus on biological elements, while most cover both biological (biotic) and physical (abiotic) attributes. In order to integrate measures of ecosystem structure, wider ecosystem categories have been suggested. Other approaches focus on a description of the food web and use the measures of trophic level to give a picture of the complexity or simplicity of the ecosystem. A detailed summary of definitions for ecosystem structure is provided in Table 15 at Annex 4.

Some questions for discussion include:

- What biological and physical elements should be included in a definition of ecological structure?
- What wider categories would be most useful for describing ecological structure?
- What mechanisms could assist integration of monitoring and/or assessment across an ecosystem?

For simplified feedback, questions on ecosystem structure please see Section B of the Feedback questionnaire (Annex 2).

1.1 Biological and physical elements

Some of the definitions for ecosystem structure focus on the biological elements of the ecosystem. For example Bremner *et al*., (2006) [1] suggest the structure of an ecosystem is the taxonomic composition, biological diversity, or presence of specific habitats or species. Other definitions suggest that ecosystem structure requires identification of both biological (biotic) and physical (abiotic) attributes (Hiscock *et al*., (2006) [2]; (Elliot *et al*., (2006) [3]; and Dernie *et al*., (2006) [4]). Abiotic elements, such as the physical structure of the substratum or the physical and chemical structure of the water column (Dernie *et al*., 2006), are argued to be highly influential in determining the sorts of marine organisms that are likely to exist at a location. Examples of the abiotic and biotic attributes of ecosystem structure provided by these references are illustrated in Table 6.

Table 6. Abiotic and Biotic attributes of ecosystem structure

Attributes	References	Bremner *et al.*, 2006 [1]	Hiscock *et al.*, 2006 [2]	Elliot *et al.*, 2006 [3]	Dernie *et al.*, 2006 [4]
Biotic	Habitat types	■			
	Habitat preferences		■		
	Substrate types	■			
	General Biology		■		
	Range & Distribution		■		
	Reproduction & Longevity		■		
	Species diversity			■	■
	Species richness			■	■
	Biomass			■	■
	Amounts of Chlorophyll			■	
	Functional Groups			■	
	Community Structure				■
Abiotic	Temperature			■	■
	Grain size (sediment type)			■	■
	Salinity				■
	Oxygen level				■
	Sea-bed type		■		■

Note: This table has simplified the different terminology to assist with comparison

Hiscock *et al.*, (2006) further differentiates between the community structure of an ecosystem (species present) and the architectural structure which is influenced by physical characteristics of the seabed, such as rock area (e.g. surface relief, crevices etc.) and sediment type (e.g. firmness, stability). The architectural structure of an ecosystem is also influenced by living organisms, such as plants and animals that create physical structures (shells, coral skeletons). These structures are, in some cases, essential for maintaining species richness and influencing ecosystem processes, for example biogenic reefs that may be an 'oasis' of species richness in often apparently barren or impoverished settings. Other species may change aspects of the physical and chemical environment by trapping silt or by facilitating oxygenation of sediments through their activities. While a range of biotic and abiotic attributes can be used to define the structure of an ecosystem, Hiscock *et al.*, (2006) [2] suggest that it may be necessary to identify 'key structural species' or 'ecosystem engineers' that play a critical role in maintaining the structural integrity of the ecosystem.

1.2 Integrating descriptions of ecosystem structure

There have been different approaches put forward for providing integrated descriptions of ecosystem approaches (Table 7). Some of these have identified classification categories under which more detailed descriptions of the ecosystem can be nested. This is currently the system being promoted within the identification of objectives for the UK marine environment (Rogers *et al.*, 2006 [10]), and options have also been suggested by Frid and Paramour, 2006 [7], and Laffoley *et al.*, 2006 [11]. While these approaches provide a useful way of dividing up and understanding the ecosystem, they may require an additional framework to promote integrated monitoring and management across the ecosystem.

Table 7. Integration categories for describing ecosystem structure

Rogers *et al*., 2007 [10]	**Frid and Paramour, 2006 [7]**	**Laffoley *et al*., 2006 [11]**
- Benthic habitats; - Sea birds & mammals; - Phytoplankton & Zooplankton; - Physical/Chemical quality of water & atmosphere	- Plankton; - Benthos - Fish - Marine Reptiles & mammals; - Seabirds; - Seafloor habitats	- Environmental - Economic - Social - Spatial - Temporal - Scientific - Institutional
Pauley *et al*., 1998 [13] - Marine Trophic Levels		

Another example of an integrated description of ecosystem structure is the calculation of **mean trophic level** (Pauley *et al*., 1998). This is described as the number of links in the food-web from a fished resource to the bottom of the food web (level of primary production). Decreases in mean trophic level (i.e. simplification of the food web) have been associated with fishing pressure and commonly referred to as 'fishing down the food chain'. Other impacts of fishing on ecosystem structure include changes in the relative abundance of species; indirect impacts on predator-prey or competition relationships; modification to the structural habitat (e.g. damage to benthic habitats through certain fishing gear use); and consequences of by-catch (e.g. increasing abundance of scavenging species) (Gislason, 2001).

This section reveals that the main approaches to defining ecosystem structure are either analytic (describe considerable detail) or synthetic (where information is combined either under categories or within integrated measures).

2. Definitions of ecosystem function

This section compares the different definitions for ecosystem function. Some definitions focus on the role of biodiversity, while others describe abiotic and biotic processes. It may be possible to define a series of categories (based on ecosystem function) which could be broken down into further divisions (i.e. indicators or indices). This would need to take account of important concepts such as ecosystem resilience and potential 'changes of state'; long-term changes; smaller changes that cause degradation but may not lead to any initial loss in ecosystem function; and the linkages between ecosystem structure and function.

Some of the questions that arise for discussion include:

- Is ecosystem function directly related to biodiversity?
- What properties and processes describe ecosystem function?
- What type of classification scheme for ecosystem function could be understood across different ecosystems at different scales?
- How does ecosystem function relate to goods and services?
- Should structure come first in describing an ecosystem, or should ecosystem functions precede this before the biological and physical elements are described?
- How can we visualise the linkages between structure and function?

2.1 The biodiversity-function debate

There is an ongoing debate on the contribution of biodiversity to ecosystem functioning. It is often assumed that biodiversity contributes directly to ecosystem function and a number of hypotheses[7] relate to this, although it is difficult to illustrate in practice. Some approaches (e.g. Bremner *et al*., 2006 [1]; Hiscock *et al*., 2006 [2]) identify key 'biological traits' that contribute to ecosystem function Table 8 for examples). These approaches tend to use the following summary definition of ecosystem function by Naeem *et al*., 2004, which emphasizes the role of biological species and habitats to functioning: '*the activities, processes or properties of ecosystems that are influenced by its biota.*'

Table 8. Biological Traits identified as indicators of functioning.

1 Maximum size	10 Living location	19 Defence mechanisms
2 Growth rate	11 Body form/exposure potential	20 Movement type
3 Longevity	12 Degree of flexibility	21 Mobility
4 Time to maturity	13 Attachment degree	22 Migration
5 Reproductive method	14 Attachment strength	23 Sociability
6 Fecundity	15 Resource capture method	24 Predictability
7 Propagule dispersal	16 Food type	25 Recruitment variability/success
8 Body design	17 Energy transfer efficiency	26 Biogenic habitat provision
9 Living habit	18 Tissue components	27 Scale of habitat provision

Source: Bremner et al., 2006 [1]

Other authors suggest that species should be considered within their functional groups irrespective of their taxonomic affinities (Hughes *et al*., 2005 [9]), and important ecosystem functions should be identified first, before the contributing biodiversity characteristics (Robson *et al*., 2006 [5]). A practical example is provided by Pasquer *et al*., (2004) [12] who review the biological carbon pump, and examine the structure and function of four species of phytoplankton and their role in the process. Another example from the fisheries management literature (described in Goodman *et al*., 2002) involves the identification of significant food web interactions, before considering the 'habitat needs' of the organisms involved in these interactions throughout their life history stages.

