JNCC Report
No. 594

Exploring the Components and Processes of Marine Ecosystems Critical to Ecosystem Service Generation

Alexander, D., Rengstorf, A., Wellard, K., de Ros Moliner, A. & Fletcher, S.

September 2016

ISSN 0963-8901

For further information, please contact:

Joint Nature Conservation Committee
Monkstone House
City Road
Peterborough PE1 1JY
www.jncc.defra.gov.uk

The Report Steering Group comprised Luca Doria, Matt Smith, Bethany Stoker and Diana Mortimer.

This report should be cited as:

Alexander, D., Rengstorf, A., Wellard, K., de Ros Moliner, A. & Fletcher, S. (2016). Defining the Components of Marine Ecosystems Critical to Ecosystem Service Generation. Marine Ecological Surveys Ltd – a report for the Joint Nature Conservation Committee. *JNCC Report No. 594*. JNCC, Peterborough.

Acknowledgments:

The authors would like to thank the following JNCC staff for their comments and contributions to the report: Luca Doria, Deanna Donovan, James Hutchison, Diana Mortimer, Matt Smith and Bethany Stoker.

This report is compliant with the JNCC Evidence Quality Assurance Policy
http://jncc.defra.gov.uk/default.aspx?page=6675.

Summary

Ecosystem service delivery in the marine environment is driven by a number of biotic and abiotic ecosystem components and processes. Examining how these components and processes influence ecosystem service delivery, both spatially and temporally, is crucial to understanding service delivery. In turn this understanding may help to inform marine spatial planning, ecosystem-based management, blue growth, impact assessments and wider management plans.

For example, whilst current policy drivers include some consideration of ecosystem services at varying scales, there is scope for further integration of ecosystem services in decision making, ecosystem monitoring and assessment. Improved understanding of ecosystem services may be particularly useful for implementing policy and legislative instruments where choices between different uses or management options are required, such as Environmental Impact Assessments or marine planning. Area-based approaches to marine policy and planning (Marine Spatial Planning, Marine Protected Areas, fisheries closures, Marine Licensing, *etc*) may be especially influenced by improved understanding of ecosystem service delivery potential.

This report explores the marine ecosystem components and processes that influence potential ecosystem service delivery, identifies which components and processes are deemed critical in the delivery process, gathers spatial data regarding ecosystem components and processes, and maps the potential for ecosystem service delivery in the UK marine environment based on these data.

The marine ecosystem components and processes described in this report can be the component or process itself (e.g. the seabed or ocean water mass mixing) or a characteristic of the component or process (e.g. sediment type or stratification).

An extensive literature review was initially conducted to gather evidence regarding the ecosystem components and processes that affect ecosystem service delivery. These were assessed against classes of ecosystem service as defined in the CICES framework (version 4.3), broken down into the three main service categories: provisioning services, regulation and maintenance services, and cultural services.

Following the initial identification of ecosystem components and processes, the report goes on to ascertain which of these are considered critical to ecosystem service delivery. In the terms of this assessment, components and processes defined as ‘critical’ were those whose removal or alteration would result in a decline or cessation in ecosystem service provision. Typical abiotic components and processes, or their characteristics, that were deemed critical include: water temperature, light attenuation, nutrient availability and water movement (wave action, tidal flows *etc*). Typical biotic components and processes, or their characteristics, regarded as critical include: recruitment and propagule supply, the presence of particular species that perform certain roles and functions (e.g. the presence of carbonate depositing species), the presence of macroalgae, and biodiversity of communities.

Using the results of a spatial data mining exercise (informed by the critical component analysis), the potential for delivery of three specific ecosystem services in the UK was mapped. One service was chosen from each section of the CICES classification. The chosen services were:

- ‘Provision of kelp (*Laminaria hyperborea*) for use in alginate, food, biofuels, medicine and other chemicals’ to represent provisioning ecosystem services;

- ‘Bioremediation of hydrocarbons in the marine environment by microorganisms’ to represent regulation and maintenance ecosystem services; and
- ‘Good’ diving experiences’, a cultural ecosystem service.

Maps for each ecosystem service were produced by combining data layers representing the critical components identified (with the exception of kelp provision, as explained below), to indicate areas where all the critical components are present and potential ecosystem service delivery may occur. The three ecosystem services produced three different results in terms of the spatial distribution of potential service delivery.

Delivery of good diving experiences was the most clearly spatially delineated of the three services mapped, in part because it was based on the greatest number of data layers. Five data layers were combined and clipped to common areas to show where ‘good’ experiential diving services could potentially be delivered. The results show those areas around the UK that are shallow enough to function as potential dive sites, are not affected by strong currents and are likely to have interesting dive features. The areas identified are typically close to shore and located around all UK coasts.

The map of the provision of kelp also considered a number of data layers. However, as the potential delivery of this ecosystem service relied on the presence of one particular species, actual distribution of kelp was the overriding factor in the final maps. As such, the final ecosystem service map reflects the known distribution of *Laminaria hyperborea* in the UK. The map indicates that this potential ecosystem service is predominantly delivered around the west coast of the UK, with Scotland, Wales, Northern Ireland and south-west England being particularly supportive of this service.

The regulation and maintenance map showed the potential for bioremediation of hydrocarbons by microorganisms in the UK marine environment. Data gathered indicated that the microorganisms responsible for bioremediation are likely to be present to some degree in all water bodies, and that the whole of the UK marine environment sits well within the range of the environmental extremes tolerated by these species. Numerous informative data layers were produced to refine the distribution of this service. However, the final map shows the service as potentially delivered across the whole of the UK marine environment. Within this geographical range the magnitude of potential service delivery will likely be heavily dependent on a number of different variables (e.g. nutrient levels, degree of wave action, *etc*).

The outputs of this report explore the components and processes of the marine ecosystem that are of particular relevance to ecosystem service delivery. The maps produced serve to test the method, highlighting that certain ecosystem services are more amenable to mapping than others, and are also likely to be useful in informing future marine planning, management options or impact assessment decisions.

Contents

1 Introduction

Many reports (e.g. EEA 2015; UK National Ecosystem Assessment 2011; Atkins *et al* 2013) on natural capital, both conceptual and applied, recognise marine systems as an important stock of natural capital assets which deliver various ecosystem services critical to supporting human life and well-being. In this sense, within the marine environment there is a set of natural capital stocks (the assets) (e.g. coastal marshes, reef systems, marine organisms) and this stock of assets may, often with appropriate management, provide one or more services (e.g. nutrient cycling, natural coastal defences, carbon sequestration). These services sometimes have to be combined with other capital inputs (e.g. human, financial) in order to produce the goods and benefits that society needs or requires (e.g. clean water provision, protection from storm damage, seafood harvest). Some of these goods and benefits are difficult to physically quantify (e.g. good air quality, equitable climatic conditions). When these goods and benefits are realised by people they can often be assigned a value which in some instances can be quantified in monetary terms (but not always) (EEA 2015).

For the purposes of this report we use the Mace *et al* (2015) definition of natural capital and in doing so specifically recognise the role of abiotic and biotic natural capital:

> *"A stock that includes all natural resources in air, water, sea, land and below-ground that support human societies. Crucially, it also includes the physical, biological and chemical processes (e.g. weathering, the water cycle, evolution, nutrient cycling, recruitment and ecological interactions). Accordingly, natural capital includes biotic and abiotic elements (as opposed to only biodiversity) and these need not be interacting, as is implicit in the definition of an ecosystem."*

However, previous studies (Medcalf *et al* 2012, 2014) have struggled to resolve marine systems sufficiently to enable a meaningful analysis of their role as natural capital assets. There is a need to better represent marine systems through the lens of natural capital thinking as they are critically important to many services, goods and benefits that support human societies (EEA 2015).

One of the difficulties in moving the natural capital framework from concept to practice in the marine system is a thorough, focused, and widely applicable understanding of *how* the components and processes of the marine system deliver these services, goods and benefits. There has been a tendency to ask the question from the perspective of the assets (i.e. what are individual assets delivering in terms of ecosystem services). This can be limiting depending on the list of assets considered and often leads to varying descriptions of ecosystem services which are not comparable at a fully interconnected, system scale.

An alternative starting point, adopted by this report, is to explore which components and processes deliver potential ecosystem services in the marine environment. This report considers both the biotic and abiotic components and processes and is not limited to only using existing classifications schemes, such as the European Nature Information System (EUNIS)[1]. In doing so the report focuses on the marine system as a whole in an effort to undertake an holistic approach. For example, components such as species, ecological communities, the seabed and sub-seabed, the water column, the atmosphere, and the functions, processes and interactions between all of these components are considered, as these are all deemed pivotal to ecosystem service delivery.

[1] European Nature Information System (EUNIS): http://eunis.eea.europa.eu/

It should be noted that this report has only considered ecosystem services from a ‘supply-side’ perspective, as defined by the European Environment Agency (EEA 2015). This perspective focuses on estimating an ecosystem's potential for service delivery, in contrast to the ‘demand-side’ perspective which estimates and values the societal benefits that are actually being realised from the flow of ecosystem services.

1.1 Objectives

The objectives of the report are as follows:

1. To provide a summary of the policy-based and obligation-based drivers for an ecosystem service approach to management and decision making in the marine environment.
2. To consider how ecosystem services are delivered by the marine environment using a ‘supply’ focussed (what the ecosystem has to offer) approach; and to set out how ecosystem service delivery is dependent on certain biotic and abiotic components of the marine system, outlining any specific relationships and specific functions that drive particular ecosystem service production.
3. To determine the critical components and processes of the marine system that are associated with the delivery of an ecosystem service, taking potential biotic and abiotic driving processes into account; and to investigate how the state of the ecosystem could affect service delivery.
4. To undertake a spatial data mining and collation exercise for the critical components of three selected ecosystem services.
5. To create preliminary maps for each of the three selected ecosystem services to show potential delivery in the UK marine environment.

These objectives are achieved through a review of existing scientific literature and spatial data; and the collation of information relating to specific components of ecosystem services and spatial information which can be mapped.

1.2 A Framework for Ecosystem Services

To begin with, a framework, or typology, of ecosystem services is needed. The Common International Classification of Ecosystem Services (CICES) framework defines classes of ecosystem services for consideration. It builds on existing classifications defined under reports such as the Millennium Ecosystem Assessment (2005) and The Economics of Ecosystems and Biodiversity (TEEB 2010) reports but focuses on ecosystem service dimensions where system services are either provided by living organisms (biota) or by a combination of living organisms and abiotic processes. According to the CICES framework, ecosystem services are split into three main categories defined as follows (definitions taken from Haines-Young & Potschin 2013 and Atkins *et al* 2013):

- **Provisioning:** all material and energetic outputs from ecosystems; they are tangible things that can be exchanged or traded, as well as consumed or used directly by people in manufacture.
- **Regulating and maintenance:** includes the ways in which ecosystems control or modify biotic or abiotic parameters that define the environment of people, i.e. all aspects of the 'ambient' environment; these are ecosystem outputs that are not consumed but affect the performance of individuals, communities and populations and their activities. Regulation and maintenance services cover the degradation of wastes and toxic substances by exploiting living processes, the mediation of flows in solids, liquids and gases that affect benefit provision as well as the ways living organisms regulate the physico-chemical and biological environment.

- **Cultural:** all the non-material, and normally non-consumptive, ecosystem outputs that have symbolic, cultural or intellectual significance.

The hierarchy of ecosystem services used in this report is shown in Table 1, which is an adaptation from CICES framework version 4.3 and Table 7.1 from the State of European Seas Report (EEA 2015). This adaptation is necessary as only those ecosystem services deemed relevant for the marine environment have been retained. For example, the services of ‘Cultivated crops’ and ‘Reared animals and their outputs’ are not relevant in the marine environment.

Table 1. A classification of ecosystem services provided by the marine environment. This is a subset of the CICES framework (version 4.3) and has been adapted from the State of Europe's seas report Table 7.1 (European Environment Agency 2015).

