The UK Marine Biodiversity Monitoring Strategy

Table of Contents

Acknowledgements: The authors would like to thank Francesca Marubini who was lead author of the previous versions of the UK Marine Biodiversity Monitoring Strategy; and the many colleagues who provided their input during the process of developing this Strategy

1 The case for the Marine Biodiversity Monitoring Strategy

This document presents a UK Marine Biodiversity Monitoring Strategy as an overarching working document providing the necessary context for the development of UK Marine Biodiversity Monitoring Programmes.

1.1 Background to marine biodiversity monitoring

The 1992 Convention on Biological Diversity paved the way for global efforts to halt the decline in biodiversity and promote sustainable use of ecosystem goods and services while maintaining ecosystem integrity. In response to commitments made to the international conventions and agreements that followed, and as a means to support relevant European and national legislation, the UK Government set out its vision for the marine environment (Defra 2002) and made a commitment to achieve "clean, healthy, safe, productive and biologically diverse oceans and seas".

To help deliver this, the need to "increase our understanding of the marine environment, its natural processes and the impact that activities have upon them" has been set as one of the five strategic goals for the marine environment (Defra 2005). It is also explicitly stated in the High-Level Marine Objectives (2009)[1], which reflect the full range of the UK Government and Devolved Administrations' policies in the marine area that "sound evidence and monitoring underpins effective marine management and policy development".

Monitoring of marine biodiversity is already taking place across several ecological components, e.g. for species such as for seabirds and cetaceans, and for habitats within protected areas and in the wider marine environment for a number of other drivers such as the Water Framework Directive (WFD) and the Environmental Impact Assessments (EIA) but there is recognition that current efforts need to be improved. This is particularly true in relation to the Marine Strategy Framework Directive (MSFD 2008) where monitoring is necessary for the assessment of whether or not targets for the indicators and criteria for assessing Good Environmental Status (GES) have been achieved.

Given the large extent of the UK marine area, the great variety of habitats contained therein and the area's inherent wealth of biodiversity, comprehensive marine biodiversity monitoring presents a considerable challenge with regard to resources required. Identification of current and future monitoring needs according to current policies and legislation, followed by review of existing monitoring to identify any gaps, overlaps or more effective ways of collecting data is necessary for each ecological component under consideration. Then integration and coordination of options between ecological components to identify further opportunities for more efficient or effective ways of collecting data are needed in order to use such resources efficiently.

It is within this spirit that the Healthy and Biologically Diverse Seas group (HBDSEG) of the UK Marine Monitoring and Assessment Strategy (UKMMAS) agreed the vision for the UK Marine Biodiversity Monitoring R&D Programme 'to develop and advise Governments on an

[1] http://webarchive.nationalarchives.gov.uk/20130402151656/http://archive.defra.gov.uk/environment/marine/documents/ourseas-2009update.pdf

integrated monitoring and assessment scheme (called 'the Scheme' in this document) for all marine biodiversity components across all UK waters'. This is an initiative led by the Joint Nature Conservation Committee (JNCC) in partnership with the statutory nature conservation bodies and working with the wider monitoring community through UKMMAS.

For an overview of the connections between the main political drivers for monitoring requirements, the UK Marine Biodiversity Monitoring Strategy, and the implementing bodies please refer to Figure 1. The leads for the development of monitoring options are indicated in the diagram where these are confirmed.

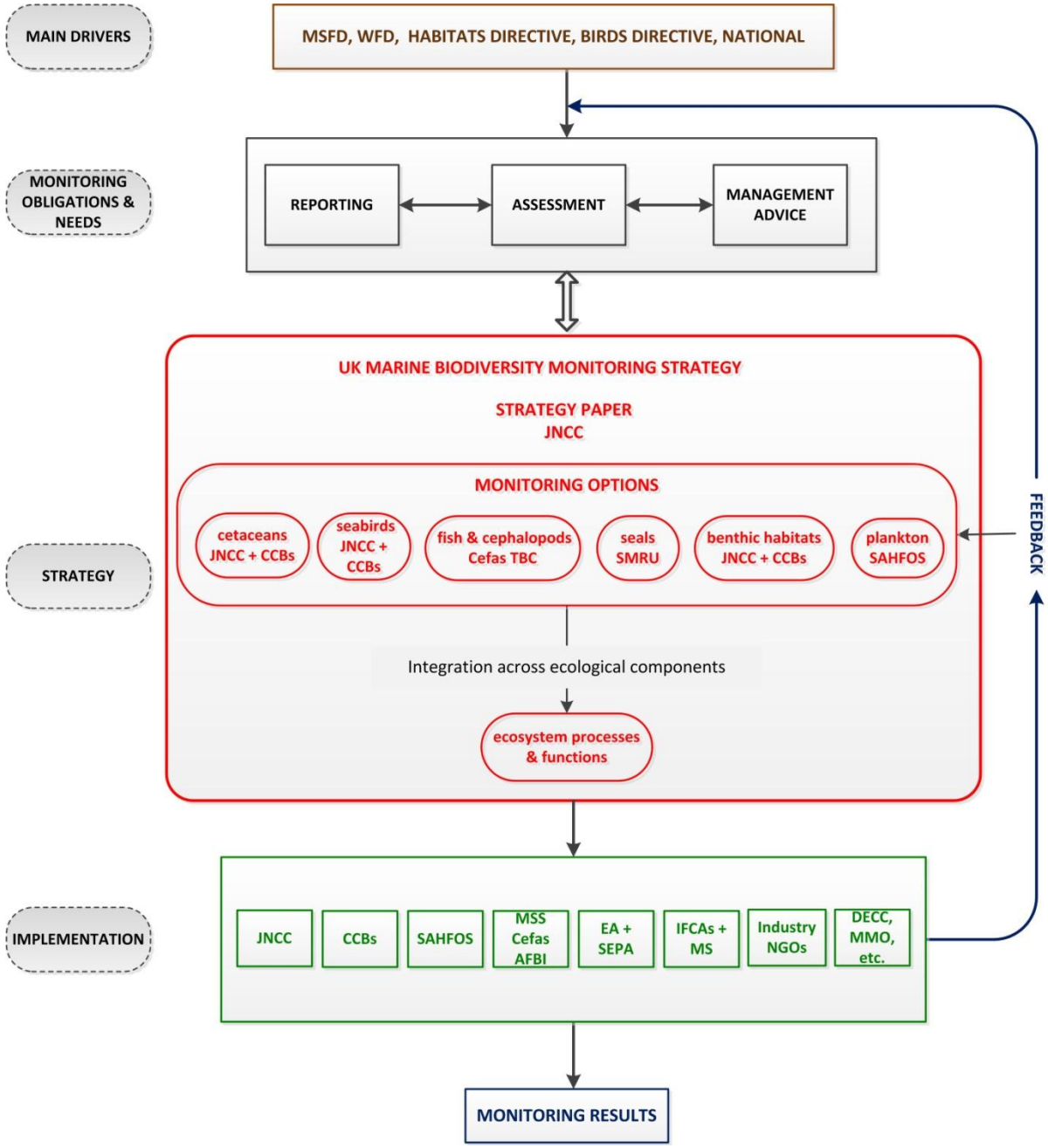

Figure1. Diagram showing the relationship between the main political drivers, the UK Marine Biodiversity Monitoring Strategy and the implementing bodies[2]. TBC – to be confirmed.

