Healthy & Biologically Diverse Seas Evidence Group
Technical Report Series:

Evaluation and gap analysis of current and potential indicators for Rock & Biogenic Reef Habitats

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Preface

The UK Marine Monitoring and Assessment Strategy (UKMMAS) aims to provide coordinated and integrated marine monitoring programmes which support periodic assessments of the state of the UK marine environment. The strategy aims to provide vital data and information necessary to help assess progress towards achieving the UK's vision of clean, healthy, safe, productive and biologically diverse seas. The overarching strategy is supported and delivered by four evidence groups; Clean and Safe Seas Evidence Group (CSSEG); Productive Seas Evidence Group (PSEG); Healthy and Biologically Diverse Seas Evidence Group (HBDSEG) and Ocean Processes Evidence Group (OPEG). These groups are responsible for implementing monitoring and observations programmes to contribute to ecosystem-based assessments of marine environmental status.

As part of the HBDSEG programme of work, a series of reviews of environmental indicators was undertaken for the following marine ecosystem components:

1. Rock and biogenic reef habitats
2. Sediment habitats
3. Deep sea habitats
4. Seabirds and waterbirds
5. Cetaceans
6. Seals
7. Plankton
8. Microbes

The aim of the reviews was to evaluate a wide range of currently available and potential indicators for marine biodiversity monitoring and assessment. This task was undertaken particularly to inform future needs of the EU Marine Strategy Framework Directive (MSFD). The work was carried out by a group of consultants and contributors and was managed by JNCC.

Each review included a process to evaluate indicator effectiveness against a set of specified scientific and economic criteria. This process identified those indicators of activity, pressure, state change/impact and ecosystem structure and function that were considered to be scientifically robust and cost effective. The indicators which met these criteria were then assessed for inclusion within an overall indicator suite that the reviewers considered would collectively provide the best assessment of their ecosystem component's status. Within the review, authors also identified important gaps in indicator availability and suggested areas for future development in order to fill these gaps.

This report covers one of the ecosystem components listed above. It will be considered by HBDSEG, together with the other indicator reviews, in the further development of monitoring and assessment requirements under the MSFD and to meet other UK policy needs. Further steps in the process of identifying suitable indicators will be required to refine currently available indicators. Additional indicators may also need to be developed where significant gaps occur. Furthermore, as the framework within which these indicators will be used develops, there will be increasing focus and effort directed towards identifying those indicators which are able to address specific management objectives. There is no obligation for HBDSEG or UKMMAS to adopt any particular indicators at this stage, based on the content of this or any of the reports in this series.

This report has been through a scientific peer review and sign-off process by JNCC and HBDSEG. At this time it is considered to constitute a comprehensive review of a wide range of currently available and potential indicators for this marine ecosystem component.

Summary

Indicators derived from species, communities and habitats within rock and biogenic reefs that are currently in use are reviewed as a contribution to the Healthy and Biologically Diverse Seas Evidence Group (HBDSEG) Assessment in continuation of work carried out in 2008 (Langmead *et al* 2008). This review focuses on those indicators currently in use in statutory monitoring and those developed through research that are in use or have potential monitoring applications. This assessment process confirms the validity of, or highlights redundancy within, existing indicators in current use in the UK. The scientific review identifies those that are not able to effectively detect a change in state caused by specific pressures or stochastic variation. Economic criteria are subsequently applied to those indicators that are judged to be scientifically robust in order to generate a long-list of recommended indicators specific to the OSPAR pressures list and key aspects of ecosystem structure and function. From this a short list of indicators has been derived and is presented as an effective suite of indicators covering the majority of pressures relevant to rock and biogenic reef habitats.

Over 219 biological indicators of the pressures or state of rocky and biogenic reef habitats are currently employed, and these are presented by specific pressure, together with the monitoring methodology, parameters measured and data collected and whether they can be used to detect change on the structure and functioning of rock and biogenic reef ecosystems.

A gap analysis has been conducted both against pressures and ecosystem structure and function attributes. This revealed important gaps in coverage, especially for climate related pressures but also for many of the key ecosystem function in rocky and biogenic reef systems such as nutrient exchange, salinity and sedimentation. Here we suggest potential indicators to fill these gaps in our knowledge.

While many of the indicators here are highly specific to pressures (contaminants), the majority of the higher organisational level indicators (state and ecosystem structure/function) respond to a variety of pressures and so attributing cause and effect to a single pressure or activity is much more difficult (especially since these pressures may not be operating in isolation e.g. the shifting baseline of climate is manifest across our seas).

Contents

1 Introduction

1.1 Aims and objectives of report

This piece of work aims to identify the most effective indicators of marine ecosystem state, pressures and impacts to allow scientifically robust assessments of marine environmental status to be made. Sets of indicators have been mapped to the HBDSEG Assessment Framework Matrix; these are taken from a number of key policy mechanisms (e.g. EC Directives) and other sources. It is recognised that there are large numbers of indicators developed through research which could be considered; this review focuses on those in use in policy and regulatory mechanisms and those of potential practical use.

1.2 Work undertaken in report

1. Review the existing indicators for rock and biogenic reef habitats.

2. Evaluate the effectiveness of the indicators against standardised scientific and economic criteria.

3. Review indicators against relevant pressures and important aspects of ecosystem structure and function.

4. Identify significant gaps and identify any indicators that may be able to fill these gaps.

5. Recommend a set of indicators for rock and biogenic reef habitats that are effective scientifically and economically and could be used in future within an integrated monitoring and assessment programme.

1.3 Introduction to rock and biogenic reefs

Rocky reef can be defined as intertidal and subtidal rocky substratum occurring in inshore coastal waters of the UK. These habitats include rocky platforms, walls and boulder fields between depths of 0-200m.

The rocky intertidal zone spans the region of the coastline from the highest vertical level reached at high water during spring tides (with associated wave splash) to the lowest level exposed to the air during low water springs. A wide variety of taxa inhabit the rocky intertidal zone, including algae, molluscs, echinoderms, cnidarians and crustaceans. Owing to the accessibility of rocky shores, intertidal species have been studied extensively throughout the nineteenth and twentieth centuries by amateur naturalists and professional researchers as model systems for the development of ecological and biological theory.

Rocky intertidal habitats exist at the margins of both the terrestrial and marine realms, and animals and algae in this ecosystem are subject to environmental challenges posed by both regimes. As a result, these organisms are affected by both aerial and aquatic climate, and provide a unique insight into the impacts of changes in both aquatic and terrestrial climatic environments. Diurnal tidal cycles and seasonal fluctuations in both sea and air temperature mean that intertidal organisms are subject to extremes of temperature with resultant fluctuations in body temperature of over 30°C frequently experienced. Additional stressors such as desiccation, current and wave forces, rapid fluctuations in salinity oxygen availability and nutrient levels mean that organisms are often living close to their physiological tolerance limits. Subtidal rocky reef ecosystems are subject to less variation in thermal conditions and wave stress but are at greater risk from turbidity, suspended sediments and the impacts of commercial activities.

