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Reviewing and Recommending Methods for Determining Reference Conditions for Marine Benthic Habitats in the North-East Atlantic Region

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Summary

The Marine Strategy Framework Directive (MSFD) (2008/56/EC) establishes a framework to protect and conserve Europe‟s marine environment with the overall aim of promoting sustainable use of the seas and conservation of marine ecosystems. To achieve this aim, the MSFD identified the achievement of „Good Environmental Status‟ (GEnS) as a key objective for marine biodiversity. Annex 1 to the Directive describes 11 qualitative descriptors that define the biological, physical and chemical characteristics of GEnS. Of these, two descriptors (D1 – Biological diversity is maintained and D6 – Seabed integrity) have been identified as important for the protection of marine benthic habitats in the North-East Atlantic.

A key step towards achieving GEnS is the establishment of environmental baselines and targets enabling the state of the marine environment to be evaluated on a regular basis. Within the MSFD, the preferred baseline against which GEnS should be assessed is the „reference condition‟ which is "a state at which impacts from anthropogenic pressures are negligible" (OSPAR, 2011b). Set against this reference condition, robust targets for achieving GEnS can be set in an ecologically meaningful manner because they do not adopt an already degraded environmental state as an acceptable baseline.

There are a number of different approaches to setting reference conditions which have been discussed and applied in a number of previous conservation measures, particularly the Clean Water Act in the US and the Water Framework Directive (WFD) in Europe. The main methods identified are:

- Existing reference condition
- Historical reference condition
- Modelled reference condition
- Expert judgement

Existing reference conditions are only relevant to the intent of the MSFD where a habitat shows minimal or no ecological effects resulting from anthropogenic activities. For example, subsistence collecting of bivalves on a muddy shore can continue for decades, but at a level that does not have a significant impact on the ecological functioning of the habitat. Such a habitat would represent reference conditions even though it had been subject to long-term human activities, because the impacts are negligible.

Finding marine habitats in reference condition in the North-East Atlantic is rare; several centuries of human activity have had an impact on most marine ecosystems. Where existing reference conditions cannot be found, the historical reference condition, which uses data collected at a time when impacts from human activities were negligible, may be used instead. Historical data, both quantitative data and descriptive information, can be found from a wide range of sources. Quantitative data, collected prior to human impacts, can provide a good indication of the reference condition. Where data are qualitative careful review and interpretation can provide insights into the conditions that existed prior to extensive human disturbance.

Where both existing reference conditions and historical reference condition data are not available or are inadequate, modelling approaches may be important. Statistical modelling, such as hindcasting and predictive modelling, which has had wide application to setting reference conditions for fresh and marine water bodies, can be used. There are also less widely used modelling approaches that may prove useful in determining or refining reference conditions in benthic habitats. These include palaeoreconstruction, ecosystem reconstruction and habitat suitability modelling.

The importance of expert judgement in all aspects of setting reference conditions has been highlighted in the implementation of the WFD. Where existing reference condition habitats or historical data cannot be found, and modelling approaches have not been developed, the use of expert judgement may be the only realistic way to determine reference conditions. In particular, panels of experts can use recent or current monitoring data to estimate reference conditions. Whilst this approach has been widely used in the WFD, it is recognised that the task is problematic. In particular, it requires careful interpretation to ensure reference conditions are not set at an already degraded „current state". Even where data are good, expert judgement is recognised as an integral part of all approaches to setting reference conditions.

A Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis identified the Existing Reference Condition approach as the ideal method for setting reference conditions. However, with an absence of known marine benthic habitats in existing reference condition other approaches are required. The SWOT analysis indicates alternatives should be selected in the following order of preference: historical, modelled and expert judgement. In many cases a combination of methods is often the most appropriate approach, depending on the nature of the habitat and the data available to support the process. A brief analysis of the historical changes and the data available to determine reference conditions was undertaken for each of the benthic habitats specified. This analysis was then used to recommend the most appropriate method, or combination of methods, for setting reference conditions for the criteria from GEnS Descriptors 1 and 6 (as identified in the Commission Decision 2010/477/EU).

For the criteria of habitat distribution, extent and physical damage a number of different approaches to the setting of reference conditions were appropriate, depending on the nature of the habitat. For those habitats where there has been no record of habitat loss due to human activities a combination of existing reference condition and expert judgement was found to be the best approach. For habitats where declines are known to have occurred as a result of human activity, reference conditions should be set using the existing and historical reference condition approach combined with expert judgement. For both approaches, the fewer data there are the more important the role of expert judgement. There are data from habitat suitability mapping programmes for many habitats. For some habitats, such as saltmarsh, seagrass beds and some deep sea habitats spatial modelling approaches are particularly important to improve reference condition data. For other habitats, however, particularly biogenic structures and those in deeper waters such as deep-sea sponge aggregations and carbonate mounds, data on distribution, extent and physical damage is much more sparse and further survey work may be required to set robust reference conditions. Although this may not be possible within current MSFD budgets and timescales reference conditions can be continually refined and updated as new information becomes available. However, the revision of targets will complicate the interpretation of sequential assessments and so where required, additional data collection should be carried out as soon as possible.

The recommended method for setting reference conditions for the biodiversity criteria of habitat and benthic condition is the use of expert opinion in combination with whatever suitable data are available. There were no specific areas of benthic habitats identified to be in reference condition for the biological criteria in the North-East Atlantic. Although it was recognised that reference conditions may exist for some habitats, such as those in the deep sea, data are often inadequate and additional research is required. The historical reference condition approach was also not often applicable; only the most accessible and commercially important benthic habitats have been the subject of detailed historical biological and ecological studies. Thus, for the majority of habitats there is no pre-impact biological data that can be used to set reference conditions. Finally, whilst some general ecological models do exist, no robust modelling approaches for determining biological condition criteria were identified. There may be locally available models for some habitats that can be identified by expert panels. Generally, the only source of data available for setting biological quality reference conditions comes from recent monitoring and research projects. However, data availability for the range of habitats the MSDF seeks to address is fragmentary and so where it is not possible to collect new data expert judgement will be the most important sole means of determining reference conditions. Expert judgement will be particularly important in ensuring the use of current state data does not result in the setting of the baseline at an already accepted state of degradation rather than the true reference condition. Systematic engagement of the research community in these issues may allow better reference conditions to be developed. However, as the experience of the WFD has shown, it is possible to estimate reference conditions for a wide range of habitats on the basis of the best available scientific knowledge and that such values can be reviewed as understanding grows.

This report has highlighted the important role expert judgement is likely to play in setting reference conditions for MSFD benthic habitats, both as the sole method and to supplement other approaches. Whilst expert knowledge is widely used in the science and implementation of conservation, there are concerns regarding its use, particularly the belief that judgements will be biased and poorly calibrated leading to poor inference and decision making. It is, therefore, recommended that in instances where expert judgement is used as the sole method to define reference conditions for benthic habitat criteria within the North-East Atlantic, a structured process such as that presented in the report, is adopted. These expert elicitation methods aim to improve the accuracy of expert judgement by reducing bias and dealing with uncertainty.

Contents

Glossary of acronyms

BGS	British Geological Survey
Cefas	Centre for Environment, Fisheries & Aquaculture Science
CSM	Common Standards Monitoring
CWA	Clean Water Act (US)
D	MSFD Descriptor
Defra	Department of the Environment, Fisheries & Rural Affairs
EA	Environment Agency
GEnS	Good Environmental Status (MSFD)
GEcS	Good Ecological Status (WFD)
HD	Habitats Directive
ICES	International Council for the Exploration of the Seas
ICG-COBAM	Intersessional Correspondence Group on Biodiversity Assessment and Monitoring
MS	Member State
MSFD	Marine Strategy Framework Directive
NEA	North-East Atlantic
OSPAR	Oslo-Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
SAC	Special Area of Conservation

1 Introduction

1.1 Background

The Marine Strategy Framework Directive (MSFD) (2008/56/EC) establishes a framework for the protection and conservation of Europe‟s marine environment with the overall aim of promoting sustainable use of the seas and conserving marine ecosystems.

In order to achieve this aim the MSFD has identified the achievement of „Good Environmental Status" (GEnS) as a key objective for marine biodiversity. Annex 1 to the Directive describes 11 qualitative descriptors, covering a number of biological, physical and chemical aspects of the marine environment. Member States must select the most appropriate descriptors for the determination of the characteristics of GEnS for their marine region[1]. The MSFD has established four European Marine Regions, based on geographical and environmental criteria: the Baltic Sea; the North-East Atlantic Ocean, the Mediterranean Sea and the Black Sea. The North-East Atlantic is further divided into five smaller sub-regions (Fig. 3) of which the waters of the Greater North Sea, Celtic Seas and the wider Atlantic are of particular importance for the UK.

Descriptors 1, 2, 4 and 6 are most directly relevant to the maintenance of biodiversity (OSPAR, 2011a) and are therefore generally known as the „biodiversity descriptors‟. For example, Descriptor 1 states that „*Biological diversity is maintained. The quality and occurence of habitats and the distribution and abundance of species should be in line with prevailing physiographic, geographic and climatic conditions*‟. This descriptor is recognised as one of the key elements of the MSFD. Achieving the objectives of the biodiversity descriptors requires the development of robust methods for monitoring and assessing the status of marine biodiversity, now and in the future, that can be applied at regional and sub-regional scales.

The condition of the environment can be considered as a graduation from unimpacted „natural" conditions to a destroyed or an irrecoverable state (Fig. 1). As part of the process of being able to assess condition, it is necessary to develop both baselines and targets against which subsequent states can be compared and therefore, assessed. Determining the „baseline conditions" for marine habitats is a fundamental precursor to the generation of robust environmental targets, and the subsequent assessment of the current status or condition of marine habitats in relation to these targets.

Within the MSFD a baseline is defined as a point against which good environmental status can be assessed (OSPAR, 2011b). However, a baseline can be set at a number of different states or points in time including current or past baselines (Fig. 2). Setting a baseline at current or past (e.g. 1980s) conditions often encompasses a degree of deterioration from unimpacted conditions and is also at risk from the problem of „shifting baselines" (Pauly, 1995; Dayton *et al.*, 1998). Baselines can shift because as ecosystems are degraded, each successive generation accepts a lower standard as normal, informed by their own personal observations of the world around them. Thus, the current view of what a healthy ecosystem should look like will be biased towards an impacted state because that is all we have ever experienced. Past states are often set in relation to the inception of an environmental policy or the first data point in a time series and so are also likely to reflect a degree of degradation. However, pristine conditions are largely unknown for most marine habitats as major human-induced alterations of ecosystem functioning, particularly in relation to the development of

[1] When a Member State considers that it is not appropriate to use one or more of those descriptors, it shall provide the Commission with a justification in the framework of the notification made pursuant to Article 9(2).

industrial fisheries, date back almost 200 years (e.g. see Pauly *et al.*, 2005; Lotze *et al.*, 2005; Airoldi & Beck, 2007). Instead, a baseline can be set as a reference condition, i.e. a condition which reflects a state at which impacts from anthropogenic pressures are absent or negligible (Box 1.)

Box 1. Definition of reference condition.

Reference Condition
A state at which impacts from anthropogenic pressures are absent or negligible

The concept of „reference condition" has been recognised to provide a means by which baselines and targets can be set in a more ecologically meaningful manner because it does not adopt an already degraded state as an acceptable baseline (OSPAR, 2011a).

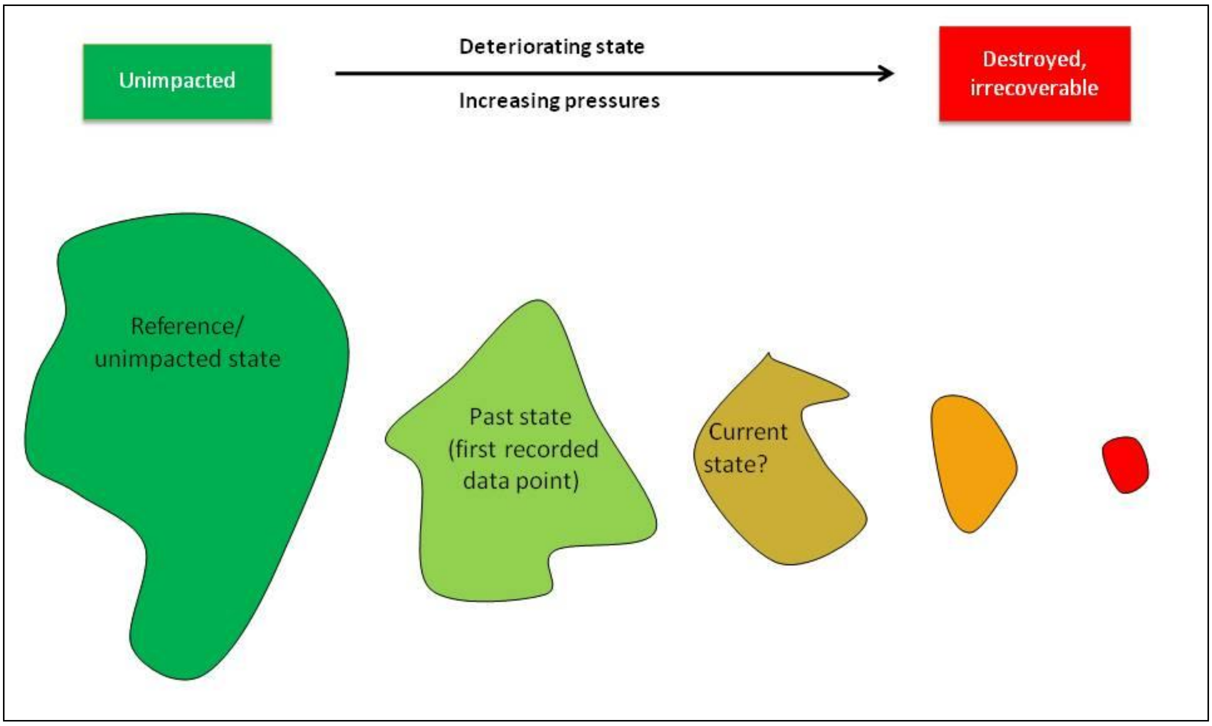

Figure 1. Illustration of how a deterioration in state over time, associated with increases in pressures and impacts, can include changes in both quality (e.g. of a habitat or population of a species) and quantity (e.g. habitat extent, population size) of a biodiversity component. Setting the baseline as 'current state' represents a very different scenario to using 'past state' or 'reference state'. Figure from Moffat *et al.*, 2011.

This definition of reference condition has also been applied to the development of baselines and targets for the EU Water Framework Directive (WFD) (Wallin *et al.*, 2003; European Commission, 2011) and the US Clean Water Act (CWA) (Gibson, 2000; Gibson *et al.*, 1996).

The use of reference condition is considered the most approprite for setting baselines for benthic habitats for the GEnS criteria and indicators set out in the Commission Decision (2010/477/EU) (OSPAR, 2011b). For seabed habitats this means a reference condition should be identified that reflects a state that corresponds to no or negligible impact from pressures, both direct (e.g. physical abrasion) and indirect (e.g. removal of typical species).

The definition of GEnS (i.e. the actual environmental target value, see Fig. 2) can then accommodate a level of deviation from such reference conditions, in terms of quality and the proportion of seabed habitats required to be at that quality. Setting targets for GEnS at a deviation from reference conditions will accommodate continued sustainable use of the marine environment. As applied in other frameworks (e.g. the Water Framework Directive), the reference condition is not necessarily the target, but is the point from which to measure change (Solheim, 2005).

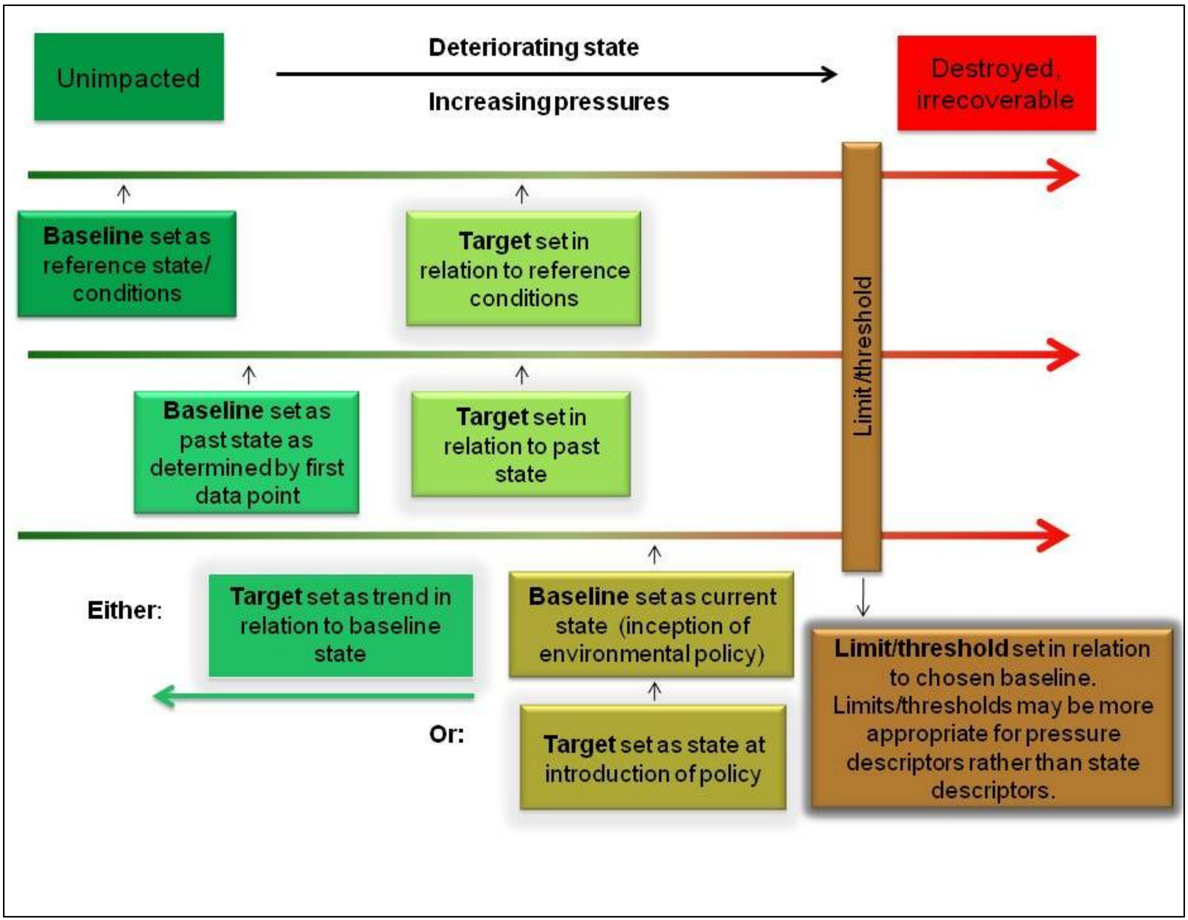

Figure 2. The conceptual relationship between various baseline conditions, targets and limits. Figure from Moffat *et al.*, 2011.

2 Project Aims and Approach

2.1 Aims

The first aim of the project is to identify, describe and evaluate the methods that could be used to set reference conditions for the MSFD biodiversity criteria most relevant to benthic habitats (D1 and D6, Box 2). These descriptors encompass criteria which are most relevant to benthic habitats (Table 1).

Box 2. MSFD biodiversity descriptors of importance to benthic habitats.

Descriptor 1 (D1): Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climate conditions;

Descriptor 6 (D6): Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected.

Table 1. MSFD Good Environmental Status (GEnS) Criteria for assessing habitats, together with an indicative list of indicator classes (adapted from Commission Decision 2010/477/EU).

GEnS Descriptor	Criterion	Indicator classes
1. Biological diversity is maintained	Habitat distribution (1.4)	• Habitat distributional range (1.4.1) • Habitat distributional pattern (1.4.2)
	Habitat extent (1.5)	• Habitat area (1.5.1) • Habitat volume, where relevant (1.5.2)
	Habitat condition (1.6)	• Condition of the typical species and communities (1.6.1) • Relative abundance and/or biomass, as appropriate (1.6.2) • Physical, hydrological and chemical conditions (1.6.3)
6. Sea floor integrity	Physical damage (6.1)	• Type, abundance, biomass and areal extent of relevant biogenic substrate (6.1.1) • Extent of the seabed significantly affected by human activities for the different substrate types (6.1.2)
	Condition of the benthic community (6.2)	• Presence of particularly sensitive and/or tolerant species (6.2.1) • Multi-metric indexes assessing benthic community condition and functionality (6.2.2) • Proportion of biomass or number of individuals in the macrobenthos above some specified length/size (6.2.3) • Parameters describing the characteristics of the size spectrum of the benthic community (6.2.4)

The second aim is to use this evaluation to recommend a specific method or set of methods to set reference conditions for each of the predominant and special (i.e. listed) marine benthic habitats in the North-East Atlantic (Fig. 3, Table 2). This will help establish ecologically meaningful environmental targets for GEnS to be set for benthic habitats in the future within the assessment framework of the EU MSFD.

2.1.1 Geographic scope

The MSFD has established four European Marine Regions, based on geographical and environmental criteria: the Baltic Sea, the North-East Atlantic Ocean, the Mediterranean Sea and the Black Sea. The OSPAR Commission is coordinating the MSFD implementation process within the North-East Atlantic Ocean region.

The geographic scope of this project will focus on the North-East Atlantic OSPAR region (Fig. 3), which includes some waters outside MSFD competence (i.e. Norway, Iceland and areas beyond national jurisdiction); and excludes some waters under MSFD competence (i.e. the Baltic Sea, the Mediterranean Sea and the Black Sea).

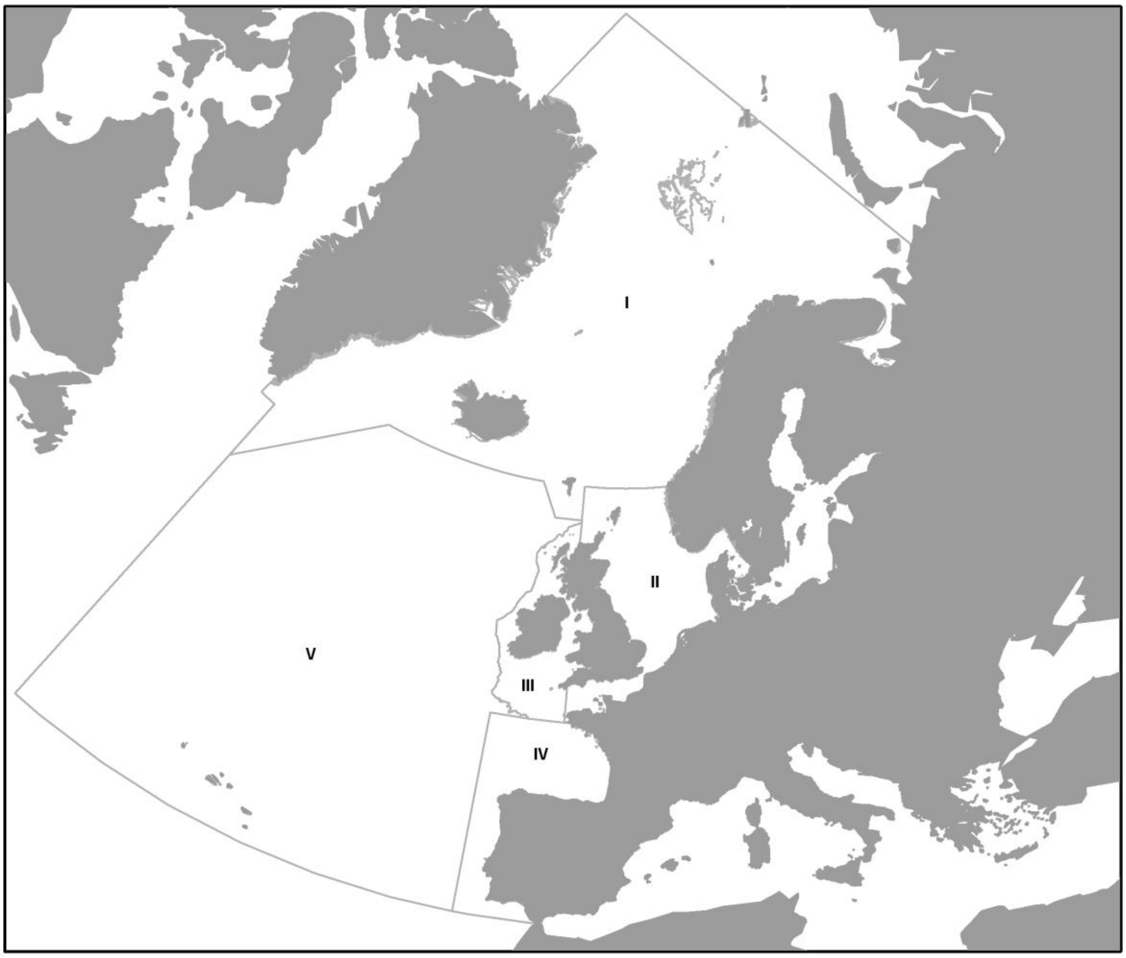

Figure 3. The North-East Atlantic: Region I – Arctic waters, Region II – Greater North Sea, Region III – Celtic Seas, Region IV – Bay of Biscay & Iberian Coast, Region V – Wider Atlantic. Data source: JNCC.