[2] CCBs – Country Conservation Bodies with inshore responsibilities: the Department of the Environment Northern Ireland (DOENI), Natural England (NE), Scottish Natural Heritage (SNH) and

1.2 Requirements for evidence

The context for monitoring is provided by policy. The Government aspirations in the field of marine nature conservation and environmental management have been set in the vision for the UK Marine Biodiversity Monitoring R&D Programme and can be interpreted to define the overall aim of marine biodiversity monitoring:

to collect the necessary evidence to fulfil marine biodiversity obligations and to provide timely and effective advice for management.

This section outlines the principal drivers for marine biodiversity monitoring. Further details on legal and policy requirements is elaborated within the monitoring options developed for each ecological component.

1.2.1 Legislative commitments

There are multiple legislative and policy instruments with requirements for UK marine biodiversity assessment and reporting at varying geographic scales and covering different aspects of biodiversity. These instruments in some cases make explicit requirements for monitoring to be undertaken while in others the need for monitoring is only implicit in the need for assessment and reporting. There are significant overlaps in the requirements for the different drivers.

The principal policy drivers for which evidence on marine biodiversity should be collected are:

Habitats Directive (HD);
Birds Directive (BD);
Water Framework Directive (WFD);
Marine Strategy Framework Directive (MSFD);
Marine and Coastal Access Act (MCAA), Marine (Scotland) Act (MSA) & Marine Act (Northern Ireland);

In addition there are also requirements under:

Wildlife and Countryside Act (WCA);
Conservation of Seals Act;
Common Fisheries Policy (CPA);
Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR Convention) – Appendix V on Biodiversity;
Convention on Biological Diversity (CBD);
Convention on Migratory Species (CMS);
United Nations Convention on the Law of the Sea (UNCLOS);
Convention on Wetlands (RAMSAR Convention).

In the application of the Strategy, it is necessary to appreciate the different levels of risk from legal challenge that come under each of the above measures should they be infringed upon. The Marine Biodiversity Monitoring and Assessment R&D programme is aiming to develop

---

Natural Resources Wales (NRW). JNCC has responsibility for nature conservation in UK offshore waters. Cefas – Centre for Environment, Fisheries and Aquaculture Science, DECC – Department of Energy & Climate Change, EA – Environment Agency, IFCA – Inshore Fisheries & Conservation Agency, MMO – Marine Management Organisation, MS – Marine Scotland, MSS – Marine Scotland Science, NGO – Non-Governmental Organisation, SEPA – Scottish Environment Protection Agency.

options for monitoring to enable assessment and reporting to the requirement and timeframes of all the above drivers.

In addition, there are also various assessment and reporting requirements that must be met by developers, industry sectors and Competent Authorities for proposed plans or projects in the marine environment. These requirements include those under the Environmental Liability Directive (ELD), EU Strategic Environmental Assessment (SEA) Directive, EU Environmental Impact Assessments (EIAs) and Appropriate Assessments (AAs), as well as the relevant UK regulations that transpose these requirements into UK law. As the responsibility for collection of monitoring data to fulfil these needs rests with industry rather than Government, and tends to be very development-specific, they have not been used to determine the objectives for biodiversity monitoring. However, there will be benefit in considering practical integration once the monitoring requirements for assessing state of biodiversity have been defined.

1.3 Exploring sources of complexity

The scope of an Integrated Marine Biodiversity Monitoring Scheme for the UK is complex; what it wants to achieve is at a large scale and truly ambitious. The main sources of complexity are:

1. Policy requirements. Monitoring is set within the regulatory system as an integral part of the adaptive management cycle. In contrast to scientific efforts in the wider pursuit of knowledge for the marine environment, the context of monitoring activities is provided by policy. The overall aim of marine biodiversity monitoring is to collect, focussing on the questions to be answered, the necessary evidence to assess whether we are being successful at conserving, protecting and managing the marine environment according to our marine biodiversity conservation, sustainable management and reporting obligations, and to provide timely and effective advice for the management of human activities both in MPAs and the wider marine environment. Policy requirements for evidence are diverse which has not only important implications for how activities should be prioritised within a monitoring programme, but also emphasises the need for close links with appropriate policy-makers.
2. Integration of monitoring across jurisdiction within the UK and integration at a European level. In order to fulfil OSPAR and MSFD obligations common approaches to monitoring and assessments have to be achieved at a UK as well as at a European level.
3. Geographical coverage. Not only do the UK seas cover a large area, but they are characterised by a high degree of diversity and complexity in terms of their physical/chemical environment, their biological components, their overlap with human activities, and their political and administrative boundaries.
4. Biological scope. Marine biodiversity consists of a multitude of components. There are requirements for monitoring set at the level of single components (e.g., species and habitats) and at the level of the ecosystem, and yet the knowledge base and the appropriate geographical scale for each of these can be drastically different.
5. Physical and chemical scope. Interpretation of biodiversity processes requires information on the physical and chemical environment and on human activities; as such, biodiversity monitoring must be well integrated with other monitoring programmes across all the UKMMAS Evidence Groups.
6. Diversity in data providers. Statutory agencies, regulators, government laboratories, industry, academia and NGOs are all currently involved in data collection, analysis

and development of monitoring activities. While this clearly constitutes a great opportunity, making the data accessible for the purpose of an integrated Marine Biodiversity Monitoring Scheme requires a high-level of coordination and good will.

Monitoring programmes with much less complexity have often encountered difficulties resulting in low effectiveness with regard to delivering against the objectives of those programmes (Lindenmayer & Likens 2010, de Jonge *et al* 2006, Magurran *et al* 2010). Among the key difficulties highlighted is the tendency to define the purpose of monitoring only at the high-level, providing little direction for the technical decisions (e.g. for power analyses, the ability to detect change and how much confidence is needed in the evidence) that ultimately determine the design of how data will be collected. It is also recognised that lack of consistency in sampling design and methods across such a programme is of major hindrance to being able to analyse data beyond the specific need of each monitoring activity.