Marine ectothermic species respond faster than terrestrial species to environmental change: the typically short lifespans and sessile or sedentary nature of the adult and juvenile stages prevents escape from changing environmental or physical regimes. The larval stage of most rocky reef species is planktonic, and therefore also provides an indication of the impacts of change in the pelagic zone. Changes in distribution and abundance are therefore likely to be driven by the direct response of organisms to changes in the environment or physical pressures acting at a local or regional scale. Marine invertebrates and macroalgae are from low trophic levels, and thus would be expected to respond quicker to alterations in local conditions than species at higher trophic levels, often showing the first response in a cascade of effects up the food chain to tertiary and apex predators. Variation in the abundance of keystone structural or functional species can alter the composition and dynamics of entire rocky communities and these small changes in environmental conditions can lead to major alterations in community structure and functioning. Taking all of the above factors into account, the rocky ecosystem is likely to be one of the most sensitive natural systems and show some of the earliest responses to climate change

Biogenic reef can be defined as benthic reefs composed of living organisms including mussels and worms that form a biogenically constructed frame, and secondary settling species such as echinoderms and crustaceans. Within the context of this study this encompasses worm reefs (*Sabellaria alveolata, S. spinulosa* and *Serpula vermicularis*), maerl, and mussel reefs (*Mytilus edulis* and *Modiolus modiolus*). Biogenic reefs are important because they stabilise sediment and increase topographic complexity, providing biotic substrate that can support biodiverse epifaunal and infaunal communities. Species diversity within a biogenic reef is often significantly greater than for the surrounding area. Biogenic reefs alter the rates of import and export of organic matter within a local system, both via the reef-forming species themselves and associated flora and fauna. By providing substrate for algal colonisation, they can also alter rates of primary production. Reef systems are important habitats for higher trophic level species including fish which utilise them as nursery and feeding grounds, and seabirds. Biogenic reefs alter local hydrodynamic conditions due to their surface profile, and can reduce turbidity via sediment trapping and filtration by founding and associated species. Biogenic reefs occur in both the inter- and subtidal zones of UK waters.

1.4 Policy background

The UK government has, for several decades, recognized the importance of a robust evidence base on environmental change to support policy and management decisions for the natural marine environment. The essential role of information on long-term change in marine ecosystems was highlighted during the initial development of conservation policies in the UK in the 1960s (Hiscock 1996, Frost *et al* 2005). It was to take a long time, however, until such information was fully incorporated into policy decision-making. This was due to both the time delay necessary to obtain the wide temporal data coverage required to detect change, and the progression of political understanding with regards to the applicability of such data to assist in the delivery policy targets and outputs.

The main statutory policy driver for rocky and biogenic reef habitats is the EC Habitats Directive, adopted by the European Community in 1992 (Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora). This is the means by which the Community meets its obligations as a signatory of the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention). The Directive applies to the UK and to its overseas territory of Gibraltar. The provisions of the Directive require Member States to introduce a range of measures including the protection of species and habitats listed in the Annexes; to undertake surveillance of habitats and species and produce a report every six years on the implementation of the Directive. The 189 habitats listed in Annex I of the Directive include intertidal rock, subtidal photic and aphotic rock and biogenic reef. These together with the 788 species listed in Annex II, are to be protected by means of a network of sites, designated by Member States as Special Areas of Conservation (SACs), and along with Special Protection Areas (SPAs) classified under the EC Birds Directive, form a network of protected areas known as Natura 2000.

The Habitats Directive introduces for the first time for protected areas, the precautionary principle; that is that projects can only be permitted having ascertained no adverse effect on the integrity of the site. Projects may still be permitted if there are no alternatives, and there are imperative reasons of overriding public interest. In such cases compensation measures will be necessary to ensure the overall integrity of network of sites.

In the UK the Directive has been transposed into national laws by means of the Conservation (Natural Habitats, & c.) Regulations 1994 and the Conservation (Natural Habitats, & c.) Regulations (Northern Ireland) 1995. These are known as 'the Habitats Regulations'. While most SACs on land or freshwater areas are underpinned by notification as Sites of Special Scientific Interest (SSSIs), for SACs that extend beyond the intertidal, positive management is promoted by wider countryside measures, while protection relies on the provisions of the Habitats Regulations.

In total 37 SACs in UK waters have been designated for reefs as their qualifying marine interest feature (Table 1), although three of these are offshore and beyond the scope of this review, falling instead into the Deep Sea Habitats report that forms part of this JNCC Assessment series (Benn *et al* 2010).

Table 1. UK SACs designated with reefs as their qualifying feature

Site name	Country	EU Code
Berwickshire and North Northumberland Coast	England/Scotland	UK0017072
Cardigan Bay/ Bae Ceredigion	Wales	UK0012712
Darwin Mounds	Offshore	UK0030317
Dornoch Firth and Morrich More	Scotland	UK0019806
Fal and Helford	England	UK0013112
Firth of Lorn	Scotland	UK0030041
Flamborough Head	England	UK0013036
Haig Fras	Offshore	UK0030353
Isle of May	Scotland	UK0030172
Isles of Scilly Complex	England	UK0013694
Loch Creran	Scotland	UK0030190
Loch Laxford	Scotland	UK0030192
Loch nam Madadh	Scotland	UK0017070
Lochs Duich, Long and Alsh Reefs	Scotland	UK0017077
Luce Bay and Sands	Scotland	UK0013039
Lundy	England	UK0013114
Morecambe Bay	England	UK0013027
Mousa	Scotland	UK0012711
North Rona	Scotland	UK0012696
Papa Stour	Scotland	UK0017069
Pembrokeshire Marine/ Sir Benfro Forol	Wales	UK0013116
Pen Llyn a`r Sarnau/ Lleyn Peninsula and the Sarnau	Wales	UK0013117
Plymouth Sound and Estuaries	England	UK0013111
Rathlin Island	Northern Ireland	UK0030055
Sanday	Scotland	UK0030069
Severn Estuary/ Môr Hafren	England/Wales	UK0013030
Solway Firth	England/Scotland	UK0013025
South Wight Maritime	England	UK0030061
St Kilda	Scotland	UK0013695
Stanton Banks	Offshore	UK0030359
Strangford Lough	Northern Ireland	UK0016618
Sullom Voe	Scotland	UK0030273
Sunart	Scotland	UK0019803
Thanet Coast	England	UK0013107
The Wash and North Norfolk Coast	England	UK0017075
Treshnish Isles	Scotland	UK0030289
Y Fenai a Bae Conwy/ Menai Strait and Conwy Bay	Wales	UK0030202

In October 2000 the EU Water Framework Directive (or WFD) was adopted (Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy). This Directive establishes a framework for the protection of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater. It will ensure all aquatic ecosystems meet 'good ecological status' by 2015. Some of the monitoring tools developed for monitoring coastal and estuarine waters for the WFD encompass ecosystem components of rocky and biogenic reefs (e.g. rocky shore macroalgal tool).