2.1.2 North-East Atlantic Habitats

The habitats covered by the MSFD Biodiversity Descriptor are:

- Predominant habitat types
- Habitats listed under Annex I of the Habitats Directive (special habitats under MSFD)
- OSPAR threatened and/or declining habitats (special habitats under MSFD)

Habitats found within transitional waters, such as estuaries, are outside the scope of the MSFD (Moffat *et al.*, 2011).

Table 2. North-East Atlantic Habitats covered by MSFD biodiversity descriptors.

Habitat group	Habitat
Predominant habitats	Littoral rock and biogenic reef Littoral sediment Shallow sublittoral rock and biogenic reef Shallow sublittoral coarse sediment Shallow sublittoral sand Shallow sublittoral mud Shallow sublittoral mixed sediment Shelf sublittoral rock and biogenic reef Shelf sublittoral coarse sediment Shelf sublittoral sand Shelf sublittoral mud Shelf sublittoral mixed sediment Bathyal (slope/upper) rock and biogenic reef Bathyal (slope/upper) sediment Bathyal (mid/lower) rock and biogenic reef Bathyal (mid/lower) sediment Abyssal rock and biogenic reef Abyssal sediment
Habitats Directive Annex I habitats	Sandbanks which are slightly covered by seawater all the time Mudflats and sandflats not covered by seawater at low tide Coastal lagoons Large shallow inlets and bays Reefs Submarine structures made by leaking gases Submerged or partially submerged sea caves Annual vegetation of drift lines *Salicornia* and other annuals colonising mud and sand *Spartina* swards (*Spartina maritimae*) Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*) Mediterranean and thermo-Atlantic halophilous scrubs
OSPAR threatened and/or declining habitats	Carbonate mounds Coral gardens *Cymodocea* meadows Deep-sea sponge aggregations Intertidal *Mytilus edulis* beds on mixed and sandy sediments Intertidal mudflats Littoral chalk communities *Lophelia pertusa* reefs Maerl beds *Modiolus modiolus* beds Oceanic ridges with hydrothermal vents/fields *Ostrea edulis* beds *Sabellaria spinulosa* reefs Seamounts Seapen and burrowing megafauna communities *Zostera* beds

2.2 Approach

2.2.1 Literature review

A desk-based review was carried out to identify and describe the existing approaches and methodologies which could be used to define reference conditions for the MSFD D1 and D6 criteria of habitat distribution, habitat extent, habitat condition, physical damage and benthic community condition (Table 1).

Consideration was given to novel approaches of determining reference conditions, including those in the early stages of development. The review included literature and guidance documentation underpinning national and international assessments of biodiversity and environmental status, in particular the EC Water Framework Directive (WFD) (2000/60/EC) and the US Clean Water Act (CWA, 1977), together with a significant number of peer-reviewed journal papers addressing the issues.

2.2.2 Evaluation of methodologies

Each of the methodologies identified for defining reference conditions was evaluated using a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis.

The SWOT analysis considers a number of factors, both internal and external to the method. The strengths and weaknesses are internal to the method, providing an evaluation of the method itself, regardless of practical constraints. Opportunities and threats are external to the method, which relate to the practical use of the method for setting reference conditions, specifically for benthic marine habitats in the North-East Atlantic. This considers real-life constraints to the use of each method such as the practicality of the method, the deadlines to be achieved and data availability.

Each method is considered against the criteria for the internal and external factors given in Table 3. The scientific robustness of the technique is considered to be particularly important factor in the overall assessment of the methods and so has been given a higher weighting (x2) than all the other factors.

Each factor is scored, from 1 to 3 (or 2 to 6 for scientific robustness), on the basis of the balance between the strengths and weaknesses or opportunity and threats as follows:

Score	Balance of evaluation
1	Only weaknesses/threats have been identified
2	Both strengths/opportunities and weaknesses/threats have been identified
3	Only strengths/opportunities have been identified

The factor scores are then summed to give a total per method that can give an indication of the preferred methods for North-East Atlantic benthic habitats in general. The total for internal factors indicates the preferred method in theory, whilst the total for the external factors indicates the likelihood that a method can be applied to marine benthic habitats in the North-East Atlantic.

Table 3. Scoring criteria for evaluation of methods for setting reference conditions.

<table>
<tr><th rowspan="10">Factors</th><th rowspan="5">Internal</th><th></th><th>Strengths</th><th>Weaknesses</th></tr>
<tr><td>Scientific robustness</td><td>• Tried and tested scientific techniques
• Easily replicated
• Statistically testable
• Reflects natural variability and current physiographic and climatic conditions</td><td>• High risk of bias and uncertainty
• Outputs difficult to validate</td></tr>
<tr><td>Transparency & Comprehensibility</td><td>• Understood by local, national and international stakeholders
• Easy to explain to a lay-audience even if the method itself is complex</td><td>• Difficult to understand and reproduce, requiring considerable explanation or use of illustrative examples</td></tr>
<tr><td>Confidence</td><td>• Method used with demonstrable success and validity
• Produces consistent results that can represent reference conditions
• Accurate outputs</td><td>• Method that is scientifically untested or gives inconsistent results
• Uncertainty in producing valid reference conditions</td></tr>
<tr><td>Data requirements</td><td>• Very little data required</td><td>• Very data hungry</td></tr>
<tr><th rowspan="4">External</th><th></th><th>Opportunities</th><th>Threats</th></tr>
<tr><td>Applicability</td><td>• Method applied to similar habitats to NEA benthic habitats
• Applicable across geographical boundaries</td><td>• Methods not tested for use in benthic habitats
• Highly site or region specific</td></tr>
<tr><td>Practicality</td><td>• Methods fully developed and easily applied within available timescales
• Straightforward approach that can be applied within a reasonable timeframe by different scientists</td><td>• Data cannot be used without considerable interpretation by experts
• Requires considerable development and testing for application to benthic habitats</td></tr>
<tr><td>Data availability</td><td>• Data readily available or easy to collect</td><td>• Data required for method rarely available</td></tr>
</table>

2.2.3 Recommending approaches for North-East Atlantic benthic habitats

The results of the SWOT analysis will indicate a hierarchy of choices of methods that can be used to set reference conditions. The results of the analysis of internal factors indicates the preferred method in „an ideal world" whilst the external factors indicate the general applicability of each method to marine benthic habitats in the North-East Atlantic.

Recommending a consistent method for defining reference conditions across all habitats is unlikely to be achievable given issues such as the variation in condition between different habitats, availability of data and the differences in the particular MSFD biodiversity criteria under consideration. The quantity and quality of data available is not the same across all habitats and indicators so it may not be possible to select the same reference condition setting method for all North-East Atlantic habitats.

Therefore, the results of the evaluation of the methods were used to construct a hierarchical decision tree, to provide an aid to selecting the most appropriate method or combination of methods to use in setting reference conditions, depending on the habitat in question, the criteria being considered and the availability of data.

A brief review was conducted for each habitat (see Section 6. Appendices) and applied to the decision tree questions to determine the most appropriate approach, or combination of approaches, for generating reference conditions for the habitats covered by the MSFD in the North-East Atlantic. The results of this review are summarised in Section 4 of this report.

3 Identification and evaluation of methods for determining reference conditions

In order to define reference conditions in a way that can allow the setting of non-shifting baselines, several general methods have been developed through practical experience, both in Europe and further afield. Experience in coastal waters as part of the Water Framework Directive has been particularly useful as the concept of reference condition is similar to that which is envisaged for the MSFD. Case studies from the US, where the Clean Water Act (CWA) has set similar quality objectives for freshwater systems, have also provided useful insights into methods used even though the definition of reference condition here is often more akin to current state, selecting least disturbed habitats (e.g. Gibson *et al.*, 1996). Whilst many of the literature and examples come from the determination of reference conditions for water quality, there are lessons that can be applied to setting reference conditions for benthic habitats.

Determining reference conditions from sites with little or no indication of stressors associated with human disturbance provides ideal reference condition data. In altered landscapes however, such as marine habitats where such sites are few or absent, alternative approaches to setting reference conditions should be employed. Several broad groups of approaches to setting reference conditions have been identified from the literature (e.g. Johnson, 2001; OSPAR, 2011a; Solheim, 2005; Wallin *et al.*, 2003). These approaches are:

(i) Existing reference conditions
(ii) Historical reference conditions
(iii) Modelled reference conditions
(iv) Expert judgement
(v) A combination of methods

3.1 Existing reference conditions

Existing reference conditions can be found only where a habitat is considered to show minimal or no ecological effects resulting from anthropogenic activities. For example, subsistence collecting of bivalves on a muddy shore may have continued for decades, but at a level that is not considered to have had a significant impact on the ecological functioning of the habitat. Such a habitat may be able to provide reference conditions even though it had been subject to long-term human activities.

The use of existing reference conditions should be the preferred approach for setting baselines where it is possible to find current habitats in locations where anthropogenic influences on seabed habitats are negligible (i.e. they are in reference condition) (OSPAR, 2011a; Borja *et al.*, 2012). The existing reference condition method is a scientifically robust basis for setting baselines which involves the straightforward use of survey data although it cannot set reference conditions for the distribution and extent of significantly depleted habitats, such as seagrass and oyster beds.

For the biological quality criteria (habitat and benthic community condition D1.6 and D6.2), the use of existing reference conditions is one of the least contested methods because reference conditions can be determined that include both spatial and temporal natural variability (Solheim, 2005). The use of existing sites of negligible impact also demonstrates reference conditions under current physiographic, geographic and climatic conditions (OSPAR, 2011a). Current physical and climatic conditions may be different to historical conditions and so an existing site with negligible impact will be more representative and incorporate the natural changes that may have occurred. The approach is also relatively transparent and comprehensible and can be easily understood by stakeholders.

The major impediment to the application of this approach is that locating genuinely unimpacted sites in many parts of the North-East Atlantic may be challenging. Human impacts have been changing ecosystems for many years (Lotze *et al.*, 2005; Airoldi & Beck, 2007) and the significant expansion of fisheries since the 1950s has left only the unproductive waters of high seas, and relatively inaccessible waters in the Arctic and Antarctic unaffected (Swartz *et al.*, 2010). Similarly, of 100 European sites selected by the BIOMARE project for long term biodiversity research, only 12 were considered to be reference sites, where human activities have not affected biodiversity to any measurable degree (Feral *et al.*, 2003). Many of these locations are fairly large (e.g. the Isles of Scilly and the Faial-Pico Channel in the Azores) and cover a number of different habitat types. Expert judgement would be required to determine if there is adequate data from these sites to determine reference conditions. If Marine Protected Areas (MPAs) begin to recover, some habitats may ultimately be considered to be in „reference condition‟ (OSPAR, 2011a) but possibly not within MSFD timescales. However, in significantly altered systems other methods are likely to be necessary to establish reference conditions.

The robustness of the existing reference condition approach also depends on the existence of areas of negligible impact containing species and habitats that are the same or very similar to those to be assessed under the MSFD. There may not be reference areas containing the precise species or habitat for which targets need to be set, but it may be possible to use an analogous species or habitats. This approach has been widely applied to streams and lakes in the US, for example using existing reference conditions from paired basins (Buffington *et al.*, 2008). However, assumptions from paired areas or species may not always be correct and so the use of data from the actual marine habitats under consideration should be the priority.

Even where there are still habitats where reference conditions are known to exist, the data required to set reference conditions may be inadequate or completely lacking. This is likely to be true for relatively recently discovered habitats such as seamounts and carbonate mounds where additional surveys of areas with absent or negligible anthropogenic impacts are required to actually define the reference conditions. Additionally, data quality may be lacking in some areas because the focus for monitoring programmes has historically been centred on polluted areas (EC, 2003a). If reference sites are known to exist, new surveys can be easily carried out, though not necessarily within available timescales and budgets. In these instances other approaches will also be required to set appropriate reference conditions.

Table 4. SWOT analysis of the existing reference conditions approach.

			Strengths	Weaknesses	Score
Factors	Internal	**Scientific Robustness**	• Straightforward use of survey data without complicated interpretation • Natural variability can be easily included and current climatic conditions represented		3 x 2 = 6
		Transparency/ Comprehensibility	• Use of survey data makes this method the most clear and transparent • Easily understood by stakeholders		3
		Confidence	• Little uncertainty in application of method	• Uncertainty that approach has identified „true" reference condition	2
		Data Requirements	• Data readily available from survey results	• Large datasets from many sites may be required to cover spatial and temporal variability	2
		TOTAL SCORE FOR INTERNAL FACTORS			**13**
			Opportunities	**Threats**	**Score**
	External	**Applicability**	• Comparable technique that can be used across habitat types and criteria • As MPA network develops more habitats will be protected and so more „reference condition" habitats should become available in time	• Limited availability of suitable habitats in the NEA that are in reference condition • Subjectivity in identifying sites where there is an absence of quantitative human pressure data • Does not allow for historical changes in habitat distribution, extent and physical damage due to human impacts	2
		Practicality		• New data collection may be necessary which can increase economic and time costs of setting reference conditions • Difficult to have confidence in whether the approach has identified „true reference" or „best in available data".	1
		Data availability	• Data quality and quantity can be easily verified	• Very limited data availability because of lack of sites in reference condition	2
		TOTAL SCORE FOR EXTERNAL FACTORS			**5**

TOTAL SCORE FOR EXISTING REFERENCE CONDITIONS	**18**

3.2 Historical reference conditions

Where existing reference conditions do not exist, historical data, describing past biological conditions at a time when impacts from human activities were negligible, may be available for setting reference conditions. Historical data can be found from a variety of sources including old survey data, natural history museum records, university collections, old maps, fishing and whaling records, ship"s logs, kitchen midden data (deposits containing shells, animal bones, and other refuse that can indicate food sources) and other archaeological information. In some cases, even images in early paintings and photographs can provide useful information on the environmental conditions of a particular time period (e.g. see Southward *et al.*, 2005). Careful perusal and interpretation of these types of records can sometimes provide an insight into the conditions that existed prior to extensive human disturbance (Buchary, 2001; Christensen, 2001; Lotze *et al.*, 2010; Thurston & Roberts, 2010).

Some historical data sets are available for setting reference conditions. For example, Houziaux and others (2011) showed how the analysis of historical data allowed a fair reconstruction of the sedimentary environment of the Belgian-Dutch part of the southern North Sea 100 years ago, bringing to light degradation patterns that happened long before scientific data acquisition. This study used a unique unpublished historical data set from sediment and macrobenthos samples and field log-books collected by Gustave Gilson between 1898 to 1939 (Gilson, 1900; 1928). The analysis of long-term changes in the data indicated that major changes in seafloor composition are linked to specific anthropogenic pressures. Studies which quantify such relationships can provide important insights required to set meaningful reference conditions.

This approach provides a moderately scientifically robust basis for setting reference conditions, depending on the quality and quantity of the available data, although expert interpretation may be required. It can be a comprehensible approach, but perhaps less transparent than the previous approach "existing reference conditions" (OSPAR, 2011a), requiring expert explanation of data sources and application. Where historical data are unpublished it may be extremely resource intensive in terms of access, transcriptions and interpretation.

A key advantage of using historical data, whatever the origin, is that it provides motivation to stakeholders as a vision of unimpacted conditions. Where data are adequate, it may also be more cost effective than intensive sampling and can provide a permanent benchmark which is not affected by the issue of shifting baselines (Pauly, 1995; Dayton *et al.*, 1998).

However, historical data alone is rarely adequate for reference condition setting because it cannot account for prevailing physiographic and climatic conditions (OSPAR, 2011a). It may also present other difficulties as many historical benthic data sets are not collected over a prolonged period of time and so do not account for natural ecosystem dynamics and variability which are crucial to the setting of ecologically relevant reference conditions. Thus, a full picture of the historical condition is unlikely to be available for any benthic habitat in the North-East Atlantic. For example, in Denmark, historical records of benthic fauna exist for a small number of estuaries. These were found to be adequate for determining reference conditions (Neilsen *et al*, 2003) although the dataset used, from 1915 – 1917 (Johansen *et al.*, 1918), is largely qualitative. The researchers found that these Danish data gave no indication of temporal or spatial variability.

Historical data will also have been collected for a variety of different purposes, possibly using different methodologies, which may compromise comparisons with current data sets (e.g. see Nijboer *et al.*, 2004). Thus, even good historical data sets are likely to need supplementing with modelled data and/or expert judgement for determining reference conditions. In particular, climatic changes and ecosystem dynamics since the period used as a reference point need to be built into any final definition of the reference condition (OSPAR, 2011a).

In the UK a number of long-term data sets, particularly those collected by marine field stations are available (Frost *et al.*, 2006). Whilst most of these datasets relate to physical, chemical and biological characteristics of the water column or rocky shore surveys (Southward *et al.*, 2005) there are a number of data sets that apply to a few benthic habitat types that could provide historical data to support reference condition setting. For example, intermittent benthic data has been collected by various researchers from the Marine Biological Association in Plymouth, from the western English Channel, starting with the work of Allen in 1895 (Allen, 1899; Capasso *et al.*, 2010). Although some of the data are semi-quantitative, were collected using a variety of different sampling gears, and may not be sufficient to describe natural dynamics, it can certainly provide useful insights into aspects of benthic condition in sediment habitats in this area before major anthropogenic change. This work represented the UK‟s contribution to the International Council for the Exploration of the Seas (ICES) and so there may be similar data sets available in other member states (see Anderson, 2002). In particular, the EU network MarBEF (Marine Biodiversity and Ecosystem Functioning) contains details of several historical datasets and reconstructions in European waters as part of the EU LargeNet project (www.marbef.org/projects/largenet/index.php) which could be useful.

In the middle of the 20th century more scientists started investigating benthic communities, probably in response to a growing awareness of the impacts of increasingly intensive fishing practices. These studies include the well-known work of Holme (1953; 1961; 1966) who studied the benthic fauna of the western English Channel. Studies were also carried out in Italy (Vatova, 1949). Time-series data on the North Sea are also available from the Dove Laboratory although collection only started in 1972. These more recent datasets are likely to provide some insights to benthic condition, and responses to anthropogenic activities, although these studies were carried out in what was likely to have been an already altered environment.

In the UK at least, quantitative historical data on marine benthic ecosystems, of the type collected by Gilson, Johansen and the MBA, are relatively scarce. Where they do exist they are generally focused on conspicuous or commercial species, particularly fish or on aspects of the water column. Data sets are often non-quantitative (Houziaux *et al.*, 2011) although analysis by Muxika *et al.* (2012) has demonstrated that historical species inventories, providing presence/absence data only, could be useful in determining reference condition values for benthic diversity. The use of such data will be determined by the biodiversity indicators selected. Few benthic habitats have survey or monitoring data prior to the major environmental changes in marine systems (Clark & Frid, 2001), particularly in offshore and deep-sea regions.

However, even if historical data are inadequate for direct use in defining the reference condition, they may provide substantial insight into pre-existing conditions of the habitats in question (OSPAR, 2011a). Thus, historical data can be used to improve the characterisation of „reference condition‟ where unimpacted sites are few in number, to supplement modelling exercises (e.g. Nielsen *et al.*, 2003) or inform reconstruction studies (e.g. Lotze & Milewski; Lotze, 2010). In all cases expert judgement will be required to ensure valid interpretations of historical data.

Some case studies involving the use of historical data to supplement other approaches to setting reference conditions have been found for marine habitats. Gaspar *et al.* (2011) used historical data combined with monitoring data and expert judgement to estimate reference conditions for intertidal rocky shores in Portugal. Similarly, Parravicini *et al.* (2011) reported the use of historical descriptions of Mediterranean habitats as reference conditions for the assessment of benthic quality but give little explanation of how this was carried out in practice. The use of historical data was found to have limited application in setting reference conditions for European lakes because of lack of data, data access and compatibility issues (Solheim, 2005).

Historical data sets are likely to be particularly important for the MSFD criteria of habitat distribution and habitat extent, as these may have changed substantially compared with current situations for some habitats. There may also be more historical data on habitat distribution and extent than habitat condition. This issue is addressed more fully for each of the MSFD habitats in Section 6.

Table 5. SWOT analysis of the historical reference conditions approach.

			Strengths	Weaknesses	Score
Factors	Internal	**Scientific Robustness**	• Where data quality and quantity is high the approach is scientifically robust		3 x 2 = 6
		Transparency/ Comprehensibility	• Transparent concept • Motivation to stakeholders: provides a vision of desirable conditions	• Interpretation of historical data less easily understood by stakeholders	2
		Confidence	• Moderate confidence as comparing with past condition	• Documentation of purpose and methods often lacking and lack of compatibility with modern data collection methods	2
		Data Requirements		• For direct setting of reference conditions, significant data are needed to encompass variability	1
		TOTAL SCORE FOR INTERNAL FACTORS			**11**
			Opportunities	**Threats**	**Score**
	External	**Applicability**	• Can provide key insights to historical condition which represents true reference condition	• Difficulty in selection of appropriate time period for determining reference condition • Does not reflect the influence of climate change and so additional data required • Historical biological data may be poorly supported by environmental data	2
		Practicality		• Data mining and interpretation of historical data may be highly time consuming	1
		Data availability	• Some near shore habitats have historical datasets • Often inexpensive to obtain data • Range of data sources available that can give insights to reference conditions	• Very few historical benthic data sets adequate to set reference condition • Very few long-term historical data sets so natural ecosystem dynamics may be difficult to determine • Data variable and often not quantitative • Data often collected for a different purpose and by different means, introducing sampling bias confounding comparison with modern data	2
		TOTAL SCORE FOR EXTERNAL FACTORS			**5**

TOTAL SCORE FOR HISTORICAL REFERENCE CONDITIONS	**16**

3.3 Modelled reference conditions

Where existing reference conditions do not exist and historical data are not available or are inadequate for use, modelling approaches can be used for setting reference conditions. Statistical modelling, such as hindcasting and predictive modelling, have been the most common and applicable approaches, particularly for the determination of physico-chemical reference values for fresh and marine water bodies (e.g. Andersen *et al.*, 2004; Højberg *et al.*, 2007; Kilgour & Stanfield, 2006; Wasson *et al.*, 2003). There are, however, other less widely used modelling approaches that may prove useful in determining or refining reference conditions in benthic habitats. Palaeoreconstruction and ecosystem reconstruction approaches are also discussed in this section.

3.3.1 Statistical modelling methods

In general, statistical techniques utilise empirical models, derived from relationships between biological and environmental variables, particularly human disturbance gradients, or between different biological parameters, to determine reference conditions.

Where reliable stress-response relationships are known, reference conditions can be predicted by modelling (extrapolating) a stress-response relationship to lower stress levels, a method known as hindcasting. In Denmark for example, Nielsen *et al.* (2003) used empirical models relating nutrient concentrations to environmental indicators including chlorophyll concentrations, eelgrass depth limits and benthic fauna biomass in an attempt to hindcast reference conditions for the Randers Fjord estuary. The study also utilised a historic benthic fauna dataset (Johansen *et al.*, 1918) thought to represent reference conditions, which indicated a dramatic change in benthic fauna had occurred. However, the definition of reference conditions for benthic community composition was found to be particularly problematic because of a lack of quantitative links between eutrophication and species composition. This was due, in part, to inconsistent benthic sampling techniques between the historic and current data sets. For the variables of cholorophyll concentration and the depth limit of eelgrass the task was found to be much simpler because valid stress-response relationships could be established.

The model of Pearson & Rosenberg (1978), which relates benthic faunal composition to magnitude of disturbance, from organic pollution to physical disturbance (Pearson & Rosenberg, 1978; Boesch & Rosenberg, 1981) was modified to meet the requirements of the WFD. Such developments may prove useful for the development of reference conditions for the MSFD. Ideally, the expected reference condition is obtained by interpolation (i.e. within the confines of the stress response variable) but extrapolation of reference conditions is often done beyond known data/relationships which reduces the confidence in the values (Johnson, 2001). Such extrapolations would obviously need to be applied with caution.

A second statistical approach makes use of well established relationships between response and predictor variables to predict expected reference condition (e.g. the response of community assemblage to a physical predictor values such as sediment type) where human impacts are minimal or absent (Karr & Chu, 1999 in Stoddard, 2006). So that predictor-response relationships are not confounded, the predictor variables should be insensitive to anthropogenic disturbance (e.g. geographic or physical variables). In this approach the empirical model has to be calibrated using reference sites, borrowed from outside the area, and assumes that the model is representative of the relationships that exist in the undisturbed condition (Johnson, 2001). In particular, there has been considerable work establishing relationships between faunal composition and environmental conditions, particularly in sediment habitats that will provide important modelling input to the setting of reference conditions for a number of habitats (e.g. see Elliott & O"Reilly, 1991; Clarke & Ainsworth, 1993). This approach was used for WFD benthic infaunal assessment in transitional and coastal waters (Phillips *et al*., 2012) so there may be scope to expand and test the methods for offshore habitats and pressures.

An example is provided by Jennings and Blanchard (2004) who used macroecological theory to predict the size and structure of fish assemblages in an unexploited ecosystem. Their method relied on relationships between size spectra, predator-prey mass ratios (PPMR) and transfer efficiency and used empirical estimates of PPMR to predict slopes of unexploited size spectra in the intensively exploited North Sea. Although determining values for lower trophic levels may be more complicated because adding more trophic levels adds more variability (Lotze & Milewski, 2004) such approaches may provide potential tools for setting reference conditions for some benthic ecosystem indicators.