Section	Division	Group	Class
Provisioning All material and biota constituting tangible outputs from marine ecosystems. They can be exchanged or traded, as well as consumed or used by people in manufacturing.	**Nutrition** All marine ecosystem outputs that are used as foodstuffs (seafood).	Biomass	Wild plants, algae and their outputs
			Wild animals and their outputs
			Plants and algae from *in-situ* aquaculture
			Animals from *in-situ* aquaculture
	Materials Marine biotic materials that are used in the manufacture of goods	Biomass/Fibre	Fibres and other materials from plants, algae and animals for direct use or processing
			Materials from plants, algae and animals for agricultural use
			Genetic materials from all biota
	Energy Biomass from marine organisms that can be used as biofuels for energy generation.	Biomass-based energy sources	Plant-based sources
			Animal-based sources
Regulation & Maintenance All the ways in which marine biota and ecosystems control or modify the biotic or abiotic parameters defining the environment of people (i.e. all aspects of the ‘ambient’ environment). These marine ecosystem outputs are not consumed, but they affect the performance of individuals, communities and populations.	**Mediation of waste, toxicants & other nuisances** Marine biota or ecosystems can mediate (neutralise or remove) waste and toxic substances that result from human activities. This mediation has the effect of detoxifying the marine environment.	Mediation by biota	Bio-remediation by microorganisms, algae, plants & animals
			Filtration/sequestration/storage/ accumulation by microorganisms, algae, plants and animals
			Mediation of smell/noise/visual impacts
	Mediation of flows Marine biota/ecosystem contribution to maintaining coastal landmasses and currents, reducing the intensity of floods, and keeping a favourable ambient climate.	Mass flows	Erosion prevention and sediment retention
		Liquid flows	Flood protection
		Gas/air flows	Ventilation and transpiration
	Maintenance of physical, chemical and biological conditions Marine biota/ecosystem contribution to the	Lifecycle maintenance, habitat & gene pool protection	Pollination and seed dispersal
			Maintaining nursery populations and habitats
			Gene pool protection

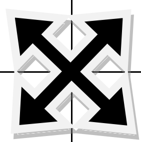
	provision of sustainable human living conditions.	Pest & disease control	Pest control
			Disease control
		Sediment formation & composition	Decomposition and fixing processes
		Water conditions	Chemical condition of salt waters
		Atmospheric composition & climate regulation	Global climate regulation by reduction of greenhouse gas concentrations
Cultural Includes all non-material marine ecosystem outputs that have physical, experiential, intellectual, representational, spiritual, emblematic, or other cultural significance.	**Physical & intellectual interactions with ecosystems & seascapes** Marine biota/ecosystems provision of opportunities for recreation and leisure as well as intellectual, emotional, and artistic development that can depend on a particular state of marine/coastal ecosystems (or where this can enhance it).	Physical & experiential interactions	Experiential use of land/seascapes in different environmental settings
			Physical use of land/seascapes in different environmental settings
		Intellectual & representational interactions	Scientific
			Educational
			Heritage cultural
			Entertainment
			Aesthetic
	Spiritual, symbolic & other interactions with ecosystems	Spiritual &/or emblematic	Symbolic
			Sacred and/or religious
		Other cultural outputs	Existence
			Bequest

1.3 A Framework for Marine Ecosystem Components

Ecosystem services are influenced by a combination of numerous biotic and abiotic components and processes that drive their delivery. In some cases, these components and processes can be unique to a specific service being delivered; conversely there may be some services that require the interaction of many different components or processes. Table 2 describes how these terms have been used in the context of this report.

Table 2: Description of the terms abiotic, biotic, components and processes. The four way arrow shows interaction between biotic and abiotic; and components and processes.

Nature of component or process / Component or process	Biotic	Abiotic
Component	Living components of the marine ecosystem (e.g. species)	Non-living components of the marine ecosystem (e.g. nutrients)
Process	Processes derived from living components (e.g. primary production)	Processes derived from non-living components (e.g. wave height)



In describing these biotic and abiotic components and processes, and their effect on ecosystem service delivery, it is often more intuitive to describe them as their associated characteristics. As such, this report has explored not only components and processes that influence ecosystem service delivery but also how their associated characteristics influence ecosystem service delivery. For example, rather than referring to the abundance of salt (an abiotic component) the report refers to salinity (a characteristic of an abiotic component).

2 Obligation-Based and Policy-Based Drivers for an Ecosystem Service Approach in the Marine Environment

The objective of this high level policy review is to look at existing and upcoming regulatory requirements (legislation, international conventions and policy) to understand to what extent ecosystem services are included in such policy and legislative instruments in order to give context to the scope of this report.

Hinchen (2014) identifies key marine biodiversity assessment obligations applicable to the UK marine environment. These obligations, in addition to other identified policies (to take account of recent changes in legislation and the development of new legislation) have been reviewed with reference to marine ecosystem services. The legislation and international obligations reviewed are as follows:

- Birds Directive 2009/147/EC
- Conservation of Seals Act (1970)
- Convention for the protection of the marine environment of the North-East Atlantic (OSPAR) (1992)
- Convention on Biological Diversity (CBD) (1992)
- Convention on the Conservation of Migratory Species of Wild Animals CMS/Bonn (1979)
- East Inshore and East Offshore Marine Plans (2014)
- Environment (Wales) Bill*
- EU Biodiversity Strategy to 2020 (2011)
- Habitats Directive 92/43/EEC
- Marine and Coastal Access Act (MCAA) (2009)
- Marine Scotland Act (2010)
- Marine Strategy Framework Directive (MSFD) 2008/56/EC
- Maritime Spatial Planning Directive 2014/89/EU
- Safeguarding Our Seas: A Strategy for the Conservation and Sustainable Development of our Marine Environment (2002)
- Scotland's National Marine Plan (2015)
- UK High Level Marine Objectives (HLMOs)
- UK Marine Policy Statement (MPS) (2011)
- UN Convention on the Law of the Sea (UNCLOS) (1982)
- Updated Environmental Impact Assessment (EIA) Directive 2014/52/EU*
- Water Framework Directive (WFD) 2000/60/EC
- Wildlife and Countryside Act (WCA) 1981

Links to each of the policies/obligations listed above are provided in Appendix 1. Legislation marked with * indicates those policies not identified in Hinchen (2014).

The original text of the instrument in question was reviewed for each of the above obligations and policies; where pieces of legislation have been fully replaced, the most recent complete text as passed (i.e. without subsequent amendments) was considered.

In considering whether ecosystem services are mentioned in these instruments, there is a need to recognise that the general concept of 'ecosystem services' is often referred to using a variety of other terms. In this review, the following similar or related terms were also searched for to assist in determining the potential for ecosystem services to be taken into account: 'natural capital', 'natural resources', 'natural capital assets', 'ecosystem based management', 'ecosystem based approach', 'sustainable management', and 'ecological services'.

The review of the identified policy and legislative instruments considers the following four questions to determine the extent to which ecosystem services are included:

- Does the text of the original obligation explicitly mention ecosystem services?
- Does the text of the original obligation explicitly mention other commonly associated terms?
- Are there mechanisms within the obligation that specifically require ecosystem services to be considered or taken into account?
- Are there mechanisms within the obligation that might allow ecosystem services to be considered or taken into account?

Each question is answered with a simple 'yes' or 'no'. The final question is somewhat subjective and is based on the expertise of the reviewer. The results of the assessment are presented in Table 3.

Table 3. The extent to which ecosystem services are included in policy and legislative instruments applicable to the UK marine environment.

Policy/ Legislation	Explicit mention of ecosystem services?	Mention of other related terms?	Includes mechanisms that specifically require ecosystem services to be considered/ taken into account?	Includes mechanisms that might allow ecosystem services to be considered/ taken into account?
Marine Strategy Framework Directive (MSFD)	No	Yes - natural marine resources - ecosystem-based approach - ecological services/ marine ecological services	No	**Yes** The inclusion of closely related terms in key areas would allow ecosystem services to be taken into account (e.g. *Programmes of measures and subsequent action by Member States should be based on an ecosystem-based approach*).
Maritime Spatial Planning Directive	Yes (only in the preamble)	Yes - natural capital - natural resources - ecosystem based approach	No	**Yes** The Directive requires Member States (MS) to have 'due regard' to impacts on natural resources and to consider economic, social and environmental aspects in establishing marine planning. Ecosystem services are not required or precluded and could be included within MS's marine planning system.
Habitats Directive	No	Yes - natural resources	No	**No** The Directive is framed around specific habitats and species, with conservation objectives specific to these.

Policy/ Legislation	Explicit mention of ecosystem services?	Mention of other related terms?	Includes mechanisms that specifically require ecosystem services to be considered/ taken into account?	Includes mechanisms that might allow ecosystem services to be considered/ taken into account?
Birds Directive	No	Yes - natural resources	No	**No** The Directive is framed around specific habitats and species, with conservation objectives specific to these.
Water Framework Directive (WFD)	No	Yes - natural resources - sustainable management	No	**Yes** The aims of the Directive are framed in terms of water quality and the aquatic environment, but it does recognise the use and management of water resources for human benefit (flood and drought mitigation, navigation, drinking water, *etc*) and enables derogations to the achievement of Good Ecological Status (GES). Ecosystem services could be used to demonstrate the need for heavily modified status or be applied in the 'disproportionately expensive' test. Ecosystem services could also be used to help develop River Basin Management Plans (RBMPs) to maximise ecosystem services while achieving GES.
EIA Directive 2014/52/EU	Yes (only in the preamble)	Yes - natural capital - natural resources	No	**Yes** Annex III includes specific reference to the use of natural resources and natural capital. Annex IV includes a requirement that the EIA report include details of likely significant effects to natural resources. These terms could be interpreted as relating to ecosystem services.
Environment (Wales) Bill	No	Yes - natural resources - sustainable management	No	**Yes** Part 1 of the Bill is concerned with the sustainable management of natural resources. The stated aim in 3(2) is to '*maintain and enhance the resilience of ecosystems and the benefits they provide*'.
Convention on Biological Diversity (CBD)	No	Yes - natural resources	No	**Yes** Article 2 makes reference to '*biological resources*', the definition of which includes reference to their '*actual of potential use or value for humanity*', which could be interpreted as relating to ecosystem services. The Convention is however only concerned with biological resources; it makes no reference to non-biological resources, so any interpretation or relation to ecosystem services would be limited.

Policy/ Legislation	Explicit mention of ecosystem services?	Mention of other related terms?	Includes mechanisms that specifically require ecosystem services to be considered/ taken into account?	Includes mechanisms that might allow ecosystem services to be considered/ taken into account?
OSPAR Convention	No	Yes - sustainable management - ecosystem approach	No	**Yes** The OSPAR Commission applies the ecosystem approach to work coherently towards a holistic approach to the problems addressed by the different OSPAR Strategies. For the purpose of the OSPAR Convention, the ecosystem approach is defined as "the comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity".
Convention on the Conservation of Migratory Species of Wild Animals	No	No	No	**No** The Convention is only concerned with specific listed species and their conservation status.
UN Convention on the Law of the Sea (UNCLOS)	No	Yes - natural resources	No	**Yes** Sets out the sovereign rights of States '*for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living'*. The Convention does not constrain how resources should be managed, meaning that this could enable ecosystem services to be considered.
Wildlife and Countryside Act (WCA)	No	No	No	**No** The Act is concerned with the protection of specific habitats and species, as listed in the Schedules, and with Public Rights of Way and protected areas.
Conservation of Seals Act	No	No	No	**No** The Act is only concerned with the protection and conservation of seals, including regulating the killing of seals.

Policy/ Legislation	Explicit mention of ecosystem services?	Mention of other related terms?	Includes mechanisms that specifically require ecosystem services to be considered/ taken into account?	Includes mechanisms that might allow ecosystem services to be considered/ taken into account?
Marine and Coastal Access Act	No	Yes - natural resources	No	**Yes** The framework nature of the Act in relation to marine plans and the Marine Policy Statement (MPS) enables the statement of policies for contributing to the sustainable development of the UK marine area. Ecosystem services are not specifically required or precluded so could be adopted within the MPS and marine plans. Marine licensing decisions must be in accordance with marine plans/MPS, such that ecosystem services could be integrated into the licensing decision making process through policies in the MPS/marine plans.
Marine Scotland Act	No	Yes - natural resources	No	**Yes** National or regional marine plans must set economic, social and marine ecosystem objectives and policies. Ecosystem services are not specifically required or precluded so could be included within marine plans. Marine licensing decisions must be in accordance with marine plans, such that ecosystem services could be integrated into the licensing decision making process through policies in marine plans.
UK High Level Marine Objectives	Yes (as ecosystem goods and services)	Yes - ecosystem approach -	No	**Yes** Some objectives specifically articulate outcomes centred around human derived benefits (achieving a sustainable marine economy; ensuring a strong, healthy and just society). The HLMOs do not set out how they should be achieved. Ecosystem services are not specifically required or precluded so could be used to achieve HLMOs. Ecosystem approach is mentioned as a way of integrating and managing a range of demands placed on the natural environment in such a way that it can be conserved and indefinitely support essential services and provide benefits for all.

Policy/ Legislation	Explicit mention of ecosystem services?	Mention of other related terms?	Includes mechanisms that specifically require ecosystem services to be considered/ taken into account?	Includes mechanisms that might allow ecosystem services to be considered/ taken into account?
Safeguarding Our Seas	Yes (as ecosystem goods and services)	Yes - natural resources - ecosystem based approach - ecosystem based management - sustainable management	No	**Yes** The term '*ecosystem goods and services*' is only used in the context of defining an ecosystem based approach. The Vision does not require ecosystem services to be considered, but it does not preclude their use. Actions are high level and not specific about how they should be achieved, although developing / taking an ecosystem based approach is part of several of the actions.
Marine Policy Statement	Yes (as ecosystem goods and services)	Yes - ecosystem based approach	No	**Yes** MPS provides a framework for the development of marine plans. It sets out key considerations that must be taken into account in the development of marine plans. It does not define how these considerations should be taken into account. Ecosystem services are not specifically required or precluded and could be included in marine plans.
East Inshore and East Offshore Marine Plans	Yes	Yes - natural capital - natural resources - ecosystem approach	Yes Objectives 2 and 7 and Policies BIO1, BIO2 and CC1 require that consideration should be given to the provision of ecosystem services	**Yes** Several Objectives and Policies (other than those already mentioned) are framed around human uses and benefits derived from the marine area. Ecosystem services are not specifically mentioned in these cases, but are not precluded either, so could be used in the delivery of policies or the achievement of objectives.
Scotland's National Marine Plan	Yes	Yes - natural capital - natural resources - ecosystem approach - ecosystem based management	Yes Policies GEN5 and, GEN9 require that consideration should be given to ecosystem services	**Yes** Ecosystem services are referred to in GEN 8 and GEN 21 without requiring them to be taken into account. This implies they could be considered in delivering these policies. Several other policies (other than those already mentioned) are framed around human uses / benefits derived from the marine area. Ecosystem services are not specifically mentioned in these cases, but are not precluded.