In June 2008 the EU Marine Strategy Framework Directive (MSFD) was adopted (Directive 2008/56/EC of the European Parliament and of the Council establishing a framework for community action in the field of marine environmental policy), requiring a systematic assessment of ecosystem state of all European regional seas. 'Good Environmental Status' (GES) targets must be set by 2012, monitoring implemented by 2014 and GES achieved by 2020. Within Annex III of the MSFD are 'indicative lists of characteristics, pressures and impacts'; and habitat typology (with special reference to priority habitats under other legislation) and biological features of the seabed including macroalgae and invertebrate bottom fauna are included, along with non-indigenous species and biodiversity. This clearly identifies a need to monitor rock and biogenic reef habitats.

In addition to these statutory policy drivers that operate at the scale of habitats, there are a number of others (largely superseded by the WFD and MSFD) that focussed on controlling the release of pollutants and monitoring their availability and movement in coastal and marine waters (e.g. Dangerous Substances Directive adopted 1976, Shellfish Waters Directive adopted 1979, Bathing Waters Directive 1976).

The most important non-statutory mandatory drivers requiring information on rock or biogenic reef habitats is Annex V of the OSPAR convention that requires protection and conservation of ecosystems and biological diversity of the maritime area (North East Atlantic). In 2003 an initial list of threatened and/or declining species and habitats was produced to prioritise conservation efforts, this included littoral chalk communities and *Ostrea edulis* beds. One mechanism of ensuring their protection is through marine protected areas, and OSPAR has criteria for the designation of OSPAR MPAs (often also SACs where designation criteria align) of which the UK currently has 63.

1.5 OSPAR/UKMMAS Assessment framework background

The assessment framework developed by JNCC was first presented to the OSPAR Convention's Biodiversity Committee in February 2007 and has since gained wide support across OSPAR as a tool to guide the development of a strategic approach to biodiversity monitoring. It has been particularly welcomed for its potential benefit in meeting the needs of the Marine Strategy Framework Directive (MSFD).

The framework takes the form of a matrix which relates ecosystem components (e.g. deep-seabed habitats) to the main pressures acting upon them (e.g. physical disturbance to the seabed). The ecosystem components have been correlated with components used by OSPAR and the MSFD. The columns of the matrix are a generic set of pressures on the marine environment, which are based on those used by OSPAR, MSFD and the Water Framework Directive (WFD). A 3-point scale of impact (low, moderate, high) reflects the degree of impact each pressure has on an ecosystem component. Each cell of the matrix has additionally been populated with a set of known indicators[1], derived from statutory and non-statutory sources, which are used to monitor and assess the state of that ecosystem component. The assessment matrix helps to highlight priorities for indicator development and monitoring programmes, based on the likely degree of each impact on the ecosystem component in question.

[1] Note: cells of the matrix where impacts have been identified currently contain a number of species and habitats on protected lists (OSPAR, Habitats Directive), which could potentially be used as indicators of the wider status of the ecosystem component which they are listed against. Should this be appropriate, certain aspect of the species or habitat (e.g. its range, extent or condition) would need to be identified to monitor/assess.

Since 2007 this approach has also been introduced to the UK's Marine Monitoring and Assessment Strategy (UKMMAS) and is being further developed by the Healthy and Biologically Diverse Seas Evidence Group (HBDSEG). The intention has been to have parallel development at UK and OSPAR levels which will help ensure similar biodiversity strategies are developed at national and international levels. It is also envisaged that the development process will benefit from wide input across OSPAR Contracting Parties.

The overall goal of the UKMMAS is to implement a single monitoring framework that meets all national and international multiple policy commitments (UKMMAS, 2007). This will identify if there are any significant gaps in the current monitoring effort and aim to minimise costs by consolidating monitoring programmes. To help meet this goal, the assessment matrix has been developed with HBDSEG to provide a useful framework that analyses components of an ecosystem and their relationships to anthropogenic pressures. The framework aims to encompass three key issues: an assessment of the state of the ecosystem and how it is changing over space and time, an assessment of the anthropogenic pressures on the ecosystem and how they are changing over space and time, and an assessment of the management and regulatory mechanisms established to deal with the impacts.

The further development of the assessment framework has been divided into five shorter work packages: 1) assessment of pressures, 2) mapping existing indicators to the framework, 3) review of indicators and identification of gaps, 4) modifying or developing indicators and 5) review of current monitoring programmes. The following work will contribute to work package 3 and will critically review indicators, identify gaps and recommend an overall suite of the most effective indicators for the ecosystem component in question.

1.6 Definitions used within the report and analysis

Definitions of activity, pressure, state change/ecological impact and ecosystem structure and function are used within this report as follows (adapted from the 2008 CP2 methodology[2]):

> ***Activity* –** Human social or economic actions or endeavours that may have an effect on the marine environment e.g. fishing, energy production.
>
> ***Pressure* -** the mechanism (physical, chemical or biological) through which an activity has an effect on any part of the ecosystem e.g. physical disturbance to the seabed.
>
> ***State change/ecological impact* –** physical, chemical or biological condition change at any level of organisation within the system. This change may be due to natural variability or occurs as a consequence of a human pressure e.g. benthic invertebrate mortality.
>
> ***Ecosystem structure and function* –** ecosystem level aspects of the marine environment (i.e. structural properties, functional processes or functional surrogate aspects) which are measured to detect change at higher levels of organisation within

[2] Robinson, L.A., Rogers, S., & Frid, C.L.J. 2008. *A marine assessment and monitoring framework for application by UKMMAS and OSPAR – Assessment of Pressures and impacts* (Contract No: C-08-0007-0027 for the Joint Nature Conservation Committee). University of Liverpool, Liverpool and Centre for the Environment, Fisheries and Aquaculture Science, Lowestoft.

the system (i.e. changes at ecosystem scales), that is not attributable to any pressure or impact from human activity e.g. natural changes in species' population sizes.

Defined pressures list

The standard list of pressures against which indicators for this ecosystem component are reviewed is taken from the generic pressures list in the latest version (v11) of the UKMMAS / OSPAR assessment framework. Those pressures which are relevant to the ecosystem component (i.e. those that cause any impact on it) are used within the critical indicators review, gap analysis and this report.