One of the advantages of using predictive approaches is that the number of sites needed for reliable estimates is usually lower than that required when using data from existing reference sites only. However, such predictive models will probably only be valid for the specific habitat type for which they are created. In the absence of reliable data from representative sites models may be considered to be little more than expert judgement (Fore, 2003). However, modifications to predictive modelling are possible when there is an absence of adequate reference data. The first modification is to use data from a „least impacted site" (Economou, 2002). Although these sites do not meet the exact criteria for reference condition, data from them may allow the establishment of relationships that can help to predict reference conditions. The second modification is to select ecologically similar sites, which are unimpacted and analogous to the site of interest, but from different regions (Hughes *et al.*, 1986). This has been widely applied in freshwater habitats (Wallin *et al.*, 2003) but may be less useful for North-East Atlantic marine habitats and would need careful consideration by experts. However, extrapolation of data from reference sites which have been deemed sufficiently similar can help to identify and understand relationships between anthropogenic pressures and a habitat or community. This approach requires good quality ecological data and since certain assumptions may have to be made, the application of expert judgement will be important.

A novel approach to modelling reference conditions for the German Baltic coast, reported to avoid artefacts from historical data sets or expert judgement, was proposed by Meyer *et al.* (2008). Reference conditions for benthic coastal communities were based on the available knowledge on the autecology (the biological relationship between an individual species and its environment) of the species present together with an inventory of the abiotic parameters present. Reference conditions were produced by including species when their autecology fell within the pre-defined ranges for the water bodies.

The scientific robustness of modelling approaches has the potential to be moderate or even high, depending on the nature of the modelling exercise and data quality. Importantly, modelling may offer the possibility of introducing current climate conditions to reference conditions. However, whilst it is suggested that models can be a powerful tool for the prediction of reference conditions for water quality (Moschella *et al.*, 2005) their application for North-East Atlantic benthic habitats is less certain. For dynamic and highly variable marine environments modelling capabilities are not yet deemed sufficient for defining reference conditions (Hering *et al.*, 2010 in Borja *et al.*, 2010) and their application in the current timescales is in doubt. Models require expert led calibration and validation so unless existing programmes are underway that can deliver MSFD needs, new modelling work is not likely to take place within the MSFD timeframes. A further limitation is the lack of (perceived) transparency by stakeholders (OSPAR, 2011a). However, it is an approach that OSPAR (2011) considers should be part of the future reporting round.

3.3.2 Palaeoreconstruction

The use of palaeoreconstruction methods, using indirect relationships between fossil remains, particularly of diatoms, and the environment to infer past conditions (ter Braak & Juggins, 1993), has been popular in respect of the US Clean Water Act and the EU Water Framework Directive. The method is particularly applicable to the development of physico-chemical reference conditions in relation to water quality in freshwater (e.g. Bennion *et al.*, 2001 and Euro-limpacs, 2005) and coastal and transitional waters (Andersen *et al.*, 2004; Clarke, K.R *et al.*, 2003, Clarke, A.L *et al.*, 2006; Kauppila *et al.*, 2005).

A more direct palaeoreconstruction technique, which uses the remains of taxa stored in the sediment to reconstruct an assemblage, is more applicable to benthic habitats. Such methods, however, are not fully developed or tested and are mostly limited to single taxa, mollusca in particular. For example, researchers at Chicago University have established that differences in the composition of molluscan remains (known as death assemblages) in sediments, in comparison to living assemblages are correlated with several aspects of human impact including eutrophication and bottom trawling (Kidwell, 2007; 2009). This research indicates the composition of a pre-impact molluscan community can be inferred from older sedimentary layers with considerable confidence (Kidwell, 2007). Similar work on UK beaches suggests that death assemblages of molluscs may prove to be good surrogates for regional biodiversity (Warwick & Light, 2002; Warwick & Turk, 2002). Although this work revealed many molluscan species were absent from current assemblages the main application is to reveal insights about taxonomic structure rather than provide actual species composition. Nevertheless, such techniques may be able to provide valid surrogates for broad biodiversity indices, including measures of natural variability, which could have application to setting reference conditions where other data are lacking or could provide a useful source of information to feed into ecosystem reconstructions.

There are additional weaknesses of the palaeoreconstruction technique for the setting of benthic habitat reference conditions. In particular, there may be poor and selective preservation of the organisms in the sediment and the method may require complex data analysis and interpretation by experts. However, such techniques may provide useful adjuncts to ecosystem reconstruction methods (described below).

3.3.3 Ecosystem reconstruction

Ecosystem reconstruction is generally a multidisciplinary modelling approach combining paleontological, archaeological, historical, fisheries and ecological data to reconstruct past changes in marine populations, habitats and water quality. This approach is closely linked to the Historical Reference Condition approach, in that reconstructions rely on historic information as well as current information to develop a theoretical state of unimpacted ecosystems under present climatic conditions.

Researchers at the Fisheries Centre of the University of British Columbia (BC) have developed modelling techniques for the reconstruction of historical marine ecosystems (Pauly *et al.*, 1998; Guenette *et al.*, 2001). For example, Ainsworth *et al.* (2008) reconstructed historical marine ecosystems in north BC, at four different points in time over the past 250 years. Their focus was on marine food webs using Ecopath with Ecosim mass-balance models to provide a „best guess" of what historical ecosystems may have looked like. Similar reconstructions have been carried out for marine ecosystems in the Straits of Georgia in British Columbia (Pauly *et al.*, 1998; Christensen, 2001), Iceland (Buchary, 2001) and the North Sea (Mackinson, 2001). The authors suggest such models can be used to create a coherent view of an ecosystem based on only piecemeal information, by using fundamental assumptions about ecosystem functioning. Furthermore, the reconstruction of the Strait of Georgia has been proposed as a historic reference condition for evaluation of present day impacts (Christensen, 2001).

Whilst the models developed in these studies were primarily concerned with changes in fish species abundance, there are benthic components such as benthic invertebrate biomass, albeit it at low taxonomic resolution. Similar studies in the North Sea have used Ecopath with Ecosim with the inclusion of low level trophic groups from benthic survey results (Kenny *et al.*, 2009). Thus, further development of ecosystem reconstruction models using these modelling techniques may prove useful in contributing to definitions of reference conditions in benthic habitats, although it has been recognised that modelling lower trophic levels may be more difficult (Lotze & Milewski, 2004). Additionally, models such as Ecopath and Ecosim models can be data hungry (e.g. see Kenny *et al.*, 2010) which may limit their application for some habitats.

Another approach is the compilation of the ecological history of an area to reconstruct historical changes in marine ecosystems over past centuries and millennia (Rick & Erlandson 2008; Starkey *et al.* 2008; Lotze & Worm 2009). For example, details of historical changes in individual populations can be used to estimate changes in biodiversity, food-web structure and ecosystem functioning (Jackson *et al.* 2001; Lotze *et al.* 2005). Several studies have aimed at reconstructing historical changes in particular regions, such as the Benguela upwelling system in Africa (Griffiths *et al.* 2004), the Outer Bay of Fundy in Canada (Lotze & Milewski 2004), the Gulf of California in Mexico (Sáenz-Arroyo *et al.* 2005, 2006) and the Wadden (Lotze 2005, 2007; Lotze *et al.* 2005) and Adriatic Seas (Lotze *et al.*, 2010) in Europe. Other studies have focused on historical changes in individual species (Rosenberg *et al.* 2004, McClenachan *et al.* 2006) or habitats (Orth *et al.* 2006; Airoldi & Beck 2007).

In these studies compilations of historical records, estimation of trajectories of change, and modelling of food-web alterations together provided new insights into ecosystem changes that can help inform reference condition setting. However, the multidisciplinary nature of the task and number of experts required means this approach can be time consuming, expensive and may not be particularly transparent. However, as with historical models such reconstructions are likely to be applauded by many stakeholders.

3.3.4 Habitat modelling

Habitat modelling may be important for setting reference conditions of habitat distribution and extent, particularly where data are incomplete. Such modelling uses a range of techniques to predict the distribution of species and communities based on their relationship with environmental parameters (e.g. substrate type, light attenuation and energy). These environmental parameters (e.g. British Geological Survey sediment data) often have full seabed coverage so it is possible to use established relationships with species and habitats to model full coverage of biological distributions. Marine models have historically been focused on predictions of specific habitats (e.g. cold water corals: Guinan *et al.* 2009; Roberts *et al.* 2005). More recently however, with a growing body of full coverage environmental data and benthic sampling, and the development of modelling techniques, full shelf habitat mapping has attracted more significant effort (e.g. Degraer *et al.* 2008; Buhl-Mortensen *et al.* 2009; Rattray *et al.* 2009). Such data have potential application for management measures introduced for the sustainable use of the seas, e.g. physical damage criteria used to establish relationships between fishing pressure and benthic community characteristics (Hiddink *et al.*, 2006a; b). In the UK, national scale habitat models have been developed in a series of iterations, the first of which was part of a European initiative, MESH (Mapping European Seabed Habitats) and subsequently UKSeaMap. An EUSeaMap has improved and harmonised predictive benthic habitat layers across the Celtic, North and Baltic Seas under the EUNIS classification, as well as broad-scale mapping of the western Mediterranean.

The SWOT analysis below is an evaluation of modelling methods in general; further consideration of the applicability of particular models is likely to be required depending on the habitat and criteria under consideration.

Table 6. SWOT analysis of modelled reference conditions approach.

Factors			Strengths	Weaknesses	Score
Factors	Internal	**Scientific Robustness**	• May avoid bias associated with expert judgement • Possible to use data to "calibrate" reference conditions e.g. between different habitats to ensure between-habitat consistencies	• Extrapolation beyond known data relationships leads to uncertainty • Models require considerable calibration and validation which can be expensive and time consuming	2 x 2 = 4
	Internal	**Transparency/ Comprehensibility**	• Many models easy to understand and explain to a lay audience	• Expert scientific knowledge may be required to understand some models and not easily explained	2
	Internal	**Confidence**	• Can assign confidence limits to outputs	• Assumptions and simplifications required for many models may increase uncertainty in predictions	2
	Internal	**Data Requirements**	• Potential to estimate reference conditions where little data exists	• Data requirements high depending on the type of modelling approach used • Some models require data from similar reference condition sites • Data on disturbance gradients also often required	2
	Internal	**TOTAL SCORE FOR INTERNAL FACTORS**			**10**
			Opportunities	**Threats**	
	External	**Applicability**	• Useful where sufficient reference site data are not available but current monitoring data are • Can provide useful information to supplement other approaches • Can allow for current physiographic and climatic conditions	• Models have worked well for water quality variables and fisheries but modelling capabilities for marine habitats not so well developed	2
	External	**Practicality**		• Time constraints mean that only already well established models can be used • Community and ecosystem models often subject to high levels of uncertainty and can be data hungry	1
	External	**Data availability**	• Data suitable for modelling available for some habitats in form of current survey data	• Lack of data for a number of habitats, particularly deep-sea habitats • Knowledge often from a few discrete locations	2
	External	**TOTAL SCORE FOR EXTERNAL FACTORS**			**5**

TOTAL SCORE FOR MODELLED REFERENCE CONDITIONS	**15**

3.4 Expert judgement

Where there is a lack of existing reference sites, historical data or modelling approaches are not appropriate, expert judgement can be particularly valuable in setting reference conditions (OSPAR, 2011a). However, as a number of weaknesses are inherently associated with this approach, caution should be exercised when it is used as the sole means of establishing reference conditions. Expert judgement may be a non-quantitative description of reference conditions as a result of the lack of data and, as such, may introduce subjectivity and bias (Solheim, 2005; Wallin *et al.*, 2003).

In the U.S. Environmental Protection Agency"s Environmental Monitoring and Assessment Program experimental use of expert judgement for setting reference conditions for freshwaters systems provides a precautionary tale. When judged against independently established criteria for identifying reference conditions, many of the expert selected reference sites had strong indications of intense human disturbance (Fore, 2003; Hughes, 1995; Whittier *et al.*, 2007). Reasons for this discrepancy included unclear understanding of what constituted reference conditions, or sites were selected for a specific condition rather than general ecological condition. Similarly, there is often a common misperception that things were always better in the past (the issue of shifting baselines) and low diversity conditions, which may be representative of an unimpacted condition, may be ignored.

Other drawbacks include the lack of clarity and low degree of transparency in assumptions used to establish reference conditions and the lack of quantitative measures for validation. However, expert knowledge may be able to incorporate temporal variability and ensure reference conditions reflect current climatic conditions although determining quantitative values may be difficult.

The importance of expert judgement to the reference condition setting process has been highlighted in the Water Framework Directive (WFD) (EC, 2011), the Clean Water Act (CWA) in the US (Gibson *et al.*, 1996; Johnson, 2001) and the MSFD (OSPAR, 2011a,b). For example, expert judgment may complement other methods of determining reference conditions as benthic experts are often able to reliably predict the ecological status of benthic samples, based only on species composition (Weisberg *et al.*, 2008; Teixeira *et al.*, 2010).

Where expert judgement is used for the determination of reference conditions, it should be governed by a number of principles (Stoddard *et al.*, 2006; OSPAR, 2011a). The determination of reference conditions through a panel of experts is always preferable to using a single individual. Confidence in the conclusions are likely to increase with the numbers of experts consulted as judgements will be more scientifically sound and comprehensible and based on sound ecological knowledge. The procedure and outcomes of applying expert judgement should be transparent and appropriately documented giving reproducible and reliable results to allow „replication" by others wherever possible. Clear documentation will also serve to make the approach more transparent and understandable to stakeholders.

Expert judgement should be an integral part of all the reference condition setting approaches. Even where reference sites and models are available, a panel of specialists will need to evaluate all the data. Interpretation of pressures data will be required and the expert judgement approach may combine historical data and opinion with present day concepts of structure and function (Solheim, 2005). Expert judgement can be used to supplement information that is available from the other methods, or allow disparate information to be brought together in a single interpretation. For example, expert judgement can be used to determine the types of species that might reasonably be expected in a particular community.

In addition, where more than one method has been used to set reference conditions, with differing results, expert judgement will be required to determine the baseline values adopted. Robust predictive models can only be developed using data that has been validated by expert judgement. For example, expert judgement may be used to extrapolate findings from one quality element to another (e.g. palaeoreconstruction using mollusc remains may be used to infer invertebrate community composition (Kidwell, 2007, 2009) or to extrapolate stress-response relationships to those expected in unperturbed sites (e.g. see Nielsen *et al.*, 2003).

Expert judgement will also be required to decide which historical data are appropriate and to agree the point in time which best represents the reference condition. Establishing when pressures may have existed, but where they did not result in environmental disturbance, is not always an easy task. Expert panels will also be required to avoid any bias as experts may tend to set their own reference conditions, employing the information from the period they felt to be „the best" (Pauly, 1995; Mee *et al.*, 2008). Although reference conditions may be defined as the conditions existing before the onset of large-scale industrial disturbances, the actual time period will obviously vary across Europe due to differences in the types of anthropogenic activities in different regions. In many areas of northern Europe this time period would correspond to the mid-1800s, whereas in the southern parts of Europe a much earlier time period would be required to attain the same state of naturalness (Euro-Limpacs, 2005).

Expert judgement in combination with models and palaeoreconstruction has been widely used in the WFD for the determination of coastal water quality (Clarke *et al.*, 2006; Kauppila *et al.*, 2005) but for biodiversity measures (benthic invertebrates), approaches have been more reliant on expert judgement alone to determine reference conditions (Carletti & Heiskanen, 2009).

3.4.1 Expert identification of best available conditions

In most Member States covered by the WFD a lack of existing reference conditions, historical data and models for benthic biodiversity has forced researchers to take a pragmatic approach to setting reference conditions. This generally involves expert interpretation of the data that is available, which is usually current monitoring data, and the selection of the best available sites with the lowest levels of disturbance to establish reference conditions.

Whilst this approach has had wide application, an awareness of the potential problems of relying on current monitoring data alone is required. There is an obvious danger that the technique leads to a baseline set at current state, not at a minimally impacted condition (i.e. at reference condition) which is a stated aspiration of OSPAR in its implementation of the MSFD to achieve good environmental status (OSPAR, 2011a). This is clearly demonstrated in the work of Paganelli *et al.* (2010) on the Italian coast of the Adriatic. Their approach was to take the definition of reference condition from the „best possible conditions" available. The authors considered it unrealistic to ever achieve conditions of actual „absence of human impact" in such a human-modified area. However, in using „best possible conditions", even from „least disturbed" areas the authors are likely to have set a baseline closer to „current state", ignoring the importance of setting a reference condition, not as a target but as a point from which to measure change in condition. Where such techniques are employed the importance of using very large data sets is stressed (Rosenberg *et al.*, 2004), as a small set of information from disturbed areas will not produce valid reference conditions.

Often the sampling sites used in estimating baselines or „reference condition" are chosen because they are considered by local experts to be „the best of what"s left". In many regions of the world, these sites bear little resemblance to the „natural condition" that might be considered to be a „reference condition", because the entire population of possible sites has been degraded by widespread human disturbance (Stoddard *et al.*, 2006; Swartz *et al.*, 2010). This approach to setting baselines is not likely to provide reference conditions and will reflect an idea of habitat condition that is subject to the problem of shifting baselines (Pauly, 1995) that using reference conditions seeks to avoid. However, as has been apparent in the implementation of the WFD it has been found to be the most pragmatic approach.

However, a „virtual" reference location approach has been proposed as a better way of using current monitoring data to set reference conditions.

3.4.2 Virtual reference locations based on expert judgement

In areas such as the Basque Country in northern Spain, where WFD habitats in transitional waters have been historically impacted by human activities, particularly over the last 150 years, and where there is no pre-industrial historical data, Borja *et al.* (2003) proposed the use of „virtual" reference locations as an expert judgement approach. The virtual reference location method uses current (or relatively recent) monitoring data in conjunction with expert judgement and experience of the area to „conceive" reference conditions for water and benthic quality criteria that would be expected to be present. A group of experts select the highest values (i.e. the 95th percentile) of a range of indicators from all data (regardless of location) collected over a significant period of time (usually 10-20 years) to create a „reference condition" data set for a non-existent location (Borja *et al.*, 2004). Existing impacted locations are then compared to this ideal. The approach has been applied to benthic habitats in the Adriatic Sea (Simonini *et al.*, 2009), northern Spain (Muxika *et al.*, 2007; Ruellet & Dauvin, 2008; Borja *et al.*, 2009a,b,) and Sweden (Rosenberg *et al.*, 2004) in addition to application for the physico-chemical status of coastal water bodies (Bald *et al.*, 2005).

Expert judgement plus current monitoring data has wide application for the setting of reference conditions (Andersen *et al.*, 2004; Rice *et al.*, 2010). Such an approach will require caution to ensure measures are the best available estimates of reference conditions rather than a representation of the best of the current condition. Without reference sites based on real data there is also an increased risk of errors in distinguishing human impact from natural variation (i.e. in classification) (Owen *et al.*, 2002). The addition of historical data, even where it is incomplete, can be a useful addition to setting reference conditions in this way.

However, expert judgement has been particularly important for the setting of reference conditions for biodiversity measures (benthic invertebrates) for the WFD, a reflection of the absence of minimally impacted habitats and a shortage of suitable historical datasets (Carletti & Heiskanen, 2009; Phillips *et al.*, 2012). Joint expert interpretation has been essential also for ensuring cross-boundary agreement between England, Wales, Scotland and Northern Ireland (pers. comm. Roger Proudfoot).

Table 7. SWOT analysis of the expert judgement approach.

			Strengths	Weaknesses	Score
Factors	Internal	**Scientific Robustness**		• Expert bias & subjectivity may be present when used in isolation • May only provide qualitative descriptions • Value of judgement highly dependent on the experience of experts and quality of data supplied	1 x 2 = 2
		Transparency/ Comprehensibility	• Transparent and simple concept to comprehend	• Some explanation and documentation of the process of using expert judgement to define reference conditions needed	2
		Confidence	• Can incorporate both quantitative and anecdotal evidence and a broad range of environmental aspects	• Potential for lack of consistency in results • Outcomes not easy to validate or attach confidence limits	2
		Data Requirements	• Low data requirements as based on experience and judgement	•	3
		TOTAL SCORE FOR INTERNAL FACTORS			**9**
			Opportunities	**Threats**	
	External	**Applicability**	• Expert judgement available for many NEA habitats • Expert judgement widely used technique, e.g. for WFD, due to data limitations in many habitats • Particularly useful when applied in combination with other methods • Expert knowledge can incorporate temporal variability and reflect current climatic conditions	• The definition for several habitats has not been agreed due to lack of knowledge	2
		Practicality	• Potential to use qualitative or anecdotal information from a range of sources • Bringing together panel(s) of experts can improve sum of knowledge • Relatively inexpensive method compared to surveys or model development		3
		Data availability	• Many habitats, especially those of conservation importance, have current survey data available to inform expert judgement	• Recent survey data tends to focus on issues of habitat extent rather than condition • Lack of knowledge for many of the offshore/ deep-sea habitats • Knowledge often from a few discrete locations	2
		TOTAL SCORE FOR EXTERNAL FACTORS			**7**

TOTAL SCORE FOR EXPERT JUDGEMENT REFERENCE CONDITIONS	**16**

3.5 Summary of Results of the Evaluation of Methods

The SWOT analysis has provided some discrimination between methods, particularly when considering the internal factors. Whilst the approach has attempted to provide a robust assessment it is recognised that there is a degree of subjectivity in the scoring method. The results indicate that existing reference condition is the preferred method for setting reference conditions (Table 8). It has been acknowledged by other researchers and programmes, particularly the WFD, that existing reference sites is by far the optimal method (European Commission, 2003a; Johnson 2001; Van Hoey *et al.*, 2010 & Borja *et al.*, 2012). Using survey data from reference condition sites is a scientifically robust and straightforward approach to setting reference conditions for many biodiversity criteria (discussed in more detail in section 4). However, the potential for the practical application of this method, as indicated by the external score, is low. A long history of human impacts in marine systems means that there are few marine habitats that are in reference condition in the North-East Atlantic. Nevertheless, where suitable sites do exist, and further research may be required to identify the presence of such areas, they should be used to define or to inform the development of reference conditions.

Table 8. Summary scores for SWOT analysis.

		Score		
Methodology	**Methods**	**Internal**	**External**	**Total**
Existing Reference Conditions	Existing data sets from sites in reference condition	13	5	18
Historical Reference Conditions	Historical data sets	11	5	16
Modelled Reference Conditions	Statistical, Palaeoreconstruction, Ecosystem Reconstruction, Habitat Modelling	10	5	15
Expert Judgement	Expert judgement panels, virtual reference locations	9	7	16

Historical data also has the potential to provide scientifically robust reference conditions and also scores highly. Where suitable data exist this method is also scientifically straightforward and robust. However, a general lack of suitable datasets means the method cannot be applied universally and so scores poorly for external factors. Its use will be determined by the availability of data on a habitat by habitat type basis. Nevertheless, where incomplete historical data or even qualitative information is available, it can provide insights into reference conditions and should be included wherever possible.

Modelling and expert judgement have low internal scores, mainly due to the potential uncertainty in the outputs to define reference conditions, particularly for expert judgement. However, it has been identified that modelling approaches have value and should be developed and used to supplement reference condition setting approaches where possible (OSPAR, 2011a,b). The ability to define levels of confidence in outputs is a significant advantage of modelled data over expert judgement.

Expert judgement scored more highly than the other methods for practical application (the external factors) because it can be used even where significant data sets are in short supply. It has been the most widely used technique in the implementation of the WFD in coastal and transitional waters where there has been a general lack of habitats that are still in reference condition and a shortage of historical data sets (e.g. Carletti & Heiskanen, 2009). However, there may be habitats where even expert judgement is lacking and further research will be required.

It is well known that reference conditions do not presently exist for most marine habitats in North-East Atlantic areas (Neilsen *et al.*, 2003; OSPAR, 2011b). The impacts of human pressures, including nutrient enrichment, fishing and habitat loss, have caused large scale changes in marine ecosystems over the past 200 years (Lotze & Milewski, 2004; Lotze, 2010; Swartz *et al.*, 2010). Thus, alternatives to the existing reference conditions approach are likely to be required for the MSFD biodiversity criteria of habitat distribution, extent and condition, physical damage and benthic community condition for each of habitats under consideration.

The MSFD and WFD are similar in concept and lessons learned from the WFD implementation process will help in implementing the MSFD (van Hoey *et al.*, 2010). It is widely acknowledged among the scientific community that none of the existing approaches for determining reference conditions is perfect and that the realisation of the principles within the Directives is based on currently available scientific knowledge. Knowledge of the inherent strengths and weakness of the various approaches or the potential problems associated with different methods is limited so it is hoped that the results of the SWOT analyses carried out in this report will go some way to improving understanding.

The identified approaches may be used either singly or in combination for establishing and/or cross-validating reference conditions (Wallin *et al.*, 2003). Establishing the most appropriate method for defining reference conditions for a particular habitat will be determined by the habitat type and its history, the availability of data and the particular criteria for which reference conditions are to be developed. These factors are considered in making recommendations for marine benthic habitats in the North-East Atlantic.