1.4 The way forward

An overarching conceptual framework (hereafter called 'the Strategy') has been developed to help with the design of a monitoring programme, to provide a structured way of prioritising monitoring, and to ensure all decisions are accurately recorded.

2 The Strategy

The implementation of an integrated Marine Biodiversity Monitoring Scheme should be seen as a long-term project to improve and better-focus existing monitoring, conducted in stages as the options become available. Implementation and realisation of the monitoring scheme is an iterative process whereby results of the monitoring activities are used to redefine expectations in the functions and, as such, in the Scheme. Prior to the realisation of the Scheme overall cost can only be estimated approximately. The optimal allocation of resources to the individual monitoring activities as well as the optimisation ('fine-tuning') of the individual sampling designs can be extracted only from the results of the scheme itself once it has been operational for some time (Vos *et al.* 2000). Furthermore, changes of external conditions such as additional or new pressures from human activities, the implementation of new management measures following a state change to unfavourable conditions, or changes to budgets, might require adaptations of the scheme. Thus the UK Marine Biodiversity Monitoring Scheme has to be understood as a 'work in progress' throughout its lifetime.

2.1 Application of the Strategy to the development of monitoring options

The UK Marine Biodiversity Monitoring R&D Programme has been set up with the specific objective of developing options to be proposed to UK Governments for an integrated monitoring and assessment scheme for marine biodiversity components across all UK waters. Thus in the first instance, the focus of the Programme is on the design of monitoring options for the individual components which were chosen as the basis to develop MSFD indicators to meet the criteria for the Descriptor Biodiversity (D1), i.e. seabirds, cetaceans, seals, fish & cephalopods, benthic habitats and ecosystem processes & functions. Monitoring within MPAs is included in the options for each of the ecological components.

The detailed operational needs will come to the fore once Governments have decided on the monitoring option(s) to be implemented. Each monitoring option proposed addresses the specific political drivers such as MSFD indicators and targets requiring the monitoring of this ecological component. Further, the options include identification of gaps in monitoring efforts, suggestions for integration and coordination of existing and future monitoring programmes and estimations of cost and benefits inherent in the particular option. Whilst this is one of the primary aims of the strategy the approach is aimed to provide a wider strategy for all biodiversity monitoring.

The different elements of the Strategy used in the development of the monitoring options are presented in Figure 2. The specific policy aspirations and legal obligations that constitute the main drivers for monitoring are identified in the options and used to formulate the 'Functions of monitoring'.

The design stage has been split into two parts – the 'WHAT to monitor' and the 'HOW to monitor'. This helps develop the process to be applied at the technical level. Detailed technical descriptions of the process are the focus of separate documentation for the application of the Strategy. Developing the descriptions of the process followed to arrive at monitoring options is under way with some options already being developed (see Appendix 1).

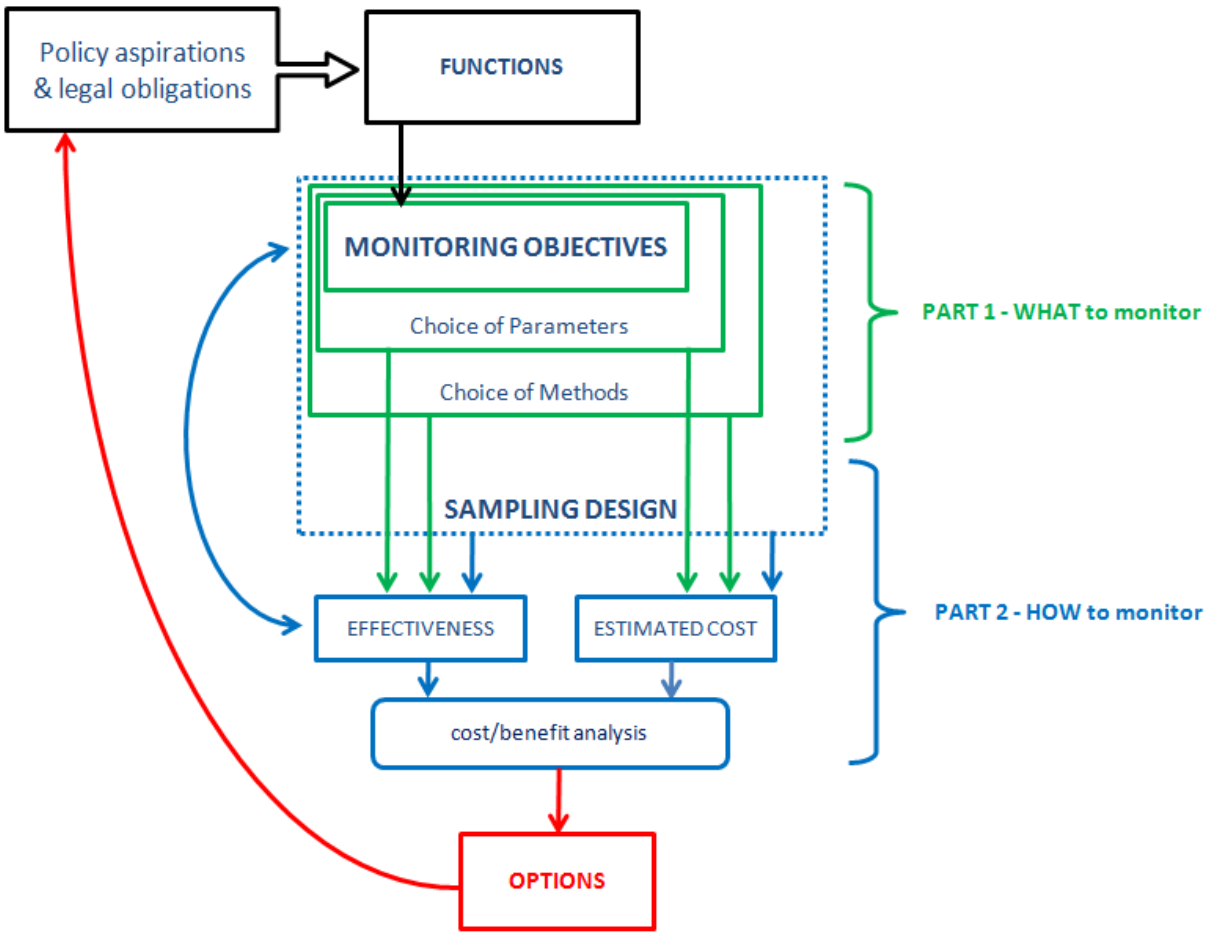

Figure 2. Schematic representation of the elements of the Marine Biodiversity Monitoring Strategy used in the development of monitoring options for individual ecological components. Colour coding representing the different stages of development process: green = WHAT to monitor; blue = HOW to monitor; red = monitoring options.