2 Methods and data sources

2.1 Data sources

A number of information sources were utilised to compile a comprehensive list of indicators currently in use; these are listed below:

a The Marine Monitoring Protocols Manual (MMPM), created for the UK Marine Monitoring and Assessment Strategy (UKMMAS), published February 2008, was the starting point for collating indicators. This resource provides a list of UK monitoring programmes and the parameters each measure.

b After initial collation of indicators from the MMPM, further information on indicators currently monitored was gathered by:

  i interrogating websites of nationwide monitoring organizations (including Scottish Environment Protection Agency (SEPA), Environment Agency (EA), Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Food Standards Agency (FSA) including the Food Standards Agency Scotland (FSAS), Marine Scotland Science (MSS) and the Health Protection Agency (HPA).
  ii consulting specific site reports outlining monitoring protocols and implementation (including Regulation 33 (2)'s of the Conservation Regulations 1994, Scottish Natural Heritage (SNH) Commissioned reports and Countryside Council for Wales (CCW) marine monitoring reports).
  iii contacting managers directly, particularly for localised monitoring programmes e.g. Special Areas of Conservation (SACs), Sites of Special Scientific Interest (SSSIs).

c Further information was gathered on indicators through consulting additional website sources for individual programmes not monitored by statutory monitoring organisations such as the Marine Conservation Society (MCS) and Wildlife Trust websites.

2.2 Methods

Data were collated on indicators covered in the MMPM, following this, OSPAR monitoring policies were investigated along with WFD implementation to elucidate any outstanding indicators omitted, with OSPAR and European Commission websites scrutinised, and recent policy documentation assessed. Having covered indicators currently in use, other potential indicators were included. This involved searching the literature previously viewed and indicator sources, and in addition:

a searching the NMBL catalogue of peer reviewed journals,

b investigating the abstract services provided by the NMBL (including ASFA, the Web of Science, NISC and Science Direct),

c searching the MarLIN database for likely sensitive species and marine habitats, d searching previously contracted reports for the JNCC (including (Gubbay, 2007, Hiscock & Kimmance, 2003, Hiscock *et al* 2005a) and the EA (such as Bremner *et al* 2006, Hiscock *et al* 2004) and,

e reviewing a number of current or recent reports with specific indicator relevance such as the English Nature Biomonitoring Report (Long *et al* 2004), the European Marine Biodiversity Indicators Report (Feral *et al* 2003) and the Proceedings of 42nd European Marine Biology Symposium (EMBS, 2007).

On completion of the search for current and potential indicators, expertise was solicited from professionals within the MBA spanning a range of specialities and spanning all levels of indicators from cellular and physiological through to ecosystem level indicators to validate indicators, add additional indicators and refine the compiled information.

3 Review of the existing indicators and critical evaluation

3.1 Current indicators

See current indicators summary spreadsheet Currentindicators&assessment.xls.

3.2 Evaluation of the effectiveness of indicators against standard scientific and economic criteria

3.2.1 Criteria used to evaluate indicators

In order to achieve a consistent critical appraisal of all indicators, the indicators for this ecosystem component have been reviewed and scored against the following set of criteria. These criteria have been built into the online indicators database application and the data has been stored electronically.

A. Scientific criteria:

The criteria to assess the scientific 'effectiveness' of indicators are based on the ICES EcoQO criteria for 'good' indicators. The scoring system is based on that employed within the Netherlands assessment of indicators for GES (2008)[3]. A confidence score of 3 – High, 2 – Medium, 1 – Low is assigned for each question. A comment is given on the reasons for any low confidence ratings in the comment box provided within the database. All efforts have been made to seek the necessary information to answer criteria questions to a confidence level of medium or high.

1. Sensitivity: Does the indicator allow detection of any type of change against background variation or noise:

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

2. Accuracy: Is the indicator measured with a low error rate:

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

If the indicator scores 1 or 2 for question 1 or 2, conclude that it is ineffective and do not continue with the evaluation –the indicator will still be stored within the database as considered but will be flagged as 'insensitive, no further evaluation required'

3. Specificity: Does the indicator respond primarily to a particular human pressure, with low responsiveness to other causes of change:

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

[3] Langenberg. V.T. & Troost T.A. (2008). Overview of indicators for Good Environmental Status, National evaluation of the Netherlands.

4. Performance:

For questions 4a-f, if a score of 1 is given, please consider if the indicator is of real use. Please justify (within the report) continuing if a score of 1 is given.

The following criteria are arranged with descending importance:

a) Simplicity: Is the indicator easily measured?

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

b) Responsiveness: Is the indicator able to act as an early warning signal?

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

c) Spatial applicability: Is the indicator measurable over a large proportion of the geographical to which the indicator metric it to apply to e.g. if the indicator is used at a UK level, is it possible to measure the required parameter(s) across this entire range or is it localised to one small scale area?

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

d) Management link: Is the indicator tightly linked to an activity which can be managed to reduce its negative effects on the indicator i.e. are the quantitative trends in cause and effect of change well known?

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

e) Validity: Is the indicator based on an existing body or time series of data (either continuous or interrupted) to allow a realistic setting of objectives:

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

f) Relatively easy to understand by non-scientists and those who will decide on their use:

Score	**3**	**2**	**1**	**Confidence**
Options	Usually	Occasionally	Rarely	

Thresholds for scientifically poor, moderate and good indicators:

Combine indicator evaluation scores for:

1. Sensitivity
2. Accuracy
3. Specificity
4. Performance

Evaluation Score	Indicator 'Effectiveness' Category
22-27	**Good**
16-21	**Moderate**
9-15 OR not all questions completed due to expert judgement not to continue	Poor

Further economic evaluation required – see section B below

B. Economic criteria:

Having identified the most scientifically robust indicators using the above stated criteria, a further economic evaluation of those most effective indicators (i.e. those falling in the good or moderate categories) is carried out using the criteria stated below.

1. Platform requirements

Score	**4**	**3**	**2**	**1**
Options	None e.g. intertidal sampling	Limited e.g. coastal vessel	Moderate e.g. Ocean going vessel or light aircraft	Large e.g. satellite or several ocean going vessels

2. Equipment requirements for sample collection

Score	**4**	**3**	**2**	**1**
Options	Simple equipment requirements e.g. counting number of organisms	Limited equipment requirements e.g. using quadrats on the shoreline	Moderate equipment requirements e.g. measuring physiological parameters	Highly complex method e.g. technical equipment operation

3. Amount of staff time required to plan collection of a single sample

Score	**4**	**3**	**2**	**1**
Options	Hours	Days	Weeks	Months

4. Amount of staff time required to collect a single sample

Score	**4**	**3**	**2**	**1**
Options	Hours	Days	Weeks	Months

5. Amount of staff time required to process a single sample

Score	4	3	2	1
Options	Hours	Days	Weeks	Months

6. Amount of staff time required to analyse & interpret a single sample

Score	4	3	2	1
Options	Hours	Days	Weeks	Months

7. Amount of staff time required to QA / QC data from a single sample

Score	4	3	2	1
Options	Hours	Days	Weeks	Months

Thresholds for economically poor, moderate and good indicators:

Evaluation Score	Indicator 'Effectiveness' Category
24-28	**Good**
19-23	**Moderate**
7-18	Poor

Those indicators which fall within the **'Good'** or **'Moderate'** economic category will then be tagged within the summary database as 'Recommended' indicators. Indicators can also be 'recommended' via expert judgement even if the evaluation of the indicator does not score well enough to be automatically recommended. This judgement will be justified within the report text.