4 Recommending methods for determining reference conditions for MSFD biodiversity criteria and North-East Atlantic habitats

The SWOT analysis has identified a hierarchy of choices of methods to be used to set reference conditions (based on scoring of internal factors). The options for setting reference conditions were found to be in the same order of preference as given in the WFD guidance with the preferred option being existing reference condition (European Commission, 2003a):

1. **Existing reference condition** (i.e. there is data from an existing undisturbed site or a site with only very minor disturbance)
2. **Historical reference condition**
3. **Modelled reference condition**
4. **Expert judgement**

The purpose of this work is to recommend methods for setting reference conditions for two of the MSFD GEnS descriptors: D1 - Biodiversity and D6 - Seabed integrity. There are, however, a range of different criteria within each of these descriptors (Table 1). These criteria fall into two broad groups based on the nature of the indicator classes and hence the kind of data that will be required to set reference conditions for each indicator.

Criterion 1.4 (habitat distribution) and criterion 1.5 (habitat extent) are closely related requiring similar spatial data sets. Physical damage (criterion 6.1) is also considered at the same time as it is concerned with the extent of biogenic reef and area of habitats affected by physical damage, and so is related to habitat distribution and extent. Many of the data sources for these criteria will be similar, including broadscale mapping and modelling programmes as well as local investigations and research for European conservation designations (such as SAC and SPAs) and MPA identification.

Similarly, the biological diversity descriptor 1 condition aspects have major links with descriptor 6 for sea floor integrity. In particular, criterion 1.6 (habitat condition) can be considered analogous to criterion 6.2 (condition of the benthic community) (Moffat *et al.* 2011). For this reason, evaluating the best reference condition setting methods for habitat condition and condition of the benthic community for individual habitats are also considered together (described in Section 4.2).

i. Habitat distribution (1.4), habitat extent (1.5) and physical damage (6.1)

The existing reference condition approach to setting reference conditions for habitat distribution, habitat extent and physical damage is important because it reflects current physiographic conditions (e.g. the sinking of the east coast of England into the sea) and climatic conditions. Many habitats have been altered by natural or climate forces that cannot be reversed and so the existing reference condition approach is required to set reference conditions for all habitats.

However, whilst the current distribution and extent of benthic habitats reflects current physiographic and climatic conditions, and can account for natural variability where data are adequate, it does not take account of the distribution and extent of habitats that have been lost in the past such as seagrass and flat oyster beds. For these habitats, defining a reference condition based only on current data would mask previous deteriorations in range and extent (OSPAR, 2011a). It will also reflect current states of physical damage. Therefore historical reference condition may also need to be considered for some habitats.

Thus, the preferred approach for the determination of reference conditions for the spatial criteria of habitat distribution, habitat extent and physical damage depends on the habitat type. Where there have been no historical changes, as a result of human impact, in distribution, extent and damage the existing reference condition is optimal. Where historical changes have taken place a combination of existing and historical reference conditions is preferred. Data availability will then determine the need to include modelling and expert judgement.

ii. Habitat condition (1.6) and condition of the benthic community (6.2)

The research carried out in this report, and most literature relating to reference conditions (e.g. Johnson, 2001; Van Hoey *et al.*, 2010; OSPAR, 2011a; Borja *et al.*, 2012), concludes that the use of existing reference sites is the optimal way for defining reference conditions for biodiversity quality criteria and indicators. However, as most marine habitats do not have locations in reference condition the methods recommended will be determined by the availability of data, models and expert knowledge for each of the habitats concerned.

Box 3. Preferred methods for setting reference conditions for MSFD GEnS Biodiversity criteria for North-East Atlantic habitats.

Habitat distribution, extent and physical damage
The optimal approach for setting reference conditions is either existing reference condition where there has been no historical habitat loss or existing reference condition in combination with historical reference condition where habitat loss has occurred

Habitat condition and condition of benthic community
The optimal method is existing reference condition. However, as most marine habitats do not have locations in reference condition the methods recommended will be determined by the availability of data, models and expert knowledge.

A hierarchical decision tree has been developed as an aid to determining the most appropriate approach depending on data availability that can be applied to the benthic habitats in the North-East Atlantic (Fig. 4). The decision tree is based on the outcome of the SWOT analysis (for the internal factors), with FOUR key branches in the order of preference of the different methods, allowing for the slight difference in approach for the two groups of biodiversity criteria. Within each of the four branches supplementary questions determine the particular nature of the habitat and data availability to determine which method or choice of methods is required to set reference conditions.

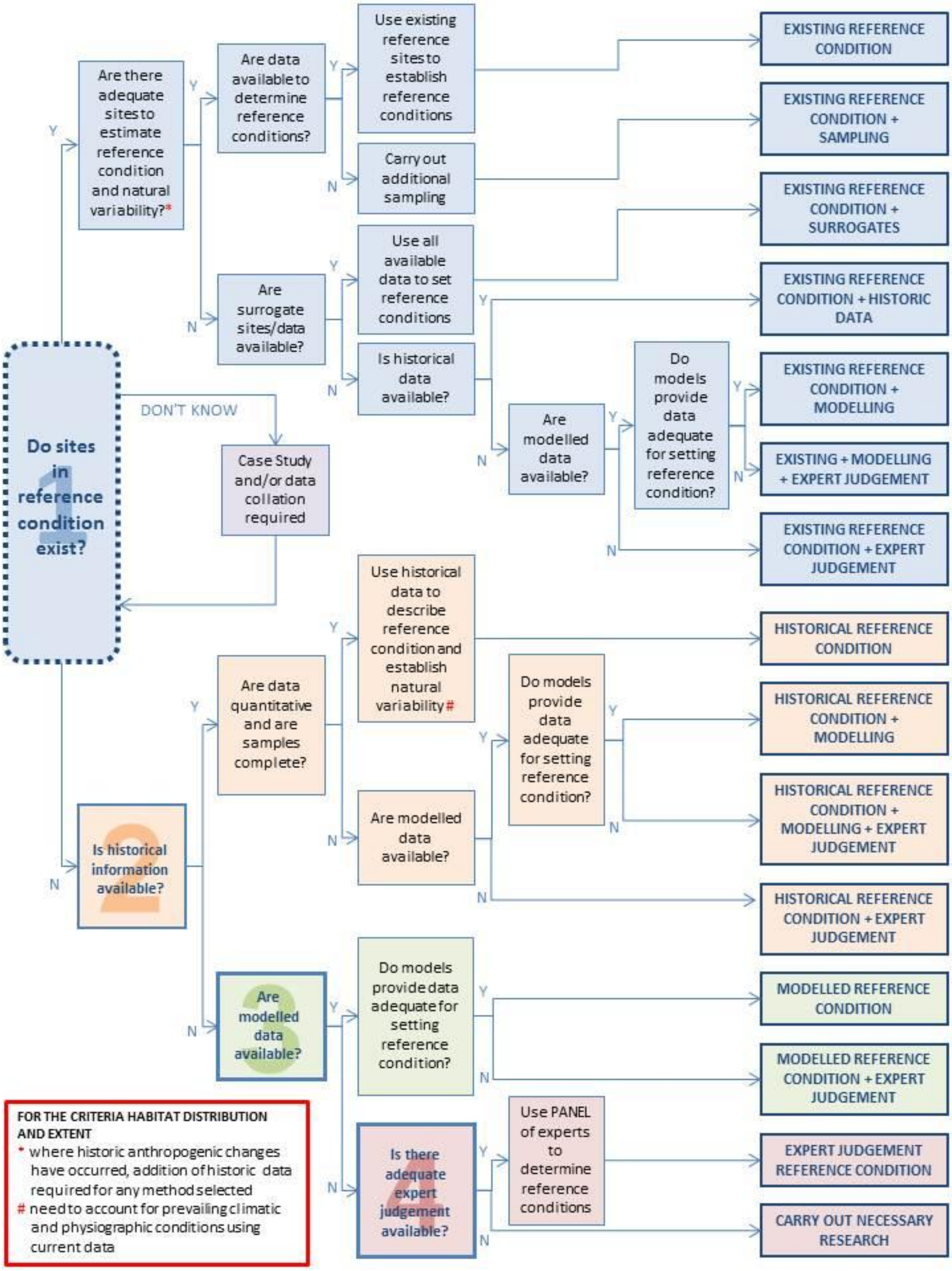

Figure 4. Decision tree for selection of methods for setting reference conditions for MSFD GEnS descriptors D1 – Biodiversity and D6 – Seafloor integrity for benthic habitats in the North-East Atlantic.

To recommend the most appropriate method, or combination of methods, for setting reference conditions a brief review of the availability of literature and data has been carried out for each habitat for each of the two groups of criteria. This has been undertaken following the decision tree format, with an assessment of the appropriateness and data availability of each method. Where a method has been identified as appropriate to setting or contributing to setting reference conditions it has been selected and included in the recommendation. An example review is given below (Table 9).

The reviews for all habitats, for the two broad criteria categories, are found in the Appendices (Sections 6.1 and 6.2) and the recommendations summarised in Sections 4.1 and 4.2.

Table 9. Example review for habitat distribution, extent and physical damage.

Method	**Analysis**	**Choice**
1.Existing reference conditions	Current UK distribution data are fairly readily available from a range of sources although there is some discrepancy between data sources. Extent data are available from the same data sources but is incomplete.	✓
2. Historical reference conditions	The distribution of this habitat has not changed due to human activities and so historical reference condition is not relevant.	
3. Modelled reference conditions	No modelling approaches identified.	
3. Expert Judgement	Some areas are mapped more accurately than others so expert judgement will be required to determine final reference conditions. Expert judgement will also be required where data are incomplete.	✓ **+ RESEARCH**

The need for additional research has also been indicated for those habitats where there appears to be a lack of suitable data or knowledge to determine reference conditions. These recommendations should be considered to be a guide as a comprehensive review of the detailed data availability for each habitat is beyond the scope of this work. The data requirements for setting reference conditions will also be highly dependent on the specific biodiversity indicators selected for setting targets and monitoring good environmental status. The exact research requirements will probably need to be determined by expert judgement and may be found to be different to the very general assessments provided here.

4.1 Recommended Methods for Habitat Distribution (1.4), Habitat Extent (1.5) and Physical Damage (6.1)

The recommended methodologies to use in setting reference conditions for each of the Annex 1, OSPAR and predominant habitats for the MSFD criteria of habitat distribution, habitat extent and physical damage are presented in Table 10.

There are several recommended approaches to the setting of reference conditions for the criteria of habitat distribution, habitat extent and physical damage. For those habitats that have not been lost due to human activities, particularly those that are primarily determined by structural features such as rock, a combination of existing reference condition and expert judgement is recommended. For many habitats, spatial modelling approaches are also available to improve or estimate reference conditions and have been recommended where available.

Where there have been past changes reference conditions should be set using existing and historical reference conditions with expert judgement. The fewer data there are the more important the role of expert judgement. For many habitats, spatial modelling approaches are also available have been recommended where available.

For many habitats, particularly relatively recently discovered habitat types such as coral gardens, deep-sea sponge aggregations and carbonate mounds, current data are inadequate to fully determine reference conditions because there are still occurrences of the habitat yet to be discovered. This is also true of biogenic habitats such as horse mussel beds where concerted efforts have more than doubled the known UK extent of this habitat in the last year (H. Edwards, NIEA pers. comm., Hirst *et al*. 2012a, b). For these types of habitats existing reference conditions may need to be set using incomplete data or habitat modelling. For some habitats further survey work is recommended but may not necessarily be possible within available timescales. However, scientific research on these types of habitats is ongoing and so reference conditions will need to be continually refined as more information becomes available.

The status of benthic marine habitats in UK waters has been assessed against a number of pressures associated with human activities (Aish *et al*., 2010). The status of habitats was measured relative to former natural conditions and refers to those conditions prevailing prior to significant anthropogenically-induced changed, which is analogous to reference conditions. The assessments were based on the best available information on current and historical habitat distribution and extent, and spatial distribution and variability in intensity of pressures or expert judgement. These assessments are likely to provide significant information that can be used to determine reference conditions for physical damage.

Table 10. Summary of recommended methods for determining reference conditions for habitat distribution (1.4), habitat extent (1.5) and physical damage (6.1) for marine benthic habitats in the North-East Atlantic.

Method key: E = existing, H = historical, M = modelling, J = expert judgement, R = research or surveys required.

		Method				
	Habitat	**E**	**H**	**M**	**J**	**Other**
Predominant Habitats	Littoral rock and biogenic reef	✓	✓		✓	
	Littoral sediment	✓			✓	
	Shallow sublittoral rock and biogenic reef	✓	✓	✓	✓	
	Shallow sublittoral coarse sediment	✓		✓	✓	
	Shallow sublittoral sand	✓		✓	✓	
	Shallow sublittoral mud	✓		✓	✓	
	Shallow sublittoral mixed sediment	✓		✓	✓	
	Shelf sublittoral rock and biogenic reef	✓	✓	✓	✓	R
	Shelf sublittoral coarse sediment	✓		✓	✓	R
	Shelf sublittoral sand	✓		✓	✓	R
	Shelf sublittoral mud	✓		✓	✓	R
	Shelf sublittoral mixed sediment	✓		✓	✓	R
	Bathyal (slope/upper) rock and biogenic reef	✓	✓	✓	✓	R
	Bathyal (slope/upper) sediment	✓		✓	✓	R
	Bathyal (mid/lower) rock and biogenic reef	✓	✓	✓	✓	R
	Bathyal (mid/lower) sediment	✓		✓	✓	R
	Abyssal rock and biogenic reef	✓	✓	✓	✓	R
	Abyssal sediment	✓		✓	✓	R
Habitats Directive Annex 1 habitats	Sandbanks which are slightly covered by seawater all the time	✓			✓	
	Mudflats and sandflats not covered by seawater at low tide	✓	✓		✓	
	Coastal lagoons	✓	✓		✓	
	Large shallow inlets and bays	✓				
	Reefs	✓		✓	✓	R
	Submarine structures made by leaking gases	✓			✓	R
	Submerged or partially submerged sea caves	✓			✓	R
	Annual vegetation of drift lines	✓			✓	R
	Salicornia and other annuals colonising mud and sand	✓	✓	✓	✓	
	Spartina swards (*Spartina maritimae*)	✓	✓	✓	✓	
	Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)	✓	✓	✓	✓	
	Mediterranean and thermo-Atlantic halophilous scrubs	✓	✓	✓	✓	
OSPAR threatened and/or declining habitats	Carbonate mounds	✓			✓	R
	Coral gardens	✓			✓	R
	Cymodocea meadows	✓			✓	R
	Deep-sea sponge aggregations	✓	✓	✓	✓	R
	Intertidal *Mytilus edulis* beds on mixed and sandy sediments	✓	✓		✓	
	Intertidal mudflats	✓	✓		✓	
	Littoral chalk communities	✓	✓		✓	
	Lophelia pertusa reefs	✓	✓	✓	✓	R
	Maerl beds	✓	✓		✓	
	Modiolus modiolus beds	✓	✓		✓	
	Oceanic ridges with hydrothermal vents/fields	✓			✓	R
	Ostrea edulis beds	✓	✓		✓	
	Sabellaria spinulosa reefs	✓	✓		✓	
	Seamounts	✓			✓	R
	Seapen and burrowing megafauna communities	✓		✓	✓	R
	Zostera beds	✓	✓	✓	✓	

4.2 Recommended Methods for Habitat Condition (1.6) & Condition of the Benthic Community (6.2)

The recommended methodology(ies) to use in setting reference conditions for each of the Annex 1, OSPAR and predominant habitats for the MSFD criteria of habitat and benthic community condition are presented in Table 11.

The most commonly recommended method for setting reference conditions for the biodiversity criteria of habitat and benthic condition is the sole use of expert opinion. This was identified as the only realistic option to setting reference conditions for almost two thirds of the habitats considered.

Most habitats are thought have a complete absence of unimpacted habitats and lack of any historical data for setting reference conditions. No robust modelling approaches for biological condition have been identified, although these may be locally available, so expert judgement remains the only realistic means of setting reference conditions. For most habitats current or recent datasets are available from monitoring programmes and research projects and whilst these data do not reflect reference conditions they can be used by experts to infer reference conditions. Such an approach has found wide application in the implementation of the WFD for benthic invertebrates in coastal waters (Carletti & Heiskanen, 2009; EC JRC, 2009). However, it should be emphasised that techniques may need to be developed to ensure the use of current data does not result in baselines set at current state rather than reference condition. Systematic engagement of the research community in these issues may allow better reference conditions to be developed.

There are a number of habitats, particularly those that are accessible to fieldwork or are commercially important habitats for which some historical datasets are available. The recommended approach for these habitats, which includes the shallow sublittoral sediments, intertidal areas, oyster beds and *Sabellaria spinulosa* reefs is the use of expert judgement in conjunction with historical reference condition data and recent data sets.

For a significant number of habitats, particularly those in deeper waters, additional research is probably required to enable expert judgement to determine robust reference conditions. However, within the budgets and timescales available reference conditions may initially be set by expert judgment and updated as new information becomes available.

Table 11. Summary of recommended methods for determining reference conditions for Habitat Condition (1.6) and Condition of the Benthic Community (6.2) for marine benthic habitats in the North-East Atlantic.

Method key: E = existing, H = historical, M = modelling, J = expert judgement, R = research required.

		Method				
	Habitat	**E**	**H**	**M**	**J**	**Other**
Predominant Habitats	Littoral rock and biogenic reef				✓	
	Littoral sediment				✓	
	Shallow sublittoral rock and biogenic reef		✓		✓	
	Shallow sublittoral coarse sediment		✓		✓	
	Shallow sublittoral sand		✓		✓	
	Shallow sublittoral mud		✓		✓	
	Shallow sublittoral mixed sediment		✓		✓	
	Shelf sublittoral rock and biogenic reef				✓	R
	Shelf sublittoral coarse sediment				✓	R
	Shelf sublittoral sand				✓	R
	Shelf sublittoral mud				✓	R
	Shelf sublittoral mixed sediment				✓	R
	Bathyal (slope/upper) rock and biogenic reef				✓	R
	Bathyal (slope/upper) sediment				✓	R
	Bathyal (mid/lower) rock and biogenic reef				✓	R
	Bathyal (mid/lower) sediment				✓	R
	Abyssal rock and biogenic reef				✓	R
	Abyssal sediment				✓	R
Habitats Directive Annex I Habitats	Sandbanks which are slightly covered by seawater all the time				✓	
	Mudflats and sandflats not covered by seawater at low tide		✓		✓	
	Coastal lagoons				✓	
	Large shallow inlets and bays				✓	
	Reefs				✓	R
	Submarine structures made by leaking gases				✓	R
	Submerged or partially submerged sea caves				✓	R
	Annual vegetation of drift lines				✓	R
	Salicornia and other annuals colonising mud and sand				✓	
	Spartina swards (*Spartina maritimae*)		✓		✓	
	Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)				✓	R
	Mediterranean and thermo-Atlantic halophilous scrubs					R
OSPAR threatened and/or declining habitats	Carbonate mounds				✓	R
	Coral gardens					R
	Cymodocea meadows				✓	R
	Deep-sea sponge aggregations		✓		✓	R
	Intertidal *Mytilus edulis* beds on mixed and sandy sediments		✓		✓	
	Intertidal mudflats		✓		✓	
	Littoral chalk communities		✓		✓	
	Lophelia pertusa reefs				✓	R
	Maerl beds				✓	
	Modiolus modiolus beds				✓	
	Oceanic ridges with hydrothermal vents/fields				✓	R
	Ostrea edulis beds		✓		✓	
	Sabellaria spinulosa reefs		✓		✓	
	Seamounts				✓	R
	Seapen and burrowing megafauna communities				✓	R
	Zostera beds				✓	

4.3 Practical considerations in applying recommended methods for determining reference conditions for MSFD biodiversity criteria and North-East Atlantic habitats

4.3.1 Principles for the use of expert judgement

The findings of this review have highlighted the important role expert judgement will play in the determination of reference conditions for the implementation of the MSFD. The use of expert knowledge is widely used in the science and implementation of conservation, usually for similar reasons to those encountered here, particularly the lack of data and the short timescales in which decisions often need to be made. However, there are many concerns regarding the use of expert judgement, particularly the belief that judgements will be biased, poorly calibrated or self-serving, therefore leading to poor inference and decision making.

The provision of accurate expert judgements requires practice with structured repetition of tasks and immediate, unambiguous feedback regarding accuracy. For example, an expert judgement workshop may start with a practice session, estimating values for which data are already available to assess accuracy. However, few experts generally have the opportunity to be involved in such training and feedback session. Therefore, that the criteria by which experts are selected, usually qualification and experience, may not correspond to the reliability of the expert judgements. Thus, the adoption and use of structured and robust procedures to gather expert judgements are required (Martin *et al.*, 2011).

Formal methods for the elicitation of expert judgement have been applied to conservation science. Whilst the details of some of these approaches may vary the steps in the process are similar. The typical steps in the process of eliciting expert judgement (which have been summarised from O‟Hagan *et al.*, 2006 and Martin *et al*., 2011) are as follows and are described in more detail in the sections below:

i. Identify the expert judgement elicitation team
ii. Determine what judgements are needed
iii. Design of the elicitation process – background and preparation
iv. Design of the elicitation process – identify, recruit and train experts
v. Elicit expert judgements
vi. Use of expert judgements

i. Identify the expert judgement elicitation team

The team tasked with eliciting expert judgement would usually consist of the following members:

a. Problem owner or client (i.e. the person or institution who specifies the problem or questions to be addressed such as what are the reference conditions for the following criteria for benthic habitats)
b. Facilitator who manages the interactions among experts and oversees the process
c. An analyst or statistician who handles calibration, elicitation procedures, the recording and processing of responses and analysis of the elicited information.
d. One or more experts to provide their knowledge or judgements

ii. Determine what judgements are needed

This stage usually involves the problem owner, the facilitator and analyst to determine what the process of eliciting expert judgement seeks to achieve and how the judgements will be used. For example, will the expert judgements form the basis of a decision directly or will they be used indirectly, such as being incorporated into a model that is subsequently used in decision making. This stage is also likely to identify the variables, such as the habitat types and criteria for which reference conditions are needed, which expert judgement will need to address. This stage may require analysis of where data are lacking.

iii. Design of the elicitation process – background and preparation

At this stage the elicitation format is determined. Elicitation can be carried out by a variety of methods including email surveys, face-to-face interviews, questionnaires or group meetings. Some processes of gaining expert judgements may use more than one of these methods. For example, the initial stage of deciding exactly what judgements need to be made, or where knowledge or data are lacking for a particular question, may need to be addressed by questionnaires first to ensure subsequent group meetings can be targeted in the most effective way.

At this stage background materials are compiled and the process of elicitation is designed. During this stage questions are tested and finalised, background materials (e.g. reports, journal articles, data etc) are compiled and scenarios to help experts understand the questions are developed. In addition, this preparation stage should address how judgements are obtained (discussion, data sheets etc), how interactions are managed, methods of analysing the expert data and the identification of the methods that will be used to address uncertainty.

iv. Design of the elicitation process – identify, recruit and train experts

Group elicitation has the most potential, since it can bring better synthesis and analysis of knowledge through group interaction. Thus, it is recommended that expert panels are required to determine reference conditions. An expert is generally considered to be someone who has substantive knowledge of a particular topic that is not widely known by others. An expert holds information about a given topic and who should be deferred to in its interpretation. This knowledge may be the result of training, research and skills but could also be the result of personal experience. Experts are not only created through formal education. The criteria for the identification of experts could include the following:

- Tangible evidence of expertise
- Reputation
- Availability and willingness to participate
- Understanding of the general problem area
- Impartiality

The members and roles of the elicitation team are also finalised at this stage. Success of the group elicitation is highly dependent on the abilities of the facilitator and this person should be chosen with particular care.

The role of the facilitator is to encourage:
- Sharing of knowledge (not opinion)
- Recognition of expertise

- The study of feedback

But must avoid

- The group being dominated by shared knowledge or over-strong opinions
- The kinds of biases found in individual assessments
- The tendency of groups towards an over-confidence (thus assessments of probabilities and uncertainty will be particularly important here)

The design process may include training the experts, such as having experts answer practice questions and develop familiarity with the elicitation style and procedure. This may be particularly useful when detailed information is to be gathered in a format an expert may be unfamiliar with, such as probability distributions and their statistical summaries. This training includes improving experts" understanding that uncertainty is a natural part of the process and that the objective of the elicitation is to capture their knowledge in a form that expresses neither too much nor too little uncertainty.

v. Elicit expert judgements

To address potential language-based misunderstandings and different interpretations of the decisions or predictions to be made, most elicitation exercises start with a discussion of the questions themselves. Pilot elicitations, particularly discussion among expert participants, can often resolve any issues of vagueness, ambiguity and context dependence.

Where an elicitation involves multiple experts information can be gathered independently and then combined by an analyst, or a group opinion can be sought. Group approaches are generally considered to be most effective method for elicitation. The most common group approaches include expert panels and Delphi methods (O"Hagan *et al*., 2005) (see below).

Expert panels foster the pooling of knowledge among experts and encourage agreement on the problem and questions at hand. However, there are a number of shortcomings of this approach. The full diversity of opinions is often lost and responses are subject to biases, including dominance of one or more members of the group, polarisation among subsets of members and a „groupthink" approach which occurs when the desire for harmony in a decision-making group overrides a realistic appraisal of all alternatives.