2.2 Processes and properties

Elaborating beyond biodiversity, some definitions consider the physical, chemical and biological properties and processes which contribute to ecosystem function (Elliot *et al*., 2006 [3]; Hiscock *et al*., 2006 [2]). Functioning within ecosystems is often referred to as processes, or groups of processes, that link different structural elements together: for example the transfer of energy up the food chain (a biotic process), or the flow of water with the tide (an abiotic process). Elliot *et al*., 2006 [3] suggest that these processes can be categorised hierarchically into four types, as illustrated in Figure 9. They also suggest that the importance of these processes is different for different habitats. For example, wave energy is an

[7] The *redundancy theory*, where biodiversity provides an insurance policy and a buffer to future change; the *rivet popper theory*, where function may change when specific species or groups of species are lost; and the *idiosyncratic hypothesis*, where function changes with changes of species richness but the direction and magnitude of change cannot be predicted (Robson *et al*., 2006).

important physico-chemical process within inter-tidal ecosystems, but is less important in estuaries.

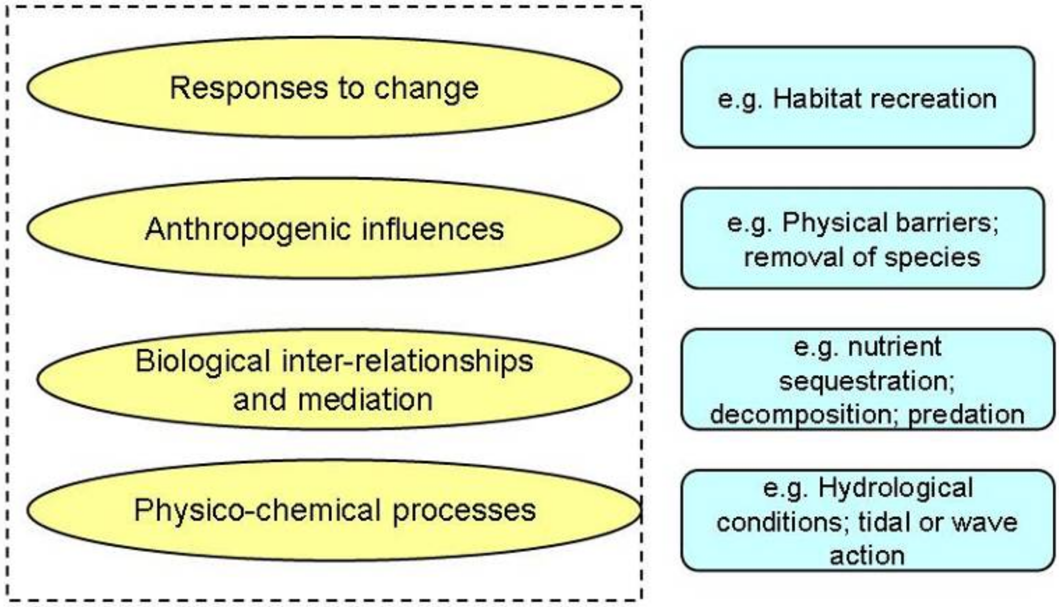


Figure 9. Hierarchical categorisation of processes.
Source: adapted from Elliot et al., 2006 [3]

Other definitions distinguish between ecosystem properties and processes, (Hiscock *et al.*, 2006 [2]), as illustrated in Table 9, and provide another way of categorising ecosystem functions.

Table 9. Properties and processes in marine ecosystems.

Properties		**Processes**
Large Scale	***Community level***	
Temperature range Salinity including maxima and minima Substratum type Light regime Turbidity Residual current strength and direction Strength of wave action Strength of tidal streams Stratification of the water column Nutrient status, and Contaminant levels	Assemblage (biotope) composition Trophic structure Resilience Resistance	Water quality affected by movement of water masses Gas exchange Nutrient exchange Primary and secondary production Bioturbation Reef-building, and Propagule dispersal brought about by movement of water masses Sedimentation

Source: Hiscock et al., 2006 [2]

2.3 Integrated measures of ecosystem function

There are also approaches to identify gross measures of ecological processes by calculating energy budgets and fluxes. Rogers *et al.*, (2007) [10] suggest that the most important indicators of function and processes are those that involve one or more of the ecosystem components (e.g. trophic links; mass or energy flux). Diaz & Cabido (2001) also define function as: '*the flow of energy and materials through biotic and abiotic components of the ecosystem*'. An example of applying this in practice is provided by Vassallo *et al*., (2006) [8] who use thermodynamic and network analysis to assess environmental quality of coastal ecosystems.

Other integrated measures of ecosystem function involve the use of indices. Within the US National Coastal Condition Report (EPA 2004) structural and functional parameters are integrated into five primary indices, namely: water quality index, sediment quality index, benthic index, coastal habitat index, and fish tissue contaminant index. Integrated ecosystem models provide another approach. Models such as EcoPath (Christensen & Walters, 2004) have developed from the measurement of mean trophic level (as described in the structure section). A number of different inputs such as diet composition, production and consumption of the species in question are required as inputs, so the model can provide indices estimates including energy efficiency, ascendancy and effectiveness of nutrient cycling. In a similar way, Ecological Network Analysis (ENA) allows the integration of different parameters for ecosystem structure and quantifies aspects of the ecosystem such as competition, energy transfer, nutrient cycles, recycling, and resilience.

Resilience is also often considered an integrated indicator of an effectively functioning ecosystem (Elliot *et al*., 2006 [3]; Dernie *et al*., 2006 [4]; Hughes *et al*., 2005 [9]), although it may be difficult to measure in practice. One option, however, would be to measure the time ecosystems take to recover following a disturbance. A related concept is that of 'ecosystem health' which has been used in, amongst other places, the Large Marine Ecosystem approach to monitoring. This essentially involves measuring a response of the ecosystem to some human intervention, such as pollution, as an indication of the impact on the efficient functioning of the ecosystem, which is an aspect of its resilience. This is largely taking the ecosystem and its function to be a black box with the measured impact response parameter being an integrated signal of the net changes to function caused by the perturbation.

2.4 Ecosystem goods and services

Ecosystem goods and services are considered by some as good indicators of ecosystem function. The UK BRAG report (Robson *et al*., 2006 [5]) uses the following definition of ecosystem function that focuses on processes that benefit humans: '*…the capacity of natural processes and components to provide goods and services that satisfy human needs directly or indirectly…*'

Within this report, the services provided by biodiversity are categorised into four areas: *Provisioning services* which provide food; *Regulatory services* providing stability (e.g. salt marshes reduce shore erosion); *Cultural Services;* and *Supporting Services*: support at key life-cycle stages (e.g. sea grass habitats providing fish nurseries). In a similar way Frid & Paramour, 2006 [7] and Laffoley *et al*., 2006 [11] provide examples of ecosystem goods and services (Table 10).

Table 10. Comparison of identified ecosystem goods and services

Frid & Paramour, 2006 [7]	**Laffoley *et al*., 2006 [11]**		
- Atmospheric gas assimilation and climate regulation - Nutrient recycling (including store of C02) - Changes to waste assimilation - Habitat functions - Food provisions - Biodiversity for society	**Biodiversity benefits** - Provision of spawning conditions & habitats - Resilience - Future use of species - Recreation - Flood & storm protection - Biogeochemical cycling - Waste degradation; - Gas & climate regulation	**Economic benefits**: *Direct* - Raw materials - Food & employment - Genetic resources - Medical resources - Ornamental resources - Spiritual & cultural values - Education opportunity - Coastal tourism - Recreation - Physical environment	- Indirect: - Flood & storm protection - Nutrient cycling - Climate regulation - Bioremediation of waste - Functional habitats

Elliot *et al*., (2006) [3] consider ecosystem services to be ecosystem functions that lead to direct benefits for humans. There is therefore some overlap between identified functions and identified goods and services (Table 11, overleaf). Nutrient regeneration, for example, is described as an ecosystem process in Dernie *et al*., (2006) [4] and as an ecosystem service in Frid & Paramour (2006) [7]. There is concern that focusing entirely on a goods and services approach may overlook important ecosystem functions that are not directly used by humans, but that may be important for the overall resilience of the ecosystem, such as the role of sea-grass and algal beds in nutrient cycling (Hiscock *et al*., 2006 [2]).

2.5 Linkages between structure and function

Ecological structure and function are intrinsically linked and some definitions provide examples on how they interact. Bremner *et al*., (2006) [1] point out how habitats that may be similar in their physical structure are different in their ecological function due to the hydrological regime or import/export processes. In a similar way, Hiscock *et al*., (2006) [2] explain how processes act together to influence the properties and structural elements of marine ecosystems. Some of these processes may be on a large scale. For example, the water currents around the UK have implications for the type of ecosystems that exist, and the recovery of habitats following disturbance (i.e. currents carrying ‘replacement’ larvae).