Policy/ Legislation	Explicit mention of ecosystem services?	Mention of other related terms?	Includes mechanisms that specifically require ecosystem services to be considered/ taken into account?	Includes mechanisms that might allow ecosystem services to be considered/ taken into account?
EU Biodiversity Strategy	Yes	Yes - natural capital - natural resources - ecosystem based management - sustainable management	Yes Requirement to map and assess ecosystem services	**Yes** Target 4 relates to sustainable use of fisheries resources and promotes an ecosystem based approach to fisheries management.
Number of instruments (out of 21)	8	18	3	16

Eight of the 21 policy and legislative instruments assessed in Table 2 specifically mention ecosystem services in their text, however, only three include mechanisms that specifically require ecosystem services to be considered or taken into account. The most specific of these are the marine plans for Scotland and the East Inshore and Offshore areas of England, which are among the most recently published instruments reviewed. The East Inshore and East Offshore Marine Plans and Scotland's National Marine Plan contain objectives and policies that require the provision of ecosystem services to be taken into account in decisions; however, they do not articulate how this should be achieved. The East Inshore and East Offshore Marine Plans also highlight a lack of understanding of ecosystem services, which is identified as a priority evidence requirement to support marine planning.

The other instrument that includes a specific mention of ecosystem services is the EU Biodiversity Strategy. The overall vision and target of the strategy makes reference to ecosystem services, which suggests that progress towards achieving the vision and target will need to be measured with reference to ecosystem services. The targets that sit below this overarching level are less specific and the actions to achieve the targets do not specifically require ecosystem services to be included, although actions to improve understanding of ecosystem services and integrate them into decision making are promoted.

EU Biodiversity Strategy Target 2 (‘*Maintain and restore ecosystems and their services*’), is of most relevance to ecosystem services, however the detail of the target is articulated in terms of ecosystems, not ecosystem services (‘*By 2020, ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems*’).

The actions under Target 2 require Member States to include ecosystem services in their reporting and accounting systems for monitoring and protecting ecosystems and this report is therefore of direct relevance to contributing to the UK's delivery of this action:

> *“Member States, with the assistance of the Commission, will map and assess the state of ecosystems and their services in their national territory by 2014, assess the economic value of such services, and promote the integration of these values into accounting and reporting systems at EU and national level by 2020.” (Action 5)*

The Green Infrastructure Strategy (Action 6b) will also include (financial) incentives to promote the maintenance of ecosystem services, but does not specifically require this. Action 7 under Target 2 promotes a '*no net loss approach to biodiversity and ecosystem services'*. This is concerned with developing future proposals about how this could be achieved e.g. through compensation or offsetting, but does not set specific requirements for Member States to achieve this, or set out how they should deliver 'no net loss of ecosystem services'. Elsewhere in the Strategy ecosystem services are mentioned in relation to the Common Agricultural Policy (CAP) and forestry. Implementation of the Strategy also makes mention of Payments for Ecosystem Services (PES), but only at an exploratory stage.

The majority of the instruments examined (17 out of 21) include one or more terms related to ecosystem services. 'Natural resources' is mentioned most frequently (in 15 of the 17 instruments), with 'ecosystem based approach' or 'ecosystem based management' being mentioned in nine of the 17 instruments. 'Sustainable management' is mentioned in five of the 17 instruments. Caution has to be applied in directly relating these terms to ecosystem services as each term may have a broader meaning. Previous work undertaken by JNCC looking at methodologies for defining ecosystem services in the marine environment identified the need to be clear about the use and definitions of terms "*A clear message is needed of what we mean by the Ecosystem Approach* (Atkins *et al* 2013). *The misuse of terminology propagates confusion*." It should be noted that the workshop to which this comment relates discussed the ecosystem approach, not ecosystem services, however, the sentiment is valid.

Although the Environment (Wales) Bill does not specifically mention ecosystem services or include mechanisms that specifically require ecosystem services to be considered, the stated aim in Article 3(2) is to '*maintain and enhance the resilience of ecosystems and the benefits they provide*'. This suggests that the inclusion of ecosystem services is integral to the delivery of the Bill. The implementation of the Bill will include the preparation of a National Natural Resources Policy (NNRP) in 2017, which will provide more detail on how the intention of the Bill will be implemented.

The older or more narrowly focussed instruments provide less scope for allowing ecosystem services to be taken into consideration. The three oldest instruments examined (The Convention on the Conservation of Migratory Species of Wild Animals, the Conservation of Seals Act, and the Wildlife and Countryside Act) make no mention of either ecosystem services or other related terms. They are also focussed on the conservation of specific listed habitats or species. The Habitats and Birds Directives also have a very specific focus on listed habitats and species. As such, none of these instruments have been assessed as including mechanisms that might allow for ecosystem services to be taken into account.

The potential for ecosystem services to be included in most (16 out of 21) of the instruments is clear. The degree to which they would be included is less certain. There is a move towards recognising what is referred to in overarching terms by the IPBES Conceptual Framework as '*Nature's benefits to people*' (Diaz *et al* 2015), but it is less clear how these should be taken into account in delivery and decision making.

3 Ecosystem Service Delivery in the Marine Environment

A literature review was conducted to reveal information on the biotic and abiotic components and processes of the marine system that influence ecosystem service delivery. This information was explored in order to ascertain which ecosystem components and processes affect each of the different classes of ecosystem services.

Specific biotic and abiotic components and processes of the marine system which affect ecosystem service delivery are defined in the glossary that accompanies this report. For the purposes of defining the components and processes of marine ecosystems that affect ecosystem service delivery, and to aid the identification of those elements that are considered critical to delivery, ecosystem services have been defined at the service 'Class' level as defined by the CICES framework adapted in this study for marine ecosystem services (see Table 1).

3.1 Literature Review Method

3.1.1 Literature Gathering

Information was gathered on a range of ecosystem components and processes that may influence ecosystem service delivery. Searches were conducted using a list of key words and a predefined list of initial biotic and abiotic components was identified by the report team, in combination with the classes of ecosystem services identified under the CICES framework that were considered relevant to the report (Table 1). As the literature review progressed more biotic and abiotic components were added to the list for consideration based on the results of the review.

A preference was given to information sourced from peer-reviewed journal articles. Three electronic databases (Science Direct, Web of Knowledge, Wiley Online Library) were searched using the list of identified key words to ensure that all databases were thoroughly interrogated, and a systematic approach to the literature review was followed. A list of key words used as search terms is included in Appendix 2.

A 'grey literature' search (i.e. non peer-reviewed literature, such as articles, theses, technical reports, agency publications *etc*) was also undertaken following the same process as that used for peer-reviewed information. The grey literature search was conducted using the Google and Google Scholar search engines and Government agency websites (such as JNCC, Natural England, Cefas, MarLIN, *etc*). A list of Government agency websites searched is included in Appendix 3.

Sources relating to information from the UK were prioritised as the focus of the report was to describe how and where ecosystem services may be delivered in the UK marine environment. In some cases, the search was widened beyond the UK to locate information relevant to the research topic. The implications of this are discussed in the confidence assessment presented below.

In other instances, expert judgement was used to provide information on links between biotic and abiotic components and ecosystem service delivery where evidence has not been sourced to inform this. This is further discussed in Section 3.2.2.

3.1.2 Data Logging Pro-forma

Information collated during the literature review was entered into a data logging spreadsheet for ease of reference, and to allow an evaluation of the sources gathered. These tables accompany this report (Electronic Appendix 1).

The information logged was divided into the following sections (worksheets within the Excel spreadsheet):

- **Provisioning**: Reference matrix for ecosystem services classified as ‘Provisioning’, showing which components and processes of the marine ecosystem influence which service classes.
- **Regulation and Maintenance**: Reference matrix for ecosystem services classified as ‘Regulation and Maintenance’, showing which components and processes of the marine ecosystem influence which service classes.
- **Cultural**: Reference matrix for ecosystem services classified as ‘’Cultural’, showing which components and processes of the marine ecosystem influence which service classes.
- **Reference Summary**: Source information, providing full reference, abstract, source type and source confidence. Each reference was given a unique code used to identify the source throughout all sheets.
- **Confidence Assessment**: A representation of the source confidence assessment used in the report, as described in Section 3.1.3.
- **Glossary**: Definitions of each biotic and abiotic ecosystem component described in the report.

3.1.3 Confidence Assessment

Confidence in the data gathered is a key consideration of this report. Confidence was assessed for individual evidence sources using the confidence matrices shown in Tables 3a-3c. These matrices use parameters such as source quality (peer-reviewed or non-peer-reviewed) as shown in Table 3a, and applicability of the study (whether the source is based on data from the UK and relates to specific ecosystem services and system components that are within the report scope) as shown in Table 3b. All confidence scores were assigned by the team undertaking the literature review using judgement to ascertain a confidence score in accordance with the protocol presented.

Overall confidence is based on the lowest common denominator in confidence from the two source tables, as shown in Table 3c (for example, a source with a high quality score and a medium applicability score would have an overall confidence of medium). Confidence classifications were entered into the relevant column in the Reference Summary worksheet for each source. The confidence assessment also has provisions for assigning confidence to ‘expert opinion’ judgements which follow the JNCC EQA Policy Guidelines (JNCC 2014).

Table 3a. Confidence assessment of the quality for the individual evidence sources.

Individual Source Confidence	Quality Requirement
High	Published, peer reviewed articles Or grey literature reports by established agencies
Medium	Does not fulfil 'high' requirement but methods are fully described, are considered fit for purpose and to a suitable level of detail Or expert opinion where component described is a well-established pathway
Low	Does not fulfil 'medium' requirement for level of detail Or no methods adopted and informed through expert judgement

Table 3b. Confidence assessment of applicability for individual evidence sources.

Individual Source Confidence	Applicability Requirement
High	Study based on UK data Or study based on exact service/component listed
Medium	Study based in UK but uses proxies for service/component listed Or study not based in UK but based on exact service/component listed
Low	Study not based on UK data Or study based on proxies for service/component listed

Table 3c. Overall confidence of individual evidence sources based on combining both quality and applicability, as outlined separately above.

Overall Source Confidence		Applicability Score		
		Low	Medium	High
Quality Score	Low	Low	Low	Low
	Medium	Low	Medium	Medium
	High	Low	Medium	High

3.2 Summary of Literature Review

Over 120 peer-reviewed and grey literature sources were reviewed as part of this report. These are detailed and summarised in the accompanying data logging proforma spreadsheet (Electronic Appendix 1).

In some cases, the information obtained from scientific journals is based upon research that was carried out in comparable temperate regions outside of the UK, but considered to be applicable in a UK context.

3.2.1 Knowledge Gap Assessment

The literature review revealed that information was more readily available for widespread or common ecosystem services or those which are directly linked to commercial exploitation. A lower volume of scientific literature was found to inform the cultural ecosystem services part of this work. This is likely due to ambiguity surrounding the anthropogenic realisation of this group of services in the marine environment.

Where supporting evidence could not be sourced, but where the report team identified that a link between a component or process and an ecosystem service existed, expert judgement (based on the collective expertise of the report team applied through group discussions) was utilised to indicate this connection. Expert judgement carries a lower confidence score than most literature evidence sources, but is still regarded as a valid evidence source. Expert judgement was predominantly utilised to inform links and influences within the Cultural and Regulation and Maintenance service categories.

3.2.2 Literature Review Limitations and Constraints

Expert judgement was applied based on logical analogy (if a service is generated from these components in X context, and Y context is similar, then a comparable service is likely to be generated), logical extension of a theory, or existing knowledge. As such, whilst attempts have been made to limit subjectivity, this should be regarded as a limitation of the report. All instances where expert judgement has been applied are fully documented in the supporting report spreadsheets (Electronic Appendix 1).

Equally critical in the outcomes of this literature review is that information has been sourced at a broad level and scale and is attributable to ecosystem service classes (e.g. wild plants, algae and their outputs) or groups, rather than specific ecosystem services of which there can be many within each service class. As such, the resolution of the data gathered is low, and it may be that there are multiple specific ecosystem services being assessed within each ecosystem service class.

It is also important to note that the results presented in this report reflect the time and resources that have been invested in the report. Confidence in the findings is also influenced by the extent of the literature review, time and budgetary constraints of the report; it is likely that literature sources with a higher confidence level would be sourced and that less application of expert judgement would be required if further time was available. It is also possible that with more time additional components and processes that affect service delivery may be identified.

