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A review of indicators and identification of gaps:
Deep-sea habitats

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ABSTRACT

A range of national and international legislation, obligations and commitments aim to promote and maintain a healthy and biologically diverse marine environment from shallow coastal waters to the deep sea. In addition, a set of Contributory Marine Objectives (CMOs) have been developed to meet the Government's overall vision for clean, safe, healthy, biologically diverse and productive seas. These objectives require sustained and routine observations of oceanic and coastal ecosystems to achieve their goals. This report evaluates the applicability of existing and suggested (where gaps have been highlighted) environmental indicators that can be used to monitor and assess the state of UK deep-sea habitats. These indicators are reviewed against potential anthropogenic pressures, ecosystem structure and function, as well as statutory obligations and CMOs.

The principal anthropogenic pressures that may have an impact on UK deep-sea habitats are identified as demersal fisheries, Oil and gas industry activities, land-based/shipping pollution and climate change. At present, there are no routine UK deep-sea environment monitoring programmes and the only protected area in UK deep water is the *Darwin Mounds* region. This investigation has identified seventeen potential indicators of impacts that can be mapped to the assessment framework, which will be used to implement an integrated monitoring programme.

The review of the anthropogenic pressures with regard to relevant indicators highlighted many gaps in current deep-sea habitat monitoring efforts. Gaps that could currently be covered or addressed by suggested indicators are:

- The impact of demersal fishing on UK deep-water habitats. This activity is not routinely monitored and its impact is unknown in the vast majority of UK deep-sea habitats, although it is thought to be the principle threat. (Indicator: photographic transects to measure extent, abundance and diversity of habitats).
- No routine monitoring programmes on the sustained impact of oil and gas industry activity on deep-sea habitats are in place, although the industry is required to perform initial environmental impact assessments. (Indicator: community change around drill sites).
- The extent and impact of litter/debris (shipping, fishing and land-based) is unknown in the deep sea (Indicator: photographic transects, will show extent but not effects).

Anthropogenic pressures that cannot be addressed with current operational indicators may be addressed by indicators that are under development. Other gaps in monitoring effort require more research to improve knowledge of the habitats and the impacts caused by the pressures. Also, monitoring effort should not focus only on 'charismatic' species (e.g. corals and sponges).

The critical review of the indicators highlighted significant gaps in their accurate implementation:

- The extent, abundance and diversity of specific UK deep-sea habitats are poorly understood, or remain unknown. Surveys still recover many species new to science and there is a paucity of knowledge of deep-sea ecological processes.
- The UK does not currently monitor bioaccumulation of contaminants of any kind in deep-sea organisms.
- There is no ecotoxicological information for deep-sea organisms.
- Molecular and biochemical indicators are potentially useful in revealing contaminant exposure and the health of species, but such techniques remain under development.

The review of the indicators in addressing ecosystem structure and function revealed that while some can be used to address ecosystem structure (e.g., photographic transects to reveal extent of specific habitats, species abundance and diversity), there are presently no indicators available to address the issue of ecosystem function directly. Within the deep sea higher biodiversity appears to support higher rates of ecosystem processes and increased efficiency with which these processes are performed. Anthropogenic effects that negatively affect biodiversity will therefore have a negative impact on ecosystem function. Indicators that monitor biodiversity may therefore act as proxies for monitoring ecosystem function.

A review of the current indicators in place suggests that regional and international statutory obligations and CMOs are not being fully addressed or fulfilled, primarily because there are no routine monitoring programmes in UK deep-sea waters. Photographic transects of the seafloor are potentially the most useful for routine monitoring and assessment of the fragile or vulnerable deep-water habitats found in UK waters and will help to address legal obligations. Such habitats include seamounts, carbonate mounds and reefs (notable for the presence of the deep-water coral, *Lophelia pertusa*), sponge aggregations, octocoral 'gardens' and chemosynthetic habitats (cold seeps and pockmarks). However, for monitoring, management and protection programmes to work successfully, we need to increase our knowledge of the location and ecology of these deep-sea habitats in UK waters.

KEYWORDS

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Background

National and international policy obligations

The UK depends on its seas to help meet a range of economic and social needs, for example, fisheries, recreation and natural resources. At the same time, they contain a range of important habitats and diverse forms of life, which are essential for the healthy functioning of the marine environment and ultimately contribute to its sustainability. For sustainable development, the resources and opportunities offered by our oceans and seas should only be utilised if we also protect their ecological processes and ecosystems (Defra, 2002). In response to this, Defra (Department for Environment, Food and Rural Affairs) embarked on the development of the UK Marine Monitoring and Assessment Strategy (UKMMAS, 2007). Within the UKMMAS, evidence groups have been established that are responsible for coordinating the work needed to achieve the goal of a sustainable marine environment (Figure 1). The Healthy and Biologically Diverse Seas Evidence Group (HBDSEG) is responsible for implementing monitoring and observation programmes covering ecosystem health, biodiversity and oceanographic processes. HBDSEG compliments the other evidence groups for Clean and Safe Seas (CSSEG) and Productive Seas (PSEG). These three groups all report to the Marine Assessment and Reporting Group (MARG), which in turn is governed by the Marine Assessment Policy Committee (MAPC). The MAPC oversees the UKMMAS structure, identifying the requirements for marine monitoring and assessment in order to meet national and international obligations and commitments.

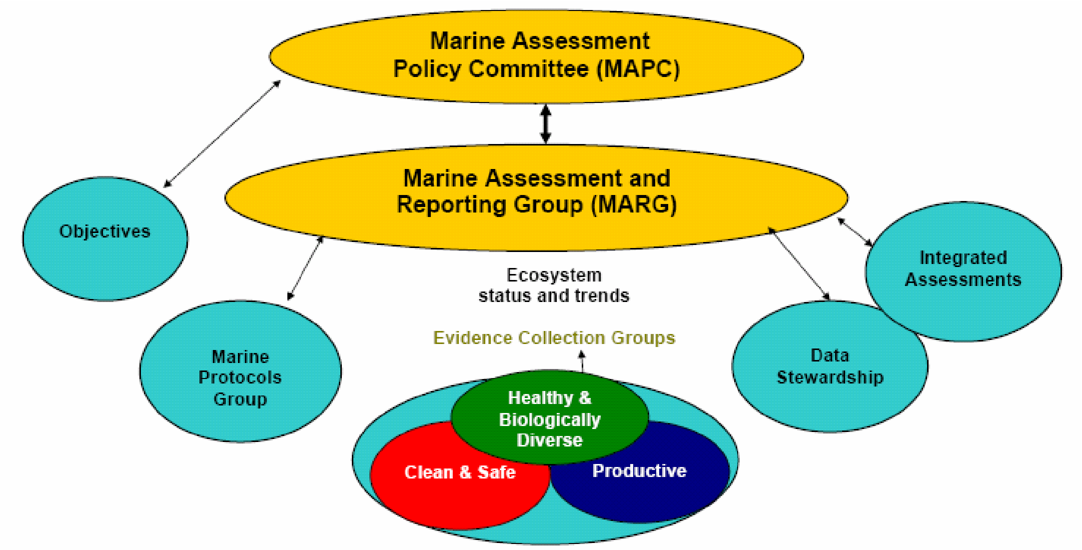

Figure 1. The UK Marine Monitoring and Assessment Structure (taken from UKMMAS, 2007)

There are a range of drivers in the UK (expressed as formal national and international legislation, obligations and commitments), which have been collated into a comprehensive list by the United Nations Environment Programme World

Conservation Monitoring Centre (UNEP WCMC) to provide support for the further development of formal UK marine objectives. A set of Contributory Marine Objectives (CMOs) has been developed by the UKMMAS three evidence groups to compliment the Government's overall vision for clean, safe, healthy and biologically diverse and productive seas. These objectives provide the overall policy framework to guide the UKMMAS. The CMOs are grouped under themes (Human Use, Healthy and Functioning Ecosystems, Optimising economic returns and Infrastructure and Social Integration) that will provide a body of work on which further development of High Level Objectives across Government and Devolved Administrations can build.

The UK is one of sixteen contracting parties to the Oslo Paris (OSPAR) Convention for the Protection of the Marine Environment of the North East Atlantic. The goals of the convention are to 1) maintain the structure and function of marine ecosystems, 2) protect its biodiversity, and 3) reduce levels of pollution, contamination and physical damage to acceptable levels (Defra, 2002). In order to meet its objectives, the OSPAR Convention has adopted several long-term strategies. The Commission's Biodiversity Committee (BDC) is delivering OSPAR's biodiversity strategy through a number of work streams to include: Ecological Quality Objectives (EcoQOs), assessment of threatened and declining species and habitats, designation of Marine Protected Areas (MPAs) and the assessment of human activities. A framework set out for assessing monitoring needs has been created by the UK and recommended for further development by OSPARs Environmental Assessment and Monitoring Committee and the ICES (International Council for Exploration of the Sea) working group on Ecosystem Effects of Fishing Activities.

The European Union also recognises the need for the monitoring and assessment of the marine environment. It is expected to finalise the draft Marine Strategy Framework Directive (MSFD) in 2008, which will require periodic assessments of the marine environment. This will include assessments on biodiversity and pressure (anthropogenic), with the aim of achieving a good environmental status for the marine environment.

The assessment framework

The overall goal of the UKMAAS is to implement a single monitoring framework that meets all the 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 reduce costs by consolidating monitoring programmes.

The assessment matrix, prepared initially for OSPAR's BDC, has been developed with HBDSEG to provide a useful framework that analyses components of an ecosystem and their relationships to anthropogenic impacts. It is hoped the framework will also fulfil prospective MSD requirements. 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 matrix relates ecosystem components (e.g. deep-seabed habitats) to the main pressures upon them. The columns (ecosystem components) have been correlated with components used by OSPAR and the draft MSD. The rows of the matrix are a generic set of pressures and their impacts on the marine environment, which are based on those used by OSPAR, MSD and the Water Framework Directive (WFD). A traffic light system 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, derived from statutory and non-statutory sources, which are used to monitor and assess the state of that ecosystem component. The assessment matrix highlights priorities for indicator development and monitoring programmes, based on the likely magnitude of each impact on the ecosystem component in question.

Development of the framework – the scope of this report

The further development of the assessment matrix 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. This report contributes to phase 3; evaluating the effectiveness and efficiency of the current indicators detailed on the matrix under the ecosystem component 'deep-seabed habitats'. Current gaps in our knowledge will be highlighted and additional/ alternate indicators will be suggested and critically reviewed. Key terminology is defined from the outset to avoid misinterpretation and a glossary is given at the end. A brief résumé of the pressures and impacts on the UK deep-sea floor is given to clarify the indicator needs of this habitat.

Introduction

Deep-sea habitats

Deep-sea sediments cover over 65% of the Earth’s surface. Microbial processes occurring there drive nutrient regeneration and global biogeochemical cycles essential to sustain primary and secondary production in the oceans (Gage and Tyler, 1991). We define the ‘deep-sea floor’ as that portion of the ocean bottom beyond the continental shelf break, which is situated at about 200m water depth in the NE Atlantic (Gage and Tyler, 1991). The deep sea is not the tranquil, monotonous environment it was once considered to be. There are a number of distinct deep-sea habitats in UK waters: abyssal plains, seamounts (rising >1000m above the sea-floor), carbonate mounds and continental slopes. Continental slopes, which form the majority of the UK deep-sea area, in turn contain a range of important habitats, such as coral mounds, sand contourites, terraces, and submarine canyons. Exposed hard rock is uncommon in the deep sea, being confined to steep continental slopes and seamounts in UK waters (Gage and Tyler, 1991). Each of these deep-sea habitats has its own distinct associated fauna. The European Nature Information System (http://eunis.eea.europa.eu/) lists the deep-sea habitat types in Europe, but this is generally considered to be incomplete and in need of development; some UK deep-sea habitat types are missing from the list.

The most extensive benthic surveys of deep UK waters (initiated by Atlantic Frontier Environmental Network) have been carried out in the UK Atlantic Margin (North and Northwest of Scotland) for the Department for Business, Enterprise and Regulatory Reform (BERR) (formerly DTI) (Bett, 2001; Hughes et al., 2003). These Strategic Environmental Assessment (SEA) surveys (Figure 2) have revealed distinct faunal habitats related both to topographic and hydrographic regimes (Bett, 2001; Hughes et al., 2003). Such surveys still recover many species that have not been formally named and there is little knowledge of the detailed ecological processes that occur in these habitats.

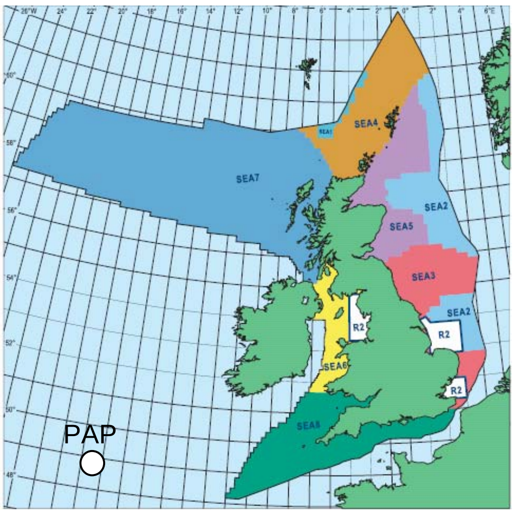

Figure 2. Map of the Strategic Environmental Assessment (SEA) areas surveyed for the Department for Business, Enterprise and Regulatory Reform (BERR) (formerly DTI). SEA areas 1, 4 and 7 included deep-water habitats. The Porcupine Abyssal Plain (PAP) time-series site is also shown

The vast majority of the deep-sea fauna derive their energy from a 'rain' of detritus from the surface waters. The main exceptions to this rule are chemosynthetic environments (hydrothermal vents and colds seeps), which are fuelled by chemicals released from the seafloor. These systems have not yet been definitively identified in deep UK waters. Although there have been reported sightings of a tubeworm seep community in the Faeroe-Shetland Channel and fluid flow (pockmark) sites in the SEA7 area (Figure 2) (Bett, 2001; Connor et al., 2006). Most pockmarks are small (10s of metres across) and do not show up on conventional surface mounted multibeamed systems. The limited number of extensive UK deep-water surveys, coupled with the lack of suitable technology needed to see such features in the deep sea, has led to mainly anecdotal evidence being available on their distribution in deep UK waters. Limited TOBI (deep-towed sidescan sonar) data in deep UK waters has revealed a large pock-mark field adjacent to the *Darwin Mounds* in the northern Rockall Trough (Bett, 2001). A large area of polygonal faults has been observed in the Hatton-Rockall Basin (Weaver et al., 2000), with traces of bacterial mats that have presumably resulted from waters being expelled along the fault planes (Colin Jacobs, pers. comm.). Further survey work is required to map these sites and study the associated fauna, before they are irreversibly impacted by human activity, as has been observed at cold-seep sites in New Zealand waters (Baco et al., 2008).

In the deep sea, low temperatures and a limited supply of food typically results in relatively low rates of growth, respiration, reproduction, recruitment and bioturbation in comparison to shallow-water ecosystems (Gage and Tyler, 1991; Smith and Demopoulos, 2003). The biomass of deep-benthic communities is less than that of shallow-water or terrestrial communities because of the low flux of energy (Smith and Demopoulos, 2003). Seamounts, carbonate mounds, sand volcanoes (e.g. the *Darwin Mounds*, NW Scotland) and submarine canyons (e.g. Whittard canyon, off the coast of Ireland) are exceptions, yielding relatively high biomass communities by focusing water flow and hence organic matter.

Some deep-sea species are known to live for several decades or even hundreds of years, and some species are adapted to seasonal changes in food supply (Gage and Tyler, 1991; Gooday, 2002). Recently, evidence has emerged from time-series studies conducted over a period of a decade or more that long-term faunal changes occur in the deep sea. It has been suggested that these shifts may reflect changes in the quality of the food delivered to the seafloor, perhaps related to climatic oscillations (Billett et al., 2001; Wigham et al., 2003). It is important to understand these natural fluctuations in deep-sea communities in order to distinguish them from those arising as a result of human impact.