In Part 1, the 'WHAT to monitor', questions are addressed in a consistent manner across the specific ecological components in order to arrive at proposed monitoring activities. During this part of the design stage decisions should be made on which area, which variable, and which population are to be monitored using which monitoring type[3].

A risk-based approach, in combination with a pragmatic use of current knowledge, are the basis of decisions made on the ecological components (i.e. which species, habitats or ecological processes) and parameters to monitor, and on sampling methods to be employed. When employing such a risk-based approach, decisions on which habitat or species to monitor are based on the identified relative risk of a habitat or species to be affected by anthropogenic pressures. There is more detail on the principle of a risk-based approach in section 5.2.1. The key output for the 'What to monitor' part of the Strategy is to set quantifiable objectives for each of the monitoring activities identified.

Part 2 is referred to as 'HOW to monitor'. Here, the focus is on identifying the most effective sampling design for each monitoring activity. Effectiveness, in this context, means how well the chosen sampling design achieves the objectives of the monitoring activity in question; in particular the required statistical significance and power. In turn, the sampling design largely determines the operational cost of the activity and the degree of certainty derived from monitoring to give the required outcome and the level of confidence in that outcome for the policy maker. The choice of design therefore is based on striking a balance between its effectiveness and its costs. The starting point for this section is a review of current monitoring activities in light of the monitoring objectives arrived at above; whether existing sampling designs could be improved is explored where necessary.

Note that the steps described here for Part 1 and Part 2 of the design stage do not necessarily have to be followed sequentially.

Finally, activities are organised into options. Each option represents possible monitoring activities for a particular ecological component with different costs and different abilities to fulfil the overall monitoring objectives (e.g. legal requirements) and to reduce uncertainty in the final evidence used in assessments.

It is not until the individual options for the monitoring activities for the whole spectrum of ecological components have been developed that it will be possible to present options for a fully integrated and coordinated Scheme. However, in the interim, individual options should be implemented, where possible, according to the needs of governments. Such interim options are valid in their own right but are likely to overestimate the cost of those activities where potential for integration and coordination across components is most likely. Integration should also be sought with other ongoing monitoring efforts such as monitoring of contaminants and oceanographic processes across UK and regional waters on a European level. While there is no doubt that cost-effectiveness is a big driver, it is also important to recognise that integrated monitoring will not only provide more comparable data across environmental and biodiversity components but will ultimately result in true ecosystem monitoring.

The document will now centre on providing details for each of the Strategy's elements; however, before doing so, and in order to avoid confusion to the reader, the next section gives a short introduction of the term 'monitoring' and how it will be applied in the UK Marine Biodiversity Monitoring Programme.

[3] For explanation of monitoring types see text box in section 4.2.1

3 The use of the term 'monitoring'

The term monitoring is so commonly used that it seems not to warrant any further explanation. However, a comparison of 'monitoring' definitions across different sources within the UK marine environment reveals that different definitions of monitoring have been applied which may lead to confusion as to what is included in a marine monitoring programme.

For example, the UK Marine Monitoring and Assessment Strategy (2006) adopted the definition by Portmann (2000): *"The taking, on a reasonably regular basis, of any form of observations relative to the (long-term) status of the marine environment, regardless of the frequency of, or purpose for which, the observations are made."* This definition focuses on marine observations '*undertaken more consistently, albeit with varying frequency, over longer periods of time*' and it excludes one-off or intermittent field observations.

In some instances this same meaning is given to the term 'surveillance' and in such cases the term 'monitoring' is used to imply that data will be collected with the specific requirement to assess a process against a known benchmark. For example, the Marine Monitoring Handbook (Davies *et al* 2001) defines 'surveillance' as '*a continued programme of biological surveys systematically undertaken to provide a series of observations in time'* and 'monitoring' as '*surveillance undertaken to ensure that formulated standards are being maintained'*. The Common Standards Monitoring Guidance (JNCC 2004) applies the definition by Brown (2000) where *'Monitoring' is an intermittent (regular or irregular) series of observations in time, carried out to show the extent of compliance with a formulated standard or degree of deviation from an expected norm'.*

In conclusion, 'monitoring' is best defined specifically within the context to which it is applied. Given the complexity of an integrated marine biodiversity monitoring programme, the UK Marine Biodiversity Monitoring R&D Programme acknowledges the value of an approach as used in the Water Framework Directive where 'monitoring' is divided into 'surveillance', 'observational' and 'investigative', monitoring each with nuances specific to the needs of the Directive.

The UK Marine Biodiversity Monitoring R&D Programme will build options for integrated monitoring by combining the most cost-effective monitoring activities that will achieve its objectives, including examples from all of the definitions above. In this document 'monitoring' is used in a very generic sense to mean '*an activity by which evidence necessary to meet the aims of the monitoring programme is collected*'.

4 Setting a clear purpose

This section presents how the legislative obligations commonly considered to be relevant for marine biodiversity monitoring (see Section 1.2) are related to providing advice for the management of human activities in the marine environment.

4.1 Providing advice for the management of human activities

Regardless of the legislation for management which is in place, managers need to take decisions on how to manage human activities based on available evidence. As monitoring

programmes are imperative in delivering such evidence, the needs of managers should be included in shaping the design of monitoring.

Whereas the functions of a monitoring programme are defined by policy, a close dialogue between managers and scientists is important in designing monitoring options, especially with regard to improving cost-effectiveness. Scientific expertise is required to develop cost-effective field methods and to provide logistic information about the monitoring options (i.e. cost, time, effort).

4.2 Functions of monitoring

The high-level aspirations stated in section 4.1 of collecting evidence to fulfil political obligations and to provide advice for management are useful to drive the direction of the Strategy. However, in order to drive the design of monitoring activities it is necessary to make them much more tangible. For the purpose of the UK Marine Biodiversity Monitoring and Assessment Scheme two main functions have been recognised:

1) to identify state and changes in state for an ecological component of biodiversity, and identify whether changes are due to natural change or as a result of anthropogenic activities, to inform the need for management measures; and
2) to identify if management measures are effective in meeting their objectives.

When designing a monitoring programme it is useful to separate these functions because they serve different purposes and achieve different benefits. They are also likely to be served best by the adoption of different monitoring activities.

When monitoring is done to inform assessments that identify the need for management measures, the evidence sought is about detecting change for which remedial action is required. The benefits gained by the management are in preventing possible damage to the ecosystem/habitat/species, but also in avoiding the cost of any restoration action that may be required following damage/loss. In principal, this function is aimed at the early detection of change before the full ecological consequences of impact have occurred. In this case the objectives for the monitoring activities will be to provide evidence that enables an assessment of state and direction of change, but also to be able to make inferences about the causes of that change in order to distinguish natural from anthropogenic causes.