These problems can be overcome by using structured approaches to group elicitation interactions, such as the Delphi method. In these approaches, anonymous estimates are elicited from individuals and shared with the group. Experts are then allowed to adjust their estimates in light of the responses of others. This type of structured approach generates group estimates for ecological parameters that usually are more accurate than the estimates of the highest-regarded expert in a group.

Although obtaining an expert consensus may be important for modelling and decision making it is also important that differences in judgement be retained and communicated to decision makers.

a. Accounting for bias

Although it is important to be aware of the potential for bias, not all experts in all elicitation processes will be biased. There are, however, a number of ways in which biases can be minimised including setting tasks that allow for deliberate practice with unambiguous feedback. Also, questions should be phrased in such a way that they are aligned with an expert"s knowledge. Bias can also be minimised by asking the same questions several times at different stages or using alternative wording (additional advice on managing bias is available – see references in Martin *et al*., 2011).

Procedures to avoid overconfidence bias which can be high when the predictability of the future is low are also available. A key approach is to elicit a lower bound, upper bound, best estimate and a level of confidence that the true estimate lies within the nominated lower and upper bounds. The last step in the process requires the expert to evaluate an interval, taking advantage of the fact that experts are much better at evaluating intervals than producing intervals.

b. Dealing with uncertainty

Eliciting the uncertainty around an estimate requires the differentiation between the two types of uncertainty:

- Epistemic or knowledge uncertainty - this uncertainty can be reduced by studying the system and acquiring additional knowledge
- Aleatory or natural uncertainty – this uncertainty can be better understood but not reduced by collecting additional data

Questions to elicit information can be posed so as to clarify which elements of uncertainty are sought and to partition them into separate questions. For example, epistemic uncertainty can be elicited by asking an expert to provide an estimate of a variable, giving the lower and upper bounds of an interval which they are 90% certain holds the true mean. For aleatory uncertainty experts should be asked to estimate values of variation and skew of the distribution of the variable from year to year.

It is not always possible to separate epistemic and aleatory uncertainty in an elicitation. However, failing to consider these sources risks experts confounding uncertainty and it is generally not possible for an analyst to partition them retrospectively.

vi. Use of expert judgements

The application and use of expert judgements is also known as „encoding". It is the process by which the elicited information is translated into quantitative statements that can be used in a model or can be used directly to make decisions. How expert judgements need to be used will be an important step in the elicitation planning process, setting the framework for the design and implementation of the elicitation.

The development of methods for improving the elicitation of expert knowledge is a growing area of research and many issues remain. For example, questions remain regarding the number and identification of experts required, how to combine judgements and how to assess reliability. However, developing a structured procedure for the process, such as that provided in the guidelines above, can significantly improve the accuracy and information content of expert judgement and ensure uncertainty is captured accurately. It is therefore recommended, that in instances where expert judgement is used as the sole method to define reference conditions for benthic habitat criteria within the North-East Atlantic, a structured process developed in line with the stages described above is adopted. Since the facilitator plays such a crucial role in the successful outcome of expert judgement elicitations it is also suggested that particular care should be taken to select someone with the necessary experience and training.

4.3.2 Cost estimates for methods of determining reference conditions

Whilst the cost implications of using a particular method of determining reference conditions will depend on the habitat type and the criteria for which reference conditions are being determined, it is useful to consider what the costs may be. There are some key recommendations of the report that have cost implications for the development of reference conditions. In particular, a lack of data has highlighted the need for the use of expert judgement to set reference conditions in many habitats, particularly for the biological quality indicators. Also, the need for additional research including survey work, to improve the determination of reference conditions has been identified for many habitats. Rough estimates of potential costs for each of the methods for determining reference conditions are provided below.

i. Existing reference conditions

Where locations in reference condition are available the cost of determining reference condition values will be dependent on the availability of data. Where data are already available reference conditions can probably be set through a desk based study. It may be necessary to start with a period of data collation from a number of different locations and then carry out data analysis to determine reference conditions. A desk-based review of three-four months, at a cost of between ***£30,000 - £40,000***, may be sufficient to determine reference conditions using pre-existing data. Additional costs may be required if validation and calibration by additional experts is required.

Costs will be considerably higher if new data collection is needed. Survey costs will be determined by the habitat type and nature of the sampling required. Geophysical surveys may be particularly expensive because of the technical nature of the equipment used and the requirement for expert interpretation of the data. Similarly, biological samples can also be expensive to analyse.

Sublittoral survey costs are generally in the region of ***£100,000+*** for a substantive survey with full sample and data analysis. Prices increase with distance away from the shore, depth of sampling and the number of samples acquired. As an example, a survey of ~6000 km^2 of sublittoral habitats, collecting 3000 line kilometres of geophysical data followed by grab, trawl and video sampling could cost in the region of ***£600,000***. Sample and data analysis and interpretation costs will also have to be added and could increase the overall cost significantly.

ii. Historical reference conditions

A desk based study is likely to be necessary for the determination of historical reference conditions. This could probably be collected within a few months at a cost of ***£30,000-£50,000*** although this may increase if special access or licences for data sets are required. Where expert judgement is needed to validate and calibrate data the additional cost of an expert workshop may be necessary. Thus, the upper limit could rise to ***£75,000 - £80,000***.

iii. Modelled reference conditions

The development of ecological models are generally fairly time consuming as significant validation and calibration with input from a number of experts may be required. For example, a six-month research project, at an estimated cost of ***£60,000 to £100,000*** may be adequate to set reference conditions for some criteria. However, where data are complex and significant testing and input from experts is needed model development could be more expensive, especially where an expert workshop is thought necessary.

iv. Expert judgement

As an example, for a panel of 12 experts attending a three day workshop at a European city costs are estimated to be in the order of ***£25,000 ± £5,000***

Costings include:
- Elicitation team staff time for the design and set up of expert panels
- Elicitation team staff time for facilitation, collation and analysis of outcomes during the workshop
- Travel, subsistence and accommodation costs of experts
- Accommodation costs for workshop venue
- Staff time to analyse and report results

It may also be necessary to employ expertise for the design and process of expert elicitation and a number of workshops may be needed, particularly where expert judgement is the sole means of determining reference conditions. Thus, determining reference conditions using expert judgement alone may cost in the region of ***£50,000 to £100,000***.

Determining reference conditions using either existing or historical reference conditions, where data are readily available, are likely to be the least expensive options, followed by the use of expert judgement. For example, the use of historical data may be appropriate for determining reference conditions for habitat distribution and extent where only collation of a number of data sources is required and little input from additional experts is needed. The most expensive option for determining reference conditions for the criteria of habitat distribution, extent and condition will be the collection of additional survey data to underpin the use of the existing reference conditions methodology.

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6 Appendices: Supporting text for recommending methods for setting reference conditions

6.1 Habitat Distribution (1.4), Habitat Extent (1.5) and Physical Damage (6.1) for marine benthic habitats in the North-East Atlantic

Where there are habitats that are similar in nature and require the use of same datasets to identify reference conditions they have been reviewed together.

6.1.1 Predominant Habitats

Littoral rock and biogenic reef

Method	Analysis	Choice
1. Existing reference conditions	Littoral rock and biogenic reefs generally refer to the reefs of *Sabellaria alveolata* and *Mytilus edulis* on hard substratum although there are also a few instances of *Sabellaria spinulosa* reefs in the littoral zone (McIntosh, 1922; Unicomarine,1998; Hendrick, 2007). Current UK distribution and extent data for littoral biogenic reefs is fairly readily available (see Holt *et al.*, 1998 and individual habitat review presented here for *Mytilus edulis* for specific references), particularly for those biogenic reefs that occur within UK Marine SACs. Many areas of the UK intertidal zone have been mapped as part of the Marine Nature Conservation Review (MNCR) (Connor *et al.*, 1997) and through Phase 1 mapping of the Welsh coast (Wyn & Brazier, 2009). Partial intertidal coverage of rock habitats is also available from the MESH project. Thus, the distribution and extent of littoral rock and biogenic reef in the UK is thought to be fairly well known. Biogenic reefs are sensitive to physical damage and changes in sediment supply so are likely to have been subject to some changes in extent and, possibly, distribution. Habitat damage in littoral rock habitats was thought to be absent in most areas of UK waters with some moderate damage due to overturning of boulders in Irish waters (Aish *et al*., 2010)	✓
2. Historical reference conditions	The distribution of littoral rock habitats is not likely to have changed significantly due to human activities. The extent of littoral rock may be slightly reduced due to coastal development but this is minimal so current distribution and extent data can be used to set reference conditions. There have however, have been losses in extent of the biogenic reefs in the littoral zone. See Intertidal *Mytilus habitat* review and Holt *et al.* (1998). There is a limited amount of historical distribution data from the 1980s for *Sabellaria alveolata* reefs on the coasts of Britain, France Spain and Portugal (see references in Holt *et al.*, 1998) although this is probably not early enough to represent true historical reference conditions due to coastal development. Some earlier reef distribution data are available for the southern North Sea (Linke, 1951), the east coast of England (McIntosh, 1923) and Devon (Wilson, 1971, 1974, 1975) for *S. alveolata* (which may actually have been intertidal reefs of *S. spinulosa*) but the studies are generally local in nature and reference conditions for all areas may not be	✓

	able to be set.	
3. Modelled reference conditions	None identified for littoral habitats.	
4. Expert Judgement	Distribution and extent data for reefs may also be compromised by problems with classification because there is not an accepted definition of exactly what constitutes a biogenic reef (Holt *et al.*, 1998; Gubbay, 2007; Hendrick & Foster-Smith, 2006). Work by JNCC to produce a robust definition is ongoing.	✓

Littoral sediment

Method	Analysis	Choice
1. Existing reference conditions	Current UK distribution data are fairly readily available from a range of sources including the series of broadscale littoral surveys that were carried out as part of the UK‟s Marine Nature Conservation Review (MNCR) (Connor *et al.*, 1997). A complete Phase 1 intertidal map is available for the Welsh coast (Wyn & Brazier, 2009). Some intertidal data are also available via the MESH programme although coverage in incomplete. A number of local habitat assessments have also been carried out as part of the UK Marine SACs designations process. The area of littoral sediments in UK waters with physical damage, due to factors such as coastal recreation and bait digging, is considered to be low (Aish *et al*., 2010).	✓
2. Historical reference conditions	The distribution of littoral sediments, which is the result of physical and geological processes over long timescales, is not likely to have changed to any great extent due to human activities. There have been changes in habitat extent, particularly in the latter half of the 20th century, mostly due to coastal development (Airoldi & Beck, 2007; Airoldi *et al*, 2008). However, loss is more usually a change in the ecological structure and functioning of the habitat so reference conditions based on current extent are likely to be representative.	
3. Modelled reference conditions	No habitat modelling programmes have been identified for the littoral zone.	
4. Expert Judgement	Some areas are mapped more accurately than others so expert judgement will be required to determine final reference condition measures.	✓

Shallow sublittoral rock and biogenic reef

Method	Analysis	Choice
1. Existing reference conditions	Shallow sublittoral rock and biogenic reefs generally refer to the reefs of the tubiculous polychaete *Sabellaria spinulosa* and the horse mussel *Modiolus modiolus,* which are covered under their own habitat categories, but also includes reefs of *Serpula vermicularis*. Most known sublittoral biogenic reef habitats, or potential biogenic reef habitats, in the UK have been mapped and data are available from JNCC (http://jncc.defra.gov.uk/page-3054). This map includes survey data from the MESH project, intertidal and subtidal surveys carried out by Natural England, CCW and SNH and offshore survey work by the JNCC. However, new reefs are still being found such as those identified in the East Coast Regional Evironmental Characterisation project (Limpenny *et al*., 2011) and Scottish Priority Marine Feature surveys (Hirst *et al*. in press a, b) so current data are probably incomplete. However, the exact location and extent of reefs is incomplete for the UK and most of Europe where there	✓

	has not yet been a modern, systematic, fit-for-purpose survey of the entire seabed (Irving, 2008; Diesing *et al.*, 2009). For rocky reef habitats recent seabed mapping work highlights the degree of uncertainty in present estimates of the UK complement of these habitats (Aish *et al*., 2010). Recent work by Cefas in one area of „potential reef" (the central English Channel) has shown that seabed sediment charts are not reliable predictors of the location and/or extent of rocky reef habitats. In a recent status assessment the overall area affected by physical damage, particularly the impacts of mobile benthic fishing gear on boulders and biogenic reefs (damage, loss, removal of species), in UK waters was reported to be limited (Aish *et al*., 2010).	
2. Historical reference conditions	The distribution of sublittoral rock habitats is not thought to have changed significantly due to human activities. The extent of sublittoral rock may have reduced slightly due to coastal development but this change is minimal so current data on distribution and extent is thought to be adequate for setting reference conditions. The sublittoral rock and biogenic reefs of *Sabellaria spinulosa* and *Modiolus modiolus* are known to have undergone historical changes in distribution and extent. There is some historical data available for the distribution and extent (see individual habitat reviews) but most of our knowledge comes from more recent studies. The reefs of *Serpula vermicularis* are also included in this habitat classification. Some reduction in the extent and distribution of this habitat has been documented in data from the 1920s as well as in several more recent reports (e.g. see Moore *et al*., 2009).	✓
3. Modelled reference conditions	The UKSeaMap and EUSeaMap 2010 projects have produced habitat models for subtidal habitats including rock and biogenic reefs. These projects have, collated information from detailed habitat maps and filled in the gaps using broad-scale physical maps (often modelled or extrapolated) to predict habitat distributions. Whilst the accuracy of the outputs from these mapping projects is spatially variable it represents the best current state of knowledge on habitat distribution. Such modelled data can be used, together with local expert judgement, to estimate current distribution and extent reference conditions for seabed habitats. Some of the maps detailing potential distribution and extent will however, require confirmation with further survey. As more data becomes available it should be added to reference condition models to improve confidence.	✓
4. Expert Judgement	Expert judgement will be required to combine the various raw and modelled data sources and ultimately to determine the reference conditions for habitat distribution, extent and physical damage.	✓

Shallow sublittoral sediments (coarse, sand, mud and mixed sediments)

Method	Analysis	Choice
1. Existing reference conditions	Habitat distribution and extent data has been collected from a large number of disparate mapping and research programmes. Much of this data has been collated in a JNCC-led international marine habitat mapping programme entitled 'Development of a framework for Mapping European Seabed Habitats', or MESH for short, which ran from 2004 to 2008 (see http://www.searchmesh.net/). More data will have been collected since the latest 2008 data included in the MESH data set. This includes data available via Environmental Impact Assessments (EIAs), marine monitoring	✓

	programmes and research such as the Regional Environmental Characterisation (REC) surveys funded by Defra through the Marine Aggregate Levy Sustainability Fund (MALSF). Data are available on the extent of physical damage to sediments in shallow water the UK, mainly due to the impacts of mobile fishing gear. These range from 15-30% of total area (Aish et al., 2010).	
2. Historical reference conditions	Generally, the greatest pressures within the marine environment are concentrated on the coastal seabed with fishing, aggregate dredging and renewable developments all affecting marine ecosystems. Whilst the overall distribution of sediment habitats is not likely to have changed, some activities that remove sediment from the seabed, particularly aggregate dredging, have changed the local extent of sediment types in some areas. There are data available that describe changes in sediment type, usually a shift from mixed to sandier sediments, as a result of intensive aggregate dredging (e.g. Robinson *et al.*, 2005; Desprez, 2000; Desprez *et al.*, 2010) but information on specific locations is more difficult to find. No historical data on changes in sediment distributions was identified.	
3. Modelled reference conditions	The UKSeaMap and EUSeaMap 2010 projects have produced habitat models for subtidal habitats including broad sediment categories. Such modelled data can be used, together with local expert judgement, to estimate distribution and extent reference conditions for seabed habitats. As more data becomes available it should be added to reference condition models to improve confidence.	✓
4. Expert Judgement	Expert judgement would be required to set reference conditions using a combination of existing and modelled data.	✓

Shelf rock and biogenic reef
Bathyal (slope/upper and mid/lower) rock and biogenic reef
Abyssal rock and biogenic reef

Deep-sea biogenic reefs refer to cold-water coral habitats, predominantly those of *Lophelia pertusa*, which is covered under the OSPAR threatened/declining habitats. Detailed information about this habitat is found in the *Lophelia pertusa* reefs review.

Method	Analysis	Choice
1. Existing reference conditions	Surveys from deep-sea UK habitats have been mapped via the MESH project but deep-sea environments are generally less well covered and so knowledge of the distribution and extent of this habitat is probably incomplete. Very little specific information was found on this habitat group but some distribution and extent data should have been identified from a number of deep-sea habitat mapping programmes that have occurred in the past few decades including the European MAST-Flux-Manche, INTERREG, HERMIONE and HERMES programmes. Exposed rock is uncommon, being confined to particularly steep continental slopes and seamounts (Bett, 2001). Deep-sea rock includes hills and seamounts. Seamounts are also considered under specific protected habitat groups so there is likely to be some overlap in distribution and extent. There was no information found on the extent of physical damage to rock habitats. There is considerable, although incomplete data on the distribution, extent and physical damage to *Lophelia pertusa* reefs (see habitat review below).	✓
2. Historical reference conditions	No historical data have been identified for deep water rock habitats. There is limited historical data for *Lophelia pertusa* which may contribute to the data required to set reference conditions.	✓

3. Modelled reference conditions	UKSeaMap and EUSeaMap have produced habitat suitability models for deep-sea rock and reef habitats. However, the deep sea biological zones are defined largely in terms of depth so seabed type data are limited and expert judgement will be required. The potential for other habitat modelling for this type of habitat have also been identified (Tittensor *et al.*, 2009; Howell *et al.*, 2011).	✓
4. Expert Judgement	The full distribution and extent of deep-sea rock and biogenic reef habitats is not yet known and reference conditions will need to be continually updated as new evidence comes to light. Expert judgement will be required to estimate reference conditions using all current data available.	✓ + **RESEARCH**

Shelf sublittoral sediments – coarse, sand, mud and mixed
Bathyal sediment – slope/upper and mid/lower
Abyssal sediment

Method	**Analysis**	**Choice**
1. Existing reference conditions	Current distribution and extent data are available for the whole range of sedimentary habitats. Much of this data has been collated in a JNCC-led international marine habitat mapping programme entitled 'Development of a framework for Mapping European Seabed Habitats', or MESH for short, which ran from 2004 to 2008 (see http://www.searchmesh.net/). Inshore areas are more accurately mapped than the deep sea because considerably more effort has been expended in surveying these areas. Although the deep sea is still largely unexplored bathyal and abyssal zones have been mapped as part of a range of international projects including the European MAST-Flux-Manche, INTERREG, HERMIONE and HERMES programmes. Some areas such as the Porcupine Abyssal Plains (PAP) have been intensively studied, presumably providing good local information on distribution and extent. The majority of deep sea habitats are sedimentary although different geological and hydrological conditions do generate different habitat types. It has now been found that continental margins and mid-ocean seafloors are much more complex ecologically than originally thought (Vanreusel *et al.*, 2010). Some data on physical damage is available, mainly for shelf sediments. This indicates an area of around 30% of seabed of most shelf waters around the UK have signs of habitat damage, mainly from demersal fishing (Aish *et al*., 2010). Data on physical damage in deeper waters was not found for sediment habitats.	✓
2. Historical reference conditions	Generally, the greatest pressures within the marine environment are concentrated on the coastal seabed with fishing, aggregate dredging and renewable developments all affecting marine ecosystems. In the deep sea changes in habitat condition are more likely to have occurred than loss of habitat so historical data for distribution and extent of sediment habitats is not required to set reference conditions.	
3. Modelled reference conditions	A number of projects have produced seabed habitat models according to the EUNIS (European Nature Information System) categorisation system for subtidal habitats, from shallow waters to the deep sea. These have been produced both at the UK national scale (UKSeaMap) and covering larger sections of the European continental shelf (MESH, EUSeaMap). The accuracy of the habitat model predictions will be much higher for inshore areas because of the higher concentration of survey data that have informed the model. It may also be possible to derive estimates for deep-sea habitats from current geological and geochemical knowledge coupled with accurate	✓

	bathymetry and remote sensing (Ramirez-Llodra *et al.*, 2010). Such modelled data can be used, together with local expert judgement, to estimate distribution and extent reference conditions for seabed sediment habitats for all the bathymetric zones within the predominant habitat list.	
4. Expert Judgement	Reference conditions for distribution and extent for the broad habitat category of subtidal sediments can be determined using current knowledge, modelling and expert judgement. However, continued research will be required to improve knowledge and reference conditions, particularly for the deep sea, on an on-going basis.	✓ + **RESEARCH**

6.1.2 Habitats Directive Annex I Habitats

Sandbanks which are slightly covered by seawater all the time

Method	**Analysis**	**Choice**
1. Existing reference conditions	The distribution of sandbanks is determined primarily by geological and hydrographic processes that generally occur over a relatively long timescale (Dyer and Huntley, 1997; Stansby *et al.*, 2006). While the physical area of some individual sandbanks may have declined due to localised pressures, the geographic spread and distribution of feature sub-types has not been reduced (JNCC, 2007). Thus, existing reference condition is adequate to determine reference conditions for the distribution and extent of this habitat. There is current distribution data for the OSPAR regions available from EUNIS and from the European Submerged Sandbanks Database (ESSD which is based primarily on information from Admiralty Charts). Sandbanks in the North Sea are fairly well documented and mapped (see Christiansen, 2009) but there are currently few comprehensive data available on the area covered by sandbanks in the UK. Current distribution and area data was however, assessed as moderate for the Habitats Directive (JNCC, 2007). Significant local mapping work has been carried out for offshore SACs (Haisborough, Hammond and Winterton candidate SAC (cSAC); Inner Dowsing, Race Bank and North Ridge cSAC; and Margate and Long Sands cSAC, and Dogger Bank cSAC) and there is an ongoing programme of work to map the extent of sandbanks across UK waters (see http://jncc.defra.gov.uk/page-1452) including offshore sandbanks which are also likely to be underestimated. Data are available on the extent of physical damage to sediments in shallow water the UK, mainly due to the impacts of mobile fishing gear. These range from 15-30% of total area (Aish *et al*., 2010).	✓
2. Historical reference conditions	Some historical data may be available from early Admiralty Charts	
3. Modelled reference conditions	There were no modelling programmes found that are specific to sandbanks but could be derived from UKSeaMap and EUSeaMap 2010.	
4. Expert Judgement	Some expert judgement is required in addition to existing reference condition. Further ground truthing survey work may be required to accurately define reference conditions.	✓

Mudflats and sandflats not covered by seawater at low tide

Method	Analysis	Choice
1. Existing reference conditions	The nature of the sedimentary processes associated with the formation of sandflats and mudflats means that their geographical range is likely to have remained the same in recent geological times. Although the physical area of some individual sandflats and mudflats are thought to have been affected by erosion, land claim or other anthropogenic pressures (Curd, 2009) there is however, no evidence that this has significantly altered the distribution of the feature. Some decreases in intertidal mudflat area due to land claim and the spread of *Spartina anglica* have been identified in the UK (JNCC, 2007) and there is work in Spain to show the changes in habitat extent since 1950 (Chust *et al.*, 2009). However, the full extent of mudflats and their loss in extent over time is not fully documented for most OSPAR Contracting Parties. Current UK distribution data are readily available from a range of sources although analysis for the Habitats Directive in 2007 reported there are no comprehensive data for the distribution or area of this habitat type in the UK (JNCC, 2007). Available data includes the series of broadscale littoral surveys that were carried out as part of the UK"s Marine Nature Conservation Review (MNCR) (Connor *et al.*, 1997) and a complete Phase 1 intertidal map of the Welsh coat (Wyn & Brazier, 2009). Some intertidal data are also available via the MESH programme although coverage is incomplete. A number of local habitat assessments have also been carried out as part of the UK Marine SACs designations process. The area of littoral sediments in UK waters with physical damage, due to factors such as coastal recreation and bait digging, is considered to be low (Aish *et al.*, 2010).	✓
2. Historical reference conditions	There are some historical data for changes to intertidal mudflats in particular areas (dating back to ~19th century) such as the Wadden Sea (Curd, 2009) and although there are data on the loss of intertidal habitats in the UK (Davidson *et al.*, 1991) it is not specific to this habitat type.	✓
3. Modelled reference conditions	There were no modelling programmes found that are specific to intertidal habitats.	
4. Expert Judgement	Expert judgement will be required to bring data sources together to define reference conditions for distribution and extent. Expert judgement will also be needed to determine if historical data are relevant as physical loss of habitat due to large scale land-claim cannot be reversed.	✓

Coastal lagoons

Method	Analysis	Choice
1. Existing reference conditions	Coastal lagoons are particularly susceptible to climate change, storms and sea-level rises (Brito *et al.*, 2011) and so current data are essential. The UK Habitats Directive Article 17 report for this habitat indicates that current UK data availability and quality are good (JNCC, 2007). There have been several relatively recent ecological studies in the Portuguese Rio Formosa (Gamito *et al.*, 2011;) and in south-east Spain (Lloret *et al.*, 2008; Perez-Ruzafa *et al.*, 2007). Most UK data will be available from studies carried out in the 1980s (see below) and local studies carried for UK Marine SACs. Data are available on the extent of physical damage to sediments in shallow water the UK, mainly due to the impacts of mobile fishing gear.	✓

	These range from 15-30% of total area (Aish et al., 2010).	
2. Historical reference conditions	The distribution of coastal lagoons in the UK is well known but information on long term distribution changes in coastal lagoons is not readily available. The reports for the UK Habitats Directive only report changes in distribution and extent since 1994 (JNCC, 2007). It is known that during the 1980s, some 30 to 40 lagoons were lost in England alone (JNCC, 2007) so changes in extent have occurred which may have affected the distribution. The physical area of some individual lagoons in the UK may have continued to decline (JNCC, 2007). Historical data will therefore be important in establishing the reference conditions but is unfortunately limited to studies from the 1980s (e.g. Barnes, 1988; 1989).	✓
3. Modelled reference conditions	No modelled data were found.	
4. Expert Judgement	Expert judgement will be required to set the reference condition for coastal lagoons as historical data are incomplete.	✓

Large shallow inlets and bays

Method	**Analysis**	**Choice**
1. Existing reference conditions	Large shallow inlets and bays are features defined by their physiographic nature rather than by a specific biological community. Therefore, the distribution of „large shallow inlets and bays" is not considered to have changed significantly over time (JNCC, 2007) and current distribution and extent is thought to adequately represent the reference condition. Data availability, at least in the UK, is considered to be good (JNCC, 2007) so extensive expert judgement is not likely to be required to set reference conditions for distribution and extent. Data are available from a number of sources including partial coverage by MESH, Admiralty Charts and local studies. The area of littoral sediments in UK waters with physical damage, due to factors such as coastal recreation and bait digging, is considered to be low (Aish *et al*., 2010). However, the extent of physical damage to sediments in the shallow subtidal, mainly due to the impacts of mobile fishing gear is higher, between 15-30% of total area (Aish *et al.,* 2010).	✓
2. Historical reference conditions		
3. Modelled reference conditions		
4. Expert Judgement	It appears minimal expert judgement would be required to set reference conditions.	