In the past the remoteness and vast extent of the deep sea has protected it to a large extent from human impacts. However, the low productivity and biomass of deep-sea ecosystems, coupled with the low physical energy of the environment increases sensitivity to such pressures (Glover and Smith, 2003; Davis et al., 2007). Moreover, high species diversity potentially could also lead to greater redundancy making communities more sensitive to human impacts (Glover and Smith, 2003). Well-publicised habitats, such as the deep-water coral reefs off the Scottish coast, are likely to get protection from human pressures and impacts. There is the danger, however, that the much more extensive areas of soft sediment, which are also characterised by high biodiversity (Snelgrove and Smith, 2002) but are not so charismatic, may be overlooked. The high species diversity of soft sediment communities believed to be maintained by small-scale environmental heterogeneity, can easily be disturbed. A multiscale spatial model synthesising information about anthropogenic drivers of ecological change has shown deep waters around the UK are highly impacted (Halpern et al., 2008). At present, there are no deep-sea monitoring programmes in UK waters. Regulations require that the oil and gas industry perform an environment description at the beginning of a project (i.e. baseline survey to feed into the Environmental Impact Assessments (EIAs)), however, this does not have to be carried out if their is sufficient existing data available (e.g. SEA surveys have been performed in the drilling area). For monitoring, management and protection programmes to work successfully, we need to increase our knowledge concerning the location and ecology of the different deep-sea habitats in UK waters (Davis et al., 2007).

Pressures and impacts on UK deep-sea habitats

Demersal fisheries

A shift from shelf fisheries to the deep sea has already led to the removal of late-maturing fish species that recover slowly (Devine et al., 2006). Deep-sea fisheries concentrate on productive areas, such as seamounts and canyon walls, where levels of biodiversity and endemism in the benthic fauna can be high (De Forges et al., 2000) although the degree of endemism can be low on north Atlantic seamounts (Hall-Spencer et al., 2007). The fishing activities cause considerable ‘collateral damage’ to the benthic ecosystem by physically destroying habitat and removing key species (Roberts, 2002; Davis et al., 2007). In particular, trawling eliminates the larger, sessile organisms such as corals and sponges that create the spatial and structural habitat favoured by other species (Tissot et al., 2004). It is likely that in its current form, deep-sea fishing is unsustainable (Davis et al., 2007).

Benthic surveys are revealing the increasing extent to which bottom-trawling is altering deep-sea coral habitats (Hall-Spencer et al., 2002; 2008). This is a particular concern because these reefs take centuries to millennia to develop (Hall-Spencer et al., 2002). A comparison of fished and unfished seamounts has revealed much lower biodiversity and biomass at fished sites (Koslow et al., 2001). In UK waters, colonies of the deep-sea coral *Lophelia pertusa* are at risk from trawling activities (Rogers, 1999; Roberts, 2002; Davis et al., 2007; Rogers et al., 2008) and some have already been impacted (Bett, 2000; Wheeler et al., 2004; Clark and Koslow, 2007; Davis et al., 2007; Hall-Spencer et al., 2007). *Lophelia* has been reported along the continental shelf, on offshore seamounts, banks and attached to carbonate mounds and sand volcanoes (e.g. *Darwin mounds*) in UK waters. The species has also been reported growing on active oil platforms and on the decommissioned Brent Spar platform (Bell and Smith, 1999). An inshore reef complex has recently been mapped in the entrance to the Sea of Hebrides and there are many records of *Lophelia* on the Rockall Bank. Recently (9th January 2008), the North East Atlantic Fisheries Commission prohibited bottom trawling and fishing with static gear from a number of large areas in the Rockall and Hatton banks (www.neafc.org), with the aim to protect deep-water corals.

The other deep-water area to receive protection (trawling ban) is the *Darwin Mounds* region, inhabited by deep-water corals as well as very delicate giant protists (xenophyophores), which can grow to sizes of 20cm or more (Hughes et al., 2003; Masson et al., 2003).

Although not as picturesque or as widely reported as deep-water corals, sponge aggregations are also at risk from trawling (Hughes et al., 2003). A photographic study on the impact of trawling on deep-sea sponges has revealed that no evidence of repair of tissues was evident after a year and many individuals died of tissue necrosis (Freese, 2001). They are described as 'being of substantial ecological significance within the UK Atlantic Margin' (Bett, 2001). Demosponge aggregations, or '*osterbund*' as they are more commonly known, have been observed at mid-slope depths (~500m) north and west of Shetland, coinciding with iceberg ploughmark terrain (Bett, 2001) in regions where the currents are elevated and resuspension and transport of particles are enhanced (Klitgaard et al., 1995). Demosponges have been impacted by trawling (Bett, 2001). The morphology of the sponges influences the occurrence and composition of the associated fauna, the majority of which use them as a substratum (Klitgaard, 1995). Unlike Demosponges, hexactinellid sponges form aggregations in areas of open sediment. The HMS '*Lightning*' and '*Porcupine*' research cruises in the late 1800s first observed hexactinellid sponge aggregations in the northern Rockall Trough (Thompson, 1873). More recent surveys have found hexactinellids to be a principle component of the megafaunal community at 1000-1400 m in the SEA7 survey area NW Scotland (Hughes and Gage, 2004; Davies et al., 2006). They also occur in the Porcupine Seabight (southwest of Ireland) (Rice et al., 1990). Hexactinellid sponge aggregations create a very distinct habitat. Analysis of the abundance and taxonomic composition of the macrobenthos suggests the presence of sponge spicule mats at the sediment surface substantially modifies the fauna by increasing the numerical abundance of macrobenthos with increasing spicule abundance (Bett and Rice, 1992).

The OSPAR list of threatened and/or declining species and habitats includes seamounts, carbonate mounds, *Lophelia pertusa* reefs and deep-sea sponge aggregations. Octocorals (sea-pens, sea-fans and soft-corals), which are known by the habitat name of 'coral gardens' by OSPAR, also are included in this list, form part of the by-catch of demersal trawls (Edinger et al., 2007). In the deeper SEA7 survey area (see Figure 2), between 2000-3500m, the soft coral *Acanella arbuscula* is highly abundant (Duineveld et al., 1997b; Hughes and Gage, 2004; Davies et al., 2006). This species has also been found at shallower depths (~1300m), where it is associated with fine sediments (Davies et al., 2006). *Acanella arbuscula* is almost always seen in association with the ophiuroid *Ophiomuseum lymani* (a deposit feeding brittlestar) (Hughes and Gage, 2004). Therefore, if the octocoral is impacted through demersal trawling then it is likely that *O. lymani* will be adversely affected too. This in turn will have repercussions on the ecosystem structure and function of that particular habitat.

Oil and Gas Industry

Initially, exploration for oil and gas resources was confined to shallow shelf seas. However, increased energy demands and the advancement of technology has meant that oil and gas exploration is moving into increasingly deeper waters, for example, the Faeroe-Shetland Channel. The expansion of the industry has provoked concerns regarding its impact on benthic communities in the deep sea. While the impact of drilling will mainly be confined to the area around the drilling structures, the impact is likely to be significant. The major source of disturbance results from drill cutting spoil smothering organisms, organic enrichment and the release of toxic chemicals (Kröncke et al., 1992; Daan and Mulder, 1996; Currie and Isaac, 2005; Jones et al., 2006; Jones et al., 2007). Thirty years of North Sea drilling have left between 1 and 1.5 million tonnes of drill cuttings on the seafloor (UKOOA, 2002). It is possible that drill cuttings will pose a greater local environmental hazard in the deep sea than in shallow water because recovery rates will be lower (Glover and Smith, 2003). Only the drill cuttings produced by excavating the initial top-hole of the well are discharged directly onto the seafloor in UK deep waters (Hyne, 2001), however, drill sediment (cuttings separated from the mud, which is recycled) and the cuttings discharged at the sea surface can settle from the upper ocean to the deep seafloor around drilling platforms (UKOOA, 1998).

The oil and gas industry recognise their environmental impact and regulations have been put in place for companies to perform environmental impact assessments. An extensive survey of the deep benthic ecosystem west of Scotland has been carried out recently in response to this requirement (Bett, 2001). This extensive survey also had a wider remit: to assess the potential impact of deep-water fisheries and provide a regional setting, enabling an assessment of larger-scale environmental processes that may not be evident at a local scale (Bett, 2001). Scientists are working with oil and gas companies to use their technology to further research in the deep sea (www.serpentproject.com). This has included determining the localised impacts of deep-sea drilling (Jones et al., 2006; Jones et al., 2007; Gates and Pullen, 2008). There is little or no information on contaminant exposure and its effect on deep-sea species. The Norwegian Deepwater Programme (NDP) is currently examining if exposure, dose and effect responses in shallow water organisms can be extrapolated to deep-sea species. This programme is also developing methods to examine uptake and effects in deep-sea species and examine hydrocarbon uptake and biomarker responses in selected invertebrates (Skadsheim et al., 2005). There is currently little or no monitoring of environmental impacts by the oil and gas industry. Therefore, aspects of the national and international legislation, obligations and commitments, or CMOs related to healthy, productive and biodiverse seas are not being fulfilled.

Climate change

The deep sea is often considered as an ‘extreme’ environment. However, this is from a human perspective. Deep-sea organisms experience far more stability in terms of water temperature, salinity and currents than do their shallow-water counterparts and may not tolerate even small changes in these environmental parameters. Individuals, populations and communities will be affected by local and regional changes in upper ocean primary productivity, organic-carbon flux and thermohaline circulation driven by climate change (Glover and Smith, 2003). Given the uncertain influence of climate change on upper ocean processes, predicting the specific impacts on deep-sea ecosystems is difficult. Some predicted broad-scale changes certainly would have catastrophic consequences on deep-sea life. The likely reorganisation in the global thermohaline circulation caused by climate change (Schmittner and Stocker, 1999;

Bryden et al., 2005) would have considerable impact on deep-sea fauna. These effects could be similar to the diversity fluctuations during the Cenozoic and Quaternary revealed by the microfossil (foraminifera and ostracod) record preserved in deep-sea sediments (Thomas and Gooday, 1996; Hunt et al., 2005). At least in some cases, reductions in diversity were caused by changes in thermohaline circulation and must have had a substantial impact on ecosystem functioning (Danovaro et al., 2008). In addition, climate-driven changes in upper-ocean biogeochemistry (Richardson and Schoeman, 2004; Orr et al., 2005) will alter the quantity and quality of food arriving at the sea-floor, driving changes in deep-sea floor community composition (Billett et al., 2001; Ruhl and Smith, 2004). Benthic biomass and abundance, bioturbation depth and rates have all been shown to be affected by food supply (Smith et al., 1998; Smith and Rabouille, 2002; Smith and Demopoulos, 2003). Therefore, changes in the rates of these processes (ecosystem function) will in turn affect the sequestration and burial of carbon.

High atmospheric carbon dioxide concentrations caused by emissions from burning fossil fuels are recognised as a primary driver of global warming, but these emissions are also acidifying the oceans (IPCC, 2007). Deep-water masses in the NE Atlantic are relatively “young” because they originate in the Greenland-Norwegian Sea by the cooling and sinking of surface water. These acidified surface waters may be transported quickly (less than 5 years) to deep-water habitats. Decreases in pH will have a particular impact on organisms that secrete carbonate (aragonite or calcite) structures (Orr et al., 2005). This is particularly applicable to the deep-water scleractinian corals that secrete aragonite skeletons because this form of carbonate is more soluble than calcite (Turley et al., 2007). It is predicted that 70% of deep-water corals will be under the aragonite saturation limit by 2099 (Guinotte et al., 2006). There have been no published experimental results on the impact of higher seawater CO_2 concentrations on deep-water corals. However, if deep-water corals respond in the same way as warm-water species, a substantial decrease in calcification would occur as a result of acidification (Kleypas et al., 2006). Coccolithophores (a group of phytoplankton that secrete carbonate scales, or liths) will also be affected detrimentally by a decrease in pH (Orr et al., 2005), and this will have implications on bentho-pelagic coupling. Changes in the phytoplankton community and the resultant biochemical composition of organic matter flux to the deep-sea floor has been shown to influence the biochemistry of deep-sea organisms, depending on their feeding adaptations and selectivity (Neto et al., 2006; Smith et al., 2008). This in turn may give some species a reproductive advantage, leading to community change, as observed at the NE Atlantic time-series station (Billett et al., 2001).

Land-based pollution

Pollutants may enter the deep-sea system if they are associated with particulate organic matter sinking from the upper ocean, as well as through long-range and long-term transportation by deep-ocean currents (Thiel, 2003). Submarine canyons along the continental shelf and slope play an important role in the transport of sediments and organic matter to deep basins and may also serve as a ‘fast-track’ for contaminants into the abyss (Ahnert and Borowski, 2000). A body of evidence shows persistent pollutants such as heavy metals, organochlorines, butyltins, polychlorinated biphenyls (PCBs) and dichloro-diphenyl-trichloroethanes (DDTs) are bioaccumulated by deep-sea fauna (Lee et al., 1997; Moore et al., 1997; Takahashi et al., 1997; De Brito et al., 2002; Harino et al., 2005). There have been few ecotoxicological studies involving deep-sea organisms because of the remoteness of the ecosystem and the difficulty of carrying out experiments either *in situ* or at the ambient pressures. Differences in the physical environment, as well as differences in the physiology, behaviour and ecology of the organisms make it potentially misleading to apply with confidence the results of toxicological research on shallow-water organisms to their deep-water counterparts (Childress, 1995; Siebenaller and Garret, 2002). Ecotoxicological studies are required to assess the effects such pollution have on the deep-sea fauna and the influence this may have on community composition.

Litter

Both marine and terrestrially derived litter has been recorded in the deep-sea environment (Galgani et al., 2000; Gjerde, 2006; Weaver and Masson, 2007). The distribution and concentration of such debris appears to be affected by hydrodynamics, submarine geomorphology and human factors (Galgani et al., 2000). Litter found in the deep sea includes fishing gear, clinker, plastic, glass bottles, metallic objects and plastic bags (Galgani et al., 2000; Weaver and Masson, 2007). Apart from the provision of an attachment substratum for sessile organisms, the impact of human debris on deep-sea benthic ecosystems is unknown.

Definition of an indicator

Indicators of environmental status are an integral part of the management systems put in place to ensure sustainable development of the marine environment. They are important for communication and for supporting the objectives of an ecosystem approach (Rogers and Greenaway, 2005). In the original tender the word indicator is 'used in a broad sense to encompass aspects of the marine environment (physical and chemical attributes, species or habitats) or of human activities which are, or could be, monitored to provide some indication of the state of the ecosystem'. The remit of the current review is to refine the use of 'broad sense' indicators to more specific methods of assessment.

In general an indicator can be defined as a parameter or value derived from a measure which provides information about the state of an environment (OECD, 1993). Indicators have two major functions:

1) They reduce the number of measurements and parameters normally required to give a precise characterisation of the environment. However, too few or even a single indicator may be insufficient to provide all the necessary relevant information.
2) They simplify the communication process by which survey results are provided by the user.

A '**performance indicator**' shows, through a direct cause and effect relationship, whether management actions needed to control the particular activity are achieving the desired performance or protection (Defra, 2005). An example of a performance indicator is the concentration of hazardous substances in the water column or sediments in comparison to the target level. Performance indicators, however, are not sufficient to enable us to say with confidence whether our seas are in a healthy state overall. This requires '**indicators of state**', which can demonstrate whether the desired state of specified physical, chemical and biological parameters have been reached (Defra, 2005). An example of an 'indicator of state' is the density of sensitive species (e.g. changes in the density of *Lophelia pertusa* may indicate impact from demersal trawling).