For the second function, i.e. when monitoring is conducted to identify if already existing management measures are being effective, monitoring results are used to test specific hypotheses concerning whether such measures have the expected effect on the ecological component being monitored. The benefit brought about by these monitoring activities is realised by establishing the most effective management measures and adapting existing ones (cease, reduce, increase) depending upon the results obtained. In this context, studies on the relationship between state and pressure as well as studies in areas with management measures established (i.e. Marine Protected Areas (MPAs)) *versus* comparable areas without such measures, are both valid examples.

4.2.1 Monitoring Types

Once the function of monitoring is determined, the next step is to choose the objective for the monitoring activity. Within the Monitoring R&D Programme Monitoring activities have been categorised according to their objectives into ‘Monitoring Types’ (see Box 1). This helps provide a structure when setting up monitoring activities.

Following an in-depth review by JNCC and HBDSEG a common view of monitoring types was formulated that could be used to normalise the language used by different drivers when defining types of monitoring. As such, activities necessary to the provision of evidence fall into one of three 'Monitoring Types'. Each of these types has specific objectives and is best suited to different survey designs (see text box on Monitoring Types[4]).

A link between functions and monitoring types has been established as follows:

- to identify the need for management measures, activities can be chosen from monitoring long-term trends and monitoring pressure-state relationships; and
- to identify whether management measures are effective, activities can be chosen from the third type of monitoring, i.e. monitoring management efficiency and/or the second type (monitoring pressure-state relationships).

The decision of which monitoring type is most appropriate for a particular monitoring activity is part of the considerations taken in the technical process used to apply the Strategy and described in the next sections on design.

[4] Note that the exact wording of the Monitoring Types might vary slightly between the individual monitoring option documents.

Box 1: The three Monitoring Types

Sentinel monitoring of long-term trends (Type 1 monitoring) – Objective: to measure rate and direction of long-term change.

This type of monitoring provides the context to distinguish directional trends from short-scale variability in space and time by representing variability across space at any one time and documenting changes over time.

To achieve this objective efficiently, a long-term commitment to regular and consistent data collection is necessary; this means time-series must be established as their power in identifying trends is far superior to any combination of independent studies.

Operational monitoring of pressure-state relationships (Type 2 monitoring) – Objective: to measure state and relate observed change to possible causes.

This objective complements monitoring long-term trends and is best suited to explore the likely impacts of pressures on habitats and species and identify emerging problems. It leads to the setting of hypotheses about processes underlying observed patterns.

It relies on finding relationships between observed changes in biodiversity and observed variability in pressures and environmental factors. It provides inference but it is not proof of cause and effect. The spatial and temporal scale for this type of monitoring activity will require careful consideration of the reality on the ground to ensure inference will be reliable; for example, inference will be poor in situations where the presence of a pressure is consistently correlated to the presence of an environmental driver (e.g. a specific depth stratum).

Investigative monitoring to determine management needs and effectiveness (Type 3 monitoring) – Objective: to investigate the cause of change.

This monitoring type provides evidence of causality. It complements the above types by testing specific hypothesis through targeted manipulative studies. The design and statistical approach that can be used in these cases gives confidence in identifying cause and effect. It is best suited to test state/pressure relationships and the efficacy of management measures.

5 The design stage

5.1 Ecological components

Marine biodiversity can be measured at several levels, from genetic biodiversity to the biodiversity of ecosystems. In most cases, processes affecting the rate of biodiversity change act on more than one such level, and therefore it is not economically feasible to monitor the complete biodiversity of an area, or a chosen site, across all such levels. Instead it is common practise to concentrate on individual ecological components which have been identified as being sensitive to pressures in a predictable fashion, and preferably being sensitive to change in advance of the whole ecosystem.

The Strategy has selected to monitor the following components: seabirds, marine mammals (cetaceans and seals), fish and cephalopods, benthic habitats, plankton, and ecosystem processes and functions. These components have been chosen to provide a match, as far as possible, with the approaches taken across the legal obligations with the aim of facilitating

a close link between the development of monitoring options and the assessment and reporting requirements. The division also fits with scientific expertise/academic communities and the approach taken at HBDSEG. It has to be noted that while the first five components make up a great proportion of the last one, i.e. 'ecosystem processes and functions', they certainly do not replace it. The first five components tend to focus on aggregating up from species or single habitats to communities. The explicit addition of 'ecosystem process and functions' as a component in its own right is to promote an ecosystem approach that focuses more directly on processes and functions, and therefore on the integration across ecological components.

Currently, implementation of the Strategy is likely to follow a step by step approach as the monitoring options for the individual components become available. General guidance on the process to be followed in doing so is already given in section 2 of this document. More detailed guidance specific to each ecological component is included within the monitoring options.

5.2 Principles

Data collection *per se* does not guarantee meaningful results. Each element of biodiversity (species, habitats) and ecological processes differ in ecological aspects including their distribution in space and time, as well as in the number and type of pressures to which they are vulnerable. This in turn means that not all ecological parameters which could be measured are equally practical or relevant to the functions of monitoring. A risk-based approach and the pragmatic application of current knowledge are used throughout the technical process to focus the design on a sub-set of key elements, parameters and methods that represent valid monitoring activities.

5.2.1 Risk-based approach

Within nature conservation, risk is most commonly defined as 'the risk to habitats and species of being adversely affected by pressures caused by human activities'. The same definition of risk is adopted by the UK Marine Biodiversity Monitoring R&D Programme. A risk-based approach is commonly adopted to reduce the scale of monitoring required; it provides a logical framework for planning and prioritising monitoring activities. Among the legislative drivers for marine biodiversity monitoring, a risk-based approach is explicitly required in the Water Framework Directive (WFD) and proposed in the Marine Strategy Framework Directive (MSFD).

The Strategy aims to ensure that habitats and species at high risk, and those ecological components most sensitive to a pressure needing to be managed for wider ecosystem impacts, receive the utmost attention when identifying monitoring priorities. Consideration of risk is introduced across several steps along the process to develop monitoring options. In the first instance, identified levels of risk drive decisions on which species, habitats or ecological components to exclude from the development of targeted monitoring activities on the basis that priority should be given to monitoring those species, habitats or ecological components identified at being at higher risk. Such identified levels also drive decisions on which ecological parameters should be prioritised with a preference for those that respond specifically to relevant pressures. However, it is not valid to assume that habitats, species and ecological components at high risk from pressures will automatically be those with the greatest monitoring requirements. For example, greater resources are needed to elucidate impacts of pressures on those components that are resilient, than on those that are highly

sensitive because the magnitude of the effect on the former is much smaller and may only become apparent at a much later stage, and therefore is more difficult to detect.