Elliot *et al*., (2006) [3] describe three different ways that structure and function interact.

Environment-Biology	Where the physico-chemical system creates the niche for organisms e.g. reduced water currents allow muddy substrata
Biology-Biology	Where resultant community is modified by biological processes e.g. predation and competition
Biology-Environment	Where biology influences physio-chemical system e.g. import or export of materials such as nutrients

Table 11. Comparison of the elements identified as ecosystem function and ecosystem goods and services.

Reference		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**11**
		Bremner *et al.*, 2006	**Hiscock *et al.*, 2006**	**Elliot *et al.*, 2006**	**Dernie *et al.*, 2006**	**Robson *et al.*, 2006**	**Vierros *et al.*, 2006**	**Frid & Paramour, 2006**	**Laffoley *et al.*, 2006**
		Functions					**Services**		
Abiotic	Energy cycling/transfer	■	■						
	Nutrient cycling/regeneration	■	■		■			■	■
	Abiotic habitat provision	■			■			■	■
	Tidal flow				■				
	Flushing rate/fresh water input			■	■				
	Heat flux			■					
	Residence time of a water mass in an estuary			■					
	Erosion-deposition cycles (of sediment)			■	■				
	Gas assimilation & climate regulation							■	■
	Waste assimilation/degradation						■	■	■
Biotic	Biotic habitat provision	■			■			■	■
	Diversity			■	■			■	
	Growth			■	■				
	Primary production			■					
	Plankton								
	Benthic organisms								
	Predation					■			
	Decomposition					■			
	Food supply	■	■					■	■
	Productivity	■	■		■				
	Spawning conditions								■
	Habitat provision								
	Adult immigration & emigration	■							
	Modification of physical processes	■	■						
Human activities	Future use of species								■
	Recreation								■
	Flood & storm protection								■
	Raw materials								■
	Employment & Tourism						■		■
	Genetic & medical resources								■
	Cultural values								■
	Education/Science								■
	Fisheries & aquaculture						■		
	Oil & Gas						■		
	Mining						■		
	Cables						■		
	Shipping						■		

Note: The elements provided here are only examples provided in the references. The authors may recognise a much larger array of functions.

3. Applying concepts of structure and function to issues of scale

Marine monitoring currently takes place at a range of different scales, ranging from water body (Water Framework Directive) and protected areas (Habitats Directive) at a local scale to ocean level processes. Before planning marine monitoring, it is often necessary to identify the ecosystem to be monitored and determine the scale at which monitoring needs to take place.

There are therefore the following related questions:

- What are the main challenges of describing ecosystem structure and function at different scales?
- What is the most useful definition of structure and function that can be applied at the local, national and regional scales?
- What definitions of structure and function allow us to integrate elements of different dimensions of the ecosystem e.g. the water column, benthic or pelagic environment?
- Can concepts of structure and function be used to i) define ecosystem boundaries for monitoring and ii) describe the ecosystem once the boundaries have been defined?

3.1 Challenges of scale

A key challenge in marine monitoring is the range of disciplines and sectors involved, and the different scales at which they understand marine ecosystems. While benthic ecologists work at the level of species or habitats (while taking into consideration larger scale processes), oceanographic studies often consider ocean-level processes over a large scale. The different dimensions of the marine environment (water column, benthic and pelagic environments) are often difficult to understand in an integrated manner.

Ecosystems also have ‘moving boundaries’. While some habitats may stay relatively stable and consistent over time (e.g. communities on rocky substratum); other systems (e.g. pelagic) can be highly variable. Changes can occur in the short-term with changes in currents or in line with decadal shifts. Some species inhabit different scales of the ecosystem at different stages of their life cycles, such as a pelagic state during larval stages and a benthic existence as an adult.

3.2 Application of structure and function definitions to different scales

The definitions that have been described so far have been used at a variety of scales (Table 14). At one end of the spectrum, Bremner *et al*., (2006) [1] uses ecological structure and function to describe habitats within special areas of conservation (SACs) on a local scale. At the other end of the spectrum, Vassallo *et al*., (2006) [8] investigate the ocean level biological carbon pump, but through investigating the structure and function of micro-organisms (phytoplankton).

A number of papers suggest the need for *nested scales* where units of measurement start at the individual cell or species level and build up to encompass an ecosystem. The range of approaches is illustrated in Table 10. The World Bank (2006) gives details on management zones beginning with community Marine Protected Areas (MPAs) building up though biosphere reserves and finally to Large Marine Ecosystems (LMEs). Laffoley *et al*., (2006) is also more focused on management zones rather than the strictly ecological units provided in the Australian and Netherlands models and the biological organisation reformulated by Elliot *et al*., (2006) [3].

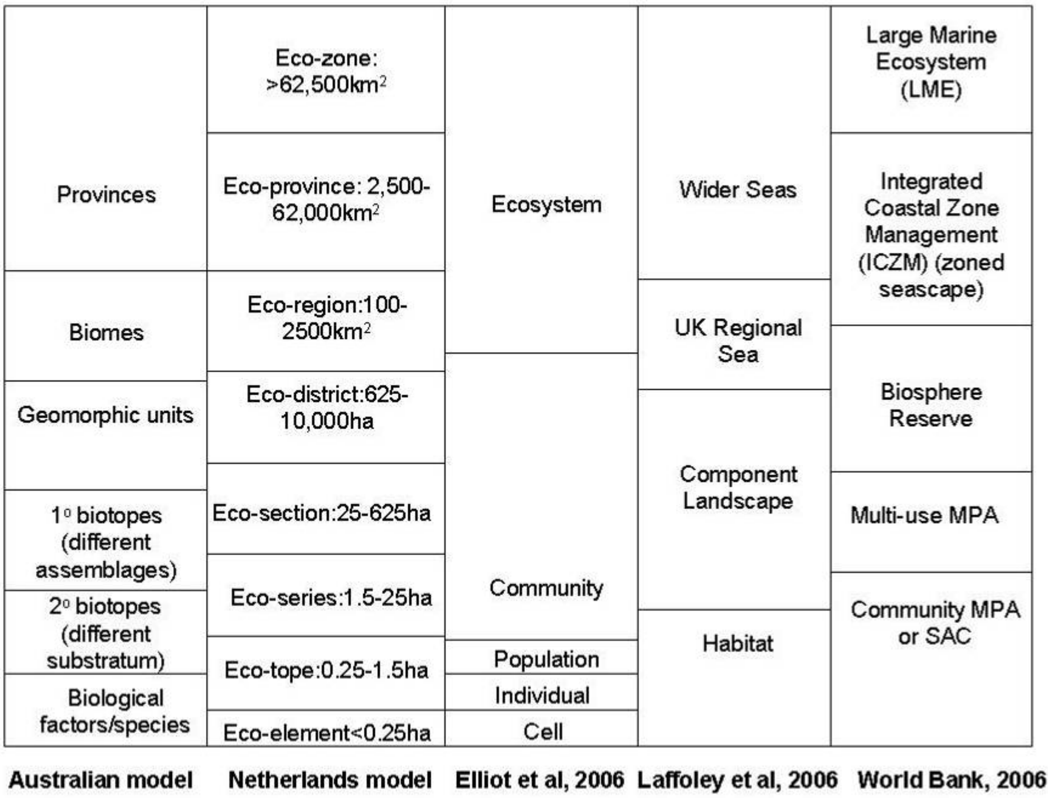


Figure 10. Different approaches to the nested scales of ecosystems.

Note: The relationship between these different approaches has been estimated.

A key consideration is whether definitions of structure and function can be used, at each of these levels, to describe the important components of the ecosystem. There is the danger that narrow definitions may leave out important aspects of the ecosystem. For example, a focus on species assemblages or abiotic processes at a habitat level may not consider processes such as decadal shifts in water currents. Another important question is whether monitoring can be matched with management units. There may not be an issue where management areas fully represent the ecosystem, but could present problems where management areas are aligned with resource use and do not constitute sensible monitoring areas or do not allow an understanding of the entire system.