3.3 Results

The results of the literature review are shown in Tables 4-6 below. These tables indicate the biotic and abiotic components of the marine environment that are considered likely to affect ecosystem service delivery. The tables provide a summary of the literature review exercise and as such the supporting spreadsheets should be referred to for specific references (Electronic Appendix 1). A full description of each biotic and abiotic component is shown in the glossary presented in Section 8.

For these tables it should be noted that blank cells do not necessarily mean that a link between a specific abiotic or biotic element and a service class does not exist but that, in the limits of time and resources available and expert judgement, this could not be identified.

Table 4. The biotic and abiotic components and processes which affect ecosystem services in the 'Provisioning' section. Links shown in dark blue represent those components for which literature evidence has been sourced; links shown in light blue represent those components informed by expert opinion. Blank cells indicate those links which are not supported by the information sources or expert judgement gathered as part of this review.

Ecosystem Service Division	Nutrition				Materials			Energy	
Ecosystem Service Group	Biomass				Biomass/Fibre			Biomass-based energy sources	
Ecosystem Service Class	Wild plants, algae and their outputs	Wild animals and their outputs	Plants and algae from *in-situ* aquaculture	Animals from *in-situ* aquaculture	Fibres and other materials from plants, algae and animals for direct use or processing	Materials from plants, algae and animals for agricultural use	Genetic materials from all biota	Plant-based sources	Animal-based sources
ABIOTIC COMPONENTS AND PROCESSES									
Water temperature	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue
Salinity	light blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	light blue	dark blue
Light attenuation	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue
Water depth	dark blue	dark blue			dark blue	dark blue	dark blue	dark blue	dark blue
Water column stratification	dark blue	dark blue			dark blue	dark blue	dark blue	dark blue	dark blue
Nutrient availability	dark blue	dark blue	light blue	light blue	dark blue	dark blue	dark blue	dark blue	dark blue
Dissolved gases	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	light blue	dark blue
Dissolved/suspended organic matter	light blue	dark blue	light blue	dark blue	light blue	light blue	light blue	light blue	light blue
pH	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue
Water chemistry	dark blue	light blue	dark blue	dark blue	dark blue	dark blue	light blue	dark blue	light blue
Tidal flows	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	light blue	dark blue
Wave action	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	light blue	dark blue
Water currents	light blue	dark blue	light blue	dark blue	dark blue	dark blue	dark blue	light blue	dark blue
Seabed mobility	light blue	light blue	light blue	light blue	light blue	light blue	light blue	light blue	light blue
Sediment type	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue
Suspended sediment	dark blue	light blue	light blue	light blue	dark blue	dark blue	dark blue	dark blue	light blue
Heterogeneous habitats availability/Physical refuge	light blue	light blue			light blue	light blue	light blue	light blue	light blue
Sea level	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue
Natural disturbance	light blue	dark blue	light blue	light blue	dark blue	dark blue	dark blue	light blue	dark blue
Large scale weather events	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue
BIOTIC COMPONENTS AND PROCESSES									
Complexity of species life cycle	light blue	light blue	dark blue	dark blue	light blue	light blue	light blue	light blue	light blue
Propagule supply	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue
Recruitment	dark blue	dark blue	light blue	light blue	dark blue	dark blue	dark blue	dark blue	dark blue
Biotic potential	light blue	light blue	light blue	light blue	light blue	light blue	light blue	light blue	light blue
Population dynamics	light blue	light blue	light blue	light blue	light blue	light blue	light blue	light blue	light blue
Grazing on micro/macroalgae	dark blue	dark blue	light blue	light blue	dark blue	dark blue	dark blue	dark blue	dark blue
Presence of predators/competitors	dark blue	dark blue	light blue	light blue	dark blue	dark blue	dark blue	dark blue	dark blue
Disruptive presence of invasive species	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	dark blue	light blue	dark blue

Table 5. The biotic and abiotic components which affect ecosystem services in the 'Regulation and Maintenance' section. Links shown in dark blue represent those components for which literature evidence has been sourced; links shown in light blue represent those components informed by expert opinion. Blank cells indicate those links which are not supported by information sources or expert judgement.

Ecosystem Service Division	Mediation of waste, toxics & other nuisances			Mediation of flows			Maintenance of physical, chemical and biological conditions							
Ecosystem Service Group	Mediation by biota			Mass flows	Liquid flows	Gas/air flows	Lifecycle maintenance, habitat & gene pool protection			Pest & disease control		Sediment formation & composition	Water conditions	Atmospheric composition & climate regulation
Ecosystem Service Class	Bio-remediation by microorganisms, algae, plants and animals	Filtration/sequestration/storage/ accumulation by microorganisms, algae, plants and animals	Mediation of smell/noise/visual impacts	Erosion prevention and sediment retention	Flood protection	Ventilation and transpiration	Pollination and seed dispersal	Maintaining nursery populations and habitats	Gene pool protection	Pest control	Disease control	Decomposition and fixing processes	Chemical condition of salt waters	Global climate regulation by reduction of greenhouse gas concentrations
ABIOTIC COMPONENTS AND PROCESSES														
Water temperature	■	■				□		□	■	■	■	■	■	■
Salinity	■	■				□		■	■	■	■	■	□	■
Light attenuation	■	■	□	■		■		■	■	□		■	■	■
Water depth	■	■		□	■	□		■	■	□	□		■	■
Stratification	■	□							■	■	■	■	■	■
Nutrient availability	■	■	□			■		□	■	■	■	■	■	■
Dissolved gases	■	□				□		■	■	□	□	■	□	■
Dissolved/suspended organic matter	■	□										■	■	□
pH	■	■				□			■	■	■			■
Water chemistry	■	□				□		□	■	■	■	■		■
Freshwater input					■									
Tidal flows	■	□	■	□	■	■	■	■	■	□	□	■	■	
Wave action	■	□	■	■	■	■	■	■	■			■	■	
Water currents	□	□	■	□	□	■	■	■	■	□	□	■	■	■
Seabed mobility	□	□	■	□	■				□	■	■			
Sediment type	■	■		□	□			■	■			■		■
Suspended sediment	■	■		□				■	■			■	■	
Heterogeneous habitats available/Physical refugee					■			■	□	■			■	
Sea level				■	■			■	■					■
Natural disturbance				□	□				■	■	■			
Large scale weather events	■	■		□	■		□		■	■	■	■	■	■
Water quality	□	□						■	□	■	■			■
BIOTIC COMPONENTS AND PROCESSES														
Complexity of Life cycle									□			□		
Propagule supply				□			■	■	■					
Recruitment				□				□	■					
Biotic potential				□				□	□			□		
Population dynamics		□							□	□				

Ecosystem Service Division	Mediation of waste, toxics & other nuisances			Mediation of flows			Maintenance of physical, chemical and biological conditions							
Ecosystem Service Group	Mediation by biota			Mass flows	Liquid flows	Gas/air flows	Lifecycle maintenance, habitat & gene pool protection			Pest & disease control		Sediment formation & composition	Water conditions	Atmospheric composition & climate regulation
Ecosystem Service Class	Bio-remediation by microorganisms, algae, plants and animals	Filtration/sequestration/storage/ accumulation by microorganisms, algae, plants and animals	Mediation of smell/noise/visual impacts	Erosion prevention and sediment retention	Flood protection	Ventilation and transpiration	Pollination and seed dispersal	Maintaining nursery populations and habitats	Gene pool protection	Pest control	Disease control	Decomposition and fixing processes	Chemical condition of salt waters	Global climate regulation by reduction of greenhouse gas concentrations
BIOTIC COMPONENTS AND PROCESSES														
Grazing														
Presence of predators/competitors														
Presence of filter feeders														
Presence of invasive/alien species														
Abundance of Scavengers														
Presence of bio-regulatory species														
Presence of carbonate depositing species														
Abundance of bacteria/microbes														
Presence of particular species														
Presence of Tributyltin (TBT) degraders														
Presence of specialized hydrocarbon-degrading microbial consortia														
Presence of macroalgae														
Presence of seagrass														
Presence of reefs														
Abundance of biota														
Biodiversity														
Eutrophication														
Abundance of food source														
Disease prevalence														
Nutrient cycling														
Confinement of population/dispersal capability														
Organism size/age														
Disturbance recovery capacity														
Bioturbation														
Bioengineering														
Biodeposition														

Table 6. The biotic and abiotic components which affect ecosystem services in the 'Cultural' section. Links shown in dark blue represent those components for which literature evidence has been sourced; links shown in light blue represent those components informed by expert opinion. Blank cells indicate those links which are not supported by information sources or expert judgement.

Ecosystem Service Division	Physical & intellectual interactions with ecosystems and seascapes							Spiritual, symbolic & other interactions with ecosystems & seascapes			
Ecosystem Service Group	Physical & experiential interactions		Intellectual & representational interactions					Spiritual &/or emblematic		Other cultural outputs	
Ecosystem Service Class	Experiential use of plants, animals and land-/seascapes in different environmental settings	Physical use of land/seascapes in different environmental settings	Scientific	Educational	Heritage cultural	Entertainment	Aesthetic	Symbolic	Sacred and/or religious	Existence	Bequest
ABIOTIC COMPONENTS AND PROCESSES											
Tidal flows	Light blue	Light blue	Light blue	Light blue		Light blue					
Wave height	Dark blue	Dark blue	Dark blue	Dark blue		Dark blue					
Large scale weather events	Dark blue	Dark blue	Dark blue	Dark blue	Light blue	Dark blue	Light blue	Light blue	Light blue		
Water quality	Dark blue	Dark blue	Light blue	Light blue	Dark blue	Dark blue	Light blue	Light blue		Light blue	
Visibility	Dark blue	Light blue	Light blue	Light blue			Light blue				
BIOTIC COMPONENTS AND PROCESSES											
Presence of predators/competitors[2]	Dark blue	Dark blue	Dark blue	Dark blue							
Presence of invasive[3] species	Dark blue	Dark blue									
Presence of macroalgae			Light blue	Light blue	Light blue	Dark blue				Dark blue	Dark blue
Presence of seagrass	Dark blue	Dark blue	Dark blue	Dark blue	Light blue	Dark blue				Dark blue	Dark blue
Presence of cold water reefs			Light blue	Dark blue	Light blue	Dark blue				Dark blue	Dark blue
Presence of iconic/wild/conservative interest species	Dark blue	Dark blue	Dark blue	Dark blue	Light blue	Dark blue		Light blue	Dark blue	Dark blue	Dark blue
presence of conservation interest species	Dark blue	Dark blue	Light blue	Light blue	Light blue	Dark blue		Light blue	Dark blue	Dark blue	Dark blue
Abundance of biota	Light blue	Light blue	Light blue	Light blue	Light blue	Light blue	Light blue	Light blue			
Biodiversity	Dark blue	Dark blue	Dark blue	Dark blue	Dark blue	Dark blue	Dark blue	Dark blue	Dark blue	Dark blue	Dark blue

[2] The link with entertainment is captured under Presence of iconic/wild/conservative interest species' category.
[3] It should be noted that this component can also be considered to contribute to disservices.

3.4 Summary of Biotic and Abiotic Components and Processes which affect Ecosystem Service Delivery

Tables 4-6 above provide an overview of the identified components of the marine system which influence ecosystem service delivery. A discussion of these results is presented below.

3.4.1 Provisioning Ecosystem Services

A considerable number of both abiotic and biotic components and processes of the marine system were identified as influencing provisioning ecosystem services. A good level of literature information was sourced for most provisioning ecosystem services; gaps in the literature gathered on provisioning services are more likely to be a reflection of the time/resource constraints than an absence of available sources.

As this service primarily relates to the extraction of biological materials, most of the components which affect service delivery are those which directly influence the presence, growth and abundance of marine flora and fauna, and many influencing components are common to all services.

Abiotic components and processes such as water temperature (e.g. Lee *et al* 2007), light attenuation (e.g. Forster & Dring 1994; Franklin & Forster 1997), water pH (e.g. Callaway *et al* 2012), sediment type (e.g. Cognetti *et al* 2001; Sharples *et al* 2013) and wave and tidal flows (e.g. Nybakken 2001; Callaway *et al* 2012) were identified as influencing all ecosystem services considered. Ecosystem services relating to aquaculture (both algae and animals) are the general exception to these common features, largely due to the amount of human input which is required as the basis for these services, resulting in effectively less input from the marine environment.

Biotic components and processes were likewise found to be generic to many ecosystem services. Common components and processes identified included propagule supply and recruitment (e.g. Cole & McGlade 1998; Armsworth 2002; Lee *et al* 2009), the presence of predators or competitive organisms (e.g. IPCC 2001), the presence of alien or invasive species (e.g. Feline *et al* 2014; Katsanevakis 2014), food availability (e.g. Naylor *et al* 2000; Gilbert *et al* 2010), disease prevalence (e.g. Kilburn *et al* 2012) and confinement of the biotic population or dispersal capability (e.g. Palmer *et al* 1996; Lenormand 2002; Pinsky *et al* 2012).