At the sampling stage, a risk-based approach may also be valid as it can drive decisions on where to focus sampling. For MSFD requirements this would entail prioritising monitoring in areas where risk is highest; if status in these areas is assessed as good then there is no further need to monitor in areas at low risk. Conversely, if good status is not achieved, then monitoring and assessment should be carried out in a stepwise manner at additional sites along a gradient of risk. Such application of the risk-based approach is appropriate "when the ecologically meaningful scale for variability in environmental conditions and impacts of pressures is relatively small" (Cardoso *et al* 2010). Since this is unlikely to be the case for a large proportion of marine biodiversity, where confidence in available data (pressure, distribution, main environmental drivers) is low, its application requires careful case-by-case consideration.

5.2.2 Current knowledge

Decisions have to be taken in delivering sensible options for monitoring and can only be based on current knowledge and the available evidence base. Available knowledge and evidence, including information on already existing monitoring activities in the UK, will thus be assessed as part of developing the monitoring options. Across the UK marine environment current understanding of biodiversity differs markedly. Some species and habitats having been the focus of targeted research for decades while others are just being discovered. Differences in current knowledge are true of their ecology and distribution as well as of the pressures acting on them. The evidence base upon which decisions will be made is therefore expected to vary. Providing a clear audit trail documenting the decisions made, the results obtained, and in particular what evidence was used and how it was interpreted at every step on the way, will play a major part in applying the Strategy.

The better a system is understood, the greater the confidence in the assessment, and the more the monitoring activities can be streamlined and focused. Once the necessary knowledge for understanding the state/pressure relationship is gained, and we have developed and implemented appropriate management measures for the protection and sustainable management of a habitat or species, the focus of monitoring activities can change or even be reduced.

In the long-term, the application of the Strategy should be reviewed at regular intervals to ensure that its outcomes, i.e. the monitoring options, remain effective. Along with adapting the individual monitoring activities to changing external conditions[5] (i.e. environmental changes, but also changes in funding), the need to amend the monitoring options could also arise. A balance will need to be struck between the need to adapt to such changes and that of ensuring consistency and maintaining key time-series in the long-term.

[5] See Section 2 of the Strategy for further details

6 What to monitor

6.1 Monitoring objectives

Clear quantifiable objectives to fulfil the needs of the relevant policy drivers have to be set for each monitoring activity to be proposed as part of a monitoring option. This provides the basis on which to choose a cost/effective sampling design in 'How to monitor'[6].

Each monitoring activity is designed to answer a specific question; it is necessary to be explicit and specific about which hypothesis will be tested and what statistical approach will be taken to analyse the data. To achieve this, the Strategy proposes to formulate clear objectives by quantifying the following aspects:

- areas/populations to be monitored
- ecological parameter and metric to be measured
- type of change to be measured
- magnitude of change
- desired level of statistical significance
- desired level of statistical power

The above stated objectives are used to design monitoring activities and calculate costs. Different monitoring activities (different survey designs, different methodologies) can then be compared by evaluating how well they achieve their stated objectives against their cost. However, it has to be noted that the true costs of each activity will only emerge once the activity has been put into practise.

6.1.1 Ecological Parameters

Choosing what should be measured requires careful consideration. For biodiversity alone there are over 40 measurements listed in the scientific literature that provide evidence towards its assessment (e.g. Magurran 2004, Bowden & Hewitt 2012) but not all of them are equally valid or practical in driving the design of options. The parameters and indices chosen need to readily and reliably provide evidence suitable for the monitoring objectives. A useful tool to carry out a selection is the Conceptual Ecological Models (CEMs); these are diagrammatic representations of the system of interest (e.g. habitat, region, protected site, etc.) which outline the interactions between key components and ecological processes (Gross 2003). Such models have already been developed by JNCC for shallow sublittoral coarse sediments (Alexander *et al* 2014), shallow sublittoral mud (Coates *et al* in press) and sublittoral rock (Alexander *et al* in press) with further CEMs in the process of being developed. Based on such models, a careful selection of the biodiversity measure(s) appropriate for the particular monitoring activity, should be made.

6.1.2 Type of change and magnitude of change to be measured

Once the parameter(s) has been identified, the hypothesis to be tested has to be made explicit. A change can be measured in different ways: for Type 1 monitoring activities, for example, change will commonly be measured as a trend over time (growth or decline) or as a change in trend over time, but for Type 2 and Type 3 a measure of difference may be

[6] Please note that the monitoring objectives are part of the 'How to monitor' in some of the options already developed, e.g. for the benthic habitats.

sought between different locations that differ in pressure intensity at any one point in time or over the period of time that management is in place.

Next, it is necessary to be explicit on the limits of acceptable change for each chosen parameter because the magnitude of change ('effect size', for example, the decrease in abundance of a species or a biodiversity indicator by 30% over a certain time period) is related to statistical power. Therefore, without setting the former, it is not possible to calculate the latter (see HBDSEG Paper 29.8.2 for more information on statistical inference).

In MSFD language the type of change and magnitude of change are referred to as targets and thresholds respectively.

The choice of appropriate magnitude of change to be measured is not straight forward; it is linked to choice of parameters and type of change to be measured. At present, well established guidelines for setting the magnitude of change to be detected in marine biodiversity monitoring do not exist and thus the focus of further work will be on establishing such guidelines. As examples are collated by applying the Strategy across the different components, the Strategy has aimed to produce guidelines (Marubini 2014) and achieve a degree of consistency across components where appropriate.

6.1.3 Desired level of statistical significance and power

The power of a monitoring programme to detect a magnitude of change depends on a number of factors including the number of samples, the inherent variability in the system monitored (high variance in a system leads to low power) and the magnitude of the change occurring (Wilding *et al* 2015). In a system exhibiting low inherent variability it will require only limited sampling effort to detect a large magnitude of change; whereas the reverse applies in a system showing high variability. In such a system it will be difficult to detect a small effect (Di Stefano 2003), and it may even be difficult to detect a large one.

Within the context of this paper we give only a short proposal of how to set levels of statistical significance and power; for more details please refer to Marubini 2014.

The level of significance is the critical probability level chosen *a priori* to hypothesis testing to accept a result of a study to be true. Studies with highly significant results give greater assurance that the result obtained could not be obtained purely by chance. The statistical power of a monitoring programme is the probability that the monitoring will detect a statistically significant change in the data despite the 'noise', i.e. natural variability, in the system. Studies with low power can only detect large changes, if any at all, because there is a high probability that no significant differences would be detected even if they existed.