Reefs

Annex I reefs occur where rocky areas or concretions made by marine animals (i.e. biogenic reefs) arise from the surrounding seafloor. There are three main types of Annex I reef:

1. Bedrock reef
2. Stony reef
3. Biogenic reef

As the main biogenic reefs (*Lophelia pertusa*, *Sabellaria spinulosa, Modiolus modiolus* and *Mytilus edulis*) are covered under the OSPAR habitat this section will deal with habitat types 1 and 2 only.

Method	Analysis	Choice
1. Existing reference conditions	Bedrock and stony reef habitats are defined by their physiographic nature and so the distribution and extent is not considered to have changed significantly over time. Thus, only current data are required to determine reference condition for distribution and extent. JNCC maintain a map showing areas of potential Annex I reef in UK offshore waters (http://jncc.defra.gov.uk/page-1448). However, the exact location and extent of reefs is incomplete for the UK and most of Europe where there has not yet been a modern, systematic, fit-for-purpose survey of the entire seabed (Irving, 2008; Diesing *et al.*, 2009). Assessments for the UK Habitats Directive Articles 17 reports indicate that distribution and area data for the rocky habitats was poor (JNCC, 2007). In a recent status assessment the overall area affected by physical damage, particularly the impacts of mobile benthic fishing gear on boulders and biogenic reefs (damage, loss, removal of species), in UK waters was reported to be limited (Aish *et al*., 2010).	✓
2. Historical reference conditions	Historical data not required.	
3. Modelled reference conditions	There is some potential for predictive modelling of rocky reefs using methods developed in a seabed mapping project in the English Channel (e.g. Coggan *et al*, 2009; Diesling *et al.*, 2009).	✓
4. Expert Judgement	Expert judgement will be required to interpret current data sources though additional survey results may be required to produce accurate reference conditions.	✓ + **RESEARCH**

Submarine structures made by leaking gases

Method	Analysis	Choice
1. Existing reference conditions	This habitat was discovered in the 1970s so there is limited historical data available and the trend in distribution and extent is unknown (JNCC, 2007). The 2007 UK Habitats Directive Article 17 report categorises distribution and extent data as poor (JNCC, 2007). However, JNCC maintain a map that shows the location of known submarine structures made by leaking gases (http://jncc.defra.gov.uk/page-1453) so the data available is continually improved. It also shows areas where gas seeps are known to occur and therefore where there may be additional submarine structures that have not yet been found. JNCC is working, through offshore surveys, to confirm the presence of Annex I submarine structures in these areas. New structures have however, been discovered as recently as 2005 (e.g. Hovland *et al.*, 2005; Judd, 2005) indicating that the JNCC map is incomplete. In a recent conservation status assessment for UK waters the status and physical damage to submarine structures was unknown (Aish *et al*., 2010).	✓
2. Historical reference conditions	No information identified.	
3. Modelled reference conditions	Areas with potential for submarine structures have been modelled (JNCC, 2007) although these do need to be verified.	
4. Expert Judgement	A recent review suggests that it is not possible to set reference areas although some modelling estimates have been made (JNCC, 2007). Further surveys would be required to set accurate reference conditions and these should be informed by expert judgement.	✓ + **RESEARCH**

Submerged or partially submerged sea caves

Method	Analysis	Choice
1. Existing reference conditions	The distribution and extent of this habitat is determined by physical and geological processes and so the distribution and range has probably not changed significantly over time in response to anthropogenic pressures. There are natural changes in extent due to the processes of erosion, particularly for caves in soft rock types such as chalk. While individual areas with caves in them may have been affected by coastal processes and development it is considered that there has been no overall decline in the geographic spread or extent of this habitat (JNCC, 2007). Thus, the existing distribution and extent represents the reference condition and accounts for current physiographic and climatic conditions. However, the Habitats Directive Article 17 report indicates data availability in the UK is poor, as much of the UK coast has not been fully surveyed (JNCC, 2007). Comprehensive surveys undertaken in Wales give an indication of the degree to which the national picture may, at present, be under-represented and that localised losses do occur with coastal engineering. No specific information was identified for this habitat in the rest of Europe. In a recent conservation status assessment for UK waters the status and physical damage to submerged sea-caves was unknown (Aish *et al*., 2010).	✓
2. Historical reference conditions	No information identified.	
3. Modelled reference conditions	No information identified.	
4. Expert Judgement	Reference conditions require additional survey work as existing reference condition data and expert judgement are likely to be inadequate.	✓ **+** **RESEARCH**

Annual vegetation of drift lines

Method	Analysis	Choice
1. Existing reference conditions	There has not been a complete national assessment of this ephemeral habitat and so data on distribution and extent is incomplete (JNCC, 2007). No information was found for the distribution and extent of this habitat in the rest of Europe. The area of littoral sediments in UK waters with physical damage, due to factors such as coastal recreation and bait digging, is considered to be low (Aish *et al*., 2010).	✓
2. Historical reference conditions	Some losses are thought to have occurred but the scale is not quantifiable at a national level. No historical data appears to be available.	
3. Modelled reference conditions	No information identified.	
4. Expert Judgement	Further survey plus expert judgement is likely to be required to supplement existing data in order for reference conditions to be determined.	✓ **+** **RESEARCH**

Salicornia and other annuals colonising mud and sand

Method	Analysis	Choice
1. Existing reference conditions	Current distribution data for *Salicornia* and other annuals colonising mud and sand in the UK, is said to be moderate in quality. The UK Habitats Directive Article 17 reports that this habitat is thought to be found throughout its entire inhabitable range (JNCC, 2007). Changes in climate are likely to lead to distribution and extent changes in the future so reference conditions may need to be continually reviewed. With the exception of current European distribution data on the EUNIS website (eunis.eea.europa.eu) and a paper by Kadereit *et al.* (2007) there was very little information found on the European distribution and extent of this specific habitat. Most research has been carried out on the broader classification of „saltmarsh" (e.g. see Dijkema, 1987; Dijkema *et al.*, 1984) so expert judgement is likely to be important in defining reference conditions for this specific habitat. The area of littoral sediments in UK waters, and associated habitats such as saltmarsh, with physical damage, due to factors such as coastal recreation and bait digging, is considered to be low (Aish et al., 2010).	✓
2. Historical reference conditions	The setting of reference conditions for saltmarsh habitats, such as those of *Salicornia*, in relation to habitat distribution and extent is particularly challenging as there have been widescale changes since Roman times (Purseglove, 1988). The Dutch have been able to use Roman descriptions to interpret the likely conditions around 100AD (De Jong, 2004) although reference conditions were considered to be set at a much later date. There was very little historical information found for the UK distribution of this habitat. There has not been a UK wide assessment of the change in area of this habitat, but there are a number of specific studies in England and Wales that may demonstrate some trends (JNCC, 2007; Burd, 1989; Burd, 1991; Cooper *et al.*, 2001; Boorman, 2003). In particular, there has been a change in the structure of the marsh vegetation from upper saltmarsh to lower saltmarsh types i.e. in part, from H1330 habitat to H1310 habitat) (Burd, 1992). Such data may inform historical reference conditions but interpretation by experts would be required.	✓
3. Modelled reference conditions	Best *et al.* (2007) suggest that an alternative to existing and historical reference conditions may be hindcasting with models that predict the extent of saltmarsh. Frost *et al.* (2004), for example, predicted saltmarsh habitats in the Humber estuary using adapted equations from Clarke and Brown (2002). Expert judgement would be required to determine values for this specific habitat within the overall saltmarsh habitat predictions.	✓
4. Expert Judgement	Reference conditions should be set using expert judgement alongside whatever historical data are available and appropriate, and current distribution and extent records. Expert judgement was used to determine habitat distribution and pattern reference conditions for the implementation of the WFD in the UK (Best *et al.*, 2007).	✓

Spartina swards (*Spartina maritimae*)

Method	Analysis	Choice
1. Existing reference conditions	Some current distribution data are available (Purseglove, 1988; Preston *et al.*, 2002; Rodwell, 2000). The UK Habitats Directive Article 17 report for this habitat assessed distribution data as moderate but extent data was poor (JNCC, 2007).	✓

	The area of littoral sediments in UK waters, and associated habitats such as saltmarsh, with physical damage, due to factors such as coastal recreation and bait digging, is considered to be low (Aish et al., 2010).	
2. Historical reference conditions	There is some information regarding the change in distribution and extent of *S. maritima* over the last 100 years (Preston *et al.*, 2002; Rodwell, 2000; Hubbard & Stebbings, 1967) and which continue today (Stewart *et al.*, 1994; JNCC, 2007). These data sources provide some historical data which may be useful when setting reference conditions.	✓
3. Modelled reference conditions	Modelling, as described for *Salicornia* habitats, may provide some insights for the reference condition setting process	✓
4. Expert Judgement	Expert judgement is likely to be important as data are incomplete, there have also been large changes in distribution and extent due to the introduction and hybridisation with other species. Expert interpretation incorporating any modelled outputs will be required.	✓

Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)

Method	Analysis	Choice
1. Existing reference conditions	The quality of UK salt meadow data are considered to be moderate and hence they have been used to provide estimates of the area for this habitat (JNCC, 2007). However, further examination of the data may be required to determine if this also represents reference conditions, as it is defined for the MSFD. Current European distribution data are available from EUNIS and extent data from Doody (2008). The quality of these data are unknown. The area of littoral sediments in UK waters, and associated habitats such as salt meadows, with physical damage, due to factors such as coastal recreation and bait digging, is considered to be low (Aish *et al.*, 2010).	✓
2. Historical reference conditions	Changes in distribution and extent are likely to have occurred in these coastal habitats, as documented in other saltmarsh areas and so historical data will be important to setting reference conditions. There is some historical data for this specific habitat providing information on changes in UK distribution and extent in the 20th Century (NBN Gateway data; Preston *et al.*, 2002; Chapman, 1947; Rodwell, 2000). There is also data from the Saltmarsh Survey of Great Britain carried out in the 1980s (Burd, 1989). However, this data are probably not complete.	✓
3. Modelled reference conditions	Modelling, as described for *Salicornia* habitats, may provide some insights for the reference condition setting process	✓
4. Expert Judgement	Expert judgement will be required to use current and historical data to set reference conditions to account for historic losses and current physiographic and climatic potential.	✓

Mediterranean and thermo-Atlantic halophilous scrubs

Method	Analysis	Choice
1. Existing reference conditions	Current UK data availability was considered moderate but incomplete with a very limited distribution in the UK (JNCC, 2007). No information was found on the distribution and extent of this habitat in Europe. The area of littoral sediments in UK waters, and associated habitats, with physical damage due to factors such as coastal recreation and bait digging, is considered to be low (Aish *et al.*, 2010).	✓
2. Historical reference	Changes in distribution and extent are likely to have occurred in these coastal habitats, as documented in other saltmarsh areas and so historical	✓

conditions	data will be important to setting reference conditions. There is some historical data for this specific habitat providing information on changes in UK distribution and extent in the 20th Century (NBN Gateway data; Preston *et al.*, 2002; Chapman, 1947; Rodwell, 2000). There is also data from the Saltmarsh Survey of Great Britain carried out in the 1980s (Burd, 1989). However, these data are probably not complete.	
3. Modelled reference conditions	Modelling, as described for *Salicornia* habitats, may provide some insights for the reference condition setting process	✓
4. Expert Judgement	Considerable expert judgement would be required to assimilate all the data and account for gaps in information.	✓

6.1.3 OSPAR threatened/declining habitats

Carbonate mounds

Method	Analysis	Choice
1. Existing reference conditions	Carbonate mounds (now generally accepted to be coral carbonate mounds (Hall-Spencer *et al.*, 2008) are widely distributed in the North-East Atlantic, however, data on precise locations and their full extent is not known (Hall-Spencer *et al.*, 2008). Habitats that occur on certain mounds are impacted, most significantly by demersal fishing. Knowledge of the proportion of habitats present on coral carbonate mounds that have been impacted by fishing is scant, since the majority of these features have not been surveyed visually. However, many of the mounds that have been surveyed visually show signs of trawling damage such as smashed corals, overturned boulders and ghost net. Additionally, analyses of vessel monitoring system (VMS) data indicates intensive demersal trawling activitiy in all of the areas where coral carbonate mounds are known to occur (Hall-Spencer *et al*., 2010).	✓
2. Historical reference conditions	There are no historical studies as these habitats were only discovered in recent years (see references in Hall-Spencer *et al.*, 2008). Human activities have not altered the extent of coral carbonate mounds themselves as they have not been subject to activities, such as mining, that would impact their structural integrity (Hall-Spencer *et al.*, 2010), therefore the lack in historical data may not be critical for setting reference conditions for this habitat. .	
3. Modelled reference conditions	No modelled data found.	
4. Expert Judgement	Carbonate mounds do not represent a single habitat type and so expert judgement is likely to be required to determine the known current distribution and extent. Further survey work would be needed to determine accurate reference conditions for habitat distribution and extent.	✓ **+** **RESEARCH**

Coral gardens

Method	Analysis	Choice
1. Existing reference conditions	While coldwater corals were discovered two centuries ago, their significance in habitat formation is only just emerging with the deployment of manned and unmanned submersibles and the development of advanced acoustics to map their distribution (Hovland *et al.* 2002; Roberts	✓

	et al. 2005). The occurrence and distribution of coral gardens in the North-East Atlantic is insufficiently known at present (Christiansen, 2010a). The current scientific information on the occurrence of non-reef corals is patchy and is not based on systematic surveys (see ICES, 2007 and Christiansen, 2010a for current known distribution). For individual locations expert judgement is required to distinguish the extent of the habitat and separate it from surrounding habitats. Whilst the sensitive nature of these habitats to bottom trawling in particular there is no comprehensive data on the extent of physical damage to coral gardens (Christiansen, 2010a).	
2. Historical reference conditions	No historical data sets were identified	
3. Modelled reference conditions	ICES (2007) compiled an initial and therefore incomplete review of soft coral records from published literature, as an indicator of possible "coral garden" occurrences so some predictive modelling may be possible.	
4. Expert Judgement	The characteristics of this habitat have not been fully defined so considerable expert judgement will be required to estimate reference conditions. Further surveys data are required to set accurate reference conditions.	✓ + **RESEARCH**

Cymodocea meadows

Method	**Analysis**	**Choice**
1. Existing reference conditions	Despite numerous studies on these sea-grass habitats, in their distribution range of Spain and Portugal, there is still poor spatial resolution and their full extent is unknown (Ayala, 2010 and references therein). Whilst the threats to this habitat are known there were no qualitative data found to describe the extent of physical damage (Ayala, 2010).	✓
2. Historical reference conditions	Declines in the distribution and abundance of this sea-grass habitat are recognised to have occurred in the past century, mainly due to deterioration of water quality (Ayala, 2010). No historical data has been identified although there may be historical records available in the relevant member states.	
3. Modelled reference conditions	No modelled data were identified.	
4. Expert Judgement	In some cases expert judgement has been used to define areas where *Cymodocea* meadows should be present (Ayala, 2010). Thus, expert judgement will be required to set reference conditions relying on current data to set historical conditions prior to human disturbance which also reflects current physiographic and climatic conditions. Additional research will also be required to improve the accuracy of reference conditions.	✓ + **RESEARCH**

Deep-sea sponge aggregations

Method	**Analysis**	**Choice**
1. Existing reference conditions	This habitat is known to be in decline (Christiansen, 2010b). Given the high intensity of bottom trawling carried out on the continental margins it is highly likely that not only the extent but also the condition of deep-sea sponge aggregations have been affected (Bett, 2000). There is also anecdotal by-catch evidence from fishermen that this habitat has declined but the extent of the decline is largely unknown, particularly as all	✓

	examples of this habitat are yet to be discovered (Christiansen, 2010b). Whilst there are good current distribution records in some areas of the North-East Atlantic the full distribution and extent of this habitat in the region is still unknown (ICES, 2009). In particular, the sponge fauna from OSPAR Region V are poorly recorded (Christiansen, 2010b). In some areas distribution is also estimated from fishing by-catch data. There is some information regarding the extent of physical damage to these habitats (see Christiansen, 2010b and references therein).	
2. Historical reference conditions	There is a small amount of historic data available on the distribution and extent of this habitat (e.g. see Carpenter *et al.*, 1870; Le Danois, 1948; Lévi & Vacelet, 1958) but this is unlikely to be sufficient to determine historic distribution and extent. The data may however, provide useful insights to reference conditions.	✓
3. Modelled reference conditions	There is some understanding of the environmental conditions required for these habitats so predictive habitat modelling approaches could be developed.	✓
4. Expert Judgement	OSPAR has identified a need for further surveys to determine the full distribution and extent of these habitats (Christiansen, 2010b). Expert judgement will almost certainly be required to bring all the different strands of information together.	✓ **+** **RESEARCH**

Intertidal *Mytilus edulis* beds on mixed and sandy sediments

Method	Analysis	Choice
1. Existing reference conditions	Good current distribution data are available at a wide geographical scale (OSPAR, 2010). However, extent data are likely to be less readily available, because of the highly patchy nature of mussel beds, and collation of data sources may be required to determine accurate reference conditions for extent. Similarly, there is also a wide body of literature available regarding the impact of fisheries on the habitat that can be used, with the aid of expert judgement to set reference conditions for physical damage.	✓
2. Historical reference conditions	Significant declines in the extent and biomass of intertidal mussel beds have been reported in the OSPAR Maritime Area and particularly in Region II. Good historic and current distribution data are available to reflect historical losses and current physiographic and climatic changes (OSPAR, 2010).	✓
3. Modelled reference conditions	No modelled data was identified.	
4. Expert Judgement	It is likely that the reference condition can be set using expert judgement interpretation of historical and existing data.	✓

Intertidal mudflats

Method	Analysis	Choice
1. Existing reference conditions	Because of the nature of intertidal mudflats and their accessibility there is likely to be good distribution and extent data, including that from early Admiralty Charts, Some intertidal data are also available via the MESH programme although coverage in incomplete. There are also data from a number of mapping programmes in the intertidal such as the Phase 1 mapping carried out in Wales (Wyn & Brazier, 2009) and other MNCR surveys.	✓

	The area of littoral sediments in UK waters with physical damage, due to factors such as coastal recreation and bait digging, is considered to be low (Aish *et al*., 2010).	
2. Historical reference conditions	Historically, there have been losses in this habitat due to a range of human induced changes including land claim, coastal development and sea-level rise. Although there is a great deal of information available for this easily accessible habitat, the full extent and loss over time is not fully documented for many European countries (Curd, 2009). OSPAR reports a need to understand the distribution, extent and condition of this habitat including how it has changed over time (Curd, 2009).	✓
3. Modelled reference conditions	Predictive modelling approaches such as that used by Zacharias *et al.* (1999) in the Strait of Georgia in British Columbia, could be used to estimate the distribution and extent of intertidal mudflats Combining shoreline morphology, temperature, salinity and tidal stream velocity data with biological field sampling enabled the researchers to develop kilometre scale habitat maps this may have application to setting reference conditions.	
4. Expert Judgement	Reference conditions are likely to rely heavily on expert judgement to interpret incomplete existing and historical data. Additional modelled data may also be useful to set reference conditions or target additional survey work.	✓

Littoral chalk communities

Method	Analysis	Choice
1. Existing reference conditions	There is a limited but good basis for assessing the extent and status of littoral chalk habitat in the OSPAR area (Tittley, 2009). There is also some data regarding the extent of physical damage, mostly carried out in the past, to this habitat.	✓
2. Historical reference conditions	The overall distribution of littoral chalk communities has remained the same in recent geological times, except for the very small outcrop (of white chalk cliffs) on Dune Island, Germany, which was lost in the 17th century as a consequence of natural erosion and quarrying (Vahlendieck, 1992). However, in the UK, local declines in extent have been recorded, due to coastal defence construction and other works (Doody *et al.*, 1991; Fowler & Tittley, 1993).	✓
3. Modelled reference conditions	No modelled data were identified.	
4. Expert Judgement	There is likely to be adequate existing and historical data to determine reference conditions without the need for significant expert judgement	

Lophelia pertusa reefs

Method	Analysis	Choice
1. Existing reference conditions	The distribution of *Lophelia pertusa* reefs within North-East Atlantic is fairly well known (Friewald *et al.*, 2004; Buhl-Mortensen *et al.*, 2010; Hall-Spencer *et al.*, 2002; Roberts *et al.*, 2005) but the total extent is unknown. There are over 2000 records of *L. pertusa* from the OSPAR area although due to uncertainties in many of the records it is not clear how many of these represent current reef habitats (Hall-Spencer & Stehfest, 2009). Most cold-water corals occur in abundance below 400 m and so the majority of these instances relate to bathyal reef areas.	✓

	Studies on physical damage to this habitat are also limited and the total extent of damage is therefore unknown. In many instances where damage has been observed it is unclear what the habitat extent was prior to destruction (see Hall-Spencer & Stehfest, 2009 and references therein). However, it is known that some NE Atlantic deep-water reefs have now been severely damaged by bottom trawling (Rogers 1999; Roberts *et al.* 2000; Fossa° *et al.* 2002; Hall-Spencer *et al.*, 2002; Freiwald *et al.*, 2004; Wheeler *et al.*, 2005). Some observations also come from fishermen‟s records. This information can provide insights to reference conditions for physical damage but expert judgement will be the most important method for their definition.	
2. Historical reference conditions	The North-East Atlantic is considered to have the best available historical data on deep-sea coral reef habitats (Hall-Spencer *et al.*, 2007) but these do not provide a complete distribution picture for this habitat (Hall-Spencer & Stehfest, 2009). However, some estimates of current extent and recent changes have been made (ICES, 2002) and the extent of the habitat is known to have declined.	✓
3. Modelled reference conditions	UKSeaMap and EUSeaMap have produced habitat suitability models for deep-sea rock and reef habitats. There is also potential for further habitat modelling for this type of habitat (Tittensor *et al.*, 2009; Howell *et al.*, 2011).	✓
4. Expert Judgement	Expert judgement will be particularly important in determining reference conditions for *Lophelia pertusa* reefs and modelling may also be required to supplement incomplete data on historic and current distribution, extent and physical damage. In the longer term additional data are required for accurate reference conditions for distribution and extent.	✓ **+** **RESEARCH**

Maerl beds

Method	**Analysis**	**Choice**
1. Existing reference conditions	European distribution data are considered incomplete and new survey can still uncover large areas in local areas (Hirst *et al*. in prep a), however, a number of studies indicate that maerl beds have declined in both extent and quality in the OSPAR area (Hall-Spencer *et al.*, 2010; Pena & Barbara, 2008). Data are available on the extent of physical damage to sediments in shallow water the UK, mainly due to the impacts of mobile fishing gear. These range from 15-30% of total area (Aish *et al*., 2010).	✓
2. Historical reference conditions	There are historical and current data available on the distribution and extent of maerl beds, with the exception of OSPAR Regions I and V (Hall-Spencer *et al.*, 2010). It is not clear how many of the historical data sets pre-date the major human induced change but most data are likely to be useful for setting reference conditions.	✓
3. Modelled reference conditions	No modelled data were identified.	
4. Expert Judgement	Reference conditions will rely on expert judgement bringing together all of the available historical and current data.	✓

Modiolus modiolus **beds**

Method	**Analysis**	**Choice**
1. Existing reference	Current European distribution data are incomplete as reports of *M. modiolus* in region IV require confirmation and there is also a great deal of	✓

conditions	uncertainty over whether records are of individuals or beds. With the exception of the recent Mapping European Seabed Habitats Programme, there is limited information on *M. modiolus* beds in the OSPAR region and so the full extent of this habitat in Europe is largely unknown. In the UK however, the known extent of *Modiolus* beds has doubled in the last year (Hirst *et al*., in press, a & b; pers. comm. H. Edwards, 2012). Thus, it is likely to be easier to set reference conditions for UK habitat distribution and extent. There are some data available on the impact of human activities, fishing in particular, on this habitat (e.g. Magorrian & Service, 1998; Strain *et al.*, 2012) which can be used towards the criteria for physical damage. In a recent status assessment the overall area affected by physical damage, particularly the impacts of mobile benthic fishing gear on boulders and biogenic reefs (damage, loss, removal of species), in UK waters was reported to be limited (Aish *et al*., 2010).	
2. Historical reference conditions	There have been significant changes in the distribution and extent of *Modiolus modiolus* beds since the 1950s, mainly due to bottom trawling (Rees, 2009). Some historical data from over a century ago are available although only a few *M. modiolus* beds are known have been surveyed over long enough time periods for evidence of change to be apparent.	✓
3. Modelled reference conditions	Computer-aided prediction, using GIS methods to overlay multiple physical and chemical factors, has been fairly successful for predicting sediment habitats. However, forecasting precisely where particular biogenic reefs should occur has been found to be less practicable due to the complex biological feedback loops involved (Rees, 2009).	
4. Expert Judgement	Expert judgement will be required to infer reference conditions from existing and historical data.	✓

Oceanic ridges with hydrothermal vents/fields

Method	Analysis	Choice
1. Existing reference conditions	On a fast spreading ridge like the East Pacific Rise (EPR) the lifetime of a hydrothermal vent field might be 12 years, while on a slow spreading ridge, such as the oceanic ridges in the OSPAR area, the lifetime is expected to be much longer. Compared with fast spreading ridge hydrothermal vents, the OSPAR habitats have not changed since they were discovered in the 1980s (Santos & Colaco, 2010). The ICES review of the nomination for this habitat agreed that there is no empirical evidence to suggest that hydrothermal vents are in decline (ICES, 2002). Existing distribution and extent would be representive of the reference condition. However, there is currently inadequate data to set accurate reference conditions for these criteria and further survey work is required. Whilst the distribution of hydrothermal vents in the OSPAR Maritime Area is known to be concentrated along the Mid-Atlantic Ridge, the actual number, location and extent of hydrothermal vents in the OSPAR area are still unknown. New data are being added all the time. For example, two new vent fields were discovered as recently as 2005 (Santos & Colaco, 2010). There is information available identifying the activities causing physical damage to this habitat. The extent of physical damage is however, unknown (Santos & Colaco, 2010).	✓
2. Historical reference conditions	Historical data are not required.	