3.4.2 Regulation and Maintenance Ecosystem Services

Regulation and maintenance ecosystem services are influenced by a number of biotic and abiotic components and processes in the marine system. The ecosystem services listed under this category are influenced by a diverse array of biotic ecosystem components and processes, reflective of the range of services considered.

Abiotic components and processes which commonly influence regulation and maintenance include water temperature (e.g. Hiscock *et al* 2004; Heinze *et al* 2015), tidal flows (e.g. Swannell *et al* 1996; Wadey *et al* 2013), wave action (e.g. Brown *et al* 2002), natural disturbance and weather events (e.g. Lohrer *et al* 2008), and salinity (e.g. Reichwaldt & Ghadouani 2012).

Biotic components and processes that influence multiple ecosystem services are less common. Components such as grazing pressure (e.g. Sunda & Shertzer 2012), the presence of predators and competitors (e.g. Beck *et al* 2001; Galil 2009), and the presence of species which perform particular regulatory roles (e.g. bioregulation) (Dubrey *et al* 2003; Mckew *et al* 2007; Cappello *et al* 2015), specialised hydrocarbon-degrading organisms (Swannell *et al* 1996) and the presence of certain habitat types, such as kelp and seagrass communities, (e.g. Mork 1996; Orth *et al* 2006; Chung *et al* 2011) are noted as frequently occurring components.

3.4.3 Cultural Ecosystem Services

Comparatively fewer ecosystem components and processes that influence cultural ecosystem services in the marine environment have been identified. It was noted that literature evidence to support the interactions was less readily available, although literature sources have been identified to support a number of the links.

Common abiotic components and processes which influence cultural ecosystem services include water quality (e.g. Jones 1998), large-scale weather events (e.g. Barbier *et al* 2011) and wave height and tidal flows (e.g. Barbier *et al* 2011).

Common biotic components and processes which influence cultural ecosystem service delivery include the presence of species or habitats of conservation importance (e.g. Beaumont *et al* 2008; Jobstvogt *et al* 2014), the presence of iconic species (e.g. Beaumont *et al* 2008; Ruiz-Frau *et al* 2013), the presence of alien or invasive species (potential to drive disservices, e.g. presence of alien species could decrease cultural value of a site (e.g. Katsanevakis *et al* 2014) and the biodiversity of living organisms (e.g. Beaumont *et al* 2008; Ruiz-Frau *et al* 2013).

4 Identifying Critical Components and Processes of Ecosystem Service Delivery

Based on the information gathered in the literature review, an assessment was conducted to identify which components and processes of the marine system are critical to ecosystem service generation. Indentifying critical ecosystem components gives a clearer understanding of the processes that lead to ecosystem service delivery. It also enables more targeted research into the condition of these critical components and how their condition affects ecosystem service delivery, facilitating management for ecosystem service benefits.

The results of the assessment are presented in Sections 4.1 – 4.3 below. In this assessment, components and processes defined as 'critical' were those whose removal or alteration would result in a significant decline in ecosystem service delivery or the ecosystem service no longer being provided. The assessments are based upon the sources gathered during the literature review and have been supplemented with additional information and expert judgement where appropriate. The critical component and process results are constrained by the results and confidence of the literature review to which there are various caveats attached (see Section 3.2.2).

Another factor to consider when assessing the critical components and processes of ecosystem service generation is how the state or quality of the environment may affect service delivery. Many of the critical components identified are likely to be negatively affected by a degradation in the overall state of the environment (defined for this report in the broadest sense of the term; the overall quality and health of the environment), ultimately affecting the capacity of the ecosystem to generate such services. The impact of ecosystem state on each critical component is assessed in the tables below and discussed further in Section 4.4.

Confidence in each assessment is provided following the protocol presented in Table 7. This assesses individual source confidence assigned as part of the literature review in combination with the level of agreement between sources to give an overall confidence assessment for the identification of each critical component.

Table 7. Critical component confidence assessment protocol.

Critical component/process confidence	Confidence requirement
Low	Strong disagreement between sources AND low-medium confidence scores for individual sources
Medium	Majority agreement between sources AND low-medium confidence scores for individual sources OR minority agreement between sources AND high confidence sources
High	Agreement between sources AND majority individual sources are medium to high confidence

4.1 Provisioning Ecosystem Services

Table 8 below indicates those ecosystem components and processes that have been identified as critical to the delivery of provisioning ecosystem services in the UK. Confidence in each component and process is assessed in line with the protocol presented in Table 7.

Table 8. Critical ecosystem components and processes identified affect that provisioning ecosystem services.

Component/process	Ecosystem Service	Rationale	Impact of Ecosystem State on Component	Confidence in component /process being critical
Water temperature	All provisioning services	Water temperature affects all provisioning services. It is considered critical to ecosystem service generation as temperature is directly related to the abundance and diversity of marine life and is a controlling component on species distribution (Cusson & Bourget 2005; Bolam *et al* 2010; IPCC 2012).	Water temperature may be affected by the state of the environment through processes such as long-term climate change (e.g. Manabe *et al* 1995; Hiscock *et al* 2004; Raaymakers, 2007) or localised anthropogenic impacts, such as from outfalls from power plants (e.g. Shawky *et al* 2013; Zhao *et al* 2015). A change in water temperature is likely to disrupt service delivery through displacing species which have limited temperature tolerances (Hiscock *et al* 2004).	High
Light attenuation	All provisioning services; especially those dependent on primary producers	Light attenuation is directly linked to the abundance and presence of many marine organisms (Nybakken 2001; Munn 2004), especially macrophytes which are responsible for a number of ecosystem services (Forster & Ding 1994; Lee *et al* 2007). Should sufficient light attenuation not be present within an ecosystem, any ecosystem services which depend upon this component may not occur.	High water turbidity and the presence of other organisms (such as a thick kelp canopy) can affect light attenuation (Birkett *et al* 1998; Devlin *et al* 2008). In such circumstances ecosystem service delivery, especially those dependent on macrophytes, is likely to be reduced.	Medium
Nutrient availability	All provisioning services	The availability of nutrients is a key component in controlling the abundance and diversity of marine	Nutrient availability is heavily tied to the state of the environment (e.g. Alvarez-Romero *et al* 2014). A lack of nutrient availability	Medium

Component/process	Ecosystem Service	Rationale	Impact of Ecosystem State on Component	Confidence in component /process being critical
		fauna and flora which produce provisioning ecosystem services (Nybakken 2001; Hiscock *et al* 2006; Lalli & Parsons 2006). A reduction in nutrient availability is therefore likely to reduce the delivery of any ecosystem services produced, and a total absence of nutrients is likely to result in non-delivery of any ecosystem service.	resulting from a poor state of the environment is considered a potential risk to ecosystem service delivery, as organisms depend upon certain nutrients to survive (e.g. Nybakken *et al* 2001; Hiscock *et al* 2006; Lee *et al* 2007). Conversely, excessive nutrient input to marine ecosystems is regarded as a source of pollution (e.g. Wilkinson *et al* 1996; Paerl *et al* 2011; Casey *et al* 2014) which may promote the propagation of harmful algal blooms which act to disrupt service delivery (e.g. Codd 2000; Gilbert *et al* 2010).	
Water chemistry	All provisioning services	Water chemistry is a broad term which encompasses many specific elements within the chemical make-up of a water body which may affect ecosystem services. As an ecosystem component water chemistry may have an influence over primary production and the distribution of flora and fauna, especially in coastal regions (e.g. Hiscock *et al* 2006; Lalli & Parsons 2006). It is understood that water chemistry is likely to be affected by numerous factors at varying scales, however it is thought to be a critical ecosystem	The state of the environment has the potential to affect water chemistry, which in turn is likely to affect ecosystem service delivery. Alterations to features such as dissolved oxygen, pH, and dissolved compounds caused by a poor state of the environment are likely to have knock-on effects on marine flora and fauna which have certain tolerance thresholds (e.g. Diaz & Rosenberg 1995; Pretterebner *et al* 2012).	Medium

Component/process	Ecosystem Service	Rationale	Impact of Ecosystem State on Component	Confidence in component /process being critical
		component with the potential to influence ecosystem service delivery due to the influence it exerts on organisms.		
Sediment type	All provisioning services	Sediment type is a well-documented controlling component which influences the distribution of marine organisms (e.g. Basford *et al* 1990; Seiderer & Newell 1999; Cooper *et al* 2011) and thus the ecosystem services they produce. Variation in sediment type influences the organisms present at the seabed. (Seitz *et al* 2013).	Ecosystem state is not likely to have an impact on sediment type unless changes are made to sediment composition or sediment is removed from the ecosystem.	High
Large-scale weather events	All provisioning services	Large-scale weather events have the potential to cause numerous disruptions to marine ecosystems, either directly through physical disturbance (e.g. IPCC 2001; Wadey *et al* 2013) or indirectly, for example increase surface run-off leading to harmful algal blooms (e.g. Gilbert *et al* 2010; Paerl *et al* 2011) or increased turbidity through disturbance to the seabed (Masselink & Hughes 2003). This disruption is likely to affect the biological components of ecosystems which deliver ecosystem services. Depending on the scale of the disturbance recovery may be possible, although if the disturbed habitats	Ecosystem state is not likely to affect large-scale weather patterns.	High

Component/process	Ecosystem Service	Rationale	Impact of Ecosystem State on Component	Confidence in component /process being critical
		have been irreparably damaged then it is possible that ecosystem service delivery may cease.		
Food availability	All provisioning services	Food availability is critical in controlling the distribution of marine organisms (e.g. Nybakken 2001) and is therefore likely to be critical to the delivery of ecosystem services reliant on marine organisms. Removal of food sources is likely to result in mortality or migration of organisms; resulting in a cessation of any ecosystem services produced.	The availability of food sources may be influenced by ecosystem state through various pathways, including through changes to the critical components listed in this assessment.	Medium
Recruitment and propagule supply	All provisioning services	Propagule supply and recruitment is critical for maintaining populations of marine organisms (e.g. Cole & McGlade 1998; Nybakken 2001; Lee *et al* 2006; Siegel *et al* 2008) and is therefore considered a critical component in the delivery of the ecosystem services by marine life. Through new additions to the adult population of ecosystem service generating organisms and the spread of propagules to new habitats, ecosystem service delivery can be maintained, whereas a lack of recruitment or cessation in the supply of propagules is likely to result in reduced or removed capacity for service	Recruitment and propagule supply is likely to be at its greatest when the environment is in a state of equilibrium (e.g. Sheppard-Brennand *et al* 2010). A change in the state of the environment may affect this ecosystem component, both directly and indirectly.	Medium

Component/process	Ecosystem Service	Rationale	Impact of Ecosystem State on Component	Confidence in component /process being critical
		generation.		

It can be seen from Table 8 above that most components and processes identified as critical to provisioning ecosystem service generation are abiotic. A smaller number of critical biotic components and processes have been identified.

In addition to the critical components and processes identified in Table 8, there are others that are important in determining the magnitude of the ecosystem service delivered, but do not meet the definition of 'critical'. These components and processes are primarily biotic. They have not been discussed in this report because changes in these would not necessarily result in a cessation of the ecosystem service, rather it would alter the pattern or frequency of service delivery. For example, grazing pressure and the presence of invasive species or competitors are important to ecosystem service generation. However, service delivery could still continue under these, and, if they were removed altogether, the service delivery would be unlikely to cease unless under extreme circumstances. There are also several abiotic components and processes which fall into this category, tidal flows, wave action and water quality being a few examples.

The assessments of the impact of environmental state on each of the critical components shown in Tables 8 indicate that the state of the environment has the potential to affect a range of ecosystem services. It should be noted, however, that not all critical components are likely to respond to a change in the state of the environment (e.g. large scale weather events), and some may be affected to a lesser degree than others.

Some components and processes which may be deemed critical to a limited number of discrete ecosystem services, which may occur over small scales, have not been included in the assessment in favour of a more generalised approach; the connection between freshwater input and aquaculture-related services is an example of this.

4.2 Regulation and Maintenance

Table 9 indicates those ecosystem components and processes that have been identified as critical to the delivery of regulation and maintenance of ecosystem services in the UK. Confidence in each component and process is assessed in-line with the protocol presented in Table 7.

Table 9. Critical ecosystem components and processes that are identified as affecting regulation and maintenance of ecosystem services (ecosystem services shown at the 'Group' level).