There is an inverse relationship between significance and power. Given a set amount of resource to maximise sample size, setting the level for significance, will determine power; for example choosing a more lenient level of significance will result in increased power (and *vice versa*). The ratio of significance and power represents the balance between the power of a monitoring activity to detect a change of a given magnitude, and the level of significance at which the change is tested, i.e. how likely it is that the observed change is a true effect. Thus deciding on what is the appropriate ratio between significance and power is essential in monitoring design.

In designing a programme for marine biodiversity monitoring, a case has been made to vary the levels of significance and power from what is often chosen by convention (i.e. significance is conventionally set to 0.05 and power to 0.80) and to set them according to the monitoring types and associated objectives. This is done in two stages; firstly, the

consequences of a study with either low significance or low power are evaluated. This is done in terms of costs involved to stakeholders and to biodiversity. According to the objectives of the monitoring programmes the ratio between power and significance is then set to reflect the resulting costs. Secondly, a consideration of the cost of monitoring is introduced as part of the design and planning process.

In order to evaluate consequences, and set levels for significance and power, it is necessary to refer to the two functions of monitoring. In principle we expect that monitoring activities carried out to identify state and the need for management measures (primarily Type 1 monitoring) should maximise power rather than significance and at least apply the same level of probability for both significance and power. A relatively lenient level of significance (significance level set to 0.2) can be applied to minimise monitoring costs because a study with high power can detect relatively small changes without requiring a big sampling effort. When monitoring activities are undertaken to identify if management measures are being effective (Type 3 monitoring), we expect the ratio of significance and power to vary from case to case according to how costs to stakeholders and biodiversity are perceived. In this case, direct consultation with stakeholders at the outset should be favoured to ensure that a close link between evidence and management exists.

7 How to monitor

7.1 Evaluating cost-effectiveness of monitoring activities

In the first instance, current monitoring activities need to be evaluated in terms of how well they satisfy the objectives arrived at (e.g. ecological parameter and metric to be measured; see section 6.1). Whenever the objectives are not fully achieved, it is then necessary to explore different sampling designs and compare their cost/effectiveness.

Choice of sampling design includes consideration of when and where samples should be taken, but also about what sampling method should be used (if several comparable ones are available) and what survey platform should be adopted. The level of detail which needs to be applied at the stage when options are proposed will undoubtedly be less than when an option is selected and a programme enters into the operational phase. It would be inappropriate and extremely time consuming to plan in full detail surveys and operational protocols for monitoring activities that may never be chosen. Therefore, at this stage cost and effectiveness can only be estimated.

7.2 Sampling design

The Strategy provides guidance on the main principles to follow when choosing a sampling design. While an *ad hoc* design may be necessary in a few cases, it is appropriate to provide guidance for the most common designs and thus enhance consistency.

Within a spatial context, the need to create a monitoring programme that is well integrated and coordinated will also have practical implications. When either two or three monitoring types are chosen for the same ecological parameter, the approach taken to design sampling should aim to ‘nest’ the more discrete temporal/spatial scale into the broader one (e.g. Monitoring pressure-state relationships nested within Monitoring long-term trends). The term

'nest' is used primarily here in a conceptual way, i.e. from the point of view of interpretation of the results, and it is valuable to interpret the results together. If the conditions are right, all efforts should be made to create a nested design in the statistical sense of the word. This would allow a much more powerful set of statistical analyses to be carried out then if the studies where analysed independently. Furthermore, this approach is likely to improve consistency from sampling to statistical analysis with further gains. This approach is particularly relevant to the monitoring of Marine Protected Areas (MPAs) which need to be monitored in their own right, but which represent only specific locations within the natural range of the habitat or species in question. It would be highly inefficient to create separate monitoring programmes for MPAs and for the same features in the wider environment; 'nesting' of MPA monitoring within that required for wider environment for the same features will be far more efficient.

In order to test the effectiveness of management measures in MPAs, potential changes in state within the MPAs need to be compared to the state of the same features in the wider environment. Therefore, the Strategy strives to ensure integration between monitoring within sites and the wider environment so that the overall assessment of biodiversity, i.e. assessing Good Environmental/Ecological or Favourable Conservation Status can benefit. Any monitoring activity planned within MPAs should be set up as an integral part of the overall monitoring of the wider environment for the habitat or species in question. For Type 1 monitoring of long term change, sampling restricted to within MPAs only will represent only part of the range of the ecological component being monitored. When Type 2 or Type 3 monitoring are required to understand the cause of change, sampling within MPAs can be dual purpose; to provide evidence of the effect of that particular pressure applicable more widely, and also to provide evidence of state within the particular MPA. Therefore, it should be prioritised within MPAs whenever appropriate.

8 Development of monitoring options

The final design stage organises monitoring activities into different sets; each of them representing a monitoring programme option. Each option differs in how far it succeeds in meeting the policy aspirations and legal obligations that were set at the onset of the design process. They also differ in the amount of resources needed to make them operational. The number of options to be provided may differ between components. In principle, the option of *status quo* should always be included to make explicit the costs and implications in terms of meeting our legal requirements from current monitoring activities.

As part of the UK Marine Biodiversity Monitoring R&D Programme, JNCC are applying the Strategy to arrive at monitoring options for the individual ecological components (habitats and species) in its remit.

9 Implementation of the UK Marine Biodiversity Monitoring Strategy

Once monitoring options for the ecological components are developed, and integration across components considered, the appropriate bodies will need to decide which of the proposed monitoring activities to take forward and to implement. Ideally this step would be completed when all the monitoring options are provided, to enable consideration of costs and benefits fairly across all ecological components. However, due to the different pace at which monitoring options can be completed, this will need to be an iterative process. Indications are that the greatest benefits from integration of monitoring between ecological components will be achieved by considering options for mobile species (cetaceans, seabirds, seals) together. Integration of targeted monitoring for mobile species with that for seabed habitats is unlikely to yield significant improvements in efficiency due to the different survey methodologies required (O'Connor, Dunn & MacLeod, in prep). Determination of which monitoring option to implement will not be a purely scientific decision. It will involve consideration of an acceptable level of risk of damage to biodiversity if changes are not monitored sufficiently, to enable timely management decisions to be made, set against the cost to society of obtaining better evidence for such decision making.

Once an option is selected, the next step in the process consists of detailed planning of the particular monitoring activities (e.g. decisions on areas, gear types, choice of sampling platform, ship time and staff). It is at this stage where practical integration of the monitoring activities through collaboration with other agencies (sharing of ship time, gear, and staff), other monitoring activities and also with marine industries, NGOs and volunteer monitoring schemes (such as exist already successfully for bird and cetacean monitoring) can be addressed in more detail.

References

Alexander, D., Coates, D. A., Tillin, H. & Tyler-Walters, H. In press. Conceptual Ecological Modelling of sublittoral rock habitats to inform indicator selection. To be published as a JNCC report.