'**Bioindicators**' are organisms or chemicals that contain qualitative information on the quality/ health of the environment/ ecosystem (Markert et al., 2003). They can be any biological species or group of species whose function, population or status can be used to determine ecosystem or environmental integrity (Mccarty et al., 2002). Bioindicator organisms can deliver information on alterations in the environment in the form of physiological, chemical or behavioural changes. '**Biomonitors**' are organisms that contain quantitative information on the quality of the environment around. A good biomonitor will indicate the presence of the pressure/ impact and also some indication of the intensity and amount of exposure (Markert et al., 2003).

A '**biomarker**' is a substance that can be used as an indicator of a biological state (Mccarty et al., 2002). The term may also refer to any feature that can be measured or observed in an organism, population or ecological community and that provides a sensitive index of exposures to, or adverse sublethal effects of contaminant pollution levels (Ryan and Hightower, 1996). To be of practical use in monitoring, a biomarker must be a quantitative or semi-quantitative surrogate for either dose or response. As qualitative indicators of exposure, they are of limited use because exposure can often be inferred by other less costly information sources such as contaminant concentration levels (McCarty et al., 2002). A suggested approach to the effective use of biomarkers in routine monitoring programmes is given by Lam and Gray (2003).

To be useful in ecological risk assessment a biomarker must meet the following requirements (compiled from Stegeman et al., 1992; Beyer, 2003; Wu et al., 2005; Anderson and Lee, 2006);

1. The assay to quantify the biomarker should be reliable (with QA), reproducible and relatively cheap and easy to perform.
2. The biomarker response should be sensitive to pollutant exposure and/ or effects in order to serve as an early warning parameter.
3. Baseline levels of the biomarker need to be established to enable the distinction between natural and contaminant induced stress.
4. The impacts of confounding factors (season, temperature, salinity etc.) on the biomarker response should be well established; preferably the biomarker will not be sensitive to confounding factors.
5. The underlying mechanism of the biomarker response and pollutant exposure should be known.
6. The relationship between the biomarker response and the long-term impact on the organism should be established.

Definition of ecosystem function and structure

Ecosystem functioning involves several processes, which can be summarised as production, consumption and transfer of organic matter to higher trophic levels, decomposition of organic matter and nutrient regeneration (Naeem et al., 1994; Danovaro et al., 2008). Terrestrial and shallow-water ecologists have recognised that altering the composition of biological communities has a strong potential to alter ecosystem functioning; biodiversity loss may impair the functioning and sustainability of ecosystems (Solan et al., 2004; Hooper et al., 2005). A recent study of the relationship between ecosystem functioning and biodiversity in the deep sea has shown that a higher biodiversity supports increased efficiency and higher rates of ecosystem processes (Danovaro et al., 2008). It is argued that because the deep sea plays a key role in ecological and biogeochemical processes at a global scale, conservation of deep-sea biodiversity is necessary for the sustainable functioning of the World’s oceans.

Ecosystem structure relates to the physical and spatial aspects of an ecosystem that are contributed by biotic composition, for example, species population density, species diversity, physical structure and biomass, and by abiotic factors, for example, sediment structure and processes such as currents and the thickness of the benthic boundary layer. If a human activity has an impact on the structure of an ecosystem (for example, demersal trawling impacting deep-water coral reef habitats), this in turn can affect the functioning of that ecosystem.

Critical evaluation of indicators

Table 2 lists the relative merits of the indicators reviewed hereafter (p20 to 35), in terms of their ability to be quantitative (intensity of pressure) or qualitative (presence of pressure). Deep-sea habitats can change dramatically on monthly scales, but it is recognised such monitoring frequency of all habitats would be prohibited by cost. The recommendations shown in Table 2 for monitoring frequency should be taken as the minimum; programmes that monitor on longer frequencies are likely to find that the impact on the habitat has caused irreparable damage.

<table>
<tr><th>Indicator</th><th>Quantitative</th><th>Nominal</th><th>Qualitative</th><th>Monitoring Frequency</th></tr>
<tr><td rowspan="2">Extent, density and biology of Reefs/ Seamounts/ Carbonate Mounds</td><td>Spatial extent, density (features per unit area), community parameters (abundance, biomass, diversity, composition …)</td><td>Ranking of ecological status (e.g. 0=completely destroyed, 5=pristine)</td><td>Skilled ‘eye’ appraisal</td><td>Total removal of ecosystem structure technically possible within a matter of hours. Technically possible to monitor demersal trawling via VMS</td></tr>
<tr><td colspan="4">Recommendations: photo / video surveys at nominal / qualitative scale; annually for high value sites and others as discovered or where monitoring (e.g. VMS) suggests impact or new threat. Physical samples required for ‘ground-truthing’ species identification and biomass measurements.</td></tr>
<tr><td rowspan="2">Extent, abundance/ density of Deep-sea Demosponges and Hexactinellid aggregations</td><td>Spatial extent, density (features per unit area), community parameters (abundance, biomass, diversity, composition …)</td><td>Ranking of ecological status (e.g. 0=completely destroyed, 5=pristine)</td><td>Skilled ‘eye’ appraisal</td><td>Total removal of ecosystem structure technically possible within a matter of hours. Technically possible to monitor demersal trawling via VMS</td></tr>
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<tr><td rowspan="2">Extent, abundance/ density Octocorals (soft corals)</td><td>Spatial extent, density (features per unit area), community parameters (abundance, biomass, diversity, composition …)</td><td>Ranking of ecological status (e.g. 0=completely destroyed, 5=pristine)</td><td>Skilled ‘eye’ appraisal</td><td>Total removal of ecosystem structure technically possible within a matter of hours. Technically possible to monitor demersal trawling via VMS</td></tr>
<tr><td colspan="4">Recommendations: photo / video surveys at nominal / qualitative scale; annually for high value sites and others as discovered or where monitoring (e.g. VMS) suggests impact or new threat.</td></tr>
</table>

Water quality/ processes (pH and temperature changes/ water flow on regional and national scales	Measurement of various parameters possible (see Theme 10 review)	Ranking schemes could be constructed (see Theme 10 review)	Presence / absence of contaminants (see Theme 10 review)	Annual surveys currently undertaken, technology exists for continuous monitoring (see Theme 10 review)
	Recommendations: Monitoring of UK deep-water quality and processes should be included and monitored as detailed in 'Theme 10 – Ocean Processes' review			
Bioaccumulation of contaminants	Measurement of various parameters possible	Ranking schemes could be constructed	Presence / absence of contaminant	Not currently developed in deep-water environments. Rapid uptake of natural organic compounds is known to occur in some taxa.
	Recommendations: Monitoring of UK deep-water quality and processes should be included and monitored as detailed in 'Theme 10 – Ocean Processes' review			
Community change & PAP community change	Spatial extent of change, community parameters (abundance, biomass, diversity, composition …)	Biotic indices and similar schemes	Skilled 'eye' appraisal	Very rapid change may be associated with trawling impacts and oil exploration. Major changes may also occur on annual / sub-annual timescales in response to subtle environmental change.
	Recommendations: photo / video surveys at nominal / qualitative scale. For fishing pressure monitor annually for high value sites and others as discovered or where monitoring (e.g. VMS) suggests impact or new threat; for oil and gas industry activity a photo / video ROV transects before and during drilling activity; for other community change assessment and monitoring work (e.g. PAP) physical samples.			
Oxidative stress and Molecular Biomarkers	Measurement of various parameters possible	Ranking schemes could be constructed	Presence of stress indicators (above basal levels)	Currently being researched in deep-water environments. Potential rate of response rapid (see above)
	Recommendations: Daily/weekly at qualitative level when source of contamination is known (i.e. through oil and gas activity), more research is needed to provide recommendations of assessing stress indicators in response to other contaminants (i.e. shipping pollutants)			
Other Biochemical and Molecular Biomarkers	Measurement of various parameters possible	Ranking schemes could be constructed	Presence of stress indicators (above basal levels)	Currently being researched in deep-water environments. Potential rate of response rapid (see above)
	Recommendations: Daily/weekly at qualitative level when source of contamination is known (i.e. through oil and gas activity), more research is needed to provide recommendations of assessing stress indicators in response to other contaminants (i.e. shipping pollutants)			

This section critically reviews each of the indicators listed in Table 1 (broken down into habitat type for clarity) against the relevant anthropogenic pressure and impact. It would be beneficial to collate results and data generated using these indicators in monitoring programmes and academic research into one central database (e.g. hosted by the British Oceanographic Data Centre). This would be a valuable resource to policy makers, regulatory authorities and researchers.

Extent, density and biology of Reefs/ Seamounts/ Carbonate Mounds

Pressure = Demersal trawling

According to the EC interpretation manual (European Commission 1996), reefs 'can be either biogenic concretions or of geogenic origin. They are hard compact substrata on solid and soft bottoms, which arise from the sea floor in the sublittoral and littoral zone'. The deep-water genus *Lophelia* is included in the list of reef-forming species. The known distribution of deep-sea corals on seamounts, oceanic islands and continental slopes in the Northeast Atlantic is detailed in Rogers (1999) and Hall-Spencer et al. (2007). These records of deep-water corals records are concentrated around the Faroes shelf, Rockall Bank, Anton Dohrn Seamount, Rosemary Bank, Hatton Bank and Bill Bailey's Bank and reflect the intensity of sampling/survey efforts (Rogers, 1999). The emerging picture is that *Lophelia* is widespread on UK continental margins. Reefs may support an abundant, distinct and diverse faunal community, creating 'biological hotspots' and can be an important habitat for commercially valuable fish species (Clark et al., 2006).

The Marine Monitoring Handbook (2001) presents a summary of general attributes that can be used as indicators of the health of reefs and to monitor of the impacts from pressures (Table 1, rows 2-5). The extent (or shape) of a reef is unlikely to change significantly over time unless it has been physically impacted by a human pressure such as deep-sea fishing. The extent of deep-sea reefs can be traced using side scan sonar, although this method does not distinguish between live and dead coral. Photographic transects are therefore more beneficial, and can also be used to determine the biotic composition of the ecosystem, which provides another indicator of the health of a reef.

The scientific literature on the effects of fishing on seamount habitats is summarised by Clark and Koslow (2007). The impact of demersal fisheries on reefs, seamounts and the associated deep-water coral, *Lophelia pertusa*, in NE Atlantic waters is discussed in papers by Roberts et al. (2000), Fossa et al. (2002), Hall-Spencer et al. (2002), Wheeler et al. (2004) and Shepard (2006). Using side-scan sonar, ROV (Remotely Operated Vehicle) footage and photographic transects these reports illustrate the mechanical damage to coral, and the trawl marks, caused by demersal trawling.

The extent of the impacts of the fishing industry is not well known, and is not monitored. At present there is no routine monitoring of the impact of demersal trawling on *Lophelia* reefs. Therefore, the UK is not meeting its statutory obligations and achieving the CMOs (detailed above). As part of phase 1 of DCUK (Deep-sea

Conservation, UK), Vessel Monitoring System (VMS, satellite tracking) data collected by the Scottish Executive from 2000-2003 was analysed and promoted as a tool for policing deep-water protected areas around the UK (i.e. the *Darwin Mounds*) (Davis et al., 2007; Moore et al., 2007). The VMS may be suitable for this purpose, but it does not indicate how the deep-sea ecosystem has been affected and may therefore not reflect the impact of this pressure on the deep-sea environment. Nevertheless, it may be useful in estimating the potential environmental impact through fishing activity. Repeated photographic surveys provide the most straightforward and cost effective method of monitoring the health of the reefs, as indicated by their extent, density and associated biology.

Extent, abundance/ density of Deep-sea Demosponges and Hexactinellid aggregations

Pressure = Demersal trawling, Oil and Gas Industry (smothering)

Although not as picturesque and as widely reported as deep-water corals, deep-sea sponge aggregations are also at risk from trawling (Hughes et al., 2003; Shepard, 2006). They harbour a wide diversity of invertebrates and constitute, next to coral reefs, one of the richest and most interesting biotopes (Bacescu, 1971). A distinction must be made between demosponges and hexactinellid sponges because they are associated with different substrata, and have their own distinct fauna (Bett and Rice, 1992; Klitgaard et al., 1995). Demosponges are found on reef/rocky substrata and hexactinellid sponges are found in open sediment. The main pressure on these sponge aggregations is demersal fishing. This activity is not monitored and its impact therefore unknown. As a result, the UK is not meeting its statutory obligations and achieving the CMOs (detailed above). The extraction of oil and gas from the seafloor produces localised affects (community change) around the drilling area, up to 250 m from the drill head (Jones et al., 2006), which may also impact on sponge aggregations.

The distribution of large demosponges in the deeper waters around the Faroe Islands and Faroe Bank is described by Klitgaard (1995). Bett (2001) reported the occurrence of demosponge dominated communities at mid-slope depths (c. 500 m) north and west of Shetland and well developed sponge communities in the north and mid SEA 4 area (see Figure 2), although they are only poorly developed in the south of the area (Hughes et al., 2003). Hexactinellid sponges were found during the HMS *Porcupine* Expedition to the northern Rockall Trough (Thompson, 1873). More recently they were observed at depths between 1000 and 1400 m NW of Scotland in the Rockall-Hatton Basin (SEA 7 survey area, Figure 2) (Hughes and Gage, 2004; Davies et al., 2006) and in dense aggregations in the Porcupine Seabight (Rice et al., 1990). At present, however, we do not have a full understanding of the distribution of these organisms. Baseline information on the distribution and density of sponge aggregations, and the diversity of the species associated with them, are currently needed.

The faunal assemblages associated with both sponge types are very distinct. Demosponges harbour species that use them as a substratum, so that the sponge morphology influences the occurrence and composition of the associated fauna. Hexactinellid aggregations are linked to increased macrofaunal abundance and richness, in particular where they are surrounded by large deposits of sponge spicules (Rice et al., 1990; Bett and Rice, 1992; Davies et al., 2006). The sponges themselves are keystone species, which provide a habitat for many other invertebrates. The extent and density of the sponge aggregations therefore may indicate the health of the ecosystem. Detailed analysis of the fauna associated with hexactinellid and demosponge aggregations will be more time consuming and expensive than photographic surveys. Photographic surveys of the extent and density of sponge aggregations may provide the most cost-effective approach to monitoring the health of their ecosystem.

<u>Extent, abundance/ density of Octocorals (soft corals)</u>

Pressure = Demersal trawling

Despite our knowledge of the existence of cold-water corals since the time of Linnaeus (1707-1778), it is only in recent years that we have begun to unravel the geological and ecological complexities of the biogenic reefs formed by deep-water corals at high latitudes (Davis et al., 2007). Studies of octocoral forests around the British Isles show that these habitats may harbour a treasure-trove of intricate interactions between undescribed species, which increases concern that unregulated trawling remains a major threat to these habitats (Myers and Hall-Spencer, 2004). The gorgonian soft coral *Acanella arbuscula* is high in abundance between 2000-3500 m, in the deeper SEA7 survey area (Figure 2) (Duineveld et al., 1997a; Hughes and Gage, 2004; Davies et al., 2006). This species has also been found at shallower depths (~1300 m), where it is associated with fine sediment and strong current regime (Davies et al., 2006). Extensive octocoral forests have recently been described along the continental shelf break off Ireland at 1km depth (Hall-Spencer and Brennan, 2004). As in the case of deep-sea sponge aggregations, more work is needed to describe the extent and abundance/ density of this poorly known faunal group in UK deep waters. The main pressure on octocorals aggregations is demersal fishing. This activity is not monitored and its impact therefore unknown. As a result, the UK is not meeting its statutory obligations and achieving the CMOs (detailed above).

Water quality/ processes, pH and temperature changes/ water flow on regional and national scales

Pressure = Interference with natural hydrological processes - Climate change (greenhouse gas emissions)

Given the great uncertainty regarding climatic influences on the surface ocean, predicting specific impacts in the deep sea is very difficult (Glover and Smith, 2003). Researchers are only just beginning to understand the potential impacts of climate change on the global thermohaline circulation (Schmittner and Stocker, 1999; Bryden et al., 2005; Scott et al., 2008), which would have a catastrophic effect on deep water ecosystems. A reduction in the thermohaline circulation would limit the influx of oxygen-rich water to the deep sea, leading to hypoxic or anoxic conditions. Problems will also arise if ocean acidification occurs as a result of increased CO_2 concentration in the atmosphere; calcifying benthic organisms (i.e. deep-water corals) will be effected detrimentally (Orr et al., 2005; Guinotte et al., 2006; Turley et al., 2007). The use of indicators such as pH/ temperature/ water flow should be fully covered by the theme ‘Topic 6, Ocean Processes’ and will therefore not be separately addressed in this review. Routine monitoring is carried by academic researchers, e.g. NOC and SAMS Elliot Line Surveys (Allen, 2007) and the Faeroe-Shetland Channel monitored by Fisheries Research Services in Aberdeen.