4 Gap analysis - Review of indicators against relevant pressures and important aspects of ecosystem structure and function

4.1 Review of indicators against pressures and identification of gaps

Please refer to the attached table: MyGapMatrixPressuresReport_v5.xls.

This gap matrix was produced as a tool to aid authors in identifying significant gaps in current or potential indicators i.e. where important pressures on the ecosystem component have no suitable indicators associated with them. All recommended indicators have been prefixed with [R] and the cells containing them are coloured green.

It should be noted that if a single indicator is associated with more than one pressure within the pressures gap matrix, it may mean that this indicator responds to a range of pressures or the synergistic effects of a combination of pressures. Such an indicator would not necessarily be able to detect change which can be attributed to each individual pressure.

In this section we first deal with gaps at the broad habitat level – thus manifest though all hierarchical subdivisions - and follow the sequential order of pressure categories within the gap matrix. The order in which they are discussed does not reflect any prioritisation of the gaps which have been identified within this assessment. Subsequently we focus on specific gaps for specific pressures in individual priority features.

For rocky and biogenic reefs, and other marine habitats, several of the physical pressures are not relevant; these are *electromagnetic changes*, *underwater noise*, *death or injury by collision*, and also the biological pressure of *visual disturbance*, and for this reason are not considered gaps in our analyses.

Across all ecosystem components of rocky and biogenic reef habitats (intertidal and subtidal) there are several notable gaps; there are no indicators for the climate change pressures of changes in *salinity* and *pH* at a regional/national level. This is unsurprising because climate driven change in salinity is small compared with irregular local and shorter term variations due to rainfall, freshwater from rivers and circulation (see below). Additionally there are no recommended indicators for salinity changes at a local scale or for the biological pressure of *genetic modification* that arguably could be important in wild stocks of commercially farmed shellfish species.

Overall within intertidal rock and biogenic reef habitats there are some pressures for which there are no recommended indicators such as *water clarity* and *changes in siltation rate*. These are less of a concern for intertidal zones due to diurnal tidal movement, although turf algae trap sediment and could be a potential indicator for rates of siltation on rocky shores. Water clarity may vary strongly between winter and summer, and also at any time following a storm due to the action of waves suspending material into the water column, and indicators for such pressures would need to be effective in the face of this large spatio-temporal variation, i.e. to be able to pick up the signal of increased siltation from land-use changes leading to increased freshwater runoff against the high background variability. For the subtidal, these gaps are not apparent since indicators exist for specifically detecting changes in water clarity such as the abundance of the colonial ascidian *Distomus* on kelp stipes, and depth of siltation on biogenic reefs.

For intertidal and subtidal priority habitats: Habitats Directive Annex 1 intertidal rock, subtidal photic rock, subtidal biogenic reef and the OSPAR habitats of littoral chalk communities, *Sabellaria spinulosa* reefs and *Modiolus modiolus* beds, there are gaps for pollutants. However, there are monitoring programmes with widespread coverage around the UK such as CSEMP, RIFE and WFD that cover the broad habitat types that encompass these priority features. Therefore, while the indicators identified do not appear within the specific biogenic categories in the pressures gap matrix as they are not presently used within SAC site condition monitoring; they are well-developed, widely applied indicators that could be used in the SAC monitoring process in the future.

For subtidal habitats generally, the indicators for emergence regimes, either at a regional/national scale due to climate change, or at a local scale due to changes to the local hydrology are not well developed. It may be possible to apply existing indicators for detecting emergence regimes changes to subtidal habitats depending on depth. Rising sea level is unlikely to be a concern at the national/regional scale due to the availability of suitable habitat above current high water levels; however, climate-driven changes in wave exposure may result in changes in ecological state of shallow subtidal habitats at local scales.

4.2 Review of indicators against ecosystem structure and function aspects and identification of gaps

Please refer to the attached table: MyGapMatrixESStructureFunctionReport_v5.xls.

An overarching gap analysis across all sub-components for the rock and biogenic reef indicators suite highlights a complete lack of existing indicators within:

- Ecosystem Function
    - Ecological
        - Export of detritus and dissolved organic material
        - Nutrient exchange

- Ecosystem Function
    - Physico-chemical
        - Dispersal of water quality characteristics
        - Gas exchange
        - Provision of coastal defence
        - Sedimentation
        - Tidal flow

- Ecosystem Structure
    - Abiotic: Salinity
        - Sea-bed type
        - Sediment Type
        - Temperature

Across all subtidal rock and biogenic reef habitats, *habitat engineering*, *delivery of recruiting organisms* and *propagule dispersal* are not currently monitored by any indicators in the UK.

However, *habitat engineering* is close to the function of biogenic habitat provision which does have indicators. *Habitat extent* is currently being monitored by three indicators, but only Biogenic reef extent is recommended in the scientific assessment. This does not provide all of the necessary information required to attribute change to any specific pressure, and is therefore highlighted as a gap that needs addressing. No indicator is currently in use to assess reproduction and longevity of the reef-building species, which arguably is more important to species assessments. For biogenic species that require monitoring at the species level in order to inform on the viability of the biogenic habitat, this is a gap.

No current indicator is in use to assess *population size* within subtidal aphotic rock habitats, but this was identified by JNCC as a ‘species indicator’ rather than one relevant to habitats. The same applies to subtidal biogenic reef (Habitats Directive Annex 1) habitats.

For *Sabellaria spinulosa* reefs (OSPAR priority habitat) no indicators are in use for *biomass* and *population size,* as methods of monitoring these parameters would often necessitate causing damage to the reef or associated organisms. Natural England recognise the need for a low level of grab sampling to obtain all of the necessary information on reef-building organisms and associated species, but not to the extent that determination of health results in damage, deterioration and decline of the reef. Alternative non-destructive indicators may be applied, such as measuring the density of worm tubes. Additionally *reproductive success* and (individual) *longevity* have no indicators; again while these are categorised by JNCC as ‘species’ functions rather than ‘habitats functions’, they both have relevance for biogenic structural habitats that depend on the functioning of the reef-building species for their continued function as habitats.

For *Modiolus modiolus* beds (OSPAR priority habitat) one current indicator was not recommended for assessing *Habitat extent*: JNCCID1029 (Eco367) Biotopes present surrounding *Modiolus* bed. This is because the identification of biotopes surrounding a biogenic reef does not provide information on the spatial extent of the reef itself, or any other structural aspect of biogenic reefs. No indicators are in current use for Ecosystem Structure: Biotic: Population size.

Many indicators for both pressures and ecosystem structure and function criteria did not pass the scientific assessment process as they were: 1. not able to attribute changes in response to any one specific pressure (e.g. JNCCID 967 Eco(305) Number of intertidal biotopes); 2. unable to detect anthropogenically-mediated change against a stochastic environmental background signal (e.g. JNCCID1055 Eco(393) Biomass of macrofauna); and 3. often were not designed to detect change in the habitat of interest itself (e.g. JNCCID1039 Eco(377) Spatial extent of biotopes surrounding biogenic reef).