Alexander, D., Colcombe, A., Chambers, C. & Herbert, R.J.H. 2014. Conceptual Ecological Modelling of shallow sublittoral coarse sediment habitats to inform indicator selection. *JNCC Report*, No. 520. 46 pp.

Bowden, D.A.& Hewitt, J. 2012. Recommendations for surveys of marine benthic biodiversity: outcomes from the Chatham-Challenger Ocean Survey 20/20 Post-Voyage Analyses Project. New Zealand Aquatic Environment and Biodiversity Report, No.91. 34p.

Brown, A. 2000. Habitat monitoring for conservation management and reporting. 3: Technical guide. Bangor: CCW.

Coates, D.A., Alexander, D., Stafford, R. & Herbert, R.J.H. In press. Conceptual Ecological Modelling of shallow sublittoral mud habitats to inform indicator selection. To be published as a JNCC report.

Cardoso, A.C., Cochrane, S., Doemer, H., Ferreira, J.G., Galgani, F., Hagebro, C., Hanke, G., Hoepffner, N., Keizer, P.D., Law, R., Olenin, S., Piet, G.J., Rice, J., Rogers, S.I., Swartenbroux, F., Tasker, M.L.& van de Bund, W. 2010. Scientific Support to the European Commission on the Marine Strategy Framework Directive. Management Group Report. EUR 24336 EN e Joint Research Centre. Office for Official Publications of the European Communities, Luxembourg. 57 pp.

Davies, J., Baxter, J., Bradley, M., Connor, D., Khan, J., Murray, E., Sanderson, W., Turnbull, C. & Vincent, M. 2001. Marine monitoring handbook. JNCC: Peterborough

Defra. 2002. Safeguarding Our Seas – A Strategy for the Conservation and Sustainable Development of Our Marine Environment, 80pp, ISBN 0 85521 005 2.

Defra. 2005. Safeguarding Sea Life – The joint UK response to the Review of Marine Nature Conservation, 40pp.

De Jonge, V.N., Elliott, M. & Brauer, V.S. 2006. Marine monitoring: its shortcomings and mismatch with the EU Water Framework Directive's objectives. Marine Pollution Bulletin, 53(1), 5-19.

Di Stefano, J. 2003. How much power is enough? Against the development of an arbitrary convention for statistical power calculations. *Functional Ecology,* **17**: 707-709.

Gross, J.E. 2003. Developing conceptual models for monitoring programs. On-line at http://science. nature. nps. gov/im/monitor/docs/Conceptual_Modelling. pdf.

JNCC. 2004. Common standards monitoring - introduction to the guidance manual. Available from: http://jncc.defra.gov.uk/page-2268. [Accessed 10/06/2015].

Hawkridge, J., Connor, D., Mitchell, I., Crutchfield, Z., Crick, M., Tasker, M. & Reid, J. with comments from the Country Agencies. Update on the UK Marine Monitoring and Assessment Strategy (UKMMAS) June 2008. JNCC 08 (N04), pp13.

Lindenmayer, D.B. & Likens, G.E. The science and application of ecological monitoring. Biological Conservation. 2010. doi:10.1016/ j.biocon.2010.02.013.

Magurran, A.E., Baillie, S.R., Buckland, S.T., Dick, J.M., Elston, D.A., Scott, E.M., Smith, R.I., Somerfield, P.J. & Watt, A.D. 2010. Long-term datasets in biodiversity research and monitoring: assessing change in ecological communities through time. Trends in Ecology & Evolution, 25(10), 574-582.

Marubini, F. 2014. Levels of statistical significance and power in marine biodiversity monitoring. HBDSEG paper 29.1.2, presented to HBDSEG 29, London, 5-6 Feb 2014.

O'Connor, J., Dunn, T. & MacLeod, K. In prep. Compatibility of offshore seabed habitat survey methods with seabird, cetacean and plankton monitoring surveys. JNCC, Peterborough.

Portmann, J.E. 2000. Review of Current UK Marine Observation in relation to present and future needs. Interagency Committee for Marine Science and Technology, publ. No 7.

Vos, P., Meelis, E. & Ter Keurs, W.J. 2000. A framework for the design of ecological monitoring programs as a tool for environmental and nature management. Environmental monitoring and assessment, 61(3), 317-344.

Wilding, T.A., Nickell, T.D., Hughes, D.J., Narayanaswamy, B.E., Burrows, M.T. & Hausrath, J. 2015. Statistical advice to the Marine Habitats Monitoring project under Framework Agreement C10-206-0387. *JNCC Report*, No. 545, JNCC, Peterborough.

Annex I: Version Control

BUILD STATUS:

Version	Date	Author	Reason/Comments
2.0	18 Dec 13	FM	First draft of the new version of the Strategy.
2.1	11 Feb 14	FM	Revised section 2.1; minor changes to Functions to incorporate HH comments on HBDSEG stats paper; ecol component section has been moved above monitoring objectives;
2.2	13 Feb 14	FM	Added section 'the design stage'; changed large chunks of what to monitor and how to monitor.
2.2pb	13 Feb 14	FM	Polished version of 2.2 (removed comments and left only introductory paragraph in section on ecological parameters)
3.0	26 Jun15	KKR	Revised version of 2.2pb; comments from SNH, NE and Defra addressed. Changes according to comments from CJ, JH, HH, JW, SP. Added: diagram showing the relationship between the main drivers, the Strategy and the implementing bodies (Fig. 1), section on implementation of strategy and annex with list of monitoring options for the ecological components and their state of progress
4.0	27 Aug 2015	KKR	Revised version of 3.0; comments from Defra, HBDSEG forum, Roger Proudfoot and DoENI addressed. Main changes: Section 2 : first section incl. Fig 2 & 3 removed; Section 3 Definition of term 'monitoring': shortened and summarised Section 4 Requirements for evidence: mainly moved to Section 1
4.1	11 Feb 2016	KKR	Edit and address remaining comments by CJ

DISTRIBUTION:

Copy	Version	Issue Date	Issued To
Electronic/ Paper/Link	2.0	18 Dec 13	Circulation is limited to CJ to receive early input into the structure; colleagues in Monitoring Programme are cc'ed for info.
Electronic/ Paper/Link	2.2pb	13 Feb. 14	Sent to CJ for circulation to Programme Board as work in progress
Electronic/ Paper/Link	3.0	24 Jun 15	Circulation within and presentation to JNCC colleagues
Electronic/ Paper/Link	3.0	26 Jun 15	Submitted to HBDSEG to be presented at HBDSEG 33 (08/09 July 2015)

Electronic/ Paper/Link	4.1	11 Feb 16	Submitted to UK Marine Biodiversity Monitoring R&D Programme Board and HBDSEG as working version to be included on JNCC website