Component/ process	Ecosystem Service	Rationale	Impact of Ecosystem State on Component	Confidence in component/ process being critical
Water temperature	Mediation by biota Gas/air flows Lifecycle maintenance, habitat & gene	Water temperature is important in controlling rates of bioremediation (e.g. Cappello *et al* 2015), spread of invasive species (Raaymakers 2007), gaseous exchange (Brown *et al* 2002), carbon sequestration (Heinze *et al* 2015), in addition to being a major	Water temperature may be affected by the state of the environment through processes such as long-term climate change (e.g. Manabe *et al* 1995; Hiscock *et al* 2004;	High

Component/ process	Ecosystem Service	Rationale	Impact of Ecosystem State on Component	Confidence in component/ process being critical
	pool protection Pest & disease control Sediment formation & composition Water conditions Atmospheric composition & climate regulation	controlling factor in determining species distributions (e.g. Hiscock *et al* 2004). Without temperatures within an appropriate range the biological aspects of the ecosystem which provide regulation and maintenance ecosystem services are unlikely to thrive, and many of the temperature mediated processes which result in these services are unlikely to take place.	Raaymakers 2007) or localised anthropogenic impacts, such as from outfalls from power plants (e.g. Shawky *et al* 2013; Zhao *et al* 2015). A change in water temperature is likely to disrupt service delivery through displacing species which have limited temperature tolerances (Hiscock *et al* 2004), may affect the rates at which processes occur in the marine environment (e.g. Lalli & Parsons 2006) and may affect the physical properties of seawater (e.g. Brown *et al* 2002).	
Light attenuation	All regulating and maintaining services with the exception of: Liquid flows Lifecycle maintenance, habitat & gene pool protection (pollination and seed dispersal) Pest & disease control (Disease control)	Light attenuation affects the distribution, abundance and productivity of micro and macroalgae and indeed all organisms which are dependent on photosynthetic processes (e.g. Forster & Ding 1994; Birkett *et al* 1998; Munn 2004; Lee *et al* 2007). Light attenuation is also regarded as important in other regulating processes, such as the natural break down of toxins in the marine environment (e.g. Dubey & Roy 2003). It may affect any ecosystem services dependent on macroalgae or other light dependent organisms or the penetration of light. In areas where light attenuation is reduced, algae are unlikely to prosper (Birkett *et al* 1998; Munn 2004), resulting in reduced potential to supply regulation and maintenance services.	High water turbidity and the presence of other organisms (such as a thick kelp canopy) can affect light attenuation (Birkett *et al* 1998; Devlin *et al* 2008). In such circumstances ecosystem service delivery, especially those dependent on macrophytes, is likely to be reduced.	Medium
Water movement (wave action, tidal flows, water currents)	All regulating and maintenance services	The movement of water through wave action, tidal flows and currents is an important ecosystem component which affects many processes in the marine environment, and thus ecosystem services. Wave action, currents and tidal flows affect the mixing of the water column (Brown *et al* 2002b), influence water chemistry and the proportions of dissolved gasses within the water column (Brown *et al* 2002), distributes nutrients (e.g. Chamberlain *et al* 2001; Corbett 2010), assist with bioremediation (Swannell *et al* 1996),	The state of the environment is unlikely to affect water movement in the open ocean, but may in nearshore or coastal environments.	High

Component/ process	Ecosystem Service	Rationale	Impact of Ecosystem State on Component	Confidence in component/ process being critical
		have an impact on flooding and flood defences (e.g. Hunt 2005; Ruocco *et al* 2011; Wadley *et al* 2013), influence the supply of propagules (e.g. Quian 1999; Gaylord *et al* 2006), and control species distributions (e.g. Taylor 1995; Little & Kitching 1996; Beck *et al* 2001; Norderhaug & Christie 2011). Water movement therefore extends influence to many ecosystem components connected to ecosystem service production, in addition to direct influences on ecosystem services.		
Recruitment and propagule supply	Mediation by biota Mass flows Lifecycle maintenance, habitat & gene pool protection	Recruitment and propagule supply is integral to the maintenance of marine ecosystems (Cole & McGlade 1998; Nybakken 2001; Armsworth 2002; Lenormand 2002; Siegel *et al* 2008). A lack of recruitment or propagules is likely to lead to a decline in the ecosystem services provided by adult populations of all biota.	Recruitment and propagule supply is likely to be at its greatest when the environment is in a state of equilibrium (e.g. Sheppard-Brennand *et al* 2010). A change in the state of the environment may affect this ecosystem component, both directly and indirectly.	Medium
Presence of carbonate/ aragonite species	Mass flows Liquid flows Water conditions Atmospheric composition & climate regulation	Calcifying species capture dissolved gasses from the water column and utilise them in the formation of shells or skeletal structures (e.g. Ware *et al* 1992; van der Heijden & Kamenos 2015) and can therefore be considered to influence the chemical condition of salt waters (Gattuso *et al* 1995) and regulate climate through carbon sequestration (Gattuso *et al* 1995; van der Heijden & Kamenos 2015). An absence of these species is likely to result in a reduced potential for the marine environment to deliver these ecosystem services.	Environmental state is likely to have an influence on the presence of carbonate/aragonite species. Changes in environmental conditions (e.g. lowering of pH due to rising CO_2 concentrations) that are outside of the thresholds tolerated by these species will likely result in a decline in the organisms, and reduced or removed ecosystem service delivery.	High
Presence of degrading organisms (e.g. hydrocarbons & TBT)	Mediation by biota	Bio-degrading organisms play an important role in regulation and maintenance of the marine environment (e.g. Swannell *et al* 1996; Dubey & Roy 2003; Cappello *et al* 2015). The presence of specific bio-degrading organisms (e.g. the breakdown of TBT by *Citrobacter braakii*, Sakultantimetha *et al* 2009) is considered critical to several ecosystem services within the ecosystem service class 'Bio-remediation by microorganisms'; without these species the services they produce cannot be delivered.	Environmental state is likely to have an influence on the presence of degrading organisms. Changes in environmental conditions that are outside of the thresholds tolerated by these species will likely result in a decline in the organisms, and reduced or removed ecosystem service delivery.	High

Component/ process	Ecosystem Service	Rationale	Impact of Ecosystem State on Component	Confidence in component/ process being critical
Presence of macroalgae	Mediation by biota Mass flows Liquid flows Lifecycle maintenance, habitat & gene pool protection (maintaining nursery populations and habitats) Water conditions Atmospheric composition & climate regulation	Macroalgae are regarded as important producers and contribute to a number of ecosystem services, including the supply of juvenile nursery ground, and habitats and critical resources for other species (e.g. Birkett *et al* 1998; Norderhaug & Christie 2011), influencing mass and liquid flows through increasing sediment retention and dampening of wave energy (Eckman *et al* 1989; Mork 1996), bioremediation (Romero *et al* 1994), gaseous exchange (Hiscock *et al* 2006), water condition (Nybakken 2001) and climate regulation through reduction of greenhouse gasses (Duarte *et al* 2005; Chung *et al* 2011; Alonso *et al* 2012).	Environmental state is likely to have an influence on the presence of macroalgae. Increased turbidity, reduced or highly elevated nutrient levels, thermal stress and the introduction of pollutants associated with poor ecosystem state, may all result in a decline in macroalgae (Hiscock *et al* 2006; Wernberg & Goldberg 2008) resulting in disruption or cessation of the ecosystem services delivered by these species.	High

Table 9 above indicates that the components and processes identified as critical to the regulation and maintenance of ecosystem services are variable and represent a mix of both biotic and abiotic components and processes. As the ecosystem services in the regulation and maintenance category are more diverse compared to provisioning services, the components and processes which affect each service are less generic and less widespread across all services, hence the inclusion of relatively specific components for some ecosystem services.

There are a number of ecosystem components and processes which have been identified as important in ecosystem service generation, yet do not meet the requirements to be deemed 'critical'. These include large scale disturbances, grazing pressure, the presence of alien and invasive species, and the biodiversity of marine life.

The assessments of the impact of environmental state on each of the critical components shown in Tables 9 indicate that the state of the environment has the potential to affect a range of ecosystem services. It should be noted, however, that not all critical components are likely to respond to a change in the state of the environment (e.g. water movement), and some may be affected to a lesser degree than others.

Confidence in the assessments is generally high, reflective of the quality of information gathered during the literature review and the level of agreement between sources.

4.3 Cultural

Table 10 indicates those ecosystem components and processes that have been identified as critical to the delivery of cultural ecosystem services in the UK. Confidence in each component and process is assessed in line with the protocol presented in Table 7.

Table 10. Critical ecosystem components and processes identified that affect cultural ecosystem services (ecosystem services shown at the 'Group' level).

Component/ process	Ecosystem Service	Rationale	Impact of Ecosystem State on Component	Confidence in component/ process being critical
Water movement (tidal flows, water currents, wave height)	Physical & experiential interactions Intellectual & represen-tational interactions	Water movement driven by tidal flows, wave energy and currents influence several cultural ecosystem services related to physical, experiential, intellectual and representational interactions with the marine environment, e.g. wave energy for recreation, the study of water currents for scientific purposes etc. (Barbier *et al* 2011; Ruiz-Frau *et al* 2013) or generation of sandy beaches through erosion of rocks by waves. The movement of water is integral to these interactions and is what sets certain areas of the marine environment apart from others in the delivery of this service. If this component was removed from the marine system the service could no longer be generated.	The state of the environment is unlikely to affect water movement in the open ocean, but may in nearshore or coastal environments.	Medium
Water quality	Physical & Experiential interactions Intellectual & represen-tational interactions; Other cultural outputs	Water quality has a direct link to the delivery of cultural ecosystem services. Marine ecosystems with higher water quality are expected to provide a greater level of ecosystem service than those with poor water quality in most respects, especially with regard to physical and experiential interactions e.g. beaches with higher water quality are likely to attract greater numbers of visitors and thus generate greater revenues (Jones 1998; Keeler *et al* 2012; Jobstvogt *et al* 2014). A reduction in water quality would therefore lead to reduced or removed capacity to provide cultural ecosystem services (Keeler *et al* 2012).	The state of the environment has a potentially large bearing on water quality (e.g. Karr & Dudley 1981; Beher *et al* 2016; Tuhkanen *et al* 2016). A lowered state of the environment is likely to result in a lowered water quality (possibly through processes such as the input of pollutants) which in turn is likely to have considerable effects on cultural ecosystem service delivery (e.g. Ungaro *et al* 2016).	High
Biodiversity	All cultural ecosystem services	The biodiversity of organisms influences cultural ecosystem service delivery by directly affecting the scale and quality of ecosystem service that can be produced by the environment; areas with a greater biodiversity are likely to offer a greater level of ecosystem service than others	Biodiversity is closely tied to the state of the environment and high levels of biodiversity can be said to be a reflection of good environmental quality (MSFD[4]; Laurila-	High

[4] Directive 2008/56/EC of the European Parliament (Marine Strategy Framework Directive)

Component/ process	Ecosystem Service	Rationale	Impact of Ecosystem State on Component	Confidence in component/ process being critical
		(Beaumont *et al* 2008; Ruiz-Frau 2013; Jobstvogt *et al* 2014), for example high biodiversity is likely to lead to greater enjoyment of a seascape, greater scientific potential and greater aesthetic connections. Without biodiversity of marine life cultural ecosystem services are likely to be much reduced or non-existent in many circumstances, especially those that are dependent on particular flora and fauna.	Pant *et al* 2015). Conversely, a decline in environmental state by variation to critical parameters (for example levels of dissolved oxygen, input of pollutants, *etc*) is likely to result in a loss of biodiversity (e.g. Diaz & Rosenberg 1995; Bianchi & Morri 2000) and the ecosystem services associated with this component (Worm *et al* 2006).	

Table 10 indicates that far fewer components and processes affecting cultural ecosystem services have been identified as ‘critical’, compared with provisioning and regulation and maintenance services. This is, in part, due to the nature of cultural ecosystem services and a reflection of the lack of evidence found to support links during the literature review.

There are also a number of important components and processes which could potentially be defined as critical, but are likely to affect ecosystem service generation on a relatively small scale. Principally this includes the presence of specific species, or groups of species, which may influence cultural ecosystem services. Examples include the presence of predators, the presence of seagrass, the presence of cold water reefs and the presence of any species of general conservation interest. The removal of any of these is unlikely to result in the general removal of an ecosystem service, rather a localised reduction.

The assessments of the impact of environmental state on each of the critical components shown in Table 10 indicate that the state of the environment has the potential to affect a range of ecosystem services. It should be noted that not all critical components are likely to respond to a change in the state of the environment (e.g. water movement) and some may be affected to a lesser degree than others.

4.4 Impact of Ecosystem State on Ecosystem Service Generation and Critical Ecosystem Components

As shown in tables 8-10, reviewed literature provides evidence that the state of an ecosystem has an influence on critical components and therefore on service delivery; this, however, cannot be considered applicable to all critical components as some, such as water movements or large scale weather events, happen at regional or even larger scales and are unlikely to be affected by a change in the ecosystem state.

5 Mapping Potential Delivery of Ecosystem Service

This section describes the gathering of spatial data and the mapping of the potential delivery of selected ecosystem services in the UK marine environment. Understanding of the spatial range, scale and patterns of ecosystem services could prove important factors to feed into future management prescriptions.

Ecosystem service mapping has been undertaken or discussed as part of several studies, notably the Mapping and Assessment Ecosystem and their Services report (Maes *et al* 2013), a study by Galparsoro *et al* (2014) and studies by Medcalf *et al* (2012; 2014).

For the purposes of this report, three ecosystem services, one from each of the provisioning, regulation and maintenance and cultural ecosystem service sections of the CICES classification framework have been selected for mapping. These services were carefully chosen based on data availability, robustness of mapping rationale, and their overall demonstrative potential for testing the mapping method. In order to accurately map the potential for service delivery it was necessary to consider the specific service within the ecosystem service classes.