3.3 Using structure and function to define marine ecosystem boundaries

There is a range of current or proposed options for defining the boundaries of ecosystems within the UK waters, as summarised in Table 12 below, and detailed in Table 16 (Annex 4) and in the figures at Annex 5. While it is not the focus of this paper to reach consensus on these boundaries, it is interesting to consider whether structure and function are useful concepts for both defining areas, and monitoring defined ecosystems.

Table 12. Different approaches to defining ecosystem boundaries in the UK marine environment (*Note: For more detail see Table 16 at Annex 4).*

Approach
Special Areas of Conservation [A]
UK Regional Seas [B]
OSPAR Areas [C]
ICES Fishing blocks [D]
ICES Eco-regions [E]
EU Marine Strategy Framework Directive [F]
Bio-geographical regions (EU) [G]
Marine Eco-regions [H]
Self Organising Maps [I]
Large Marine Ecosystems (LMEs) [J]

The majority of approaches above use elements of ecosystem structure to define ecosystem boundaries. For example, physical components - such as temperature, depth and water currents - are used to define the UK Regional Seas. Hydrological, oceanographic and bio-geographic elements are used to define areas proposed in the EU Marine Strategy Framework Directive. Other areas may have been defined along political boundaries (e.g. OSPAR areas), according to stakeholder use (Vierros *et al*., 2006 [6]), or based on areas suitable for management (e.g. ICES Fishing blocks).

By contrast, a wider range of information is often required to describe the ecosystem once its boundaries have been defined. The Large Marine Ecosystem (LME) approach (Duda & Sherman, 2002) requires monitoring that covers biological and physical attributes of the ecosystem, as well as socio-economic and governance elements. Within each of these modules, a series of indicators is identified (Table 9). Some of these require measurement of abundance or species presence (e.g. biodiversity), while others measure composite indexes such as ‘health indices’. The LME approach is currently used at a global level to define very large areas of ocean. An interesting consideration is whether similar modules can be used to categorise ecosystems monitoring at the UK level.

Table 13. Modules (Categories) used within the LME approach

1) **Population & Ecosystem Health Module** • Eutrophication • Bio toxins • Pathology • Emerging disease • Health indices	3) **Socio-economic module** • Human forcing • Sustainability of long-term socio-economic benefits • Integrated assessments
2) **Productivity Module** • Photosynthetic activity • Zooplankton biodiversity • Oceanographic variability	4) **Fish & Fisheries module** • Biodiversity • Finfish • Shellfish • Demersal species • Pelagic species
	5) **Governance Module** • Adaptive management • Stakeholder participation

There are only a few approaches that use ecosystem function to define ecosystem boundaries. One example is the use of Self Organising Maps (SOMs[8]) which model functional components (as well as structural components) and develop maps that illustrate areas with similar functioning characteristics. SOMs can be used to rapidly identify regions of similarity and can address potential shortcomings of administrative zones that do not represent ecosystem functionality.

4. Comparison of definitions to structure, function and scale

This document has provided an overview of the different approaches and definitions to ecosystem structure and function. The range of models that have been described are summarised in Figure 11.

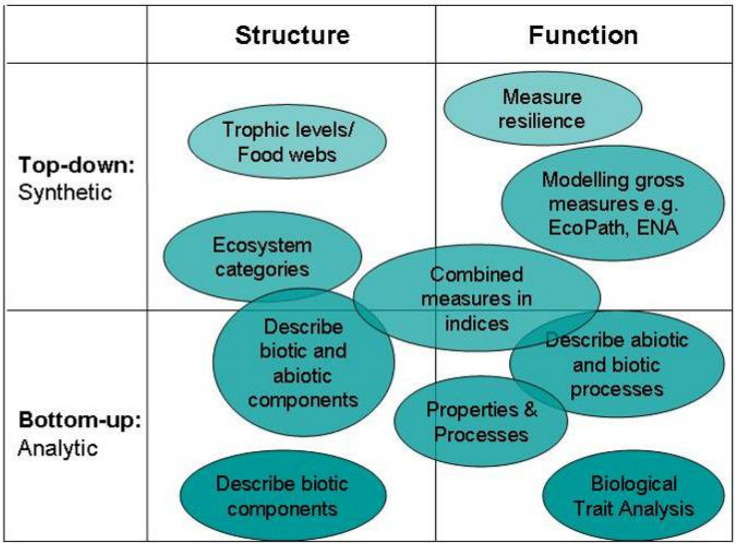


Figure 11. Range of models for defining ecological structure and function.

At one end of the spectrum, there are bottom-up approaches where each element of the ecosystem is described in detail, and due to the detail is most often used at the local scale. At the other end of the spectrum there are a range of top-down approaches that attempt to integrate elements of the ecosystem into a reduced number of parameters, or group attributes under broader headings or categories (for example the LME approach). Some of these approaches are more synthetic than others are, for example grouping attributes into categories that cover large regional scales may still allow considerable detail within each category. In contrast, some modelling approaches synthesize all ecosystem processes into one or two measures, such as energy flow. Alternatively, indices are also used that combine different aspects of structure and function, but require a judgement on what is considered important within different environments.

Monitoring at a local scale often focuses on the biological structure of the ecosystem and considers function as an influence of the biodiversity present. However, there are also approaches that consider the biological, chemical, and physical processes that make up ecological function. A key question is whether structure or function provides the initial framework. Some definitions investigate important functions of an ecosystem and then consider how biodiversity contributes to this. Others suggest that the goods and services

[8] Also see UNEP 2006 www.unepwcmc.org/resources/publications/UNEP_WCMC_bio_series/27.htm

should be identified first before structural elements are described. However, it is worth noting that while the goods and services approach is probably of primary interest to policy makers, it may ignore important process of the ecosystem that underpin efficient and resilient functioning.

There is a move towards spatial management of the marine environment, which will need to be supported by marine monitoring. Structure and function have been used in varying degrees to define marine ‘eco-regions’, and a range of different zoning techniques have been suggested for UK and European waters. An interesting consideration is whether the use of structure and function may improve zoning for marine monitoring.

Each of the definitions mentioned has advantages and disadvantages when using them practically at different scales and for different ecosystem components. For example, biological trait analysis is particularly effective for assessing habitats, but may not be suitable for monitoring ecosystems on a regional sea level. The challenge will be to determine whether there is an effective way of combining the bottom-up and top-down approaches so that we are able to sufficiently monitor detailed elements of significant habitats, but also scale-up monitoring or assessments to provide information to managers at the ecosystem level. It may be necessary to develop a worked example of how definitions of structure and function can be practically applied at a range of scales and environments.

Table 14 overleaf also provides further analysis of the different approaches and illustrates which models the different references fall into. This categorisation is to some extent subjective, so we welcome your feedback on this.

Table 14. Comparison of different definitions of structure and function monitoring and mapping ecosystems.

	Definition of Structure & Function	**Structure** Biological (Biotic)	Biotic/Abiotic	Integrated Categories	Trophic Levels	**Function** Biodiversity focus	Properties Processes	Integrated measures	Goods & Services	**Scale** Local	Sub-Regions (within UK)	UK-wide	European	Global
1	Bremner, Paramour & Frid, 2006	■				■				■				
2	Hiscock *et al.*, 2006		■			■	■			■				
3	Elliot *et al.*, 2006		■				■	■			■			
4	Dernie *et al.*, 2006		■				■				■			
5	Robson *et al.*, 2006 (BRAG UK)	■							■	■				
6	Vierros *et al.*, 2006		■						■				■	■
7	Frid & Paramour, 2006			■					■		■	■		
8	Vassallo *et al.*, 2006		■					■						■
9	Hughes *et al.*, 2005					■								
10	Rogers *et al.*, 2007			■				■	■		■	■		
11	Laffoley *et al.*, 2006		■	■					■			■		
12	Pasquer *et al.*, 2007	■				■							■	■
13	Pauley *et al.*, 1998				■									■

	Use of structure & function to define ecological zones	**Structure** Political or Administrative boundaries	Biological (Biotic)	Biotic/Abiotic	Integrated Categories	Trophic Levels	**Function** Biodiversity focus	Properties Processes	Integrated measures	Goods & Services	**Scale** Local	Sub-Regions (within UK)	UK-wide	European	Global
A	SACS		■	■			■				■				
B	UK Regional Seas			■								■			
C	OSPAR Regions	■									■	■			
D	ICES Fishing boxes	■											■	■	
E	ICES Eco-Regions		■	■	■	■				■		■			
F	EU Marine Strategy			■								■		■	
G	Bio-geographical regions									■					■
H	Marine Eco-regions (MEOW)									■					■
I	Self Organising Maps		■	■					■			■			
J	LMEs		■	■	■	■			■	■					■

Annex 2: Wider consultation

1. Feedback questionnaire

A General Questions

A1	**Name**	
A2	**Organisation**	
A3	**Email address**	
A4	**Your area of expertise**	
A5	**The scale(s) you work at**	

A6 Are concepts of structure and function useful for marine monitoring?