Bioaccumulation of contaminants

Pressure = Oil and Gas Industry, Shipping and Land-based pollution (Contamination by hazardous substances - heavy metal, synthetic/ non-synthetic and hydrocarbon contamination; Physical loss of habitat by smothering or sealing)

A limited number of reports have documented bioaccumulation of contaminants in deep-sea benthic invertebrates (Lee et al., 1997; Moore et al., 1997; Takahashi et al., 1997; De Brito et al., 2002; Harino et al., 2005; Svendsen et al., 2007). These persistent compounds, whose presence in the environment is a clear indication of anthropogenic pollution, include organochlorines (e.g. DDT, HCB and PCBs found in pesticides, fungicides and coolants/ paints), organotins (e.g. TBT, used in antifouling paint), polycyclicaromatic hydrocarbons (Oil and Gas Industry water soluble contaminants and PCBs, by-products of combustion) and heavy metals (e.g, Cu and Cd)

If baseline levels are known, it is suggested deep-sea organisms can be used as biomonitors of contaminants (Moore et al., 1997; Roberts et al., 2000). However, often no distinction is made between contamination (raised levels of contaminant in comparison with the background level) and the impacts of the contamination (Olsgard and Gray, 1995). The effect of anthropogenic contaminants on freshwater and coastal marine organisms has been the subject of intense scientific investigation for many years. The USEPA Ecotox database (http://cfpub.epa.gov/ecotox/) includes over 220,000 records on aquatic species from tests on >4000 species and >7000 chemicals. None of these tests was performed on deep-sea organisms. It would be misleading to apply the results of shallow water toxicological research to deep-sea species, because their physiology, behaviour and ecology differ from their shallow-water counterparts (Sarah Murty, pers. comm.). Some studies have shown that the bioavailability of contaminants may be modified at high pressure, leading to alteration in the toxicity of a compound (Skadsheim et al., 2005). Although the deep-sea amphipod *Eurythenes gryllus* has been suggested as a sentinel species for monitoring levels and biological effects of contaminants in the deep sea (Camus et al., 2006), it may not be a good biomonitor of contaminant levels from a direct source (i.e. oil and gas drilling activity) because variable pollutant concentrations in these species may result from feeding in spatially remote resources, i.e. distant from high contaminant levels (Koschinsky et al., 2003). The UK is not currently monitoring bioaccumulation of contaminants of any kind in its deep waters, in contravention of statutory obligations and the CMOs listed above.

Community change

Pressure = Oil and gas industry (Contamination by hazardous substances - heavy metal, synthetic/ non-synthetic and hydrocarbon contamination; Physical loss of habitat by smothering or sealing)

The main direct impact on the deep-sea benthos from the oil and gas Industry is through the dumping of drill cuttings although in the deep sea only cuttings from the excavation of the top hole are dumped at the seafloor. The content of drilling muds (used to prevent 'blow outs' and to lubricate the drill bit) is controlled by statutory and EU regulations. In the mid 1990s oil-based muds were replaced with light synthetic muds, but research showed these synthetic muds were not broken down naturally in seawater and so were phased out in the early 2000s (UKOOA, 1998). New regulations stipulate the use of water-based muds, although in some areas synthetic muds are still allowed. Many of the common effects on the fauna from drilling activity have been attributed to the discharge of cuttings contaminated with oil-based drilling mud (Olsgard and Gray, 1995). The most recent research into the impact of drilling on the deep-sea environment has assessed the physical disturbance caused by the discharge of cuttings (Jones et al., 2006; Jones et al., 2007; Gates and Pullen, 2008). Chemical contaminant effects in the deep sea have not been monitored.

Changes in faunal composition have been used to assess the impact of drilling on the local environment (Olsgard and Gray, 1995; Jones et al., 2006; Mojtahid et al., 2006; Jones et al., 2007; Gates and Pullen, 2008). Benthic communities reflect the effects of removing or reducing the fitness of some of their component species (Attrill and Depledge, 1997). Effects attributed to toxicity and sediment disturbance/ smothering associated with drilling activities are evident in the benthos to distances of 50 to 250 m from deep-water platforms (Peterson et al., 1996; Jones et al., 2006; Jones et al., 2007), although this can vary with current regime and nature of the drilling activity (Jones et al., 2007). While there is some research modelling the dispersion of sea-surface discharged drill sediment (Khondaker, 2000; Hannah and Drozdowski, 2005), little is known about the potential extent and affect on deep-sea ecosystems. Factors other than the simple volume of drill cuttings, such as their particle size, hydrographic conditions, depth and the type of mud used are important variables in determining the extent of the impact to the community (Olsgard and Gray, 1995).

Remotely Operated Vehicles (ROVs) have been successfully used to assess the impact of the oil and gas industry on the ecosystems surrounding drilling platforms (Jones et al., 2006; Jones et al., 2007; Gates and Pullen, 2008). Since ROVs are already in place and are primarily used to monitor the drill well and drilling platform, they offer a cost effective method of monitoring the impact of drill cuttings on megafaunal (photographic transects) and macro/meiofaunal (push cores) communities. High resolution video and photo transects are superior to grab samples in determining megafaunal community composition around a drill site because they reveal patterns within megafaunal species assemblages at community and disturbance scales, without introducing additional disturbance through physical sampling (Solan et al., 2003; Jones et al., 2006). ROVs can also be used to take push cores for macro- and meiofaunal analysis and the data generated used in conjunction with the megafaunal data to obtain a detailed picture of the effects of drilling on the benthic environment (Gates and Pullen, 2008).

The toxicity of the water-based drill mud is thought to be minimal; it is quickly diluted if released into the environment. Nevertheless, ecotoxicological research on the mud has shown some degree of toxicity in marine organisms, although this depends on the species involved and the contaminant (Terzaghi et al., 1998). The effects of these water-based muds are currently being tested on deep-sea echinoderms (Sarah Murty, pers. comm.). Nevertheless, the impact of a complex mix of contaminants when influenced by a suite of environmental variables is difficult, if not impossible to predict from laboratory experiments, and so further research *in situ* is needed in this area. It may be possible to separate impacts resulting from physical disturbance from toxic effects (Olsgard and Gray, 1995). Physical disturbance (i.e. sedimentation/smothering from drill cuttings) results in a reduced number of species, dominated by a few opportunistic species resulting in greatly reduced values of diversity indices (Olsgard and Gray, 1995; Jones et al., 2006; Jones et al., 2007).

There are some problems with using community change as an indicator of the impact of the oil and gas industry drilling activity in deep-sea ecosystems. The main problem encountered with deep-sea ecological research is that often little or nothing is known about the ecology of the organisms. In the case of sub-lethal toxic effects, the primary disadvantage is that communities may respond slowly to disturbance, so that by the time community change is detected, it is already too late. There are no 'universal' indicator species that can be used to detect the early stages of impact from contaminants released by drilling (Gray et al., 1990; Olsgard and Gray, 1995). Non-toxic impacts (i.e. sedimentation) do show a relationship between diversity and dose (Olsgard and Gray, 1995; Jones et al., 2006; Jones et al., 2007). Analysing biological samples and identifying species can be time-consuming and costly; expertise in taxonomy may also be lacking. Biological samples should be taken in conjunction with chemical samples (e.g. for heavy metals and hydrocarbons), and samples for particle size analysis. However, toxicological studies around oil wells have shown no information was lost by analysing the results at family level, resulting in a substantial cost saving (Olsgard et al., 1997). If an early warning system is required, methods other than changes in community (e.g. changes at the biochemical/immunological level) may be more suitable for monitoring the impact of oil and gas drilling. Effects will first occur at the lower levels of organisation before they manifest at the community or ecosystem level (Kropp, 2004).

While there is some research on the affects of the oil and gas industry on community change (Jones et al., 2006; Jones et al., 2007; Gates and Pullen, 2008), there is little or no monitoring effort at this level. Regular monitoring of the environment surrounding drill structures are needed to comply with the statutory obligations and CMOs listed above.

Oxidative stress and Molecular Biomarkers

Pressure = Oil and gas industry, Shipping and land-based pollution (Contamination by hazardous substances - heavy metal, synthetic/ non-synthetic and hydrocarbon contamination; Physical loss of habitat by smothering or sealing)

A number of molecular, biochemical, histological, immunological, physiological and behavioural indicators can potentially serve as biomarkers of exposure, stress and adverse effects (Anderson and Lee, 2006; Sarkar et al., 2006). Biomarkers have been used to indicate the exposure of shallow-water organisms to pollutants. Although the study of biomarkers in deep-sea animals is in its infancy, they may be a potentially powerful tool in future monitoring programmes (Kropp, 2004). Research on using biomarkers in deep-sea animals is currently under development at the National Oceanography Centre, Southampton through the SERPENT project (Sarah Murty, pers. comm.), at IRIS & Akvamiljø through the Norwegian Deepwater Programme (http://www.iris.no/Internet/akva.nsf), and at the Norwegian College of Fishery Science (Camus and Gulliksen, 2005; Camus et al., 2006; Pampanin et al., 2006).

Immunological biomarker responses provide evidence of the deleterious effects of anthropogenic contaminants. Responses include changes in lysosome (digestive organelles) composition, integrity and morphometric parameters, and coelomocytes (cells that respond to injuries, host invasion and cytoxic agents). The antioxidant defence properties of deep-sea invertebrates is under development in Norway and includes three biomarkers for oxidative stress: Glutathione (metabolic detoxification), Total Oxygen Scavenging Capacity (capability of tissue to neutralise reactive oxygen species) and Catalase (an enzyme that catalyses H_2O_2 to $2H_2O + O_2$) (Larsen et al., 2002; Camus and Gulliksen, 2005; Camus et al., 2006). Oxidative stress is caused by an imbalance between the production of reactive oxygen and a biological systems ability to readily detoxify the reactive intermediates or easily repair the resulting damage. Antioxidant studies on mussels have shown that it is necessary to record baseline levels of these biomarkers at specific sites, before monitoring work commences, as relatively large differences among sites may occur naturally (Larsen et al., 2002).

Further work needs to be undertaken to determine if deep-sea species found in UK waters can be used for this type of study. Firstly, a suitable sentinel species (or range of species) must be found; the deep-water coral *Lophelia pertusa* and "*Pogonophora*" tube worms (Siboglinid polychaetes) have been deemed unsuitable for such a study because the enzyme activity/ antioxidant levels were found to be below detection limits (Larsen et al., 2002). The giant deep-sea amphipod *Eurythenes gryllus* has been suggested as a sentinel species for monitoring levels and biological effects of contaminants (Camus et al., 2006). This species is widespread and abundant in the deep ocean (it has been recorded at depths of 7500m; Thurston et al., 2002) and baseline data on its antioxidant capabilities has been determined (Camus and Gulliksen, 2004). *Eurythenes gryllus* is a highly mobile species, however, and sessile or slow moving species may be more suitable for assessing impacts from discrete contaminant sources (i.e. drill sites). Echinoderms are widespread and diverse in the deep sea and a number of reasons have been proposed for their use in ecotoxicological studies in shallow waters, which are also applicable to deep-water studies (Sarah Murty, pers. comm.):

1) Benthic and infaunal echinoderms have direct contact with sediment-bound contaminants
2) They can be of reasonable size, giving sufficient tissue quantities for analysis
3) They have a key phylogenetic position, and the closest known relatives of the chordates
4) An extensive body of ecotoxicological work has been carried out on shallow-water echinoderms from eggs to adults, so that deleterious effects caused by various toxicants are well documented
5) They are relatively sedentary and therefore representative of a study area

Ecotoxicological studies on echinoderms are under-development at the National Oceanography Centre, Southampton. The aim is to assess the gene expression of a metabolic enzyme (Citric Synthase) and two molecular chaperones (Ubiquitin and 70kDA Heat Shock Protein) in an analog deep-sea echinoid. It is important to note that stress experienced by deep-sea species during recovery may affect the gene expression of stress response biomarkers; this needs to be addressed before molecular biomarkers can be used in deep-sea species with confidence (Chris Hauton pers. comm.) Future work may aim to characterise patterns of stress-induced gene expression and correlate them to different stressors. This could be especially valuable in multiple stressor environments where toxicity may result from the cumulative effects of many stressors, each with many interactions (Snell et al., 2003). It is also important to correlate gene expression with adverse effects on the animal, so that inferences can be made on organism and ecosystem health (Snell et al., 2003).

Caution must be applied when using biological responses to identify exposure to contaminants, to monitor changes in contamination levels and to provide an early warning system of environmental deterioration. Biomarkers must first fulfil a list of requirements (listed in the introduction of this report) and then consideration given to the time required for the initial induction, maximum induction, adaptation and recovery of a biomarker stress response, and the suitability of the response organism (Wu et al., 2005). Six hypothetical time-integrated responses of biomarkers have been recognised and clearly demonstrate that the use of biomarkers without a thorough understanding of their initial induction, maximum induction, adaptation and recovery periods can lead to erroneous conclusions. Precise times for these processes (which will differ between animal groups and stressor type) must be understood so that sampling intervals are designed to avoid under or over estimation of pollution levels (see Wu et al., 2005, for more details). Temporal variation in antioxidant enzyme activity has been observed in shallow-water species and deep-sea hydrothermal vent mussels (Company et al., 2006). This has been related to temporal variations of reproductive status (Company et al., 2006) and highlights the need for understanding temporal changes in baseline levels. A mixture of contaminants can make it difficult to relate biomarker responses to a particular contaminant class (Anderson and Lee, 2006) and certain types of chemicals may elicit a response much more rapidly than others (Wu et al., 2005). Some biomarkers respond well to contaminant exposure but are not useful in the field because of high natural response variability (Huggett et al., 2003).

The use of these biomarkers to monitor contaminants in the deep sea is being developed. They offer potential advantages for future monitoring by helping to achieve statutory obligations and CMOs.

Other Biochemical and Molecular Biomarkers

Pressure = Oil and gas industry, Shipping and land-based pollution (Contamination by hazardous substances - heavy metal, synthetic/ non-synthetic and hydrocarbon contamination)

Other biochemical and molecular level biomarkers, which have been used in shallow-water ecotoxicology studies, are potentially applicable to deep-sea organisms. Sewage sludge is known to contain high concentrations of metals (Forstner and Wittman, 1983) and deep-sea industrial activities are possible sources of heavy metal contamination (Koschinsky et al., 2003). The concentration of heavy metals in deep-sea holothurians has been suggested as a proxy for sediment heavy metal concentration (Moore et al., 1997), although, bioaccumulation provides no information on the health of the animal. Metallothioneins are non-enzymatic proteins that protect against metal toxicity. They have the potential to be used as biomarkers of exposure and therefore function as early warning signals of the presence of heavy metals (Sarkar et al., 2006). Invertebrate metallothionein studies have mainly focused on molluscs, with some work on deep-sea hydrothermal mussels (Company et al., 2006). Metallothionein induction can be estimated by different analytical methods (differential pulse polarography, radioimmunoassay, spectrophotometry, ELISA), by molecular approaches (protein expression) or as a function of the metals bound to the metallothioneins (Sarkar et al., 2006).