3. Modelled reference conditions	No modelled data were identified but with a better understanding of how there features are formed it may be possible to predict their occurrence and inform future survey efforts	
4. Expert Judgement	Expert interpretation of the current knowledge of distribution and extent can be used to set reference conditions but without further survey will not provide an accurate measure.	✓ + RESEARCH

Ostrea edulis beds

Method	Analysis	Choice
1. Existing reference conditions	It has been reported to be difficult to obtain a broad picture of the current distribution of *O. edulis* beds in the OSPAR region as much information remains hidden in grey literature and project reports (Haelters & Kerchhof, 2009). Similarly, there is insufficient information available to assess the overall extent of *O. edulis* beds in the OSPAR area. Data are available on the extent of physical damage to sediments in shallow water the UK, mainly due to the impacts of mobile fishing gear. These range from 15-30% of total area (Aish *et al*., 2010).	✓
2. Historical reference conditions	Declines in native oyster beds have occurred in European waters over the past 200 years with particularly significant changes in the 20th century (Haelters & Kerckhof, 2009). The extent, decline, and in some cases disappearance of *O. edulis* beds is well documented with some historical data available (Korringa, 1946, 1951, 1952; Yonge, 1960; Edwards, 1997; Haelters & Kerchhof, 2009; UMBSM, 2007). This would need to be utilised in setting reference conditions.	✓
3. Modelled reference conditions	No modelled data was identified.	
4. Expert Judgement	Expert judgement, will be required to use the historic and current available data to set estimates of reference condition for distribution and extent. OSPAR notes that consideration should be given to bringing together a specialist working group made-up from experienced scientists from the Contracting Parties where *O. edulis* is most common (Haelters & Kerchhof, 2009). Further research or additional data collation may be required to provide more reliable measures.	✓

Sabellaria spinulosa reefs

Method	Analysis	Choice
1. Existing reference conditions	Data on the current extent and decline of this habitat are limited to a few well studied locations and so are probably not complete. Aggregations of *S. spinulosa* range from crusts, veneers and patches to extensive reefs such as those found in the Wash and the production of a definition of exactly what constitutes a reef is ongoing (Gubbay, 2007, Hendrick & Foster-Smith, 2006). The need to create an inventory of possible reefs, on the basis of agreed characteristics, has been identified in the UK (Gubbay, 2007). True stable reefs, as opposed to crusts of *S. spinulosa*, are believed to be rare or have a very restricted distribution (Holt *et al.*, 1998). Natural variability also plays a part in changes in the extent of this habitat type which have been recorded in some parts of its range (OSPAR, 2010). Nevertheless, a better knowledge of the natural variation in extent, density and population structure of reefs is required (Holt *et al.*, 1998). There are also fairly clear links between human activity and physical damage to *S. spinulosa* reefs from benthic trawling (Pearce *et al.*, 2007;	✓

	2011a,b; references in Holt *et al.*, 1998), which can be used help determine reference conditions for the physical damage criteria. In a recent status assessment the overall area affected by physical damage, particularly the impacts of mobile benthic fishing gear on boulders and biogenic reefs (damage, loss, removal of species), in UK waters was reported to be limited (Aish *et al.*, 2010).	
2. Historical reference conditions	Subtidal *Sabellaria spinulosa* reefs are reported to have been lost in at least five areas of the North-East Atlantic (Jones *et al.*, 2000). Historical data are available for the German Wadden Sea (Hagmeier & Kändler, 1927), the Island of Sylt (Riesen & Reise, 1982) and Norderau area (Reise & Schubert, 1987) and in some areas of the UK (Taylor & Parker, 1993; Warren & Sheldon, 1967). Increases in the western North Sea have been reported between 1986 and 2000 (Rees *et al.*, 2007) and new areas of reef are still being identified (e.g. see Limpenny *et al.*, 2011).	✓
3. Modelled reference conditions	Habitat suitability modelling may be possible for *Sabellaria spinulosa.*	
4. Expert Judgement	The setting of reference conditions for habitat distribution, extent and physical damage will require expert judgement to supplement incomplete historical and current data.	✓

Seamounts

Method	Analysis	Choice
1. Existing reference conditions	Seamounts are formed by geological processes and so distribution and extent of the physical structure is unlikely to be changed by anthropogenic activities. There are documented cases of extensive damage to seamount communities in some parts of the world but little is known about natural fluctuations in physical structure of the seamount features themselves (Santos *et al.*, 2010). Thus, reference conditions for the criteria of distribution and extent can be described using existing data alone. Whilst there is considerable information on the distribution of seamounts in the official OSPAR database, the data are incomplete (Santos *et al.*, 2010). Over the next 10 years the numbers of known seamounts will dramatically increase due to the continuous acquisition of new bathymetry data and the continuous improvements in mapping techniques. No quantitative data on physical damage to this habitat were found.	✓
2. Historical reference conditions	Historical data not required to determine reference conditions for distribution and extent.	
3. Modelled reference conditions	No modelling approaches were identified.	
4. Expert Judgement	Existing reference condition data are incomplete so some expert judgement may be required. Further surveys to identify seamounts are required to accurately describe reference conditions.	✓ + **RESEARCH**

Seapen and burrowing megafauna communities

Method	Analysis	Choice
1. Existing reference conditions	The OSPAR definition for this habitat potentially covers a wide range of communities and biotopes, stretching from Scottish sea lochs to the abyssal plain (Curd, 2010). Plains of fine mud with burrowing megafauna cover large areas at depths of “200 m or more” (Curd, 2009). The	✓

	bibliography in some of the OSPAR areas on this habitat is very limited and knowledge of this habitat‟s total distribution and extent in the OSPAR region is poor (Curd, 2009). Data are available on the extent of physical damage to sediments in shallow water the UK, mainly due to the impacts of mobile fishing gear. These range from 15-30% of total area (Aish *et al*., 2010).	
2. Historical reference conditions	The risk of habitat loss is considered to be low so historical data are not required for setting reference conditions.	
3. Modelled reference conditions	It may be possible to produce predictive habitat suitability models for this habitat (e.g. see Kelly *et al.*, 2001; Méléder *et al.*, 2010).	✓
4. Expert Judgement	Considering the lack of data for setting reference conditions considerable expert judgement will be required. Further data would also be required.	✓ + **RESEARCH**

Zostera beds

Method	**Analysis**	**Choice**
1. Existing reference conditions	There have been significant declines in the distribution and extent of seagrass beds throughout the world due to a number of factors including disease, fishing disturbance and nutrient enrichment (Tullrot, 2009). There was mass dieback of *Zostera marina* throughout Western Europe and elsewhere during the 1920s and mid-1930s due to a wasting disease (Tullrot, 2009). More recently, declines have also been reported in the Wadden Sea and the UK for both *Z. marina* and *Z. noltii* (Den Hartog & Polderman, 1975; Jones *et al.*, 2000; Davison and Hughes, 1998). Seagrass beds are also subject to natural changes in distribution and extent (e.g. see Cunha *et al.*, 2005). Thus, current and historical data are both required to set reference conditions for this habitat‟s distribution and extent. Data are available on the extent of physical damage to sediments in shallow water the UK, mainly due to the impacts of mobile fishing gear. These range from 15-30% of total area (Aish *et al*., 2010).	✓
2. Historical reference conditions	Some data available (see expert judgement)	✓
3. Modelled reference conditions	Habitat suitability modelling has been used to produce predictive mapping of seagrass beds (Holmes *et al.*, 2007; Kelly *et al.*, 2001) which may have some application for setting reference conditions.	✓
4. Expert Judgement	Historical and current distribution and extent data are available (see Davidson & Hughes, 1998) but incomplete for many countries and expert judgement was found to be an important information source for the OSPAR Background Document for *Zostera* beds (Tullrot, 2009). Also, assessment of changes in the distribution and status of *Zostera* (eelgrass) species in the UK has been hindered by misidentification, rendering some historical records suspect (Kay, 1998). Thus, expert judgement will also be required to develop reference conditions from interpretation of all data sources.	✓

6.2 Habitat Condition (1.6) & Condition of the Benthic Community (6.2) for marine benthic habitats in the North-East Atlantic

Where there are habitats that are similar in nature and require the use of same datasets to identify reference conditions they have been reviewed together.

6.2.1 Predominant habitats

Littoral rock and biogenic reef

Method	Analysis	Choice
1. Existing reference condition	It is not known if there are littoral biogenic reefs in reference condition. Considering the extent of human activities in the coastal zone it seems unlikely although hard substrata habitats are not subject to the extensive physical damage from trawling as is experienced in the subtidal zone.	
2. Historical reference condition	Historical reference conditions unknown as most biological data are from current or recent monitoring programmes (see expert judgement).	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	Most biological data comes from current or recent monitoring programmes, particularly in relation to UK Marine SACs (see Holt *et al.*, 1998 for details). Expert judgement will be required to estimate reference conditions from current data or determine whether any locations are in reference condition.	✓

Littoral sediment

Method	Analysis	Choice
1. Existing reference condition	Coastal waters are, and have been, subject to considerable human pressures with littoral sediments particularly affected by coastal development and eutrophication. Areas still existing in reference condition are likely to be few if there are any at all.	
2. Historical reference condition	Historical research has not been identified for littoral sediments although these may be locally available.	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	There is a considerable body of current and recent research investigating the biology of littoral sediments in the OSPAR region (e.g. Beyst *et al.*, 2001). A good understanding of the relationships between faunal composition and environmental conditions also exists (e.g. see Gray & Elliott, 2010 and references therein). Expert judgement will be required to set reference conditions, inferred from the large body of current monitoring and research data.	✓

Shallow sublittoral rock and biogenic reef

Method	Analysis	Choice
1. Existing reference condition	This habitat type has considerable overlap with the individual habitat listings for *Sabellaria spinulosa* reefs and *Modiolus modiolus* reefs although it also includes reefs of *Serpula vermicularis*. These habitats are vulnerable to physical damage and existing reference conditions are not thought to exist.	
2. Historical reference condition	There is a limited amount of historical data on biogenic reefs such as *Sabellaria spinulosa* (see section 6.2.35) but very little on sublittoral rock and other biogenic reef types (Holt *et al.*, 1998).	✓
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	There are a number of recent studies that have been carried out on biogenic reefs (see relevant sections). Reference conditions will be best set using expert judgement and use of current monitoring data informed by limited historical data.	✓

Shallow sublittoral sediment

Method	Analysis	Choice
1. Existing reference condition	Coastal waters are generally subject to the greatest pressures with impacts from eutrophication (particularly in very nearshore areas), fishing, aggregate dredging, infrastructure developments and more recently offshore renewable energy developments. Existing reference conditions are therefore unlikely to be present in the current day.	
2. Historical reference condition	There are a number of historical datasets for sediment habitats, which were first properly investigated in the early years of the 20th century by researchers working in the North Sea (Gilson, 1900; 1928), the English Channel (Allen, 1899) and Danish waters (Petersen, 1914, 1915, 1918) with further important studies in the middle of the century (e.g. Holme, 1953, 1961 & 1966; Vatova, 1949; Thorson, 1957). The applicability of such data will depend on several factors including the purpose and method of study. Such studies are unlikely to provide adequate data to set reference conditions directly but the data can certainly provide useful insights into the magnitude and direction of any changes that have occurred.	✓
3. Modelled reference condition	No modelling approaches suitable for biological reference conditions were identified.	
4. Expert judgement	The biology and ecology of marine sediments has been the subject of intensive study since these early investigations and there is a large body of data describing faunal patterns and their relationships to environmental conditions, such as sediment type (e.g. see Gray & Elliott, 2010 and references therein). However, despite the identification of such relationships marine sediment habitats are still highly variable and expert judgement will be required to set reference conditions for the biological quality criteria. This approach has been used in the UK for the setting of WFD reference conditions for sediment habitats, based on the analysis of data from minimally impacted locations and expert judgement of representatives of the Marine Benthic Invertebrate Task Team (Phillips *et al.*, 2012). Expert judgement will be required to infer reference conditions from monitoring data with some input from available historical studies.	✓

Shelf sublittoral rock and biogenic reef
Bathyal rock and biogenic reef
Abyssal rock and biogenic reef

Deep-sea biogenic reefs refer to cold-water coral habitats, predominantly those of *Lophelia pertusa*, which is reviewed under the OSPAR threatened/declining habitats. Detailed information on this habitat is found in the review under the OSPAR section (6.2.3). This review, therefore, relates primarily to rock habitats in these deep-sea habitats.

Method	Analysis	Choice
1. Existing reference condition	No specific information could be found on the biology of shelf/bathyal/abyssal rock habitats. Although deep-water habitats are less impacted than coastal waters extensive damage to deep-water reefs have been observed (see *Lophelia* review). Therefore, existing reference conditions for biological indicators may not be available or may be too few in number to provide adequate data. However, there may be rocky habitats in reference condition. Additional research would probably be required to determine such locations.	
2. Historical reference condition	Historical reference conditions are generally unknown as most biological data are from current or recent monitoring programmes.	
3. Modelled reference condition	No modelling approaches to determining biological reference criteria have been identified.	
4. Expert judgement	Very little specific information was readily available for shelf/bathyal/abyssal rock habitats. A study by Tyler & Zibrowius (1992) reports the fauna of rock habitats in the deep sea are poorly known but no more recent information could be found. There is however, likely to be some overlap with other specific habitats such as seamounts and sponge aggregations on rock. Expert judgement, and potentially additional research or data collation, will be required to determine reference conditions for this habitat type in the three different bathymetric ranges of the deep-sea. The biology and ecology of *Lophelia* reefs have been fairly well studied (see review in Section 6.2.3). Data from these studies can be used to assist experts in identifying reference conditions.	✓ + **RESEARCH**

Shelf sublittoral sediment – coarse, sand, mud and mixed sediments
Bathyal sediment – slope/upper and mid/lower
Abyssal sediment

Method	Analysis	Choice
1. Existing reference condition	Although anthropogenic disturbances, including fishing, mining, oil drilling, bioprospecting, offshore renewable energy developments and climate change, in the deep-sea are increasing (McClain & Hardy, 2010; Bett, 2001) there may be existing locations that are in reference condition in this vast habitat. The scale of offshore environments means that considerably large impacts are usually required to cause changes in the properties of the substratum large enough to have broad ecosystem consequences (Halpern *et al.*, 2008). However, Glover & Smith (2003) suggest that deep-sea ecosystems may be substantially modified before the natural state is fully understood highlighting the need for further research.	

	The deep sea is still relatively unknown with high rates of species and habitat discoveries still occurring (Ramirez-Llodra *et al.*, 2010). There have been a number of research projects investigating biological patterns in deep-sea sediments (e.g. Buhl-Mortensen *et al.*, 2009; Ellingson, 2001; Ellingson, 2002; Gray, 2000). Expert judgement would be required to determine if such survey data can be considered to be from reference sites.	
2. Historical reference condition	Some historical data from the deep sea are available, such as that from the British Challenger Expedition (1872-1876) but such data are largely incomplete and semi-quantitative. This type of data are unlikely to be particularly useful for setting reference conditions for biological condition.	
3. Modelled reference condition	No approaches to biological modelling that could be applied to setting reference conditions for deep sea sediment habitats were identified.	
4. Expert judgement	Technological developments have greatly accelerated research in deep-sea habitats, particularly over the past decade (McIntyre, 2010) so there is considerable current data available. There have been a large number of recent studies investigating the benthos of the predominantly muddy sediments of the deep-sea (e.g. Zezina, 1997; Dauvin & Vallet, 2006; Buhl-Mortensen *et al.*, 2010). Several of these studies also include data on anthropogenic pressures although there was no evidence found of quantitative relationships. Glover *et al.* (2010) found several examples of studies in bathyal regions that had a time-series element to them. Abyssal studies include research of the EU Marine Science and Technology (MAST II) project at abyssal sites in the north Atlantic (Glover *et al.*, 2001; Rice, 1995) and work at the Porcupine Abyssal Plain (PAP) by the Census of the Diversity of Abyssal Marine Life (CeDAMar) project (e.g. see Bett, 2001). These projects provide a large body of current biological data from a range of abyssal habitats in the OSPAR region. For example, CeDAMar has provided a baseline for species diversity of abyssal plains, including data on natural variability in response to surface water productivity (McIntyre, 2010. The zonation of fauna has also been documented (see Howell *et al.*, 2002). Studies that have established the relationships between species distributions and community structure in shallower sublittoral habitats (e.g. see Clarke & Ainsworth, 1993; Sanders, 1968; Gray, 1974) may also prove useful to setting reference conditions for deep-sea sediment habitats. Therefore, it may be possible to estimate reference conditions via expert interpretation of current data. However, additional research will probably be required to define accurate measures; recent research has shown that deep water habitats are much more complex ecologically than originally thought (Vanreusel *et al*., 2010).	✓ + **RESEARCH**

6.2.2 Habitats Directive Annex I habitats

Sandbanks which are slightly covered by seawater all the time

Method	Analysis	Choice
1. Existing reference condition	Sandbanks are not defined by the presence of particular species. The diversity and types of community associated with this habitat are determined by sediment type together with a variety of other physical, chemical and hydrographic factors. Of the sites assessed as part of the Common Standards Monitoring (CSM) condition assessments, 47% were	

	found to be in unfavourable condition. Expert judgement would be required to determine if any of the remaining sites are currently in reference condition.	
2. Historical reference condition	No data prior to the 1980s were found.	
3. Modelled reference condition	No suitable modelling approaches were identified for Sandbanks which are slightly covered by seawater all the time.	
4. Expert judgement	There are biological studies of sandbanks from a number of different areas including the North Sea (Willems *et al.*, 1982; Vanosmael *et al.*, 1982), the Solway Firth (Axelsson *et al.*, 2006), the coast of Wales and the Irish Sea (Robinson *et al.*, 2012) and the Bay of Biscay (Galparsoro *et al.*, 2012). Expert judgement will be required to determine if any sites are currently in reference condition. In addition, in the absence of suitable data, expert judgement will be required to identify the most suitable areas for further survey work?	✓

Mudflats and sandflats not covered by seawater at low tide

Method	Analysis	Choice
1. Existing reference condition	Littoral mudflat and sandflat habitats have been subject to a wide range of, sometimes, low level impacts in the course of the past century. In particular, habitats may have changed due to the effects of the removal of target species, increased nutrients, pollution, invasive species, and through channel modification and marsh colonisation. Thus, it seems unlikely that there will be littoral mudflat and sandflat habitats in reference condition.	
2. Historical reference condition	There are some historical data such as the well-defined communities of Petersen (1914, 1915, 1918) and Thorson (1957) – *Macoma* community for muds and *Tellina* for sands. These data may provide some insights to reference conditions.	✓
3. Modelled reference condition	No appropriate modelling approaches were identified for littoral mudflat and sandflat habitats.	
4. Expert judgement	The current community structure of intertidal flats is well studied in many European areas, particularly in the Wadden Sea and in the UK (see Elliot *et al.*, 1998 and Curd, 2009 and references therein) due to their importance, accessibility and ease of study. Although most datasets cover estuarine sites, which are covered by the WFD not the MSFD, there is a considerable body of data on the current condition of these habitats, many of which can be located at the MarBEF LargeNet site (www.marbef.org/projects/largenet/data.php). Reference conditions would be best set by expert judgement using any historical data that is available in conjunction with current monitoring data and an understanding of the ecology of this habitat.	✓

Coastal lagoons

Method	Analysis	Choice
1. Existing reference condition	The location of coastal lagoons between land and sea subjects them to strong anthropogenic pressures due to tourism and/or heavy shellfish/fish farming (Aliaume *et al.*, 2007). Diffuse pollution is an additional threat, mainly through agricultural and/or industrial effluents and domestic sewage drainage (Aliaume *et al.*, 2007). It seems unlikely that there are locations of this habitat that can be considered to be in reference	

	condition but this would need to be verified by experts. The determination of reference conditions is further complicated because each lagoon has its own unique set of physical and biological characteristics such that a „typical" lagoon does not exist.	
2. Historical reference condition	The earliest biological studies on coastal lagoons in the UK, southeast Spain and Portugal appear to be from the 1980s (Barnes, 1988, 1989; Gamito *et al.*, 2011; Perez-Ruzafa *et al.*, 2007). Whether these can be considered to provide historical reference conditions would also require expert judgement on the timing of the major impacts on these habitats. No data prior to the 1980s were found.	
3. Modelled reference condition	No modelling approaches were identified that would be suitable for determining reference conditions in coastal lagoons.	
4. Expert judgement	More recent data are available from the UK (e.g. Bamber *et al.*, 1992; Bamber, 2004). The considerable physical (e.g. salinity, tidal exchange) variety found in coastal lagoons has made the provision of a „typical" species list difficult (JNCC, 2007). For example, EUNIS provides details of species characteristic of this habitat but the list appears to be incomplete. There are however, characteristic lagoonal invertebrate fauna that are said to show little regional variation, even within Europe (JNCC, 2007). There is literature available on the impact of anthropogenic activity on the benthic fauna associated with lagoons (OSPAR, 2000). In the UK there were found to be gaps in data for the process of setting reference conditions for saline lagoons for the WFD (Environment Agency, 2012). The absence of a typical lagoon ecology also means that even with expert opinion determining reference conditions is likely to be problematic.	✓

Large shallow inlets and bays

Method	**Analysis**	**Choice**
1. Existing reference condition	There was limited biological data identified for large shallow inlets and bays in the UK with the only data located coming from ecological assessments for UK SACs (Williams, 2006). Therefore, it is difficult to determine if there are any sites currently in reference condition.	✓
2. Historical reference condition	No historical data was located.	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	Data on European representatives of this habitat are probably available but local expert knowledge will be required to locate the appropriate information. Typical species lists are reported to be difficult to produce because of the considerable physical diversity of this habitat (JNCC, 2007). However, habitats such as *Zostera*, maerl and *Modiolus modiolus* beds which are found within this habitat type will have their own specific reference conditions (see relevant reviews in this section). Considerable expert judgement, combined with the limited data available, would be required to set reference conditions for this diverse habitat. Habitat typologies may also be required. Further research may be needed.	✓

Reefs

Annex I reefs occur where rocky areas or concretions made by marine animals arise from the surrounding seafloor. There are three main types of Annex I reef:

1. Bedrock reef
2. Stony reef

3. Biogenic reef

As the main biogenic reefs (*Lophelia pertusa*, *Sabellaria spinulosa, Modiolus modiolus* and *Mytilus edulis*) are covered under the OSPAR habitat this section will deal with habitat types 1 and 2 only.