Yes	**No**	**Please explain**

B Questions on ecosystem structure

B1 Should a definition of ecosystem structure include a breakdown of the biotic and abiotic elements of ecosystem structure?

Yes	**No**	**Comments**

B2 Should a definition categorise structural elements by their functional role in the ecosystem?

Yes	**No**	**Comments**

B3 Do you have a preferred definition of ecosystem structure?

Yes	**No**	**Provide details**

C Questions on ecosystem function

C1 Should a definition of function include a breakdown of the biotic and abiotic processes?

Yes	**No**	**Comments**

C2 Should function be measured using integrated characteristics such as energy flow?

Yes	No	Comments

C3 Should a definition of ecosystem function focus on ecosystem goods and services?

Yes	No	Comments

C4 Should ecosystem function be split into properties and processes?

Yes	No	Comments

C5 What aspects do you think should be used within a practical definition of structure and function?

Structure			Function			
Biological (Biotic)	Physical (Abiotic)	Wider Categories	Biodiversity	Properties & processes	Integrated measures	Goods and Services

C6 Do you have a preferred definition of ecosystem function?

Yes	No	Provide details

D Your comments on this discussion document

D1 What additional definitions or approaches that should be considered in this discussion document?

D2 What other literature should be considered?

2. Broad Stakeholder Group (Institutions)

1. DEFRA
2. JNCC
3. Natural England
4. Environment Agency
5. British Geological Society (BGS)
6. NOC Southampton
7. Sea Mammal Research Unit (SMRU)
8. Met Office
9. Marine Environmental Change Network (MECN)
10. Sir Alister Hardy Foundation for Ocean Science (SAHFOS)
11. Marine & Coastguard Agency (MCA)
12. NERC
13. Food Standards Authority (FSA)
14. CEFAS
15. Countryside Council for Wales (CCW)
16. Welsh Assembly (WAG)
17. Scottish Environmental Protection Agency (SEPA)
18. Scottish Natural Heritage (SNH)
19. Scottish Executive Environment & Rural Affairs Department (SEERAD)
20. Fisheries Research Service (FRS) (Marlab)
21. Wildlife Trusts: Policy Division
22. Scottish Wildlife Trust
23. Biodiversity Scotland - Marine Working Group
24. Scottish Association for Marine Sciences (SAMS)
25. Agri-Food & Biosciences Institute (AFBI) & DARDNI
26. Environment & Heritage Service (EHS)
27. Fisheries Research Service (FRS) (Marlab)
28. Marine Biological Association
29. Marine Conservation Society - Seasearch
30. The Crown Estate
31. Natural History Museum
32. WWF
33. IMAREST
34. Zoological Society, London
35. University of British Columbia
36. University of Liverpool
37. University of Exeter
38. University of Plymouth
39. Plymouth Marine Laboratory
40. University of Wales, Bangor
41. University of York
42. University of Stirling
43. University of Southampton: National Oceanography Centre
44. University of Hull
45. HR Wallingford
46. UNEP Coral Reef Unit
47. UNU – United Nations University
48. IUCN
49. BRAG working group
50. NOAA

3. Suggestion monitoring framework

The following monitoring framework was put forward by one individual during the consultation period:

	Definable features	**Survey & Monitoring**	**Notes**
Structure/properties			
Physical features (i.e. habitat composition)	Abundance of topographical features on rock/hard substrata	Objective could be: maintain at or improve from baseline level) Describe the abundance of topographical features including surface relief, texture, substrate, sediment etc.	List and scale from MNCR recording form for habitats: use complete list
	Extent of topographical features including (e.g.) intertidal width	Aerial extent of major substratum types	Acoustic survey will only detect topographical features – don't become another Emperor
	Disturbance of topographical features	Degree of stability and scour. Evidence of rock fracture Evidence of sediment disturbance Evidence of siltation over expected range	Particularly difficult to assess unless (e.g. Lyme Bay) seabed rocks with attached fauna.
Biological features	Key structural species	Abundance of conspicuous species that are key structural species including bioturbation	Use meaningful measures – be pragmatic, not perfectionist (beware of statistical fascists)
Structure and function including resilience potential	Species richness and abundance	Semi-quantitative abundance	Semi-quantitative so that countable and colonial (and solitary species) included
Functioning			
Physical and chemical processes	Salinity* Wave exposure Tidal stream Stratification Light penetration/turbidity Temperature*	Measure salinity No obstructions No obstructions Measure temp profile Transmissometer recorder In-situ recorders	*Strictly this should go in properties - enclosed areas only Get the HO to include temperatures probes in all tide gauges!
Biological processes	Structure of key functional species (space providers, grazers, predators)	Abundance of food species (plankton surveys) Abundance of major grazers (e.g. urchins) Abundance of major suspension feeders Abundance of predators	Monitor abundance of zoo and phytoplankton on a regional scale Major suspension feeders such as mussels may alter turbidity and food availability
Biological condition	Observations of disease and fouling	Note any disease or fouling (e.g. sea fans)	Difficult to monitor disease (e.g. bacterial infection) may only be conspicuous for a short period

Note: Overarching all site specific monitoring, there is a need to undertake broad scale or regional repeat surveys of water 'quality' (contaminants, nutrient levels, temperature, salinity) as well as phyto and zooplankton type and abundance as those features will often 'drive' broad-scale change and may result in local disasters (e.g. toxic algae).

Annex 3: Workshop outputs

1. Workshop agenda

How can we use concepts of structure and function to integrate the ecosystem approach within marine monitoring?

Sponsoring organisation: JNCC

Facilitating organisations: MRAG & UNEP-WCMC

Chair: Susan Gubbay

AIMS

To reach consensus on the use of, definitions and application of structure and function concepts for practically implementing the ecosystem approach in UK marine monitoring systems.

OBJECTIVES

1) Consider the application of ecosystem structure and function concepts as a framework for UK marine monitoring;
2) Reach consensus on the most appropriate definitions for ecosystem structure and function.

MAIN ACTIVITIES

The workshop will be split into four sections:

Section 1: Introduction and Overview

- Overview of the linkages between the ecosystem approach, monitoring and concepts of ecosystem structure & function.

Section 2: Application of ecosystem structure and function concepts

- Discussion on the potential use of ecosystem structure and function concepts as a framework or tool for UK marine monitoring.
- Review of practical uses of structure and function concepts at different scales.

Section 3: Comparison of different definitions to ecosystem structure and function

- Review of different models for understanding ecosystem structure & function.
- Discussion on advantages and disadvantages of different models.

Section 4: Identifying appropriate elements of a definition and reaching consensus

- Identification of elements required in a good definition.
- Agreement on the way forward and next steps.

OUTPUTS

- Proposed definitions of ecosystem structure and function concepts for UK marine monitoring.
- Updated discussion document, incorporating the outputs of the workshop.