Cytochrome P450 plays a key role in the biotransformation of contaminants that include dioxins, PCBs and PAHs (Sarkar et al., 2006). It is expressed during exposure to contaminants and has been used as a biomarker of pollution in the North Sea in the sea star *Asterias rubens* (Den Besten et al., 2001). Deep-sea studies have focused on cytochrome expression in fish (Kropp, 2004) and further research is needed if Cytochrome P450 is to be used in deep-sea invertebrates. DNA integrity can also be used as a biomarker of pollution; the integrity of DNA can be greatly affected by genotoxic agents, causing DNA strand breaks, loss of methylation and formation of DNA adducts (Ericson et al., 2002). DNA adducts are sensitive biomarkers of exposure to genotoxic contaminants and are considered to be a cumulative index of current and past exposure (Ericson et al., 2002). DNA integrity studies have been carried out on deep-sea fish and hydrothermal vent invertebrates (Pruski and Dixon, 2003; Kropp, 2004), but have so far not been used as a biomarker of pollution.

These potential biomarkers will be subject to the same limitations as detailed for Oxidative stress/ Molecular biomarkers. The use of biomarkers in the deep sea to monitor contaminants is in its infancy. The stress experienced by the organism during retrieval from the seafloor may affect the biomarkers being targeted; this problem needs to be addressed before such biomarkers can be used with confidence. Nevertheless, this approach may provide powerful tools in future monitoring programmes and offer the potential to help achieve statutory obligations and CMOs.

Litter

Pressure = Shipping and land-based pollution (Contamination by plastics of various type and morphology)

A variety of anthropogenic litter (or debris) finds its way into the deep ocean, although plastics account for the major part because of their poor degradability. Glass or metal objects, as well as fishing gear debris can also occur in appreciable quantities (Galgani et al., 1996; Galgani et al., 2000). Little information is currently available concerning anthropogenic debris in the deep sea because considerable resources are required to undertake such a study. One survey on the French continental slope found that plastic bags accounted for a very high percentage of total debris and most debris was concentrated in canyons descending from the slope onto the abyssal plain (Galgani et al., 1996). Photographic transect work could be amalgamated with monitoring work of the UK deep-water benthos. A recent research cruise to the Whittard Canyon, SW Ireland (Weaver and Masson, 2007), revealed no evidence of litter accumulation (Paul Tyler, pers comm.). However, another recent (June 2007) study coordinated by MESH (Mapping European Seabed Habitats) in the SW Approaches (320 km southwest of Lands End) revealed extensive fishing gear debris and plastic bags concentrated in the canyons in the survey area (www.searchmesh.net). Spatial variation in the concentration of debris may be related to the hydrographic regimes, geomorphological factors, anthropogenic activities and river inputs (Galgani et al., 1996; Galgani et al., 2000). More work is required in UK deep waters to assess the distribution and abundance of litter.

Smaller items such as plastic pellets (or nurdles/ mermaids tears, the raw material of plastic products) and microscopic fragments of plastic from biodegradable composites and abrasive substances are also polluting the oceans. These fragments are widespread in the ocean and may persist for centuries (Thompson et al., 2004). They can contain high concentrations of hydrophobic organic contaminants and have been shown to be important agents in the transfer of contaminants to organisms that ingest them (Teuten et al., 2007). Research on these small contaminants has so far focused on shallow water and coastal benthic environments. The impact of these pellets and fragments on the deep-sea environment is unknown. Advice from shallow-water plastic pellet/debris specialists may assist the design of a sampling protocol for monitoring the impact of plastic pellet debris on the benthos in deep UK waters. The impact of litter in UK deep-waters is not currently addressed; therefore statutory obligations and CMOs are not being achieved at present.

Arrhis phyllonyx

Pressure = ?

Arrhis phyllonyx is a cold-water deep-sea amphipod (not shrimp, as detailed on the OSPAR matrix, this term is attributed only to decapod crustaceans) that has its southernmost distribution limit at the Orkney Isles in the NE Atlantic (Lincoln, 1979). This species is included in the UKs Biodiversity Action Plan (UKBAP), which was drafted in response to the Convention on Biological Diversity signed in 1992. Being at the limit of its distribution, making it liable to considerable physiological stress, *A. phyllonyx* is not a good indicator species for UK deep waters generally.

Cold seep/ pockmark location, biology and diversity

Pressure = Oil and gas industry, Demersal fishing (Smothering/sealing; contaminants)

There are few reports of chemosynthetic habitats (cold seeps and pockmarks) in UK deep waters (Bett, 2001; Colin Jacobs and Veerle Huvenne pers. comm.; Connor et al., 2006). These sites are potentially important because they have very distinct associated fauna (Hovland and Judd, 1988; Dando et al., 1991). Because little research has been carried out on chemosynthetic environments in UK deep waters, it is difficult to predict how they will be impacted by demersal fishing activity and the oil and gas industry (Rogers et al., 2008). A pockmark field has been highlighted in the SEA survey (Bett, 2001) and pockmark fields have been mapped in deep UK waters (Connor et al., 2006), but little is known about the associated biology. More research on these chemosynthetic habitats is required before efficient assessment and monitoring can be carried out in accordance with statutory obligations and contributory marine objectives.

PAP community change

Pressure = No specific or single impacting activity (Changes in species or community distribution, size/ extent or condition); Climate change

The Porcupine Abyssal Plain (PAP) is situated 270km southwest of Ireland (Figure 2) at a depth of c. 4850 m. The site has been studied since 1989, with the aim of determining how the seabed community and geochemistry of the sediments change in response to a highly seasonal input of organic matter from the overlying waters (Billett and Rice, 2001). The site was chosen for its distance from the continental slope and Mid-Atlantic Ridge, making it relatively free of any downslope sediment transport. Long-term change has been observed in the invertebrate megafauna at the PAP over a period of 10 years (Billett et al., 2001). This change has been termed the '*Amperima* Event', characterised by an increase in abundance of the holothurians *Amperima rosea*, and *Ellipinion molle* by more than two orders of magnitude (Billett et al., 2001). The community change seems to be linked to a change in the quality rather than the quality of the OM reaching the seafloor (Billett et al., 2001; Wigham et al., 2003). Recent studies have shown that changes in the resources available to the animals can influence their reproductive biochemistry, depending on the feeding mode and selectivity of the species (Neto et al., 2006; Smith et al., 2008).

Although the PAP is not located directly in UK waters, the time-series provides a unique data set on deep-sea community change in the NE Atlantic, which may help us to understand faunal shifts that occur directly in UK deep waters. The PAP time-series also helps to meet a statutory obligation and CMO that is not adequately covered by the other indicators suggested so far: 1) 40 - United Nations Framework Convention on Climate Change, 2) 8b – characterise ocean and atmospheric processes to contribute to the overall UK understanding of environmental interactions.

Identification of additional indicators needed to satisfactorily address key aspects of ecosystem structure and function, and identification of any critical gaps

The overarching critical gap in satisfactorily attempting to monitor key aspects of ecosystem structure and function is our lack of knowledge of deep-sea systems. While some of the indicators suggested can be used to address ecosystem structure, there are presently no indicators available to address the issue of ecosystem function directly. Ecosystem functioning involves a range of processes, which can be summarized as the production, consumption and transfer of organic matter to higher trophic levels, organic matter decomposition, and nutrient regeneration (e.g. Danovaro et al., 2008). This has been measured in terrestrial and shallow-water ecosystems by quantifying the rates of energy and material flow between biotic and abiotic compartments; for example, biomass production, organic matter decomposition, nutrient regeneration, or other measures of material production, transport or loss (Danovaro et al., 2008).

Although they lack photosynthetic primary production, deep-sea ecosystems can be highly dynamic. In the Northeast Atlantic (at the Porcupine Abyssal Plain) large fluxes of highly labile organic matter arrive at the seafloor following the spring phytoplankton bloom (Billett et al., 1983). Deep-sea ecosystems react rapidly and vigorously to this freshly deposited phytodetritus, and it has been linked to the seasonal variability in reproduction and recruitment in certain species, relatively rapid growth rates, and seasonal growth-banding in skeletal parts of deep-sea deposit-feeding invertebrates (Gage and Tyler, 1991; Tyler et al., 1992). Owing to the remote nature of the deep sea and the associated logistical constraints in sampling, the available data concerning the fate of phytodetritus (organic matter) pulses as well as its consumption and transfer between trophic levels are scattered and often contradictory, hampering global carbon modelling and anthropogenic impact assessments. While experimental procedures have examined the fate of phytodetritus at the seafloor (Witte et al., 2003), approaches such as this are expensive, and not suitable for use as routine indicators.

Within the deep sea, higher biodiversity appears to support higher rates of ecosystem processes and increases the efficiency of these processes (Danovaro et al., 2008). For example, higher benthic diversity may increase bioturbation, (with a consequent increase of benthic fluxes and redistribution of food) and promote higher rates of detritus processing, digestion and reworking (therefore increasing organic matter remineralisation). Anthropogenic effects which negatively impact biodiversity will therefore have a negative impact on ecosystem function. The indicators discussed in this review that monitor biodiversity may therefore act as proxies for ecosystem function, until further conclusive data on ecosystem processes in the deep sea (such as organic matter production, consumption and transfer) are available.

Ecological extinction caused by over fishing has been shown to precede all other pervasive human disturbance to marine ecosystems, and in coastal ecosystems this is thought to have led to profound structural and functional changes (Jackson et al., 2001). With the unregulated nature of fisheries in the deep-sea waters of the UK there is a clear danger that a similar situation may develop. While some indicators detailed in this review can be used to monitor ecosystem structure, no indicators can be suggested to satisfactorily address the issue of impacts on ecosystem function. Monitoring obvious impacts (e.g. destruction of *Lophelia* reefs) may overlook more subtle changes which may take place.

Review of Pressures vs. Indicators

Pressure (Impact)	**Indicators**	**Comments**
Fishing - demersal trawling (habitat structure changes – abrasion; removal of target species)	- reef extent and density - reef biology - extent and biology of carbonate mounds - Seamount diversity; evidence of destruction - Extent/ density/ biology of deep-sea sponge aggregation (hexactinellid and demosponge aggregations) - Extent and abundance of octocorals	The only protected habitats in UK deep water from demersal fishing are the *Darwin Mounds*, which are home to *Lophelia pertusa* bushes and their associated fauna. There are currently no regulations or monitoring programmes in place to assess and monitor demersal trawling in UK deep water habitats.
Oil and gas industry (habitat transformation by smothering or sealing)	- Community change around oil and gas industry drill sites - Cold seep/pockmark extent and biology - Extent/density/biology of deep-sea sponge aggregation (hexactinellid and demosponge aggregations)	Impact from the oil and gas industry will be localised around the drilling structure. Regulations are in place for initial environmental impact assessment, but little or no monitoring and assessment work is carried out during and after the impact. More research is required on the location/extent/biology of lesser known habitats (cold seeps/ pockmarks) and the resulting impact from the oil and gas industry
Oil and gas industry (contamination by hazardous substances)	- Community change around oil and gas industry drill sites - Bioaccumulation of contaminants - Molecular biomarkers - Oxidative stress biomarkers - Other biochemical and molecular biomarkers	Oil and gas industry regulations prohibit oil- or synthetic-based drillings muds. These have been replaced with water-based muds that are thought to disperse quickly, therefore being less toxic to the environment. Research is being undertaken to examine the toxicity of water-based mud on deep-water fauna.
Land-based pollution and shipping (physical disturbance)	- litter/ debris/ lost fishing gear abundance and distribution	No system is currently in place to monitor the extent and impact of litter/debris/lost fishing gear on the UK deep water habitat.
Climate Change (temperature/ water flow)	- Porcupine Abyssal Plain - Temperature - salinity - acidity	This set of indicators should be fully covered and critically reviewed by Theme 10, ocean processes. The impact of climate change on deep-sea organisms remains unknown

Land-based pollution (Contamination from hazardous substances – synthetic and non-synthetic compounds)	- Bioaccumulation of contaminants - Molecular biomarkers - Oxidative stress biomarkers - Other biochemical and molecular biomarkers	While bioaccumulation of land-based contaminants is known to occur in deep-sea fauna, the effects on the organisms are unknown. Biomarkers will help to determine the response and health of the sentinel organisms.
Land based pollution (contamination by hazardous substances - heavy metals)	- Bioaccumulation of contaminants - Other biochemical and molecular biomarkers (metallothioneins)	Bioaccumulation of heavy metals has been shown in deep-sea fauna, although the effects are unknown. Metallothioneins have been used as biomarkers of heavy metal exposure in shallow-water animals. This could be developed for monitoring deep-sea habitats.
Shipping (contamination by hazardous substances)	- Bioaccumulation of contaminants - Molecular biomarkers - Oxidative stress biomarkers - Other biochemical and molecular biomarkers	While bioaccumulation of shipping-based contaminants is known to occur in deep-sea fauna, the effects on the organisms are unknown. Biomarkers will help to determine the response and health of sentinel species.
No specific or single impacting activity (Changes in species or community distribution, size/ extent or condition)	- reef extent and density - reef biology - extent and biology of carbonate mounds - Seamount diversity; evidence of destruction - Extent/ density/ biology of deep-sea sponge aggregation (hexactinellid and demosponge aggregations) - Extent and abundance of octocorals - Porcupine Abyssal Plain (PAP) time series	To be able to cover comprehensively (using indicators) the impacts from non-specific pressure, all deep-sea habitats should be included in a regular assessment and monitoring programme. Baseline levels and natural fluctuations need to be understood and determined for monitoring programmes to be of value. The PAP time series is the only deep-sea time series station in the Atlantic and it offers the closest (to UK deep-water) and longest temporal data set on ecosystem change over time.

Evaluation of statutory obligations and contributory marine objectives against potential indictors for monitoring UK deep-sea habitats

<u>UK Statutory obligations </u>(listed in UNEP WCMC (2006) report)

1 - Conservation (Natural Habitats &c.) Regulations 1994 (Habitat Regulations- England & Wales Legislation; Northern Ireland 1995 No. 380)

<u>Indicators</u>
Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Reef biology; Carbonate mounds; Seamounts; Deep-sea demosponge and hexactinellid aggregations; Octocorals; Community change around oil and gas industry drill sites; Cold seep/ pockmark location, biology and diversity.

Containing five Parts and four Schedules, the Conservation Regulations provide for the designation and protection of 'European sites', the protection of 'European protected species', and the adaptation of planning and other controls for the protection of European Sites. The Regulations enable the country agencies to enter into management agreements on land within or adjacent to a European site, in order to secure its conservation. The objective of the regulations is to achieve favourable conservation status of habitats and species (UNEP WCMC, 2006). The only UK deep-water site that has conservation status is the *Darwin Mounds* region, which contains *Lophelia pertusa* bushes. The indicators not linked to *L. pertusa* listed above could be used as evidence to secure protection for additional corresponding habitats under this regulation.

5 - Environment Act 1995 (c. 25)

<u>Indicators</u>
Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Reef biology; Carbonate mounds; Seamounts; Deep-sea demosponge and hexactinellid aggregations; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Water quality; Bioaccumulation of contaminants; Community change around oil and gas industry drill sites; Molecular biomarkers; Oxidative stress biomarkers; Other biochemical and molecular biomarkers; Litter - abundance and distribution; Cold seep/ pockmark location, biology and diversity; Porcupine Abyssal Plain time series.

The Environment Act 1995 requires relevant authorities to have regard for nature conservation, with the aim to protect, manage and conserve the environment (UNEP WCMC, 2006). This is not currently being fulfilled with regard to UK deep-sea habitats, with the exception of the *Darwin Mounds* region, as previously discussed. The indicators of habitat extent and biology, and community change (listed above) could be used in monitoring programmes aimed to protect, manage and conserve deep-sea habitats around the UK. Biomarker indicators (molecular oxidative stress), have the potential to be used to monitor the health of species, but these indicators are currently under development.

7 - UK Biodiversity Action Plan (BAP) 2002

Indicators

Reef biology; Carbonate mounds; Seamounts; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Community change around oil and gas industry drill sites; Cold seep/ pockmark location, biology and diversity

The UK BAP aims to conserve the UKs biodiversity through action plans to halt biodiversity decline by 2010 (UNEP WCMC, 2006). The 2007 BAP list includes deep-water habitats described by OSPAR. The indicators listed can be used to monitor biodiversity levels in particular habitats. Little or nothing is currently known about UK deep-water habitats although impacts from human activities are already evident (Bett, 2000; Wheeler et al., 2004; Jones et al., 2006; e.g. Clark and Koslow, 2007; Davis et al., 2007; Jones et al., 2007). Further research into their biology and ecology is urgently required for the implementation of effective assessment and monitoring programmes to help achieve the UK BAP objective.