In terms of potential indicators to fill the gaps, for abiotic structural aspects it is hard to assign ecological indicators. Often changes in structural abiotic factors e.g. temperature are manifest as structural biotic changes e.g. changes in range and distribution of species (Mieszkowska *et al* 2005, 2006). Recommendations are discussed in detail within section 7.2.

5 Conclusions and recommendations

5.1 Database report tables

Please see attached Excel files:
MyGapMatrixESStructureFunctionReport.xls
MyGapMatrixPressuresReport.xls

5.2 Identification of an effective indicator set

It is clear from the summary tables that there are a wide variety of indicators available for monitoring rock and biogenic reef habitats. Here we focus on the indicators of state/impact and ecosystem structure and function and not the indicators of pollution (that are widespread across different habitats and thus not rock and biogenic reef specific).

These indicators essentially fall out into a number of groups – those concerning intertidal and subtidal rocky reefs (see Tables 2 and 3 below) and those that are specific to biogenic reefs (these are well developed and have been used for SAC condition monitoring for sites with biogenic features).

Out of the ecological indicators (ecosystem state or structure and function), half (21) were recommended. Four scored highly in both scientific and economic evaluation due to their specificity to individual pressures. However, the indicator JNCCID 968 Eco (306) Depth of siltation on *Sabellaria alveolata* reef is not able to infer a specific causal activity, since siltation can arise from a number of land-based and maritime activities. Others showed change generic to a number of anthropogenic pressures but were the only measures for that habitat or habitat component that are available, such as the extent of intertidal reefs. Few indicators showed just changes in ecological state (e.g. JNCCID 1053 Eco(391) Proportion of damaged tissue due to epiphytic growth on *Eunicella verrucosa*, JNCCID 968 Eco(306) Depth of siltation on *Sabellaria alveolata* reef, JNCCID 977 Eco(315) Reference code list used for shellfish species ID). Most of the indicators show change in ecological state but also infer some changes in either the structure or function. Three indicators provided information on state and multiple attributes of both ecosystem structure and function (JNCCID 903 Eco(244) Intertidal species composition and abundance; JNCCID 995 Eco(333) Abundance of individual species; and JNCCID 1027 Eco(365) Abundance of associated species on biogenic reef). Two indicators, both developed to assess the impact of boulder turning, provide information on the structural components only. Several indicators provide information on multiple aspects of ecosystem structure and/or function. This does not mean that they lack specificity, rather that the information obtained can indicate changes in several aspects of the ecosystem. For example JNCC 903 Eco(244) Intertidal species composition & abundance provides information on changes in *species richness* and *diversity*, *biomass*, *community structure*, and therefore may shed light on functional change such as *primary/secondary production* and *trophic complexity*.

Nine out of 11 physiological indicators were recommended. All physiological indicators monitoring responses at the sub-organismal level e.g. bioassays, enzymatic or endocrine activity scored highly in both scientific and economic assessments. Out of the physiological indicators, most of these are indicators of state (7) and two provide information on ecosystem structure and function: JNCCID 1111 Phy(449) Oyster embryo bioassay and JNCCID 1107

Phy(445) Intersex in gastropods, since both provide a measure of impact on reproductive successes and species longevity.

Species composition and abundance indicators are widely accepted for detection of change caused by several pressures including climate change, local hydrographic change, organic pollution, physical loss and damage and some biological pressures such as non-native species and the removal of target and non-target species. It is important to note that these indicators are sensitive to individual pressures if applied correctly and can shed light on changes in ecosystem structure or functioning. Using expert knowledge to interpret data collected will facilitate the attribution of observed changes or trends to specific activities or climatic drivers. However, assessing the entire intertidal or subtidal community can be time intensive and laborious; using a reduced list of strategically selected taxa which are known to be sensitive to one or more pressures can increase the detection power of monitoring efforts, by for example including species that are sensitive to specific changes.

Certain species/taxa within rocky reef communities are known to be temperature sensitive and changes in the abundance and distribution would highlight impacts caused by climate change (Mieszkowska *et al* 2005, 2006). Changes in the abundance of filter-feeding species could be applied to determine changes in sediment load and turbidity, whilst ephemeral species would indicate alterations in water quality (e.g. *Ulva* spp.). Changes in organic pollutant concentrations could be detected by a shift in community composition away from filter-feeders towards grazers and a resultant reduction in local biodiversity. Whilst methods for detecting impacts for organic enrichment are well developed for soft sediment benthic habitats (e.g. AMBI biotic index), less success has been achieved to date in applying similar methods to rocky habitats.

The spatial extent of the change, i.e. local/regional/national can be contextualized by ensuring that the same indicator and monitoring methodology are employed throughout UK programmes. This would provide broadscale information to allow SAC managers to determine whether the changes at a site level have resulted from changes in a localised pressure or are manifestations of regional change.

In addition to those species or taxa that tell something about the pressures and/or functioning of rock and biogenic reef systems, it is important to include species of conservation importance and non-native species. Changes in the abundance and distribution of these species often not specific to a particular pressure and therefore cannot ascribe causal effect. Priority features must be monitored to determine whether rare, scarce or threatened species and habitats are declining, especially those for which Natura 2000 sites were designated to protect, in order to evaluate MPA effectiveness. Invasive species are another group that need to be monitored to understand vectors of spread, subsequent impacts on native communities and how the shifting baseline of climate may assist their future colonisation.

For monitoring biogenic reef communities, in addition to these more generic indicators of species composition and abundance, it is important to monitor location, extent, structural integrity. For this assessment process, each parameter was requested to be listed as a separate indicator, however, these spatial attributes should be combined to form a single indicator to ensure that all of the necessary spatial information required to provide an assessment of physical state is obtained.

Please also see the attached Excel file for indicators that have been 'Accepted' into the effective indicator set and the 'Reasons for decision': Currentindicators&assessment_v5.xls

Table 2. Recommended shortlist of indicators for rocky and biogenic reefs (Climate and hydrological changes)