The ecosystem services selected for mapping are shown in Table 11.

Table 11. Ecosystem services selected for mapping from each main ecosystem service section in accordance with the CICES framework (version 4.3).

Section	Division	Group	Class	Ecosystem Service
Provisioning	Materials	Biomass	Fibres and other material from plants, algae and animals for direct use or processing	Provision of kelp (*Laminaria hyperborea*) for use in alginate, food, biofuels, medicine and other chemicals
Regulation & Maintenance	Mediation of wastes, toxins and other nuisances	Mediation by biota	Bioremediation by microorganisms	Bioremediation of hydrocarbons in the marine environment by microorganisms
Cultural	Physical and intellectual interactions	Physical and experiential interactions	Physical use of seascapes	Delivery of ‘good’ experiential diving experiences

Data for the selected ecosystem services was initially gathered through a data mining exercise before the collated data layers were mapped. The outputs of these exercises are discussed in detail in the following sections.

5.1 Data Mining

In order to map potential ecosystem service delivery in the UK, the available spatial data on the components and processes which affect them were collated through a data mining exercise. The specific datasets that were sought are outlined in the respective ecosystem service sections (5.2.1 – 5.2.3) presented below. The outputs from the literature review and identification of critical ecosystem components and processes were used to inform the search.

A variety of geographic databases and online mapping facilities were searched for data potentially suitable for mapping ecosystem services and/or their critical biotic and abiotic components. Marine geographic data can be viewed and acquired from a range of data portals, including European-funded data networks, governmental bodies, academic institutions, conservation agencies and consultancies. Marine geographic data types range from point data (e.g. species distribution) and polygon data (e.g. predicted seabed substrate and habitat), to one-dimensional raster layers of the seabed (e.g. remotely-sensed bathymetry data) and multi-dimensional oceanographic data of the water column. The latter are usually derived from numeric models which compute complex hydrodynamic information for several depth bands and time scales, needing further processing to be used for mapping. In some instances these model outputs have already been further processed into meaningful and ready-to-use data layers, such as the *spring peak tidal stream* data derived from the POLCOMS numeric model[5].

A non-exhaustive geographic data inventory for the UK Exclusive Economic Zone (EEZ, defined as the maximum spatial extent for consideration in this report) is provided in Electronic Appendix 2. While most of these data are freely available, some require registration, while others may be restricted to privileged users or subscription services.

Due to the time and resource constraints it was decided to only include datasets that were already digitised, in GIS format, and freely available. The constraints of this are further discussed in Section 5.4 and details of specific datasets that have been identified, but which were not included in the report, are shown in the relevant sections below.

Confidence in the individual data layers that feed into the mapping outputs has been assessed using the confidence score matrices shown in Appendix 4. The full results of the confidence assessment are presented in Appendix 5 and summarised in Tables 12-14.

The confidence assessment assigns partial confidence scores to data quality parameters, including data age (vintage), spatial resolution adequacy, acquisition method and the degree of ground-truthing undertaken, which were added together to derive an overall confidence score. The latter is then categorised into high, medium or low overall confidence classifications. The assessment was designed to allow evaluation of confidence for all varying data types used in this report, ranging from point data derived from field observations to modelled or remotely sensed oceanographic raster data.

Within the scope of this report geographic data were considered suitable if they were:

i) a direct measure or proxy for biotic and abiotic components or processes affecting the spatial patterns of the marine ecosystem service under consideration;
ii) of sufficient resolution (i.e. cell size) to capture relevant spatial variation within the UK EEZ;
iii) fully covered all or some of the relevant area of the UK EEZ;
iv) already digitised and/or processed into a meaningful data layer;
v) free of charge and available to access.

The results of the data mining exercise are presented as a mapped distribution for each data layer in the context of each ecosystem service in Section 5.2. Expanded details of each data layer are available in Electronic Appendix 2.

5.2 Mapping of Ecosystem Services

Potential ecosystem service delivery maps were created by combining the various data layers as grid files and shapefiles in ArcGIS (version 10.3). Each data layer was overlain and clipped to the UK Exclusive Economic Zone (EEZ). The shapefiles were then clipped to

[5] POLCOMS model produced by the British Oceanographic Data Centre: https://www.bodc.ac.uk

common areas to show potential areas where the specific ecosystem service could be delivered.

Caveats, limitations and restrictions associated with the mapping outputs produced are presented in Section 5.4.

5.2.1 Provisioning ecosystem services – Fibres and other material from plants, algae and animals for direct use or processing: Kelp (*Laminaria hyperborea*)

The kelp species *Laminaria hyperborea* provides multiple ecosystem services, especially within the provisioning category. Kelp is exploited in a range of European and Asian countries for the production of alginate, food, biofuels, medicine and other chemicals (McHugh 2003). French and Norwegian kelp industries, for example, harvest 50,000 tonnes of *Laminaria digitata* and 200,000 tonnes of *L. hyperborea* annually for alginate production (Edwards & Watson 2011). Kelp also delivers important regulation and maintenance services, including primary production, nutrient cycling, bioengineering and flood and erosion prevention (Yesson *et al* 2015). The environmental requirements and spatial distribution of common kelp species, including *L. hyperborean,* around the British Isles have been well documented (e.g. Kain 1971; Nauderhaug & Christie 2011; Yesson *et al* 2015), making this species a suitable candidate for the mapping exercise.

Peer-reviewed literature was sourced to identify the biotic and abiotic components affecting the provisioning services delivered by kelp, in particular *L. hyperborea*. Water temperature, salinity and nutrient (i.e. nitrate and phosphate) availability are important components limiting the species' biogeographical range to the North East Atlantic (Kain 1971; Nauderhaug & Christie 2011). Within waters of the UK EEZ, *L. hyperborea* distribution is largely driven by the availability of hard substrata for attachment, the availability of light for photosynthesis, certain exposure preferences to tidal and wave energy, and biotic components such as grazing, competition and anthropogenic exploitation (Kain 1971; Yesson *et al* 2015).

L. hyperborea distribution data was obtained from the Ocean Biogeographic Information System (OBIS) database[6]. A total of 9,692 data points for *L. hyperborea* were available within the UK EEZ, out of which 9,581 were available and accessible for use in this report. The species' life span is thought to be up to 20 years (Kain 1971) and the inclusion of outdated or historical observations could be misleading. Following methods by Yesson *et al* (2015), the data points were therefore further filtered to include those collected from the year 2000 onwards, resulting in a total of 3,662 distribution points. (For a full list of databases used to inform this dataset please see Appendix 6). Due to time constraints associated with the report, other data sources for the distribution of kelp, such as the National Biodiversity Network (www.nbn.org.uk/) or Marine Recorder (http://jncc.defra.gov.uk/page-1599) were not considered.

Table 12 summarises the main ecosystem components that effect the spatial distribution of *L. hyperborea* and thus the potential for ecosystem service delivery. The table also summarises the data layers needed to map the component and the source material used in the creation of the maps. Confidence in each data layer is assessed in full in Appendix 5. Full references and details of source data layers are presented in Electronic Appendix 2.

Maps of each ecosystem component produced based on the data outlined in Table 12 are presented in Figures 1-9.

[6] Ocean Biogeographic Information System database: http://www.iobis.org

Table 12. Biotic and abiotic components influencing provisioning of ecosystem service delivery of *L. hyperborea.* Please see Electronic Appendix 2 for full reference of each data source and data resolution/scale and Appendices 5 and 6 for details of the confidence assessment.

Component/ process	Rationale	Data layer	Data source	Confidence in data layer
Laminaria hyperborea distribution	The provisioning service delivered by kelp is largely dependent on its occurrence and abundance.	*L. hyperborea* distribution	OBIS	High
Temperature	Water temperature constrains the latitudinal and vertical distribution of kelp (Van den Hoek 1982; Yesson *et al* 2015). Water temperatures in the UK EEZ are within the range tolerated by *L. hyperborea*.	Mean Sea Surface Temperature (Figure 1)	Bio-ORACLE	Medium
Salinity	Kelp generally grows in fully saline waters and the absence of *L. hyperborea* from the Baltic is thought to be due to reduction in salinity (Kain 1971). The species' preferred salinity range is 30-40ppt (Tyler-Walters 2007).	Salinity (Figure 2)	Bio-ORACLE	Low
Nutrient availability	The availability of nutrients is a key component in controlling the abundance and diversity of marine fauna and flora (Hiscock *et al* 2006). Upper and lower limits of nutrient availability for kelp growth have not been established as nutrient requirements are highly interdependent with other components such as light, water motion and temperature (Dayton 1985). Nutrient storage has also been observed for *Laminaria* species (Dayton 1985). Generally, nutrient availability is thought to constraint the latitudinal distribution of Kelp to the NE Atlantic (Yesson *et al* 2015).	Nitrate (µmol/l), Phosphate (µmol/l) (Figures 3 & 4)	Bio-ORACLE	Low
Light attenuation & availability	Kelp requires light for photosynthesis and light availability is directly linked to the abundance and distribution of the species in UK waters. For Laminarians, one percent of surface irradiance is considered to be the lower limit (Luning 1980).	Diffuse attenuation coefficient at 490nm (m^{-1}); Photosynthetic-ally available radiation (Einstein m^{-2} Day^{-1}) (Figures 5 & 6)	Bio-ORACLE	Medium
Tidal currents	*L. hyperborea* grows in weak to moderately strong tidal currents of up to 3 knots (1.5 m/sec.) (Tyler-Walters 2007).	Spring peak tidal flow (Figure 7)	POLCOMS, ABPmer	Medium
Wave action	Wave action defines the upper limit of kelp distribution in the water column. *L. hyperborea* has been reported absent from sheltered areas and also from areas of extreme wave action since the stiff stipe is likely to snap or holdfasts tear off (Tyler-Walters 2007).	Mean annual wave height (Figure 8)	POLCOMS, ABPmer	Medium

Component/ process	Rationale	Data layer	Data source	Confidence in data layer
Sediment type/seabed habitat	Kelp requires hard substrate such as bedrock, boulders, cobbles, pebbles or man-made structures to grow on (Kain 1971; Yesson *et al* 2015). Taking into account light availability and energy exposure, kelp habitat is restricted to low to high energy infralittoral rock as well as sublittoral macrophyte-dominated sediment.	EUNIS classes considered suitable: A3.1, A3.2, A3.3,A5.5 (Figure 9)	EUSeaMap	Medium

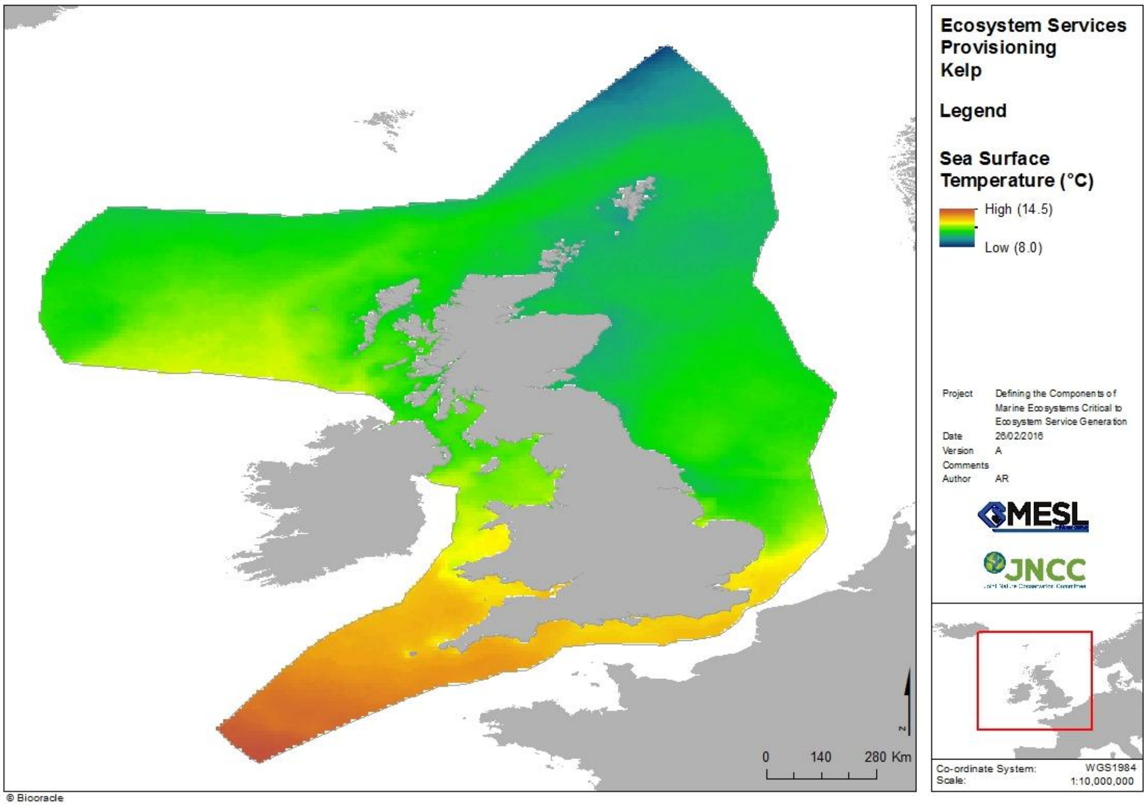


Figure 1. Sea surface temperature, mapped according to Bio-ORACLE data. Sea surface temperature has a direct influence on kelp growth and distribution, with water temperatures above 17°C being typically less favourable (Kain 1971; Van den Hoek 1982).