Method	Analysis	Choice
1. Existing reference condition	This habitat description covers a wide range of community types and the characteristics of stony reefs were the subject of a recent workshop (Irving, 2009). Some bedrock reefs include deep water communities (for example, see SAC Selection Assessments for Hatton Bank and Rockall) that may best be considered under other directives, e.g. *Lophelia pertusa* reefs, *Sabellaria spinulosa* etc. Therefore, it is difficult to determine if sites in reference condition exist as the term "Reefs" covers a wide range of reef habitats.	
2. Historical reference condition	Historical data are limited but there is a historical comparison rocky sublittoral biota at Hilsea Point Rock (Plymouth) after fifty years (Hiscock, 2005) which may be useful for some reef habitat types.	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	There are datasets available for some rocky and stony reefs in shelf seas although much is only available in the grey literature (for example CCW Marine Monitoring Report Series) and a number of studies carried out in support of SAC designation. However, expert judgement will be required to provide definitions of this habitat type and to determine which datasets are suitable for this broad habitat group. Additional research is also likely to be required to determine reference conditions for this habitat group.	✓ + **RESEARCH**

Submarine structures made by leaking gases

Method	Analysis	Choice
1. Existing reference condition	There are a number of anthropogenic activities that can affect this habitat, particularly trawling. There is limited information available on the specific impacts to this habitat although the biological and physical structure of the habitat in the Braemar „pockmarks" are known to have been partially impacted by bottom trawling which has dispersed, fragmented and possibly buried some of the carbonate formations (JNCC, 2007). In 2007 it was reported that much of the interest feature was still intact (JNCC 2007a) so there may be some locations that are in reference condition. However, expert judgement is probably needed to make this assessment. No data was identified that could be used to determine existing reference condition.	
2. Historical reference condition	There were no historical or trend data found for this habitat (JNCC, 2007).	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	The majority of the literature related to submarine structures made by leaking gas is focussed on the geology of this phenomenon with little data on actual habitat condition. There have been a few site specific studies from the North Sea (see JNCC, 2008a and 2008b and references therein) and the Kattegat (between the Baltic and North Seas) (Jensen *et al.*, 1992) which provide some data on the species present. EUNIS also lists a number of associated fauna but no list of „typical" species was available (JNCC, 2007). Therefore, it is unlikely that accurate reference conditions could be defined using current data so expert judgement and additional	✓ + **RESEARCH**

	research would be needed.	

Submerged or partially submerged sea caves

Method	Analysis	Choice
1. Existing reference condition	Partially submerged (i.e. intertidal) caves, especially on chalk shores, are susceptible to human disturbance from trampling, stone-turning and damage to rocks through removal of piddocks (JNCC, 2007). Sessile organisms colonising sublittoral sites at the eastern end of the English Channel already have to contend with fairly high levels of siltation but may be vulnerable to increases in turbidity and levels of sedimentation from fishing, aggregate extraction and spoil dumping ((Cefas, 2001). However, the biota of littoral and sublittoral caves is adapted to survival in conditions with a great deal of disturbance from surge and scour. It is therefore likely that cave dwelling species are inherently robust (ERT 1997). Submerged caves are generally unsuitable areas for fishing and are therefore unlikely to be damaged or deteriorated as a direct result of fishing activity. There may, therefore, be examples of sea caves close to reference condition although expert judgement would be required to determine this.	
2. Historical reference condition	No historical data was located.	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	Biological data are limited to a few site specific surveys carried out for collection of evidence for SAC designation (Howson, 2000; Bunker & Holt, 2003). As there are reported to be no data outside the SAC network, and these are often from particularly well developed cave systems, these data are probably not sufficient to determine representative reference conditions in the UK. There is no list of representative species for this habitat provided by EUNIS. Therefore, expert judgement coupled with existing data are likely to provide inadequate information upon which to set reference conditions and further surveys from a more representative set of caves is needed.	✓ + **RESEARCH**

Annual vegetation of drift lines

Method	Analysis	Choice
1. Existing reference condition	The most important factors impacting the drift line, both currently and in the past, relate to sediment availability, beach management and other physical disturbances. In particular, artificial re-profiling of shingle beaches for flood protection has affected many locations for this habitat on key sites in southern England: reducing the cover of drift line habitat and preventing it from reaching its full potential. Other types of human disturbance such as trampling, beach cleaning and recreational use are limiting the extent of this type of habitat (JNCC, 2007). It seems unlikely that reference conditions exist for this habitat.	
2. Historical reference condition	There are some site specific surveys from the 1980s, such as the Orford Shingles in Suffolk (Fuller & Randall, 1988) and Dungeness (Fuller, 1985; Ferry & Waters, 1985) but some areas may have highly distinctive flora. Some species are ephemeral but no data on natural dynamics, or historical data, could be found.	

3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	There is some information on the typical plant species associated with this habitat (see references in JNCC, 2007) although the coverage of UK habitats is reported to be less than adequate (Rodwell, 2000). The Common Standards Monitoring Guidance for Vegetated Coastal Shingle Habitats (JNCC, 2004) also provides information on associated communities although classification can be difficult (JNCC, 2007). Further survey and/or research plus expert judgement is required to supplement existing data in order for reference conditions to be determined.	✓ + **RESEARCH**

Salicornia and other annuals colonising mud and sand

Method	**Analysis**	**Choice**
1. Existing reference condition	Relatively recent research in support of the WFD found no evidence of existing reference conditions for saltmarshes in the UK (i.e. those sites showing no or insignificant anthropogenic impacts) (Best *et al.*, 2007).	
2. Historical reference condition	Historically, reference conditions may have existed in some parts of the country, however, reclamation, flood control and defence have been undertaken since Roman times with particularly active work undertaken, e.g. in the Wash, since the mid 1600s (Purseglove, 1988). Little historical information seems to be available on the biology of this specific habitat. Most research appears to start in the 1980s but is mostly concerned with loss of the habitat itself rather than changes in biological condition (e.g. Hill, 1988; Burd, 1989).	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	Selecting a suitable time when reference condition was likely would probably require expert judgement in each member state where these habitats occur as the history of human activities varies geographically. There is current information available on the plant species found in this habitat but the faithfulness to habitat is low or unknown and previous conservation assessments have not been able to produce a list of „typical" species (JNCC, 2007). For this reason available trend data at the UK-level was not found to be particularly meaningful. There are also a number of contemporary studies on the macroinvertebrate fauna associated with saltmarsh habitats (see Adnit *et al.*, 2007 and the references therein). Expert judgement will be required to set reference conditions for the biological indicators, together with available current research and monitoring data.	✓

Spartina swards (*Spartina maritimae*)

Method	**Analysis**	**Choice**
1. Existing reference condition	Relatively recent research in support of the WFD found no evidence of existing reference conditions for saltmarshes in the UK (i.e. those sites showing no or insignificant anthropogenic impacts) (Best *et al.*, 2007). The absence of sites in existing reference condition is supported by the recent CSM site condition assessments carried out for *Spartina* swards which found 100% of the habitat investigated to be in unfavourable condition because of declines in the amount of *S. maritima* and *S. alterniflora* (JNCC, 2004).	

2. Historical reference condition	Some historical data, albeit only from the last 50 years or so, is available (e.g. Hubbard & Stebbings, 1967).	✓
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	Selecting a reference condition time is likely to require expert judgement in each member state where these habitats occur as the history of human activities in saltmarsh habitats is likely to vary geographically. Expert judgement will be required using recent survey and the limited historical data available.	✓

Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)

Method	**Analysis**	**Choice**
1. Existing reference condition	Relatively recent research in support of the WFD found no evidence of existing reference conditions for saltmarshes in the UK (i.e. those sites showing no or insignificant anthropogenic impacts) (Best *et al.*, 2007). There are data available assessing the current „state" of this habitat in parts of the European Atlantic region. These include data from the UK CSM assessments for conservation area (Williams, 2006) and studies in Portugal where some marshes on the Lima estuary are reported to remain in an undisturbed ecological condition (Sousa *et al.*, 2007). Some information on seasonal dynamics of the habitat is also available from this research. In the UK the CSM assessments showed 75% of the current habitat to be in unfavourable condition (JNCC, 2007).	
2. Historical reference condition	No historical data was found on habitat condition for this habitat.	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	Selecting a reference condition time is likely to require expert judgement in each member state where these habitats occur as the history of human activities varies geographically. The plant species associated with this habitat are well known (see JNCC, 2007 and references therein) but there were few studies of the associated community found. EUNIS provides details of lists of characteristic species but the benthic community associated with this habitat depends on location with large geographical variation. Expert judgement is needed to set reference conditions but further research may be required for this specific variant of saltmarsh habitat.	✓ **+** **RESEARCH**

Mediterranean and thermo-Atlantic halophilous scrubs

Method	**Analysis**	**Choice**
1. Existing reference condition	A recent CSM condition assessment for UK SACs found 15% of this habitat in the UK to be in unfavourable condition (Williams, 2006) although very little data was found relating to the specific biology of this habitat type.	
2. Historical reference condition	Very little current or historical data was found relating to the biology of this specific habitat type.	
3. Modelled	No modelling approaches identified.	

reference condition		
4. Expert judgement	Flora species lists are available but very few show a high degree of faithfulness, at least in the UK (JNCC, 2007). It appears that available data may not be sufficient to determine reference conditions and additional research is likely to be required.	**RESEARCH**

6.2.3 OSPAR threatened/declining habitats

Carbonate mounds

Method	**Analysis**	**Choice**
1. Existing reference condition	The condition of carbonate mounds is not impacted by human activities, however, the habitats that occur on certain mounds are impacted, most significantly by demersal fishing. Knowledge of the proportion of habitats present on carbonate mounds that have been impacted by fishing is scant and the potential for recovery uncertain (Turley, 2007). It is possible that there are habitats in reference condition, with further examples to be discovered, but there is probably not enough data available to set reliable reference conditions.	
2. Historical reference condition	The biology and ecology of these habitats has only been studied in the last 10-15 years so data are limited (see Hall-Spencer *et al.*, 2010).	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	The occurrence of carbonate mounds in the OSPAR Maritime Area is not fully known and there is little information on any changes in the species associated with the habitat (Hall-Spencer, 2008). Carbonate mounds do not represent a single habitat type and so expert judgement is likely to be required. Coral gardens and *Lophelia pertusa* reefs can (presumably) be excluded as they are considered as a separate OSPAR threatened habitat.	✓ **+ RESEARCH**

Coral gardens

Method	**Analysis**	**Choice**
1. Existing reference condition	Whilst there is data available on species present these are known for only a few local areas and there is currently no agreed definition of species composition or density of organisms (Christiansen, 2010).	
2. Historical reference condition	There are no known scientific records or time series data about changes in this habitat type, particularly due to trawling, so it is not possible to determine their historical condition, distribution and abundance based on post-fishing surveys (Hall-Spencer *et al.*, 2007).	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	There is no agreed definition of this habitat. Without further survey work there is not likely to be adequate knowledge to set accurate reference conditions.	**RESEARCH**

Cymodocea meadows

Method	Analysis	Choice
1. Existing reference condition	In most of its range the *Cymodocea* meadow habitat is subject to a range of anthropogenic activities, particularly channel dredging but also eutrophication, pollution and coastal development (Ayala, 2010). In some countries the habitat is thought to be in an acceptable state and some are now within protected areas. However, it is unlikely these represent pre-impact conditions. Thus, current sites in existing reference condition are not likely to be available to set reference conditions.	
2. Historical reference condition	No historical information on the biological structure and composition was identified.	
3. Modelled reference condition	No modelled information on the biological structure and composition was identified.	
4. Expert judgement	There have been many current studies on the communities associated with *Cymodocea* meadows although these are usually focussed on particular locations and therefore information is patchy (Ayala, 2010). It has been recommended by OSPAR 2010 that more research is required to gain sufficient information on habitat and ecology and thus expert judgement is also needed.	✓ + RESEARCH

Deep-sea sponge aggregations

Method	Analysis	Choice
1. Existing reference condition	These habitats have only relatively recently been discovered and the full distribution is still unknown. Bett (2001) suggests that in the environment where these habitats generally occur, they "may, in part, already be influenced by the actions of deep-sea trawling as the impacts of deep-sea trawling may be encountered practically anywhere within the UK Atlantic Margin". Evidence of human activities (trawl marks and discarded fishing gear) was also observed at all sites investigated by Howell *et al.* (2007). Existing sites in reference condition are therefore likely to be very few in number if they occur at all.	
2. Historical reference condition	There is some historical data on species composition available from early research cruises (e.g. see Carpenter *et al.*, 1870; Le Danois, 1948; Lévi & Vacelet, 1958) but these data are not sufficient to determine historical reference conditions as they do not provide fully quantitative data. They can, however, supplement current research on deep-sea sponge aggregations (see references in Christiansen, 2010).	✓
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	Expert judgement will be required to use the limited current and historical data that is available to set reference conditions though the level of accuracy is likely to be uncertain. Additional research is also necessary to set accurate reference conditions.	✓ + RESEARCH

Intertidal *Mytilus edulis* beds on mixed and sandy sediments

Method	Analysis	Choice
1. Existing reference condition	Significant declines in the biomass of intertidal mussel beds have been reported in the OSPAR Maritime Area, particularly in the Greater North Sea (OSPAR, 2010). It is not known if there are existing areas in	

	reference condition but it seems likely that some patches may remain in difficult to access areas.	
2. Historical reference condition	Some historical data are also available, particularly data from the Wadden Sea that has been mapped since the 1950s (see references in OSPAR, 2010), probably prior to the most significant changes in habitat extent and condition.	✓
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	A number of factors, particularly the commercial importance of mussels and ease of studying intertidal areas, mean that this habitat has been very well studied. Interpretation of the wealth of current data and available historical studies by experts is likely to be sufficient to set reference conditions for the biological quality indicators for this habitat.	✓

Intertidal mudflats

Method	Analysis	Choice
1. Existing reference condition	Historically, the biological structure and function of intertidal mudflat habitats have been affected by a number of anthropogenic factors particularly organic enrichment, pollution from industrial and domestic activities and more locally oil spills (Elliott *et al.*, 1998 and reference therein). Thus, existing reference conditions are not likely to be easily located.	
2. Historical reference condition	Although no specific historical datasets on intertidal mudflats were found there is some historical data on the structure of marine habitats that can inform the reference condition setting process (e.g. Petersen, 1914; 1915, 1918; Thorson, 1957; Jones, 1950).	✓
3. Modelled reference condition	The impacts of a range of human disturbances on intertidal mudflat communities are fairly well understood and predicted by a number of models (Pearson & Rosenberg, 1978; Gray, 1982). These models could be useful in informing reference conditions for this habitat.	
4. Expert judgement	The current and recent community structure of intertidal flats is well studied in many European areas, particularly the Wadden Sea and in the UK (see Elliot *et al.*, 1998 and Curd, 2009 and references therein). Therefore, good background data are available for certain areas due to their importance and accessibility, and their ease of study. Reference conditions can best be set by expert judgement using existing data and knowledge of relationships between species and human disturbance in combination with whatever historical data can be found and models where required.	✓

Littoral chalk communities

Method	Analysis	Choice
1. Existing reference condition	Anthropogenic factors such as sewage and nutrient discharge and, in some areas, non-native species means there are not likely to be sites that can be considered to be in reference condition.	
2. Historical reference condition	There is a description of chalk shore communities from the late 16th century to date but this is limited to the floral communities of Kent shores (Price & Tittley, 1972). No historical data could be found for the total community of organisms found in these habitats but the floral data may provide insights to reference conditions.	✓
3. Modelled reference condition	No modelling approaches identified.	

4. Expert judgement	The scarcity of this habitat type (mostly limited to England and France) means most of the chalk coast in the UK has management designations and there is regular monitoring for the Habitats Directive and WFD. Thus, there are a number of recent time-series datasets available for this habitat (see Tittley, 2009 and the references therein). Reference conditions would need to be determined by expert judgement interpretation of this current monitoring data.	✓

Lophelia pertusa reefs

Method	**Analysis**	**Choice**
1. Existing reference condition	It is unclear if there are *Lophelia pertusa* reefs in reference condition. There is considerable evidence of the damage to *Lophelia* reefs, particularly due to bottom trawling. Over the past 10 years reductions in the condition of *L. pertusa* reefs have been well documented for Norway, Sweden, Iceland, the UK and Ireland (see references in Hall-Spencer & Stehfest, 2009) with old records of human impacts to *L. pertusa* reefs off France (Joubin, 1922a). A 2004 review of cold-water coral reefs by the United Nations Environment Programme (UNEP) indicated most reefs showed signs of physical damage with some reefs in the North-East Atlantic are known to have become completely lost as a result of bottom trawling (Friewald *et al.*, 2004). Thus, locations known to be in reference condition may be in short supply. However, Hall-Spencer & Stehfest (2009) report some sites have escaped major habitat degradation, possibly because large reefs present difficult grounds to trawl. Thus, there may be a few sites currently in reference condition for this habitat. A number of these have been studied but it is unclear if the data are adequate to determine reference conditions. Hall-Spencer *et al.* (2007) collated a database of bathyal coral reef habitats in the North-East Atlantic to determine their diversity before the habitats become too heavily impacted by bottom fishing gear. Expert judgement would be required to determine if any of the data can be used to set reference conditions.	
2. Historical reference condition	Historical reference conditions are generally unknown as most biological data are from current or recent monitoring programmes.	
3. Modelled reference condition	No modelling approaches to biological condition have been identified.	
4. Expert judgement	Expert judgement will be required to use data from existing reference sites, if they can be identified, together with research carried out on a range of sites at different levels of impact to estimate reference conditions.	✓ **+** **RESEARCH**

Maerl beds

Method	**Analysis**	**Choice**
1. Existing reference condition	Extraction of maerl has been carried out in Europe for hundreds of years. Initially, the quantities extracted were small, being dug by hand from intertidal banks, but in the 1970s c. 600,000 tonnes of maerl was extracted per annum in France alone. Other impacts include scallop fishing, coastal development and sewage discharge. There have been well-documented declines in condition of maerl beds in most OSPAR regions (Hall-Spencer *et al.*, 2010). Therefore, it is unlikely that many, if any, existing sites are in reference condition.	

2. Historical reference condition	No data on historical reference conditions for the biology of maerl habitats could be found.	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	There is data on the decline in biological condition, which can be related to certain impact factors (Hall-Spencer *et al.*, 2010). Therefore, reference conditions will have to be determined using expert judgement plus survey data from the highest quality habitats that remain and knowledge of changes that have occurred.	✓

Modiolus modiolus beds

Method	Analysis	Choice
1. Existing reference condition	There have been substantial changes in these habitats since the 1950s mainly due to bottom trawling. Only a few *M. modiolus* beds are known to have been surveyed over long enough time spans for evidence of change to be apparent (Veale *et al.*, 2000; Service & Magorrian 1997; Holt *et al.*, 1998). However, the loss of *M. modiolus* beds has been well reported and it seems unlikely that sites in reference condition currently exist although recent advances in the number of known beds offers some scope for comparisons (e.g. Hirst *et al*. in press a & b).	
2. Historical reference condition	There is very limited historical data on the biological condition of *M. modiolus* beds.	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	A series of surveys at Strangford Lough in Northern Ireland, conducted before and after intensive fishing trawling documented changes in the community composition in relation to this activity (Strain *et al.*, 2012) which may provide some insights to the reference condition. However, data on biological condition is limited (see Holt *et al.*, 1998; Rees *et al*. 2008; Sanderson *et al*., 2008; Rees, 2009). Thus, expert judgement will be required to determine reference conditions for this habitat.	✓

Oceanic ridges with hydrothermal vents/fields

Method	Analysis	Choice
1. Existing reference condition	The study of vent fauna is at a relatively early stage of development limited by the relatively short time that has elapsed since their discovery and the difficulties associated with researching such inaccessible habitats. Therefore, due to the general lack of data, it is unknown if any sites are currently in reference condition.	
2. Historical reference condition	No historical data are available as they are a recently discovered habitat.	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	Some areas, such as the vents to the south of the Azores, have been the focus of intensive research programmes funded at national, international and EU levels (Santos & Colaco, 2010). Whilst species lists are known for vent habitats communities species composition is often transient and variable not only at short time scales of days and seconds but also over	✓ + **RESEARCH**

	decades and such changes are not well understood. Expert knowledge is currently the only means of setting reference conditions for the biological indicators for vent habitats and additional research is required to fully understand the biology and ecology of these unique communities.	

Ostrea edulis beds

Method	Analysis	Choice
1. Existing reference condition	Considering the significant impacts of human activities on *Ostrea edulis* beds in the 20th century it seems unlikely that there will be examples of this habitat in reference condition.	
2. Historical reference condition	Various studies of the fauna of native oyster have been reported for the Oosterschelde (Korringa, 1946, 1951), Irish waters (Smyth & Roberts, 2010), Loch Ryan (Millar, 1961, 1968; Howson *et al.*, 1994) and the Essex oyster beds (Mistakidis, 1951). Korringa (1951) listed over 250 species of epifauna on the shells of *Ostrea edulis* in the Oosterschelde. These provide some historical data although expert judgement will be required to determine if the ecology of the habitat was significantly impacted by human activities at the time the research was carried out.	✓
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	There have been relatively few studies on the whole benthic community associated with *Ostrea edulis* beds, notably epifaunal species, as the general focus in most studies is on the oysters themselves (Haelters & Kerckhof, 2009). With limited historical and current data on the biological condition of the habitat as a whole, expert judgement will be required to determine reference conditions.	✓

Sabellaria spinulosa reefs

Method	Analysis	Choice
1. Existing reference condition	*Sabellaria spinulosa* reefs have almost certainly suffered widespread and long lasting damage due to the activities of bottom fishing and aggregate dredging (Pearce *et al.*, 2007; 2011a, b; Holt *et al.*, 1998 and references therein). However, the stable extensive reefs known to occur in the Wash may provide reference conditions although expert opinion would be required to identify areas which have not been impacted by shrimp fishing activities.	
2. Historical reference condition	Most early published records of local marine fauna refer only to the widespread presence of individuals of *Sabellaria spinulosa*, or at least fail to mention dense aggregations, reefs or accretions (Holt *et al.*, 1998 and references therein). There is, however, a review of the biology in the Wadden Sea that provides limited historical data on the biology of *Sabellaria spinulosa* reefs (Hagmeier & Kändler, 1927; Riesen & Reise, 1982) that may provide some insights to the reference condition.	✓
3. Modelled reference condition	No modelling approaches to biological condition identified.	
4. Expert judgement	There have been a number of studies of the biology and ecology of *S. spinulosa* reefs since the review of biogenic reefs by Holt and others (1998). These studies include ecological assessments carried out for SACs (e.g. see Foster-Smith & White, 2001) and research funded by the Marine Aggregate Levy Sustainability Fund (e.g. see Pearce *et al.*, 2011a, 2011b). Expert judgement will be required to apply the data available to setting biological reference conditions.	✓

Seamounts

Method	Analysis	Choice
1. Existing reference condition	Data that are available tend to be from a limited number of locations (see references in Gubbay, 2003) therefore it is difficult to determine if sites in reference condition exist.	
2. Historical reference condition	The practical difficulties and limited attention given to sampling the benthic fauna of seamounts in the last century means there is a paucity of information on the benthos (Gubbay, 2003; Santos *et al.*, 2010).	
3. Modelled reference condition	No modelling approaches identified.	
4. Expert judgement	Expert judgement will be required and although research into these habitats continues (e.g. see Schlacher *et al.*, 2012) there is unlikely to be adequate data available to inform the setting of accurate reference conditions and further research will be required.	✓ + RESEARCH

Seapen and burrowing megafauna communities

Method	Analysis	Choice
1. Existing reference condition	Identifying locations in biological reference condition is unlikely as repeated disturbance from demersal fishing gear has occurred in many habitats where this habitat exists, particularly the North Sea and the Bay of Biscay (Jennings & Kaiser, 1998) resulting in observable changes in community structure (Hily *et al.*, 2008). There may, however, be examples of this habitat that have not been subject to intensive fishing pressure in deep waters.	
2. Historical reference condition	There was no historical data identified; burrowing megafauna are difficult to sample using traditional ship-borne equipment, and most of the information on their ecology has been obtained in the last two decades using scuba diving and underwater video (Hughes, 1998).	
3. Modelled reference condition		
4. Expert judgement	The understanding of the structure and dynamics of the habitat in question is still very patchy (Curd, 2010) and although considerable advances have been made in studies of some of the major characterising species of this habitat, there is a lack of long-term observational studies on natural variability. Thus, expert judgement will be particularly important in setting reference conditions for this habitat. Further research may be required to determine accurate biological reference conditions.	✓ + RESEARCH

Zostera beds

Method	Analysis	Choice
1. Existing reference condition	There are probably very few, if any, locations where *Zostera* beds can be thought to be in reference condition. This habitat has been subject to a number of significant impacts in the last 70-80 years, particularly wasting disease, fishing disturbance, non-native species invasions and nutrient enrichment.	
2. Historical reference condition	Most historical records appear to concentrate on the occurrence and distribution of seagrass beds, particularly in relation to wasting disease. No historical data on the biological condition of eelgrass beds was identified.	
3. Modelled	No modelling approaches were identified for the biological structure and	

reference condition	dynamics of this habitat.	
4. Expert judgement	A considerable volume of recent research has been undertaken on *Zostera* ecology. Current data includes detailed species lists for a number of the major British eelgrass beds (see Davidson & Hughes, 1998 and references therein) and the structure of the beds themselves. There are also studies on the natural dynamics of seagrass beds. However, in the absence of existing reference conditions and historical data, expert judgement will be required to set reference conditions for this habitat.	✓