Ecosystem Component	**Climate change**					**Hydrological changes (local)**				
	Atmospheric climate change	**Temperature changes - regional/national**	**Water flow changes (tidal & ocean currents) - regional/national**	**Emergence regime changes (sea level) - regional/national**	**Wave exposure changes - regional/national**	**Temperature changes - local**	**Water flow changes (inc. tidal currents) - local**	**Emergence regime changes - local**	**Wave exposure changes - local**	**Water clarity changes**
5.1 Intertidal rock & biogenic reef habitats	Eco(244) Intertidal species composition & abundance (903)	Cli(205) Replicated quadrat counts for barnacles (864) Cli(207) SACFORN scale abundance (866) Cli(208) Replicated timed searches (867) Eco(244) Intertidal species composition & abundance (903) Eco(273) Opportunistic macroalgae (932) Eco(418) Intertidal reef extent (1080) Eco(432) Total extent of macroalgal bed (1094)	[R] Eco(244) Intertidal species composition & abundance (903)	Eco(244) Intertidal species composition & abundance (903) Eco(305) Number of intertidal biotopes (967) Eco(418) Intertidal reef extent (1080) Eco(432) Total extent of macroalgal bed (1094)	Eco(244) Intertidal species composition & abundance (903) Eco(418) Intertidal reef extent (1080) Eco(432) Total extent of macroalgal bed (1094)	Eco(244) Intertidal species composition & abundance (903) Eco(418) Intertidal reef extent (1080) Eco(432) Total extent of macroalgal bed (1094)	Eco(244) Intertidal species composition & abundance (903) Eco(418) Intertidal reef extent (1080) Eco(432) Total extent of macroalgal bed (1094)	Eco(244) Intertidal species composition & abundance (903) Eco(418) Intertidal reef extent (1080) Eco(432) Total extent of macroalgal bed (1094)	Eco(244) Intertidal species composition & abundance (903) Eco(418) Intertidal reef extent (1080) Eco(432) Total extent of macroalgal bed (1094)	Eco(325) Mussel shell weight (987) Eco(432) Total extent of macroalgal bed (1094)

Ecosystem Component	Climate change					Hydrological changes (local)				
	Atmospheric climate change	**Temperature changes - regional/national**	**Water flow changes (tidal & ocean currents) - regional/national**	**Emergence regime changes (sea level) - regional/national**	**Wave exposure changes - regional/national**	**Temperature changes - local**	**Water flow changes (inc. tidal currents) - local**	**Emergence regime changes - local**	**Wave exposure changes - local**	**Water clarity changes**
5.3 Subtidal rock & biogenic reef habitats	not applicable	Eco(217) Density/ proportion of Laminaria in kelp forests (876) Eco(218) Subtidal species composition & abundance (877) Eco(363) Location of biotope (1025) Eco(365) Abundance of associated species on biogenic reef (1027) Eco(380) Subtidal biogenic reef extent (1042) Eco(391) Proportion of damaged tissue due to epiphytic growth on Eunicella verrucosa (1053) Eco(299) Habitat extent of subtidal biogenic reef (1326)	Eco(235) Depth limit of reef (894) Eco(218) Subtidal species composition & abundance (877)	Eco(218) Subtidal species composition & abundance (877)	Eco(218) Subtidal species composition & abundance (877)	Eco(218) Subtidal species composition & abundance (877) Eco(363) Location of biotope (1025) Eco(365) Abundance of associated species on biogenic reef (1027) Eco(380) Subtidal biogenic reef extent (1042)	Eco(235) Depth limit of reef (894) Eco(306) Depth of siltation on Sabellaria alveolata reef (968) Eco(363) Location of biotope (1025) Eco(365) Abundance of associated species on biogenic reef (1027) Eco(398) Frequency of biotope occurrence (1060) Eco(437) Species present on biogenic reef (1099) Eco(438) Presence of key species (1298)	Eco(218) Subtidal species composition & abundance (877)	Eco(218) Subtidal species composition & abundance (877) [R] Eco(365) Abundance of associated species on biogenic reef (1027)	Eco(218) Subtidal species composition & abundance (877) Eco(235) Depth limit of reef (894) Eco(325) Mussel shell weight (987) Eco(363) Location of biotope (1025) Eco(365) Abundance of associated species on biogenic reef (1027) Eco(380) Subtidal biogenic reef extent (1042) Eco(398) Frequency of biotope occurrence (1060)

Table 3. Recommended shortlist of indicators for rocky and biogenic reefs (chemical, physical and hydrological changes)

Ecosystem Component	**Pollution and other chemical changes**				**Physical loss**		**Physical damage**			**Other physical pressures**		**Biological pressures**			
	Other substances released in accordance with community legislation or inter-national conventions	**De-oxygenation**	**Nitrogen & phosphorus enrichment**	**Organic enrichment**	**Physical loss (to land or freshwater habitat)**	**Physical change (to another seabed type)**	**Physical removal (extraction of sub-stratum)**	**Physical damage (abrasion & other physical damage)**	**Siltation rate changes**	**Litter**	**Barrier to species movement**	**Intro-duction of microbial pathogens**	**Introduction or spread of non-indigenous species & trans-locations**	**Removal of target species**	**Removal of non-target species**
5.1 Intertidal rock & biogenic reef habitats	Phy(447) Lysosomal membrane stability (1109)	Phy(446) Kills in zoobenthos in relation to eutro-phication (1108)	Eco(244) Intertidal species composition & abundance (903) Eco(273) Opportunistic macroalgae (932) Eco(325) Mussel shell weight (987) Eco(432) Total extent of macroalgal bed (1094) Phy(446) Kills in zoobenthos in relation to eutro-phication (1108)	Eco(273) Opportunistic macroalgae (932) Eco(325) Mussel shell weight (987) Eco(432) Total extent of macroalgal bed (1094)	Eco(418) Intertidal reef extent (1080)	Eco(418) Intertidal reef extent (1080)	Eco(418) Intertidal reef extent (1080)	Eco(244) Intertidal species com-position & abundance (903) Eco(400) Percentage cover of species as an indication of boulder turning (1062) Eco(418) Intertidal reef extent (1080)		Eco(244) Intertidal species com-position & abundance (903)	Eco(244) Intertidal species composition & abundance (903)	Mic(78) E.coli in Shellfish (737) Mic(79) Faecal coliforms in Shellfish (738) Phy(440) Amnesic Shellfish Poisoning (ASP) in biota (1102) Phy(441) Diarrhetic Shellfish Poisoning (DSP) in biota (1103) Phy(442) Paralytic Shellfish Poisoning (PSP) in biota (1104) Phy(443) Phycotoxin species (phyco-toxin in biota) (1105)	Eco(244) Intertidal species composition & abundance (903) Eco(336) Abundance of Sargassum muticum (998) Eco(432) Total extent of macroalgal bed (1094)	Eco(244) Intertidal species com-position & abundance (903)	Eco(400) Percentage cover of species as an indication of boulder turning (1062) Eco(244) Intertidal species composition & abundance (903)