TIME LINE

Time	Activity	Detail	Time	Chair/Speaker
SECTION 1: INTRODUCTION & OVERVIEW				
9.00-9.05	Welcome to the workshop	Introductions of the participants	5 mins	JNCC
9.05-9.15	Aims and objectives of the workshop	Why are you here? What will the workshop will cover?	10 mins	Ian Payne
9.15-9.25	Wider context: Ecosystem Approach	Overview of the ecosystem approach and the EU/International perspective Links between the ecosystem approach and concepts of structure & function.	10 mins	Presented by Susan Gubbay
9.25-9.30	Clarification questions		5 mins	Facilitated by Susan Gubbay
SECTION 2: THE APPLICATION OF STRUCTURE & FUNCTION				
9.30-9.45	Overview of Discussion Document: Part I	Current use of structure and function; potential for application	15 mins	Emily Cocoran
9.45-10.00	Workshop activities	'Pin spots to the Plaice'	15 mins	Facilitated by Charlotte Howard
10.00-10.45	Plenary discussion	Group discussion on the use of structure and function as a framework for monitoring.	45 mins	Facilitated by Susan Gubbay
10.45-11.00	Coffee Break		15 mins	
SECTION 3: COMPARING DIFFERENT DEFINITIONS				
11.00-11.20	Overview of Discussion Document: Part II	Overview of the different models that are used for structure and function	20 mins	Charlotte Howard
11.20-11.30	Introduction to group activity	Directions for the groups and give voting sheets	10 mins	Charlotte Howard
11.30-12.30	Group activity: Advantages & Disadvantages of different definitions	Group split into groups of 4-5 people (i.e. 4 groups) Group 1: Using ecosystem structure and function as a framework Group 2: Using ecosystem structure and function to inform selection of indicators Group 3: Scalability issues Group 4: Linkages between ecosystem structure & function	1hr	Facilitators of Groups: - Emily Cocoran (1) - Suzannah Walmsley (2) - Ian Payne (3) - Charlotte Howard (4) Sue Gubbay to move between groups.
12.30-13.10	Lunch		40 mins	
13.10-14.10	Group feedback	Each group to feedback on findings	1hr	Facilitated by Suzannah Walmsley
SECTION 4: IDENTIFYING THE APPROPRIATE ELEMENTS OF A DEFINITION & REACHING CONSENSUS				
14.10-14.20	Scoring matrix	Voting on different definition models against different criteria	10 mins	Facilitated by Suzannah Walmsley
14.20-14.40	Coffee Break		20mins	
14.40-15.30	Plenary discussion	Discussion on the advantages and disadvantages of different definitions (and alternatives) as well as the elements required for a good definition.	50mins	Facilitated by Susan Gubbay
15.30-15.40	'Re-pin the spot'	Health Check: Re-pin the spot on the chart. Has anyone changed position?	10 mins	Facilitated by Charlotte Howard
15.40-15.55	Next steps & wrap up		15 mins	Susan Gubbay
15.55-16.00	Next steps of project		5 mins	JNCC: Jane Hawkridge

2. Workshop participants

Ecosystem structure and function

12 June 2007

	Name	Organisation
1	Jane Hawkridge	JNCC
2	Paolo Pizzola	JNCC
3	Annabelle Aish	JNCC
4	David Connor	JNCC
5	Ben Dean	JNCC
6	Jo Myers	Defra
7	Dan Laffoley	Natural England
8	Robert Gatliff	BGS
9	John Siddorn	Met Office
10	Peter Burkill	SAHFOS
11	Stuart Rogers	Cefas
12	John Pinnegar	Cefas
13	Anne Henderson	SEPA
14	Matt Service	AFBI
15	Eric Achterberg	NOC
16	Louise Cunningham	SEERAD
17	Alison Miles	EA
18	Peter Wright	FRS
19	Sue Gubbay	Independent
20	Charlotte Howard	MRAG
21	Emily Cocoran	UNEP-WCMC
22	Ian Payne	MRAG
23	Suzannah Walmsley	MRAG

3. Workshop invitees

Name	Organisation
Jane Hawkridge	JNCC
Paolo Pizzola	JNCC
Charlotte Johnston	JNCC
Annabelle Aish	JNCC
Jim Reid	JNCC
Ben Dean	JNCC
David Connor	JNCC
Jo Myers	Defra
Paul Leonard	Defra
Dan Laffoley	Natural England
Eleanor Hill	Natural England
Simon Brokington	Natural England
Roger Proudfoot	EA
Alison Miles	EA
Robert Gatliff	BGS
Ian Boyd	SMRU
John Siddorn	Met Office
Rosa Barciela Fernandez	Met Office
Peter Burkhill	SAHFOS
Roger Proctor	POL
Stuart Rogers	Cefas
Simon Jennings	Cefas
John Pinnegar	Cefas
Bill Sanderson	CCW
Kirstie Dernie	CCW
Anne Henderson	SEPA
George Lees	SNH
Joe Breen	EHS
Matt Service	AFBI
Paul Somerfield	PML
Eric Achterberg	NOC
Chris Frid	University of Liverpool
Keith Hiscock	MBA
Mike Elliot	University of Hull
David Connor	JNCC
Ian Bainbridge	SEERAD
Louise Cunningham	SEERAD
Simon Greenstreet	FRS
Bill Turrell	FRS
Peter Wright	FRS
Mike Kendall	PML

4. Working group outputs

Four working groups were held during the workshop. The following section summarises the questions that were asked of each group and their feedback presented in note form.

4.1 Group 1: Using ecosystem structure and function as a framework for UK marine monitoring programmes

Questions addressed to the group:

- Which definitions of structure and function would be useful in designing a framework for UK marine monitoring?
- How might these definitions you have selected help? Can you give examples or suggestions?
- What are the difficulties or practicality issues that might arise for the different definitions and how might these be overcome?

Feedback from the group

Biological traits
- Useful but too narrow, misses out ocean processes, composite indices etc.
- Makes a contribution and helps to provide context

Processes and properties
- Yes valuable and would be a higher order in a nested set [produce an option for nested definitions?]
- Can be scalable
- Could help for contextual indices
- Fundamental characteristics that must be monitored
- Medium to long term deviations from mean
- Need a minimum set of indicators/indices which provides maximum power to detect change

Integrated measures
- Limited relevance for monitoring, but more important for assessment and reporting on obligations and improved management
- Useful for measuring ecosystem health and condition
- It also provides feedback loops to monitoring

Ecosystem goods and services:
- Important but not directly relevant to shaping monitoring
- Indirectly essential
- Important as a communication link and way of articulating results of monitoring

Linkages:
- Provides broader and indirect context – helps in thinking
- Not useful for constructing a framework (would the linkages group disagree?)
- Importance to have confidence in monitoring data

Challenges:
- Criteria to base judgements on what is being monitored and where the gaps are;
- How to maximise coherency
- How to bring together information (cross-disciplines)
- Optimising analytical power (identify scale for the biggest impact)
- The basics are not yet comprehensive (e.g. WFD monitoring)
- Getting the most out of available resources

4.2 Group 2: Using ecosystem structure and function to inform selection of indicators or environmental parameters

Questions addressed to the group:

- Which definitions of ecosystem structure and function would be useful in selecting indicators for UK marine monitoring?
- How might these definitions you have selected help? Can you give examples or suggestions?
- What are the difficulties or practicality issues that might arise for the different definitions and how might these be overcome?

Feedback from the group

Biotic:
- Crucial but not sufficient
- Fundamental to know what is there
- What about abiotic factors – cannot understand changes without understanding the context

Processes/Properties:
- Are properties structure?
- Properties are tangible
- Processes difficult to measure – When is a process a function? (Naeem feedback?)
- Do we need to know process if a property is blatant – e.g. bottom trawling
- Understanding process needs research and then can feed into property monitoring

Integrated measures:
- Too many unknowns
- Data hungry and complex
- Can be dangerous if outputs are not sufficiently understood

Goods and Services
- High level
- Focus on economics
- Should be the final goal to feed into
- Some quick and useful indicators
- Others may be difficult to measure and require indirect measures

Both top down and bottom up approaches are required

4.3 Group 3: Scalability issues

Questions addressed to the group:

- Which definitions of ecosystem structure and function are most easy to scale up or down – i.e. to use at the local, UK-wide and regional or international level (e.g. Europe/UNEP Regional Seas/LME).
- How might these definitions you have selected help? Can you give examples or suggestions?
- What are the difficulties or practicality issues that might arise for the different definitions and how might these be overcome?

Feedback from the group

- There are a number of terms in use e.g. Ecosystem Health and Ecosystem Management
- It is important first to understand what is meant by an ecosystem i.e. something which has biotic and abiotic components; is self contained and cohesive for example the north sea could be said to have 4 'ecosystems' defined by depth, stratification, mixing, productivity, fronts and biology. Super-imposed on this is sediment/geology
- Structure and function are components of ecosystems
- A key challenge for understanding scale in marine ecosystems is the 3-dimensional considerations with water as the connecting factor.
- Out of the hierarchical scale options provided the Netherlands model has a good hierarchy but very geographically rigid; while the Australian model has biological and biogeochemical relevance but needs tighter definitions

4.4 Group 4: Linkages between ecosystem structure and function

Questions addressed to the group:

- What are the important linkages between ecosystem structure and function?
- How can consideration of these linkages help us inform a monitoring programme?
- Does consideration of these linkages pose any difficulties or practicality issues for monitoring?