9 - Nature Conservation (Scotland) Act 2004

Indicators

Reef biology; Carbonate mounds; Seamounts; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Community change around oil and gas industry drill sites; Cold seep/ pockmark location, biology and diversity

The Nature Conservation (Scotland) Act aims to protect and enhance Scottish biodiversity (UNEP WCMC, 2006). The majority of UK deep-water habitats are included in the Scottish sea area. Little or nothing is currently known about these deep-sea habitats and they have already been impacted by human activities (Bett, 2000; Wheeler et al., 2004; Jones et al., 2006; e.g. Clark and Koslow, 2007; Davis et al., 2007; Jones et al., 2007). The indicators listed could be used to monitor biodiversity levels and allow compliance with this act.

Regional Statutory Obligations (listed in UNEP WCMC (2006) report)

10 - Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (the "Habitats Directive")

Indicators

Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Reef biology; Carbonate mounds; Seamounts; Cold seep/ pockmark location, biology and diversity.

The Habitats Directive aims to maintain or restore natural habitats and wild species to favourable conservation status, and introduce robust protection for those habitats and species of European Importance which are listed in its Annexes (UNEP WCMC, 2006). Annex I (list of habitats included in the directive) includes habitats in UK deep water (e.g. reefs, submarine structures made by leaking gases). Seven new offshore SACs have been proposed and are under consultation (David Connor Pers. Comm). In respect to UK deep-water habitats, this Directive is not currently being fulfilled. There is a paucity of information on these habitats, although there is evidence of impacts from human activities (Bett, 2000; Wheeler et al., 2004; Jones et al., 2006; e.g. Clark and Koslow, 2007; Davis et al., 2007; Jones et al., 2007). The effective indicators listed above could be used to assess and monitor deep-sea habitats covered by the Directive. Baseline levels need to be determined to implement effective monitoring programmes before further impact from human activity occurs.

11 - Council Directive on the assessment of the effects of certain public and private projects on the environment 85/337/EEC (the "EIA Directive")

Indicators
Community change around oil and gas industry drill sites; Cold seep/ pockmark location, biology and diversity

This Directive aims to undertake environmental assessment of plans and projects (UNEP WCMC, 2006). This includes oil and gas drilling and exploration, and demersal fishing activity. Impacts to the environment by the oil and gas industry are not regularly monitored. Environmental surveys are carried out by the oil and gas Industry, but these may be insufficient to assess the full extent of their environmental impacts. Therefore, the aims of this Directive are at present only partially fulfilled. The indicators listed above could be used to provide environmental assessment of plans and projects that may affect deep-sea habitats.

12 – Strategic Environment Assessment (SEA) Directive 2001/42/EC

Indicators
Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Reef biology; Carbonate mounds; Seamounts; Deep-sea demosponge and hexactinellid aggregations; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Water quality; Bioaccumulation of contaminants; Community change around oil and gas industry drill sites; Molecular biomarkers; Oxidative stress biomarkers; Other biochemical and molecular biomarkers; Cold seep/ pockmark location, biology and diversity.

The aim of the Strategic Environmental Assessment Directive is to protect the environment from adverse effects of construction and development, and to monitor adverse and beneficial environmental effects (UNEP WCMC, 2006). There are some regulations in place for the oil and gas industry to provide environmental impact assessments for work carried out in the UK deep waters. This has been augmented by the SEA surveys (Figure 2), which documented various deep-sea habitats northwest of the UK. While the SEA surveys mapped the occurrence of different deep-sea habitats, detailed surveys of the biology within each specific habitat (e.g. deep-sea sponge aggregations) were not made. The indicators listed can be used to facilitate the environmental impact assessment process and fill in knowledge gaps. The list of indicators includes biomarkers/biomonitors for impacts not currently monitored (e.g. contamination through hazardous substances) that need to be addressed to fulfil the SEA Directive obligations. These indicators are still under development.

18 - Urban Waste Water Directive 91/271/EEC 1991

Indicators
Water quality; Bioaccumulation of contaminants; Molecular biomarkers; Oxidative stress biomarkers; Other biochemical and molecular biomarkers.

The principle aim of the Directive is to protect the environment from adverse effects of sewerage discharges (UNEP WCMC, 2006). This Directive is best addressed by inshore monitoring, although impacts have been recorded in deep-sea habitats. No large sewage outfalls directly discharge into the deep sea, however, contaminants, possibly originating from sewage outfalls, have been found in deep-sea organisms (Lee et al., 1997; Moore et al., 1997; Takahashi et al., 1997; De Brito et al., 2002; Harino et al., 2005; Svendsen et al., 2007). Canyons can act as a fast-track contaminant route to deep-sea environments and this would be of particular importance SW of the UK (Weaver and Masson, 2007). Bioaccumulation levels of contaminants could be used to measure exposure, although the effects of bioaccumulation in deep-sea organisms are unknown. The biomarker indicators have good potential for monitoring adverse effects from contaminants, but they are currently under development.

19 – Common Fisheries Policy (CFP) (1983)

Indicators
Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Reef biology; Carbonate mounds; Seamounts; Deep-sea demosponge and hexactinellid aggregations; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Cold seep/ pockmark location, biology and diversity.

The persistence of trawling damage in the deep sea (Bett, 2000; Wheeler et al., 2004; Gage et al., 2005) coupled with low recovery rates makes the deep sea highly susceptible to demersal fishing. The CFP aims to manage living and aquatic resources to provide sustainable economic, environmental and social conditions (UNEP WCMC, 2006). It is likely that in its current form, deep-sea fishing is unsustainable (Davis et al., 2007). Trawling damage to different deep-sea habitats has already been revealed in UK waters (Bett, 2000; Hall-Spencer et al., 2002; Wheeler et al., 2004; Clark et al., 2006; Davis et al., 2007). The long-term effects on deep-sea organisms other than corals is unknown (Gage et al., 2005). The obligations of the CFP regarding the sustainable management of the ecosystem are not currently being fulfilled. More research is required on the effects of the impact of demersal fishing in the deep sea.

Implementing the use of the indicators listed will enable the monitoring and assessment of the impacts of demersal trawling on deep-sea habitats.

20 - The protection of deepwater coral reefs from the effects of trawling (in an area north west of Scotland) EC Council Regulation (2003)

Indicators
Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Reef biology.

This EC Council Regulation prohibits the use of bottom trawl or other towed gear that contacts the sea bottom by vessels and protects deepwater coral reefs from the effects of trawling in an area (*Darwin Mounds*) north west of Scotland (UNEP WCMC, 2006). The indicators listed above need to be integrated into a monitoring programme that will determine impacts on the deep-water coral reef in this protected area. The Vessel Monitoring System (VMS – satellite tracking) can also be used as a tool for policing this deep-water protected area (Davis et al., 2007; Moore et al., 2007)

27 - North East Atlantic Fisheries Commission Convention (1982)

Indicators
Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Reef biology; Carbonate mounds; Seamounts.

The North East Atlantic Fisheries Commission have recently (9th January, 2008) prohibited bottom trawling and fishing with static gear from a number of large areas in the Rockall and Hatton banks (www.neafc.org), with the aim to protect deep-water corals. The Vessel Monitoring System (VMS, satellite tracking) could be used as a tool for policing these deep-water protected areas (Davis et al., 2007; Moore et al., 2007). When the VMS highlights there may have been a threat from fishing activity, the indicators listed above could be used to assess and monitor the impacts.

28 - OSPAR Biological Diversity and Ecosystems Strategy (2003)

Indicators
Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Reef biology; Carbonate mounds; Seamounts; Deep-sea demosponge and hexactinellid aggregations; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Community change around oil and gas industry drill sites; Litter - abundance and distribution; Cold seep/ pockmark location, biology and diversity.

The OSPAR Biological Diversity and Ecosystems Strategy was set up with the aim of protecting and conserving the ecosystems and biodiversity of the North East Atlantic from the impacts of all human activities, except pollution (UNEP WCMC, 2006). Many different deep-sea habitats exist in deep UK waters and the OSPAR list includes a number of deep-water habitats for which general actions and measurements are being developed. In addition, OSPAR is developing the designation of OSPAR MPAs and the code of conduct for deep-sea research. The indicators listed above could be used in a programme to assess and monitor human impacts on the habitats included on the OSPAR list, and be used to ensure the protection and conservation status is effective.

Global (as listed in UNEP WCMC (2006) report)

31 - Convention on Biological Diversity (CBD) (1992)

Indicators

Reef biology; Carbonate mounds; Seamounts; Deep-sea sponge aggregations (sponges and surrounding benthos); Octocorals; Community change around oil and gas industry drill sites; Cold seep/ pockmark location, biology and diversity.

The CBD (1992) was set up with the aim of achieving a significant reduction in the current rate of biodiversity loss by 2010 at the global, regional and national level to benefit all life on Earth (UNEP WCMC, 2006). UK deep-sea habitats are currently not regularly monitored; therefore there is a paucity of information on the biodiversity of these ecosystems. The implementation of routine monitoring using indicators listed above could be used to monitor changes in biodiversity in the variety of deep-sea habitats found in UK waters. These indicators would be used to highlight biodiversity impacts through pressures such as demersal fishing and oil and gas industry drilling activities.

32 - Convention on Biological Diversity - CBD - Jakarta Mandate (adopted in 1995, 1998 and updated in 2004)

Indicators

Reef biology; Carbonate mounds; Seamounts; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Community change around oil and gas industry drill sites; Cold seep/ pockmark location, biology and diversity.

The CBD - Jakarta Mandate was initiated to promote the conservation and sustainable use of marine and coastal biodiversity. It requires countries to develop and implement strategies for sustainable use and protection of biodiversity (UNEP WCMC, 2006). While the oil and gas industry are required to carry out limited environmental surveys, there are no regulations to minimise the impacts of demersal trawling on the deep-sea habitats in UK waters. The indicators listed could be used to assess and monitor UK deep-sea habitats to ensure the obligations of the CBD are being fulfilled.

34 - FAO Code of Conduct for Responsible Fisheries (1995)

Indicators

Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Reef biology; Carbonate mounds; Seamounts; Deep-sea demosponge and hexactinellid aggregations; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Cold seep/ pockmark location, biology and diversity

In the deep sea, the UK is not currently meeting the obligations of the FAO Code of Conduct for responsible Fisheries, which aims to 'conserve, manage and develop living aquatic resources, with due respect for the ecosystem and biodiversity' (UNEP WCMC, 2006). With the exception of the *Darwin Mounds* region, the UK deep-water habitat is unprotected from demersal fishing activity. Trawling damage to different deep-sea habitats has already been revealed in UK waters (Bett, 2000; Hall-Spencer et al., 2002; Wheeler et al., 2004; Clark et al., 2006; Davis et al., 2007). The indicators listed above would enable the monitoring and assessment of demersal fishing activity on the range of deep-sea habitats found in UK waters that may be susceptible to such activity.

40 - United Nations Framework Convention on Climate Change (UNFCCC) (1994)

Indicators

Porcupine Abyssal Plain time-series site

The UNFCCC aims to tackle the challenge posed by climate change. All parties signed up to the Framework agree to 'promote and cooperate in systematic observation and development of data archives related to the climate system' (UNEP WCMC, 2006). The Porcupine Abyssal Plain time-series site fits into this framework by providing a unique time-series dataset of community change in the deep sea adjacent to UK waters. The continuation of this time-series station will help the UK to fulfill the obligations of the UNFCCC. Ocean processes (temperature, pH, currents etc.) will be covered by the 'Theme 10 - Ocean Processes' review.

42 – World Summit on Sustainable Development 2002 (WSSD)

Indicators

Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Reef biology; Carbonate mounds; Seamounts; Deep-sea demosponge and hexactinellid aggregations; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Cold seep/ pockmark location, biology and diversity.

The WSSD plan of implementation aims to decrease declines in biodiversity by 2010 and establish protected marine areas by 2012 (UNEP WCMC, 2006). UK deep-sea habitats are currently not regularly monitored; therefore there is a paucity of information on how to assess if there is a decline in the biodiversity of these ecosystems. The implementation of the indicators listed above will enhance our knowledge of biodiversity in the variety of deep-sea habitats found in UK waters. The indicators can then be used to monitor changes in biodiversity at these sites.

Contributory Marine Objectives (listed in the development of CMOs report (2007))

Theme A – Human use

1a - Achieve and maintain the sustainable and productive use of biological resources which maximise socio-economic benefits whilst minimising the unsustainable negative impacts on habitats and species.

Indicators

Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Reef biology; Carbonate mounds; Seamounts; Deep-sea demosponge and hexactinellid aggregations; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Cold seep/ pockmark location, biology and diversity.

It is not clear what may be considered a sustainable or unsustainable negative impact in relation to deep-sea benthic ecosystems. When the impact leads to loss of a slow-growing species with restricted distribution, such as *Lophelia*, even low levels of impact may be considered unsustainable. The potential environmental impacts of 'low level' biodiversity loss, however, are impossible to assess.

Demersal fish stocks are a biological resource in the UK deep-waters that may be covered by CMO 1a. In addition, biodiversity could be a potential biological resource – deep-sea species (e.g. sponges) are increasingly being used to extract novel pharmaceuticals. Deep-sea fisheries concentrate on productive areas, such as seamounts and canyon walls. These are areas where levels of biodiversity of the benthos are high (De Forges et al., 2000), so fishing activities cause considerable 'collateral damage' to the benthic ecosystem by physically destroying habitat and removing key species (Roberts, 2002). In particular, trawling eliminates the larger, sessile organisms such as corals and sponges that create the spatial and structural habitat favoured by the commercially important fish and their prey (Tissot et al., 2004) and form micro-habitats for smaller benthic species. Intense fishing activity means that the same area of the seafloor may be trawled repeatedly, causing long-term damage to coral communities by preventing recovery or recolonisation (Clark et al., 2006). The long-term effects on marine organisms other than corals are largely unknown (Gage et al., 2005), which makes it unclear how these impacts might influence the long-term sustainability of the functioning of these deep-sea communities. Nevertheless, it is likely that in its current, largely unregulated form, deep-sea fishing is unsustainable (Davis et al., 2007).

It is clear that deep-sea habitats in the UK have already been impacted through human activities (Bett, 2000; Hall-Spencer et al., 2002; Wheeler et al., 2004; Clark et al., 2006; Davis et al., 2007). With the exception of the *Darwin Mounds* region, demersal trawling remains largely unregulated in UK deep-waters, and no regular monitoring procedures are in place. Although as part of phase 1 of DCUK (Deep-sea Conservation, UK), Vessel Monitoring System (VMS, satellite tracking) data collected by the Scottish Executive from 2000-2003 was analysed and promoted as a tool for policing deep-water protected areas around the UK (i.e. the *Darwin Mounds*) (Davis et al., 2007; Moore et al., 2007).

The objectives of CMO 1a are not currently being achieved in relation to deep-water habitats. The indicators listed could be used to monitor and assess the UK deep-sea habitats that may be particularly susceptible to impacts from demersal fishing. Commercially important deep-sea fish species are associated with, and can aggregate around, some of the habitats containing key structural biota (e.g. corals and sponges) that can be impacted by the trawling. It would not appear to make economic sense to prohibit fishing in areas that are already impacted; rather, the protection should cover 'pristine' areas (located by predictive modelling and surveys). Preserving the integrity of these habitats will help achieve and maintain the sustainable and productive use of the biological resources.