Ecosystem Component	**Pollution and other chemical changes**				**Physical loss**		**Physical damage**			**Other physical pressures**		**Biological pressures**			
	Other substances released in accordance with community legislation or inter-national conventions	**De-oxygenation**	**Nitrogen & phosphorus enrichment**	**Organic enrichment**	**Physical loss (to land or freshwater habitat)**	**Physical change (to another seabed type)**	**Physical removal (extraction of sub-stratum)**	**Physical damage (abrasion & other physical damage)**	**Siltation rate changes**	**Litter**	**Barrier to species movement**	**Intro-duction of microbial pathogens**	**Introduction or spread of non-indigenous species & trans-locations**	**Removal of target species**	**Removal of non-target species**
	[R] Phy(447) Lysosomal membrane stability (1109)	[R] Phy(446) Kills in zoobenthos in relation to eutrophication (1108)	[R] Eco(218) Subtidal species composition & abundance (877) Eco(325) Mussel shell weight (987) [R] Eco(365) Abundance of associated species on biogenic reef (1027) [R] Eco(380) Subtidal biogenic reef extent (1042) [R] Eco(437) Species present on biogenic reef (1099) [R] Phy(446) Kills in zoobenthos in relation to eutrophication (1108) [R] Eco(299) Habitat extent of subtidal biogenic reef (1326)	Eco(325) Mussel shell weight (987) Eco(342) Notable species of macroalgae (of conservation interest) (1004) [R] Phy(447) Lysosomal membrane stability (1109) Phy(451) Shellfish population condition (1113) [R] Eco(299) Habitat extent of subtidal biogenic reef (1326)	Eco(307) Distance between recognisable Sabellaria alveolata reefs (969) Eco(309) Percentage of low lying, relict Sabellaria alveolata reef (971) Eco(310) Presence of recognisable Sabellaria alveolata reef (972) Eco(311) Reef condition (Scale 1-7) (973) Eco(312) Reef height (Sabellaria alveolata) (974) [R] Eco(299) Habitat extent of subtidal biogenic reef (1326)	[R] Eco(306) Depth of siltation on Sabellaria alveolata reef (968) [R] Eco(299) Habitat extent of subtidal biogenic reef (1326)	[R] Eco(380) Subtidal biogenic reef extent (1042) [R] Eco(299) Habitat extent of subtidal biogenic reef (1326)	[R] Eco(218) Subtidal species composition & abundance (877) Eco(363) Location of biotope (1025) [R] Eco(365) Abundance of associated species on biogenic reef (1027) [R] Eco(370) Density of biogenic reef forming species (1032) [R] Eco(372) Size frequency (1034) [R] Eco(380) Subtidal biogenic reef extent (1042) [R] Eco(299) Habitat extent of subtidal biogenic reef (1326)	[R] Eco(306) Depth of siltation on Sabellaria alveolata reef (968) [R] Eco(299) Habitat extent of subtidal biogenic reef (1326)	Eco(218) Subtidal species composition & abundance (877)	Eco(218) Subtidal species composition & abundance (877)	Mic(78) E.coli in Shellfish (737) Mic(79) Faecal coliforms in Shellfish (738) Eco(325) Mussel shell weight (987) Eco(391) Proportion of damaged tissue due to epiphytic growth on Eunicella verrucosa (1053) Phy(440) Amnesic Shellfish Poisoning (ASP) in biota (1102) Phy(441) Diarrhetic Shellfish Poisoning (DSP) in biota (1103) Phy(442) Paralytic Shellfish Poisoning (PSP) in biota (1104) Phy(443) Phycotoxin species (phycotoxin in biota) (1105) Phy(449) Oyster Embryo Bioassay (1111) Phy(451) Shellfish population condition (1113)	Eco(218) Subtidal species composition & abundance (877) Eco(365) Abundance of associated species on biogenic reef (1027)	Eco(265) Average catch rate of oysters (924) Eco(315) Reference code list used for shellfish species ID (977)	Eco(218) Subtidal species composition & abundance (877) Eco(365) Abundance of associated species on biogenic reef (1027)

5.3 Recommendations for areas for development to address significant gaps

It is clear that there is a great diversity of monitoring programmes with their own methodologies that have been established in response to specific objectives for marine habitats in UK waters. Complementarily with pre-existing monitoring programmes, however, is not always factored into the design, resulting in duplication of effort in some instances. Not all of the data are centrally available or comparable, and while this does not constitute a gap per se, there is scope for future harmonisation of monitoring effort. Compliance with the MSFD and other policy obligations will be best achieved via the development of an integrated assessment and monitoring process with uptake at the national level. This provides an important opportunity to achieve integration of approaches to monitoring change in the marine environment.

Climate change is arguably one of the greatest threats to the integrity of marine ecosystem structure and function www.mccip.org.uk. Indicators have been well developed and implemented in monitoring around the coast of the UK through the MarClim programme for the rocky shores www.mba.ac.uk/marclim. However, there is no comparable set of indicators for subtidal reefs and this currently constitutes a gap. Some information on the changes in community composition could be obtained from ongoing data collection on the abundance of subtidal organisms, but no specific climate indicator species have been developed to date. The MarClim protocols would be readily transferable to subtidal reefs, and present an opportunity for future development.

Indicators for specific pressures associated with climate change, in particular pH and salinity are currently absent for rock and biogenic reef habitats. In the near future it may be possible to develop indicators based on emergent scientific research. For monitoring impacts of ocean acidification for example, indicators such as calcification rate (Gazeau *et al* 2007; Findlay *et al* 2009), health and immune system responses within molluscs (Beesley *et al* 2008, Bibby *et al* 2008) and muscle wastage in echinoderms (Wood *et al* 2008) could be developed for widespread implementation. The use of *Mytilus edulis* in the health and immune studies also flags the opportunity to directly monitor the impacts of ocean acidification on an Annex 1 habitat. The relative abundance of *Elminius modestus* could be a good intertidal indicator for changes in salinity within estuaries, as it is known to have a wider salinity tolerance than native barnacle species. As explained above, changes in salinity at regional and national scales are small in comparison to local salinity variation. Assessments of recent alterations in salinity at regional and national levels within the Charting Progress 2 reporting process suggest that future changes will not significantly impact coastal marine ecosystems (Huthnance *et al* 2010). One consideration is that *Elminius modestus* is not a native species so additional pressures such as those arising from climate change may also affect its abundance and distribution (Mieszkowska *et al* 2005).

The existing indicator JNCCID 1094 Eco(432) Total extent of macroalgal bed could also be applied to address a current gap, providing information on changes in response to alterations in wave exposure. As kelp species favour high wave energy environments, their presence and dominance within communities could be used to track climate-driven changes to local wave height and the impacts of increased storm surge.

The assessment process employed for this review involved the disaggregation of indicators to their lowest level, meaning that their ability to detect change to some pressures has been lost in certain cases. Within monitoring programmes, a number of indicators are frequently used in combination to assess a site, demonstrating how individual indicators can be more powerful in detecting change when employed as part of a suite. By splitting existing habitat status indicators down into individual parameters for this review, the added value gained by employing an integrated indicator is not clear.

Rapid detection of physical and biological pressures is often currently limited by the need to monitor specific species or habitats several times before change can be identified and quantified. The development of physiological and molecular assessment tools to enable rapid detection of the impacts of these pressures is currently underway within scientific research organisations. The advantage of these novel approaches over conventional community level metrics is in the speed of detection, both of changes at a sub-organismal level to specific pressures and the wider ecosystem impacts. The application of such techniques will assist in the development of rapid response monitoring programmes and contribute to achieving good environmental status in our regional seas.

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