Feedback from the group

An illustration of how it may be possible to link structure and function, taking North Sea cod as an example.

Structure	**Function (important processes)**
Fish size structure	Reproduction Life span equiv to resilience Recruitment
Zooplankton & phytoplankton community over time	Spatial and temporal productivity
Issues/Challenges	
- Monitoring: scale issues; effort only at a small scale and have to scale up to give input into models - Need for underpinning process research - Need to be able to quantify acceptable changes (of structure and function) in relation to ‘goods and services	

Annex 4: Detailed Comparison Tables

Table 15. Comparison of structure and function definitions used in marine monitoring (Definitions are summarised and columns are blank where no information in the reference is provided)

Reference		Structure	Function	Spatial Scale	Temporal Scale
1	Bremner, Paramour & Frid, 2006	- *Taxonomic composition* of communities - Biological diversity - Presence of specific habitats or species	Activities, processes or properties of ecosystems that are influenced by its biota *Naeem et al., (2004)*	Applied to SAC areas	
2	Hiscock *et al.*, 2006	- *Architectural structure*: Non biological - *Community structure:* Biological (relative abundance of species) NB: overlap between abiotic & biotic	Mode of action by which the system fulfils its purpose or role, as determined by its component elements. Ecosystems functioning mediated by *activities of species* and species that provide critical services are *key functional species.* Also refers to: Activities, processes or properties of ecosystems that are influenced by its biota *Naeem et al., (2004)*	*Nested approach:* ecosystems can be large as the North sea and small as bacterial in the gut of a fish NB: *Connectivity* between ecosystems	- *Seasonal variation:* presence & absence of species - *Long-term variation***:** cyclic patterns
3	Elliot *et al.*, 2006	- *Composition of the biological community* & - *Quantity and distribution of the abiotic materials* NB: overlap between abiotic & biotic	The rate (higher-level) processes within and between structural components within an ecosystem. A healthy ecosystem is one that functions well and has capacity to resist or recover from disturbance: *resilience.*	*Nested approach*: Units of measurement: - Cell; - Individual; - Population; - Community; - Ecosystem	
4	Dernie *et al.*, 2006	- Abiotic & - Biotic factors	Processes, or groups of processes, that link different structural elements together. 1) *Physical & chemical environmental processes* e.g. pH, salinity, stratification 2) *Biological mediated processes* e.g. predation, competition 3) *Marine food webs*, productivity & nutrient cycling The ability for a ecosystem to maintain its structure and functional integrity when subject to stressors is described as *resilience*	*Nested approach:* of seas in wider regional seas context	

5	Robson *et al.*, 2006 (BRAG UK)	- Biodiversity	The sum of all natural processes within the ecological subsystems.	Recognises that ecosystems operate at many spatial & temporal scales	
6	Vierros *et al.*, 2006			Units of measurement: Spatial areas defined by *stakeholders use of space*	Map *stakeholder-use* over time
7	Frid & Paramour, 2006	- Species & Habitats	Processes and activities that keep a system working. Activities, processes or properties of ecosystems that are influenced by its biota *Naeem et al., (2004)*	Units of measurement: *Marine landscape types*	Evidence for changes needed on *long time frames*
8	Vassallo *et al.*, 2006	- Biodiversity - Abiotic & Biotic components linked to ecosystem function	Flow of energy and matter between interdependent biotic and abiotic components.		
9	Hughes *et al.*, 2005		Dynamic and complex processes that support or undermine resilience		
10	Rogers *et al.*, 2007	- Species - Habitats; - Physical & chemical components	Important properties of ecosystem: resilience; persistence & productivity Ecosystem function and processes that involve one or more of the ecosystem components: trophic links, mass/energy flux etc.	*Unit of measurement:* Separate management regions need to be identified using boundaries of physical and biological processes	
11	Laffoley *et al.*, 2006	- Biological communities		*Nested scales* - Wider sea - Regional sea - Component landscape scale - Habitats	*Elements discussed:* - Irreversible changes - Past impacts, shifting baselines - Long-term political ambition
12	Pasquer *et al.*, 2007	- Abundance; - Diversity - Influencing factors: light & nutrients	Functioning of species e.g. role of phytoplankton in biological carbon pump		

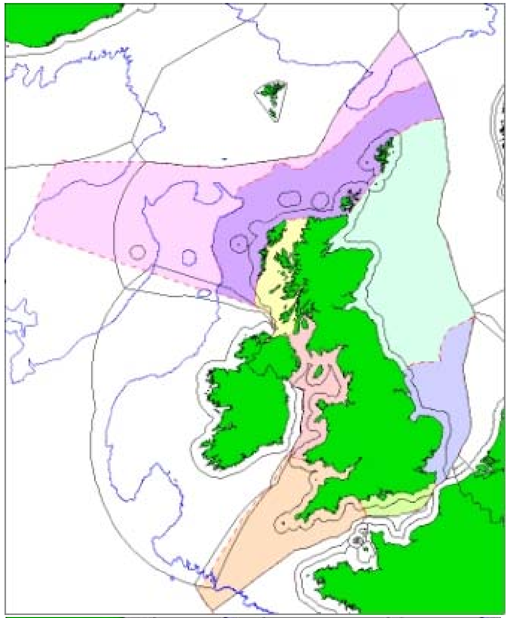
Table 16. Different approaches to ecosystem scale (and mapping) and their relation to concepts of structure & function (columns are blank where no information in the reference is provided)

	Approach	Reference	Scale	Categories that are used to define this area	Are concepts of structure & function used in defining the area?
A	**Special Areas of Conservation (SACs)** (NB – SACs + SPAs = Natural 2000 sites; terrestrial SACs & some inter-tidal/estuaries = SSSIs)	Protected areas extracted from World Database on Protected Areas (WDPA) in April 2007 supplied by UNEP World Conservation Monitoring Centre (UNEP-WCMC) (WDPA custodian).	Initially land-area and territorial seas (out to 12nm), now extended to 200nm. (work underway to identify offshore SACs & SPAs)	**Annex 1 habitats:** - Representatively; - Relative area of habitat; - *Conservation of structure & function* - Global assessment **Annex 2 Species:** - Proportion of UK population - Conservation of important features for species - Isolation of species; - Global assessment **Additional principles:** - Priority status - Rarity - Geographic range - Special UK responsibilities - Multiple interest	Structure and Function is used as part of the criteria to select Annex 1 habitats. The relevance of both criteria depends on the habitat.
B	**UK Regional Seas**	Vincent et al., 2004 (JNCC Report)	Modified from ICES fishing boxes and regional seas defined by OPSAR (overlap with waters of neighbouring countries) RS1 Northern North Sea RS2 Southern North Sea RS3 Eastern Channel RS4 Western Channel & Celtic Sea RS5 Atlantic South West Approaches RS6 Irish Sea RS7 Minches & Western Scotland RS8 Scottish Continental Shelf RS9 Faroe-Shetland Channel RS10 Rockall Trough & Bank RS11 Atlantic North West Approaches	- Temperature - Depth - Currents	Physical attributes (temperature, depth & current) are the main concepts used to define the regional sea areas.
C	**OSPAR areas** (NBN Gateway)		North-East Atlantic further divided into: OB1 Arctic (deep sea) OB2 Atlantic (deep sea) OB3 Boreal (shelf & slope) OB4 Boreal-Lusitanean (shelf & slope) OB5 Lusitanean-Boreal (shelf & slope)	Politically defined areas	Areas used to monitor biodiversity and marine pollution against the objectives of the convention