3a - Achieve and maintain the productive use of the marine environment by extractive industries to meet national needs for the security of energy supply and a built environment whilst preventing unsustainable negative impacts on habitats and species

Indicators
Water quality; Bioaccumulation of contaminants; Community change around oil and gas industry drill sites; Molecular biomarkers; Oxidative stress biomarkers; Other biochemical and molecular biomarkers

Oil and gas exploration and activity are moving further into UK deep waters, with a potential impact on the biological communities in these areas. The environmental impact of oil and gas exploration is well documented in shallow UK waters (e.g. North Sea), but the impact in deeper waters is poorly known (Jones et al., 2006; Jones et al., 2007). The principal environmental impact through the oil and gas Industry activity is through the discharge of drill cuttings onto the seafloor from the top of the bore-hole, which impacts through smothering and sealing. At present, the oil and gas industry are required to carry out baseline environmental surveys, as part of initial Environmental Impact Assessments. This does not have to be carried out if sufficient environmental data already exists for the area (e.g. SEA surveys commissioned by BERR). Still, little is known about the biology, diversity and ecosystem functioning of many of these habitats, so it is difficult or impossible to predict the sustainability of these to the impact of drilling activity. It is possible that drill cuttings will pose a greater local environmental hazard in the deep sea than in shallow water because recovery rates may be lower (Glover and Smith, 2003).

Following the start of production, there is no requirement to perform environmental monitoring, although some operators do so. There is clear evidence that the activities of the oil and gas industry have negative impacts, although these tend to be very localised (Olsgard and Gray, 1995; Jones et al., 2006; Mojtahid et al., 2006; Jones et al., 2007; Gates and Pullen, 2008). Community change around drilling structures can be used to monitor the impact of drill cuttings discharged to the benthos. Such work has shown that sessile organisms are impacted heavily by smothering and sealing (Jones et al., 2006; Jones et al., 2007). The re-establishment of communities after cessation of drill cuttings disposal is still largely unknown as is the impact of chemical contamination in deep-sea organisms. The lack of knowledge on the recovery of deep-sea habitats in UK waters also makes it difficult to predict the sustainability of the ecosystem to drilling activity.

The principal indicator currently utilised is the change in macrofaunal community structure around a drill site; it is the most effective indicator at present to monitor impacts during and after drilling activity (Jones et al., 2006; Jones et al., 2007; Gates and Pullen, 2008). Chemical contamination biomarker indicators are under development (Sarah Murty, pers. comm.; Camus et al., 2006). Further research into the effects of drilling activity on the sustainability of the surrounding habitat (e.g. effect of the extent of disturbance on community recovery and the recovery rate) needs to be implemented before CMO 3a is achieved.

4a - Achieve and maintain the sustainable and productive use of the marine environment with respect to the provision of goods & services to meet national needs

Indicators
Bioaccumulation of contaminants; Molecular biomarkers; Oxidative stress biomarkers; Other biochemical and molecular biomarkers

The anthropogenic pressures relevant to, and that can have impacts on, deep-sea habitats as listed in CMO 4a are transport (shipping) and disposal. At present, the UK deep sea is not used for routine disposal purposes. The full environmental impact of any future disposal proposals (including those linked to carbon sequestration) would have to be considered individually on a case by case basis. This is beyond the scope of this review.

The potential impact of shipping on UK deep-sea habitats is that of contamination from persistent polluting compounds such as hydrocarbons and organotins (e.g. TBT, used in antifouling paint). While deep-sea animals have been shown to bioaccumulate some of these compounds (Moore et al., 1997; Takahashi et al., 1997; Roberts et al., 2000; De Brito et al., 2002; Harino et al., 2005), the effects on the animals, and therefore the sustainability, is unknown. To minimise adverse impacts on the deep-sea habitat, release of these compounds should be limited or prohibited. If the release of these compounds were to persist, to achieve CMO 4a, time-consuming and costly monitoring of the bioaccumulation of these compounds in the deep-sea environment and the effects this has on the health of the animal (through biomarkers or *in situ* experimentation) needs to be undertaken.

Theme B - Healthy functioning ecosystems

1b - Support, and where appropriate restore, the distribution, extent and character of marine 'landscapes' and habitats.

Indicators
Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Seamounts; Deep-sea demosponge (reef/ rocky substrata) and hexactinellid (open

sediment) aggregations; carbonate mounds; Octocorals; Community change around Oil and Gas Industry drill sites; Cold seep/ pockmark location, biology and diversity.

The distribution, extent and character of deep UK habitats have been most extensively mapped by the SEA surveys commissioned by BERR (Bett, 2001; Davies et al., 2006). In relation to the UK deep-sea habitats, CMO 1b is particularly relevant to demersal fishing and oil and gas exploration, which impact the physical environment. The oil and gas industry is required to carry out baseline environmental surveys before drilling activity, and the impact of such activity is localised. With the exception of the *Darwin Mounds* region, demersal trawling activity is not regulated or monitored and its impact is widely observed in UK deep-water habitats (Bett, 2000; Hall-Spencer et al., 2002; Wheeler et al., 2004; Clark et al., 2006; Davis et al., 2007).

The initial draft of CMO 1b aimed to 'ensure the *natural* distribution, extent and character of marine landscapes and habitats are maintained', which did not allow for any room for human activities that have an impact on biodiversity i.e. demersal fishing, because 'natural' was equivalent to 'pristine' (ECG Chairs, 2007). To support the distribution, extent and character of UK deep-sea habitats the current extent of the impact through fishing activity needs to be quantified. Fishing activity may then be confined to areas that have already been impacted. The indicators listed above could be used initially to map the extent of the current impact (coupled with the potential use of VMS; Davis et al., 2007) and then used to assess and monitor demersal fishing and oil and gas drilling activity in UK deep waters in support of the distribution, extent and character of the deep-sea habitats.

2b - Support, and where appropriate restore, biodiversity and ecological patterns and processes

<u>Indicators</u>
Reef biology; Carbonate mounds; Seamounts; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Community change around oil and gas industry drill sites; Cold seep/ pockmark location, biology and diversity.

As deep-water biodiversity is poorly understood, it is not clear to what extent biodiversity change is taking place. Furthermore, little is known about the ecological patterns and processes in this environment. With regard to impacts caused by anthropogenic pressures, the most studied habitats in UK deep-waters are those associated with deep-water corals. The main pressure affecting these habitats is demersal trawling, which negatively impacts biodiversity and ecological patterns and processes, by the removal of the coral as unwanted by-catch (Hall-Spencer et al., 2002; Clark et al., 2006; Davis et al., 2007). The impact of trawling on other deep-sea benthic communities on the Atlantic Margin is also widespread (Bett, 2001), but its effects remain a matter of speculation (Hughes et al., 2003). There are likely to be direct and indirect effects on the infaunal macrobenthos in the trawl path. By reducing the epifauna, the macrobenthos may be indirectly affected through removal of habitat (e.g. sponges), the reduction of other biological interactions and the reduction of habitat heterogeneity generally. Direct impacts on the infauna is likely via the ploughing action of the trawl gear on the seafloor (Hughes et al., 2003). Oil and gas drilling activity also affects biodiversity and ecological patterns and processes, but its impacts are localised around the drilling structure. The longevity of this impact is unknown in deep waters. The relative areas of the impact of drilling sites and deep-water trawling are very different. One trawler performing 4-6 trawls a day at 3-4 knots for fours hours will cover an area of 10 km^2 a day (Merrett and Haedrich, 1997); one oil and gas drilling installation impacts an approximate area of 0.1 km^2 through the deposition of drill spoil on the seafloor (Jones et al., 2006).

The indicators listed can be used to assess and monitor the biodiversity of the UK deep-water habitats against the pressures that may impact them (Table 1). The lack of knowledge concerning deep-sea habitats coupled with the indirect effects some pressures may have on biodiversity (e.g. persistent contaminant compounds, climate change) also make it difficult to satisfactorily address CMO 2b. Given the remote and complex nature of the UK deep-water areas, restoring biodiversity, ecological patterns and processes following potential impacts may not be feasible. Deep-sea observatories (e.g. planned ESONET observatories around Europe) could provide means of monitoring remote deep-sea sites. Emphasis should therefore be made on supporting the preservation of biodiversity and ecosystem function.

3b - Prevent those anthropogenic activities which affect the physical and hydrographical conditions in the marine environment from negatively impacting on ecosystem integrity and viability in an unsustainable manner.

<u>Indicators</u>
Reef extent and density notable species - *Lophelia pertusa* and *Madrepora oculata*; Reef biology; Carbonate mounds; Seamounts; Deep-sea sponge (demosponge (reef/ rocky substrata) and hexactinellid (open sediment)) aggregations; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Community change around oil and gas industry drill sites; Cold seep/ pockmark location, biology and diversity.

Anthropogenic activities known to affect physical conditions in the UK deep-sea environment are demersal fishing and the drilling activity of the oil and gas industry. It is not viable to prevent or prohibit these activities (CMOs 1a and 3a, aim to achieve or maintain the maximum benefits of these activities, whilst minimising unsustainable impacts on species and habitats), however, their activities could be regulated (or regulated further in the case of the oil and gas industry) so that further unsustainable negative impacts are reduced. Limited regulations are in place for the oil and gas industry to carry out environmental impact surveys, but no regulations on demersal fishing are in place. The indicators listed could be used to assess and monitor the affects of these anthropogenic pressures on the variety of UK deep-sea habitats that are susceptible to impacts from these pressures. The oil and gas industry structures may have a small-scale effect on currents. However, it is unlikely, overall this will negatively impact deep-sea ecosystems, indeed, they may locally enhance biodiversity; for example, *Lophelia* has been reported growing on active oil platforms and on the decommissioned Brent Spar platform (Bell and Smith, 1999).

Climate change may also affect the physical and hydrographical conditions of UK deep-water habitats. Hydrographical impacts will be covered by the 'Theme 10 – Ocean Processes' review. Physical changes may be highlighted by the indicators listed above (extent of features), although such changes may initially be very subtle e.g. ocean acidification affecting deep-water coral skeletal structure.

4b - Prevent those anthropogenic activities affecting the chemical and biological characteristics of the marine environment from negatively impacting ecosystem processes, and the range, distribution, diversity and health of species and communities in an unsustainable manner

Indicators

Reef extent and density; notable species, *Lophelia pertusa* and *Madrepora oculata*; Reef biology; Carbonate mounds; Seamounts; Deep-sea demosponge and hexactinellid aggregations; Deep-sea sponge aggregations biology - sponges and surrounding benthos; Octocorals; Water quality; Bioaccumulation of contaminants; Community change around oil and gas industry drill sites; Molecular biomarkers; Oxidative stress biomarkers; Other biochemical and molecular biomarkers; Cold seep/ pockmark location, biology and diversity.

The anthropogenic pressures on the UK deep-water environment relating to CMO 4b are wide-ranging. These pressures, which can affect the chemical and biological characteristics of the deep-sea marine environment, include oil and gas drilling activity, demersal fishing, land-based pollution, greenhouse gas emissions (climate change), and shipping (persistent contaminating compounds and hydrocarbon release/spillage). The most comprehensive studies of the range, distribution, diversity and health of UK deep-sea species and communities are those carried out as part of the BERR SEA surveys (initiated by Atlantic Frontier Environmental Network) (Bett, 2001; Davies et al., 2006). Levels of chemical contaminants in the sediments were also taken during the SEA surveys.

The range and distribution of habitats could be mapped and subsequently monitored against pressures using existing data (SEA surveys) and some of the relevant indicators listed. Little is known about the ecological processes of deep-sea habitats, which prohibits the inclusion of indicators that can highlight or warn of negative impacts on these processes. Likewise, the diversity of species and communities are also poorly understood in the deep-water habitats around the UK; new species are routinely encountered and often species remain unnamed. Some habitats (e.g. deep-water corals) are more understood than others (e.g. pockmark communities), but this should not be taken as a reflection of the habitats importance. Indicators listed relating to the biology of the habitat could be used to monitor their biodiversity, but a better understanding of these habitats is required for the indicators to be of value. Only recently, have methods to monitor the health of deep-sea species and communities (molecular and biochemical biomarkers) begun to be developed. Presently, the most relevant indicator to monitor health is through community change, although the primary disadvantage is that communities may respond slowly to disturbance, so that by the time community change is detected, it is already too late to prevent the impact.

5b - Prevent anthropogenic inputs of contaminants from reaching concentrations in the marine environment that present a significant risk to marine habitats and species.

<u>Indicators</u>
Water quality; Bioaccumulation of contaminants; Community change around oil and gas industry drill sites; Molecular biomarkers; Oxidative stress biomarkers; Other biochemical and molecular biomarkers.

Land-based and shipping contaminants (e.g. persistent compounds, heavy metals and hydrocarbons) can reach the deep sea and are bioaccumulated in deep-sea organisms (Lee et al., 1997; Moore et al., 1997; Takahashi et al., 1997; De Brito et al., 2002; Harino et al., 2005; Svendsen et al., 2007). However, the effects of such bioaccumulation on deep-sea species, and the community as a whole, remain unknown. Therefore, threshold contaminant levels (above which significant risks occur) cannot be suggested as indicators to monitor and assess contaminant risks to the deep-sea environment. Contaminants released by oil and gas industry activity are thought to produce only localised effects, with water-based drill muds being quickly diluted and dispersed. However, no studies on the effects of such contaminants have been undertaken on deep-sea organisms. Research into molecular and biochemical biomarkers of contaminant exposure are under development. In the future, these may provide potential indicators of contaminant exposure and species health. Community change is currently the best indicator of contaminant exposure in deep-sea organisms. It may also be difficult to ascribe community change solely to contaminant exposure; other factors, such as physical disturbance, may also contribute to the effects.

7b - Prevent anthropogenic sourced litter from reaching levels which present a significant negative impact to marine habitats and species.

<u>Indicator</u>
Litter - abundance and distribution

Accumulation of litter and debris in the deep sea is not currently monitored or quantified. Quantification of litter/debris levels can be included in deep-sea habitat monitoring programmes. The effects of anthropogenic sourced litter on deep-sea biota are largely unknown, because there is no research on the effects of such debris on the deep-sea environment. No indicators (i.e. given levels of anthropogenic sourced litter) are in use to indicate whether negative impacts to deep-sea marine habitats and species are occurring.

8b - Characterise ocean and atmospheric processes to contribute to the overall UK understanding of environmental interactions

Indicator
Porcupine Abyssal Plain time-series site.

As it covers the largest area of any ecosystem on Earth, the deep sea plays an important role in biogeochemical cycling; although quantitative data on this is scarce. The on-going bentho-pelagic coupling time-series research at the Porcupine Abyssal Plain (PAP) site makes it the only current indicator that has the capacity to be used to address CMO 8b. The time-series was set up with the aim to determine how the seabed community and geochemistry of the sediments change in response to a highly seasonal input of organic matter (OM) from the overlying waters (Billett and Rice, 2001). The seasonal input of OM has been shown to vary in quantity (Lampitt et al., 2001) and composition, both of which can affect the biochemistry of the benthic fauna (Neto et al., 2006; Smith, 2008; Smith et al., 2008). However, the change in community structure observed at the PAP appears to be linked to a change in the quality rather than the quality of the OM reaching the seafloor (Billett et al., 2001; Wigham et al., 2003; Smith et al., 2008). Further research will help to link changes in the phytoplankton community in the upper ocean (which have been shown to be influenced by climatic change; Richardson and Schoeman, 2004) to changes in the quantity and composition of the OM flux and the affect this has on the deep-sea community.

Statutory obligations and CMOs not covered by the current set of indicators

Statutory obligations and CMOs listed here are not relevant to the UK deep-sea habitat.