D	**ICES Fishing areas**	http://www.fishonline.org/information/maps/ices.php Created by the Danish Institute for Fisheries Research (DIFRES). ICES 29 November 2006 Hans Mose Jensen	ICES Areas (or boxes) labelled from I to XVI. The various ICES Areas are also sub-divided into rectangles that can allow further desegregation of the data.	- Selected areas for aggregating fisheries data	Neither structure nor function is used to define the areas.
E	**ICES Eco-regions (proposed)**	Created by the Danish Institute for Fisheries Research (DIFRES). **http://www.ices.dk/marineworld/fishmap/ices/** (CEFAS)	Greenland and Iceland Seas Barents Sea Faroes Norwegian Sea Celtic Seas North Sea South European Atlantic Shelf Western Mediterranean Sea Adriatic-Ionian Seas Aegean-Levantine Seas Oceanic northeast Atlantic	- Contours of and the integrity of regions shelves - Taking into account existing political, social and economic management divisions	Biological structure is not used to define the area, but is used to describe the ecosystem once the boundaries are mapped. Categories of structure include: Oceanographic/Biographic/Ecology **Physical** •Salinity & stratification •Circulation & transport **Biological** •Phytoplankton •Fish/shellfish •Seabirds •Marine mammals **Habitats** •Coastal habitats •Offshore habitats •Deep-sea habitats Impacts are also mapped e.g.: Hazardous substances; Eutrophication; •Fishing activities; Maritime transport; Offshore gas; Climate Change; Habitat disturbance; Litter

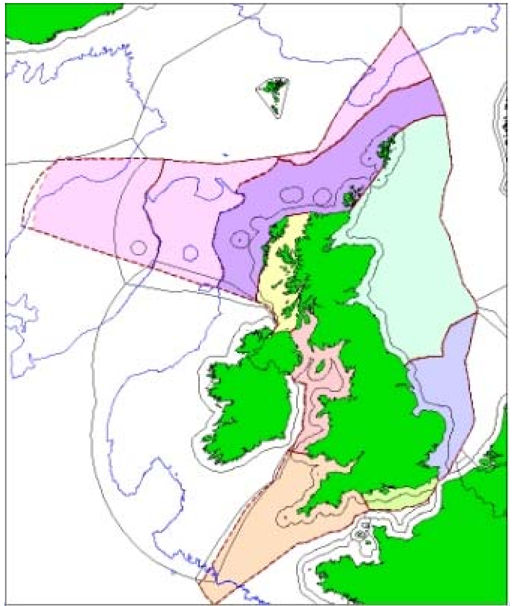
F	**EU Marine Strategy Framework Directive**	EU Parliament & Council Proposal COM (2005) 505 final SEC (2005) 1290	Marine sub-regions of North East Atlantic: - **Greater North Sea** including Kattegat; English Channel, marine waters of Belgium, Denmark, France, Germany, Netherlands, Sweden & UK - **Celtic Seas:** marine waters of UK & Ireland - **Bay of Biscay & Iberian Coast:** marine waters of France, Portugal & Spain; - **Atlantic Ocean:** waters of Portugal surrounding the Azores & Madeira, and of Spain surrounding Canary Islands	Stated as using hydrological, oceanographic & bio-geographic aspects.	Within these areas required to monitor: - **Physical & chemical elements:** bathymetric; temp; currents; salinity - **Habitat types**: physical & chemical characteristics, mapped special habitat types; other special areas - **Biological elements**: description of biological communities associated with habitats (plankton, benthic & fish); Population dynamics; Abundance - **Other attributes** nutrient cycling; state of chemical pollution; other elements
G	**Bio-geographical regions**	Council Directive 92/43/EEC (adopted 23rd Oct 2000)	Steppic; Pannonian; Black Sea; Boreal; Continental; Atlantic (most UK) Alpine Macaronesian Mediterranean (Gibraltar)	Temperature tolerances	
H	**Marine eco-regions**	www.worldwildlife.org/MEOW/	Coasts & Shelves (up to 200nm) (Does not cover pelagic or deep benthic environments) UK waters covered by three to four of the eco-regions: - 71: - 36: - 225:	Mosaic of existing and recognised spatial units (Nest within broader tiers of Realms & Provinces)	Based on current administrative or spatial units therefore not necessarily using structure or function to define the areas
I	**Self-organising maps**	UNEP 2006 www.unep-wcmc.org/resources/publications/UNEP_WCMC_bio_series/		Statistical methods used to recognise patterns in structure or function (Artificial Neural Networks 2: ANNs)	Can use either **structure** or **function (process)** elements to define an area Can be applied to any **scale** and define **functional units**
J	**Large Marine Ecosystem (LME)**	Duda & Sherman (2002) http://www.edc.uri.edu/lme/clickable-map.htm	LME: Celtic-Biscay Shelf LME: North Sea	•Population & Ecosystem Health Module •Productivity Module •Socio-economic module •Fish & Fisheries module •Governance Module	

Annex 5: Comparison of eco-regions

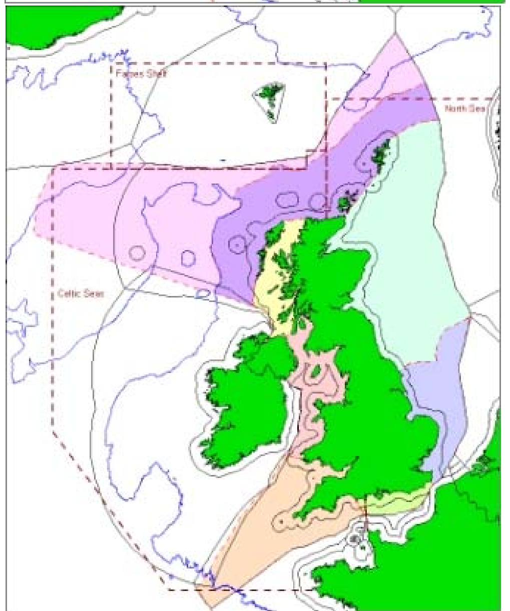


Reporting Areas for Charting Progress (Defra, 2005)

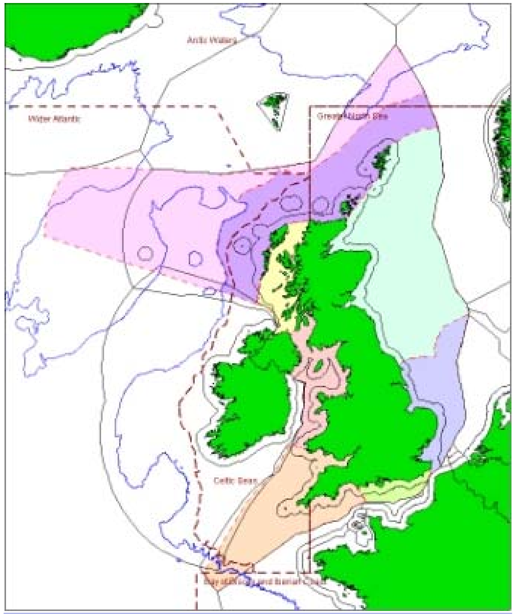
- Rockall Trough & Faeroe/Shetland Channel Atlantic North West Approaches
- Scottish Continental Shelf
- Northern North Sea
- Southern North Sea
- Eastern English Channel
- Western English Channel, Celtic Sea & South-West Approaches
- Irish Sea
- Minches & West Scotland
- 1500 depth contour
- EEZ boundaries



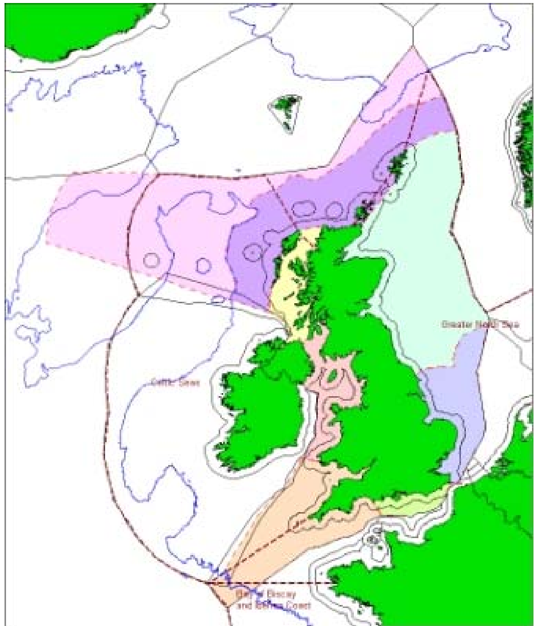
JNCC Regional Seas



ICES Eco-Region



OSPAR Regions



EU Marine Strategy proposed

Annex 6: References

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