UK Statutory obligations

2	Food and Environment Protection Act 1985 (FEPA)
3	Conservation of Seals Act 1970
4	Countryside & Rights of Way Act (CROW) 2000
6	Sea Fisheries (Wildlife Conservation) Act 1992
8	Wildlife and Countryside Act (1981)

Regional Statutory obligations

13	Water Framework Directive (WFD) Directive 2000/60/EC
14	Council Directive 79/409/EEC on the conservation of wild birds (the "Birds Directive")
15	Environmental Liability Directive (2004/35/CE)
16	Shellfish Hygiene Directive (EC2073/2005; EC2074/2005 and regulations EC853/2004; EC854/2004)
17	Shellfish Waters Directive 79/923/EEC 1979
21	Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA) (1995)
22	Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (New York, 1992) (ASCOBANS)
23	Bergen Declaration: Ministerial Declaration of the FifthInternational Conference on theProtection of the North sea (2002)
24	Bern Convention for the Conservation of European wildlife and natural habitats (1982)
25	Convention for the Conservation of Salmon in the North Atlantic Ocean (TIAS 10789), 1982
26	International Convention for the Conservation of Atlantic Tunas (1966)
28	OSPAR Eutrophication Strategy (1997)

Global Statutory obligations

30	Agreement on the Conservation of Albatrosses and Petrels (ACAP) (2004)
33	Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (1975)
35	International Convention for the Regulation of Whaling (1946)
36	International Plan of Action for Reducing Incidental catch of Seabirds in Longline Fisheries (1998)
37	International Plan of Action for the Conservation and Management of Sharks (1999)
38	The Convention on Wetlands of International Importance especially as Waterfowl Habitat (The Ramsar Convention) (1971)
39	United Nations Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks (2001)

41	World Heritage Convention (1972)

CMOs Theme A – Human use

2a	Achieve and maintain the sustainable and productive use of renewable energy to meet EU and UK needs.
5a	Prevent contaminants, toxins, and microbiological and radioactive contamination of seafood from reaching concentrations that present a significant risk to human health.
6a	Prevent contaminants, toxins, and microbiological and radioactive contamination of marine and coastal ecosystems from reaching concentrations that present a significant risk to human health.
7a	Prevent anthropogenic sourced litter from reaching levels which affect amenity (aesthetics & safety) value of the marine environment.

CMO Theme B - Healthy functioning ecosystems

6b	Minimise ‘undesirable disturbance’ in the marine environment arising from eutrophication.

CMOs Theme C - Optimising economic returns and Infrastructure

1c	Promote and maintain sustainable and viable maritime industries.
2c	Promote efficient access to, and use of marine data and information.
3c	Achieve and maintain fit-for-purpose regulatory regime with demonstrable environmental benefits whilst reducing administrative and financial burdens.
4c	Maintain an effective evidence base for decision making in the marine environment.
5c	Maintain the ability to identify and respond to current and future pressures of climate change on the marine environment

CMOs Theme D - Social integration

1d	Provide and maintain adequate opportunities for stakeholder engagement and participation in the decision making process.
2d	Provide and maintain effective communication, education, and knowledge transfer with respect to marine issues.
3d	Reduce social exclusion and promote social cohesion in coastal communities.
4d	Promote and support dynamic and sustainable coastal economies.

CMOs Theme E – Operational and decision support

1e	Protecting life and property on the coast
2e	Protecting life and property at sea
3e	Predicting health risks

4e	Responding to natural disasters
5e	Responding to man made disasters
6e	Improved weather forecasting
7e	Improved climate projection
8e	Management of energy resources
9e	Ensuring maritime security

Glossary

Keystone species – a species that has a disproportionate effect on its environment relative to its abundance; an ecosystem may experience a dramatic shift if a keystone species is removed.

Sentinel species – serve as proxies for ecosystem health

Glossary of acronyms

BDC (OSPAR Commissions) Biodiversity Committee
BERR Department for Business, Enterprise and Regulatory Reform
CMO Contributory Marine Objective
CSSEG Clean and Safe Seas
Defra Department for Environment, Food and Rural Affairs
EcoQOs Ecological Quality Objectives
ESONET European Sea Floor Observatory Network
HBDSEG Healthy and Biologically Diverse Seas Evidence Group
ICES International Council for Exploration of the Sea
MAPC Marine Assessment Policy Committee (MAPC)
MARG Marine Assessment and Reporting Group (MARG)
MPA Marine Protected Areas
MSD Marine Strategy Directive
OSPAR Convention Oslo Paris Convention
ROV Remotely Operated Vehicle
SAC Special Area of Conservation
SEA Strategic Environmental Assessment
TOBI deep-towed sidescan sonar
UKMMAS UK Marine Monitoring and Assessment Strategy
UNEP WCMC United Nations Environment Programme World Conservation Monitoring Centre
WFD Water Framework Directive

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Table 1. Outline table to report on review of indicators

Indicator	**Source** (policy driver/reference)	**Status** (in use - no. yrs; underdevelopment; under consideration; used outside UK)	**Geographic coverage** (local; country; UK; Europe)	**Parameter(s) measured** (including units of measurement)	**Description** (Briefly describe purpose and application)	**Pressure(s)** (against which indicator is used	**Impact(s)** (for which indicator is used)	**Effectiveness** (of indicator to address impact e.g. directly effective, indirectly effective, ineffective; give reasons)	**Aspect of ecosystem health assessed** (state taxon or habitat if relevant)	**Comments** (on development or implementation requirements)
Habitat extent (and distribution) - reef (notable species *Lophelia pertusa* and *Madrepora oculata*), sponge (demosponge and hexactinellid) aggregations, carbonate mounds, seamounts, octocorals	Extent of feature is a reporting requirement of the Habitats Directive.	Habitats not monitored in UK waters. The US South Atlantic Fishery Council and Pacific Fisheries Council have drafted proposals to protect and monitor deep-water coral reefs. (Some monitoring of seamounts underdevelopment in the US and New Zealand), The US has applied some small-scale research into the ecology of octocorals, but no formal monitoring system is in place.	Most deep sea where habitat occurs	Extent of reef (Area)	Extent of feature is a reporting requirement of the Habitats Directive. Extent of habitats are unlikely to change significantly over time unless direct disturbance through a human pressure is involved.	Fishing - demersal trawling; Oil and gas industry	Habitat extent - destruction, loss, smothering	Directly effective in determining the impacts.	Detrimental impacts on the extent of the habitat will impact its ecosystem functioning.	The extent of a deep-sea reef is shown by side scan sonar, although this does not distinguish between live and dead coral. Photographic transects can be used to reveal the extent of the reef. Photographic transects may also be used to measure the extent of carbonate mounds, sponge aggregations, seamounts and octocorals. However, the distribution of these habitats is poorly understood in some areas. In addition, chemosynthetic environments have not been extensively researched or described in UK deep waters, with exception of the pockmarks adjacent to the Darwin Mounds. Research on the location and extent of these deep-sea habitats is needed so they can be included in an assessment and monitoring programme
Habitat physical biotic structure - notable species (e.g. corals, sponges) and density		Habitats not monitored in UK waters. The US South Atlantic Fishery Council and Pacific Fisheries Council have drafted proposals to protect and monitor deep-water coral reefs. (Some monitoring of seamounts underdevelopment in the US and New Zealand), The US has applied some small-scale research into the ecology of octocorals, but no formal monitoring system is in place.	Most deep sea where habitat occurs	Notable species and density (i.e. number individuals per square metre)	Density of habitats are unlikely to change significantly over time unless direct disturbance through a human pressure is involved.	Fishing - demersal trawling; oil and gas industry	Habitat structure - destruction of notable species, decrease in density	Directly effective in determining the impacts.	Detrimental impacts on the physical structure and density of the habitat will impact associated fauna and ultimately its ecosystem functioning.	Photographic transects may be used to measure the physical biotic structure and density of species in reefs, carbonate mounds, sponge aggregations, seamounts and octocorals.
Community structure and composition (specific habitats - reefs, sponge aggregations, carbonate mounds, seamounts, octocorals - and general deep-sea habitat)		Habitats not monitored in UK waters. The US South Atlantic Fishery Council and Pacific Fisheries Council have drafted proposals to protect and monitor deep-water coral reefs. (Some monitoring of seamounts underdevelopment in the US and New Zealand), The US has applied some small-scale research into the ecology of octocorals, but no formal monitoring system is in place.	All deep sea	Community parameters (abundance, biomass, diversity, composition)	Community structure and composition are unlikely to change significantly over time unless direct disturbance through a human pressure is involved. Each deep-sea habitat supports a distinct faunal community	Fishing - demersal trawling, climate change (oil and gas impacts covered separately - see below)	Change in community structure and composition by trawling/anthropogenic change of ocean processes	Directly effective in determining the impacts.	Detrimental impacts on community structure and composition will impact the functioning of that ecosystem	Photographic transects can be used to analyse the community structure and composition. Physical samples may be required to 'ground truth' species identification and complete biomass measurements. Regular monitoring is required to distinguish between natural change and that driven by anthropogenic pressures. Research on the location, extent and biology of chemosynthetic deep-sea habitats is needed so they can be included in the assessment and monitoring programme.

Water quality (performance indicator)		Water quality will be addressed by the indicator review for theme 10 - ocean processes	NE Atlantic	Water quality - Temperature, salinity, acidity	Changes in temperature, salinity and pH may influence the presence and distribution of species (along with recruitment processes and spawning behaviour).	Climate change - Greenhouse gas emissions	Temperature changes - national/regional; Water flow - changes in thermohaline circulation; pH - CO_2 ocean acidification.	Indirectly effective in addressing the impact. However, baseline levels and natural fluctuations in water quality need to be described to enable correct identification of changes through anthropogenic pressures including climate change.	Physical environment - temperature/ salinity/ pH - all variables that can affect growth, metabolic rate and general ecosystem health	It should be ensured that the indicator review for Theme 10 - ocean processes - adequately covers monitoring of ocean processes in the deep sea
Bioaccumulation of contaminants	Moore et al., (1997) Analytical Chemistry 358, 652-655	Limited scientific literature, especially in UK deep water.	Localised points in the NE Atlantic and Pacific	Levels of organochlorines, organotin compounds, polycyclicaromatic hydrocarbons and heavy metals compared against baseline levels	Persistent anthropogenic compounds reach the deep sea. Measuring contaminant levels and comparing against baseline levels will determine if contamination is increasing	Oil and gas industry, Land based Pollution, Shipping	Contamination by hazardous substances	Indirectly effective; if baseline levels are known, bioaccumulation can give information on the level of contamination.	Does not address organism or community health because the effects of bioaccumulation are not known in deep-sea organisms.	There are few reports on bioaccumulation of contaminants in UK deep water. Baseline levels are needed to initiate monitoring processes.
Community change around oil and gas industry drill sites (biomarker)	Jones et al., (2007) Marine Biology 151, 1731-1741	In use in shallow water; limited use in the deep sea. Routine monitoring of community change does not take place.	NE Atlantic	Species abundance and diversity	Changes in faunal abundance and biodiversity that are above the natural variation can indicate impacts through toxicity or habitat change	Oil and Gas industry	Contamination by hazardous substances and physical loss of habitat	Directly effective in indicating if an impact has occurred.	Changes in ecosystem structure (species abundance and diversity) can be extrapolated to the health of the ecosystem studied.	
Molecular biomarkers		Under development at the National Oceanography Centre, Southampton	NE Atlantic	Gene expression of biomarkers of stress (Citric Synthase, Ubiquitin and 70kDA Heat Shock Protein) in echinoderms	Up-regulated gene expression and the activities of stress-inducible defensive proteins and metabolic enzymes can be used as biomarkers of environmental and pollutant induced stress. The number of mRNA transcripts from toxicant induced genes are an indication of the level of an organisms stress response.	Oil and gas industry, Land based pollution, Shipping	Contamination by hazardous substances	Directly effective in assessing exposure to a contaminant. They can provide information about which biochemical pathways are impacted by toxicant exposure and the likely mechanism of toxic action.	It can be difficult to relate changes in gene expression to whole organism responses that have ecotoxicological significance like survival, growth and reproduction. Changes in gene expression must be correlated to adverse effects in the animal for direct inferences on organism and ecosystem health.	These molecular biomarkers are under development and require further study before they are utilised in deep UK waters.
Oxidative stress biomarkers	Camus et al., (2006) Marine Environmental Research 62, S403-S404	Under development at Akvamiljø Caspian (owned by International Research Institute of Stavanger, Norway to carry out environmental services to the oil and gas sector) and recorded in deep-sea amphipods	Norway	Total oxygen scavenging capacity, Glutathione activity and Catalase activity	Xenobiotic molecules (PAHs, metal chelates, AHAs) are potential sources of oxygen radicals. A change in the antioxidant biomarkers may be used to indicate contamination levels.	Oil and gas industry, Land based pollution, Shipping	Contamination by hazardous substances	The biomarkers can be directly effective in addressing the impact	Health of 'sentinel species' may be extrapolated to indicate the health of the ecosystem	More work is required to find sentinel species in the UK, assess baseline levels and determine the initial induction, maximum induction, adaptation and recovery of the biomarker.

Other biochemical and molecular biomarkers		Used in shallow-water studies, potential for development for deep-sea biomonitoring	General and localised points in the deep sea where activity occurs	Metallothioneins/ Cytochrome P450 expression/ DNA Integrity	These biomarkers have been successfully used in shallow-water ecotoxicological studies and have potential for use in the deep sea to measure exposure and effect to heavy metals and persistent anthropogenic compounds	Oil and gas industry, shipping, land based pollution	Contamination by hazardous substances	These biomarkers can be directly effective in assessing exposure to a contaminant. They can provide information about which biochemical pathways are impacted by toxicant exposure and the likely mechanism of toxic action.	Health of the 'sentinel species' may be extrapolated to indicate the health of the ecosystem. However, it can be difficult to relate changes in gene expression to whole organism responses that have ecotoxicological significance like survival, growth and reproduction.	Collaborations with shallow-water ecotoxicological scientists will facilitate the development of these techniques in the context of deep-sea monitoring.
Litter - abundance and distribution	MESH survey (http://searchmesh.net/)	not in use	All deep sea - localised accumulation (e.g. Canyons)	Abundance of large litter/ debris	Enumerating litter/debris in UK deep-waters will determine the impact land based and shipping 'dumping' has on the deep-sea ecosystem. The litter may also introduce hydrophilic contaminants into the deep sea.	Land and ship based pollution	Litter - physical disturbance	Indirectly effective - photographic transects may be good at enumerating debris, but contamination from small plastic pellets has not been quantified in the deep sea	Accumulation of litter/ debris may have a detrimental effect on the benthic community by introducing hydrophilic contaminants	More research is needed in UK deep waters. Collaborations with shallow-water litter/debris scientists may help to determine and monitor litter/debris levels in deep UK waters.
Arrhis phyllonyx	included on UK BAP species list		Polar species		*Arrhis phyllonyx* is included on the UK Biodiversity Action Plan list of priority species.			Ineffective		This species is at the Southernmost limit of its distribution in the deep-waters North of Scotland. As it may already be under physiological stress, it is unlikely to be useful as an indicator.
Porcupine Abyssal Plain time series	Billett et al., (2001) Progress in Oceanography 50, 13-25	In use - the time-series station has been the focus of research since 1989 by the National Oceanography Centre, Southampton	NE Atlantic	Benthic community composition, organic matter flux, sediment biogeochemistry, biochemistry of the megafauna	This time-series station was set up with the aim of determining how the seabed community and geochemistry of the sediments change in response to a highly seasonal input of organic matter from the overlying waters. This research is indicating how climate change affects deep-sea communities.	Climate change/ No specific or single impacting activity	Changes in species or community distribution and flux of organic matter	Directly effective in addressing impact of climate change on the deep-sea ecosystem.		
Ecosystem processes (production, consumption and transfer) using biodiversity as a proxy	Danovaro et al., (2008) Current Biology 18, 1-8	not in use	All deep sea areas	Biodiversity	Biodiversity may be used as a proxy for ecosystem function; a reduction in biodiversity leads to a reduction in ecosystem processes	Climate change, fishing activity, contamination from hazardous substances, no specific or single activity	Changes in ecosystem function	Indirectly effective in addressing the impact. A reduction in biodiversity has been related to a reduction in ecosystem functioning	Ecosystem function of the general deep-sea habitat as well as functioning of specific habitats	Until sound data on ecological processes (production, consumption and transfer of organic matter) can be quantified in the deep sea (this is an area requiring targeted research), biodiversity may be used as a proxy of ecosystem function.