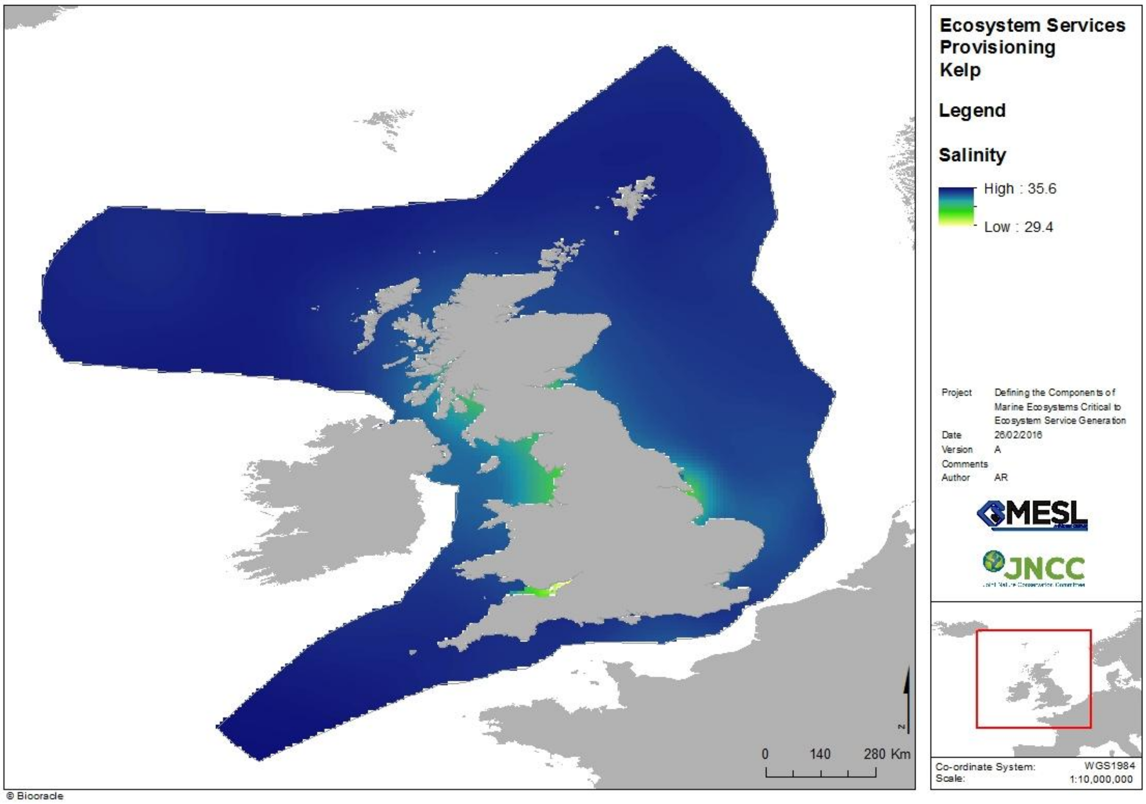


Figure 2. Salinity, mapped according to Bio-ORACLE data. Salinity is a controlling factor on kelp distribution; high (full, 30-35ppt) salinity is typically required for kelp to prosper (Tyler-Walters 2007).

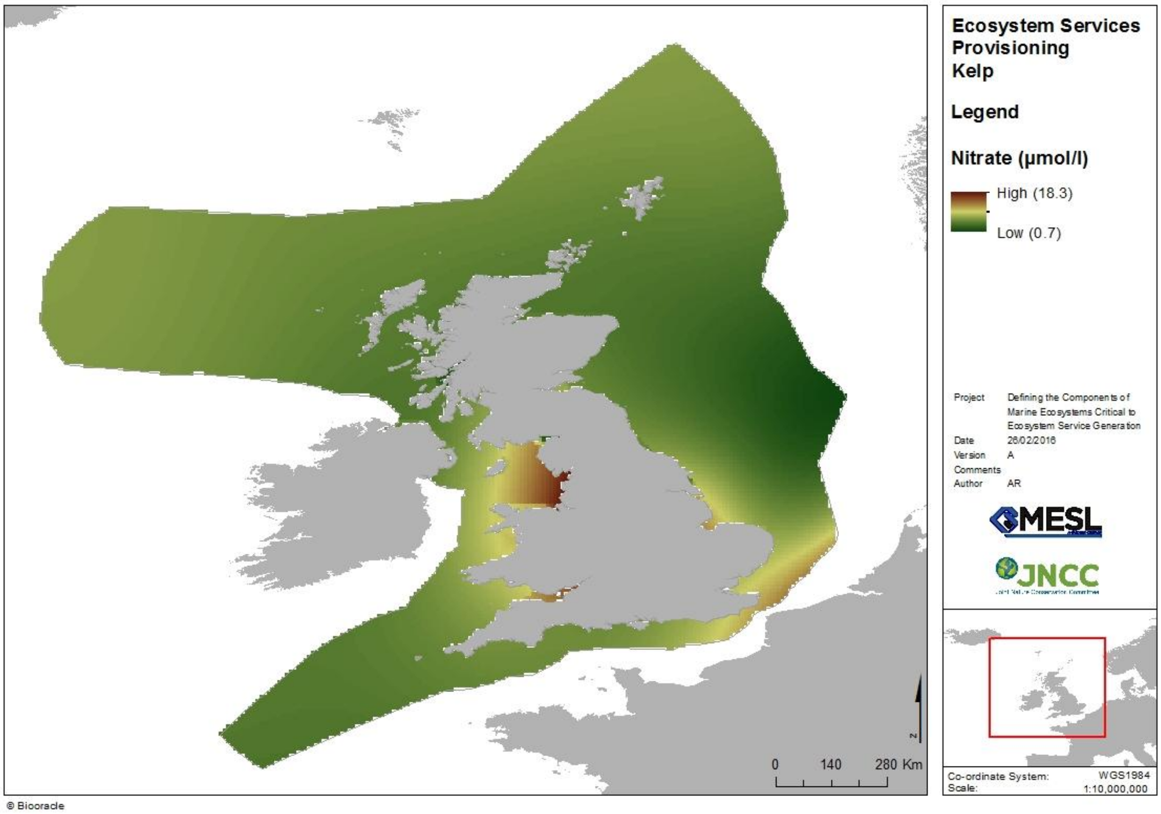


Figure 3. Concentration of nitrate, mapped according to Bio-ORACLE data. Higher nutrient availability is likely to promote kelp growth (Yesson *et al* 2015).

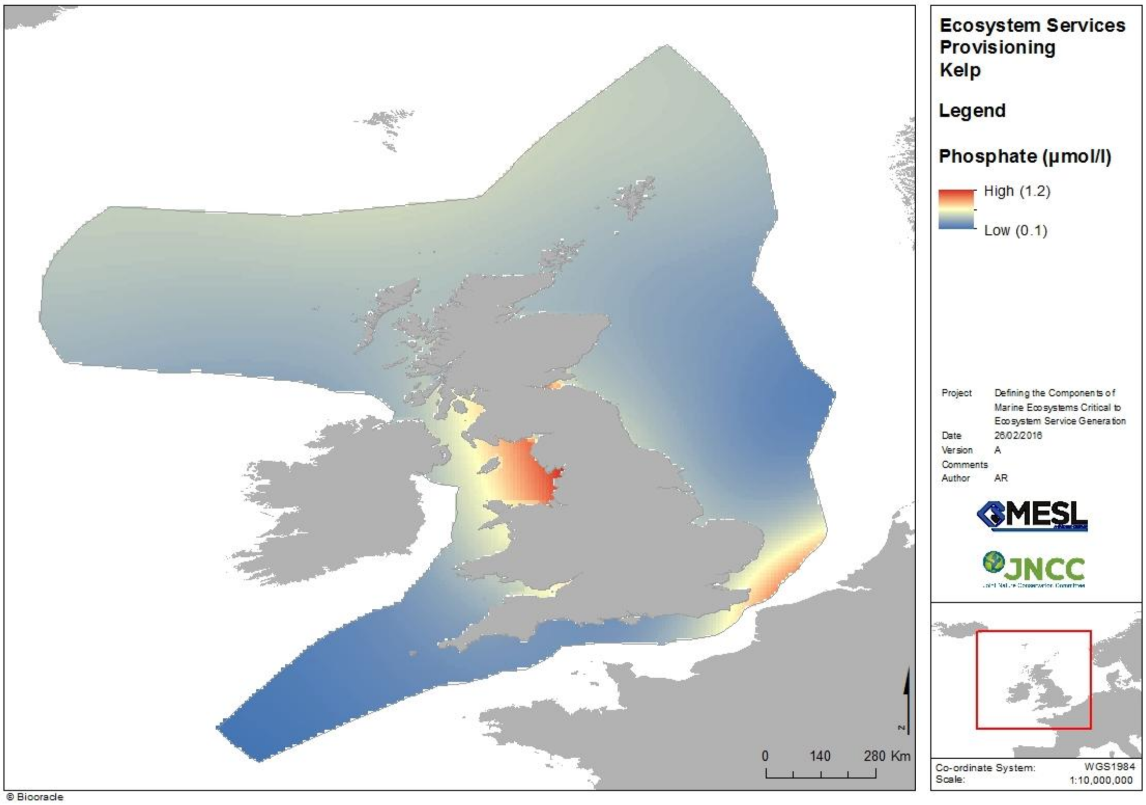


Figure 4. Concentration of phosphate, mapped according to Bio-ORACLE data. Higher nutrient availability is likely to promote kelp growth (Yesson *et al* 2015).

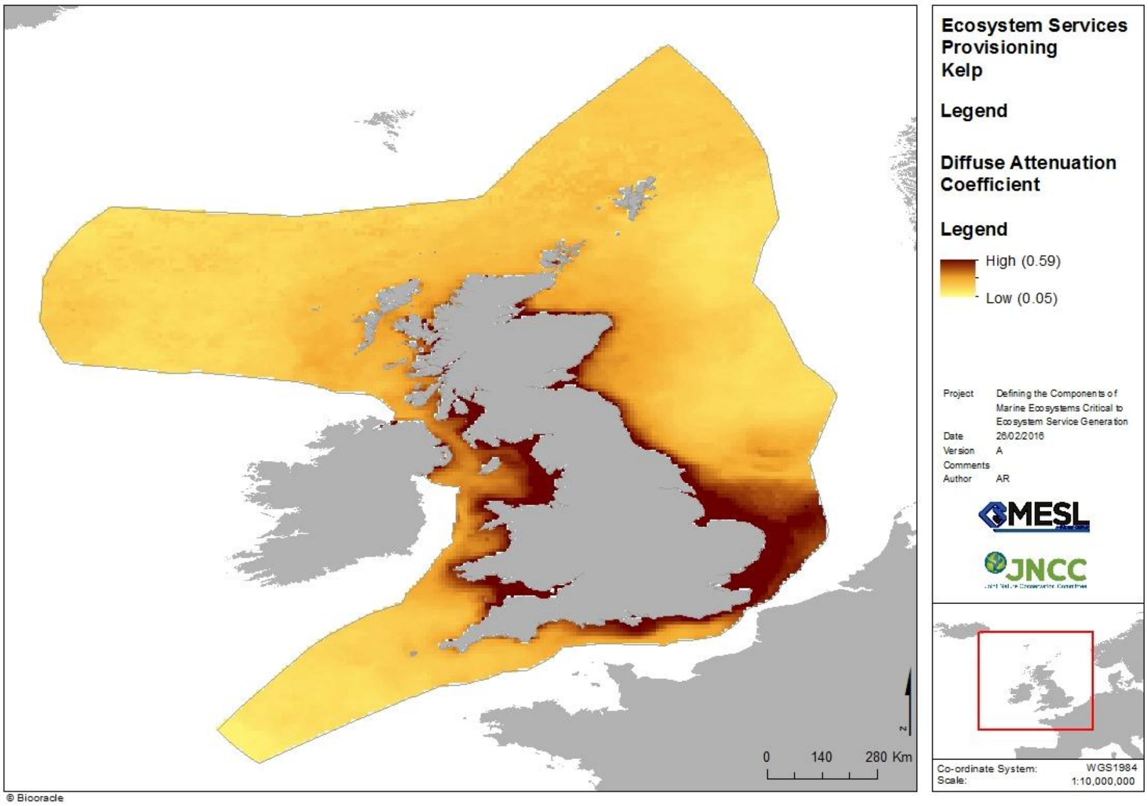


Figure 5. Light attenuation, mapped as diffuse attenuation coefficient according to Bio-ORACLE data. The attenuation of light is necessary for kelp growth (Luning 1990), thus kelp is likely to prosper more in places with a lower attenuation coefficient.

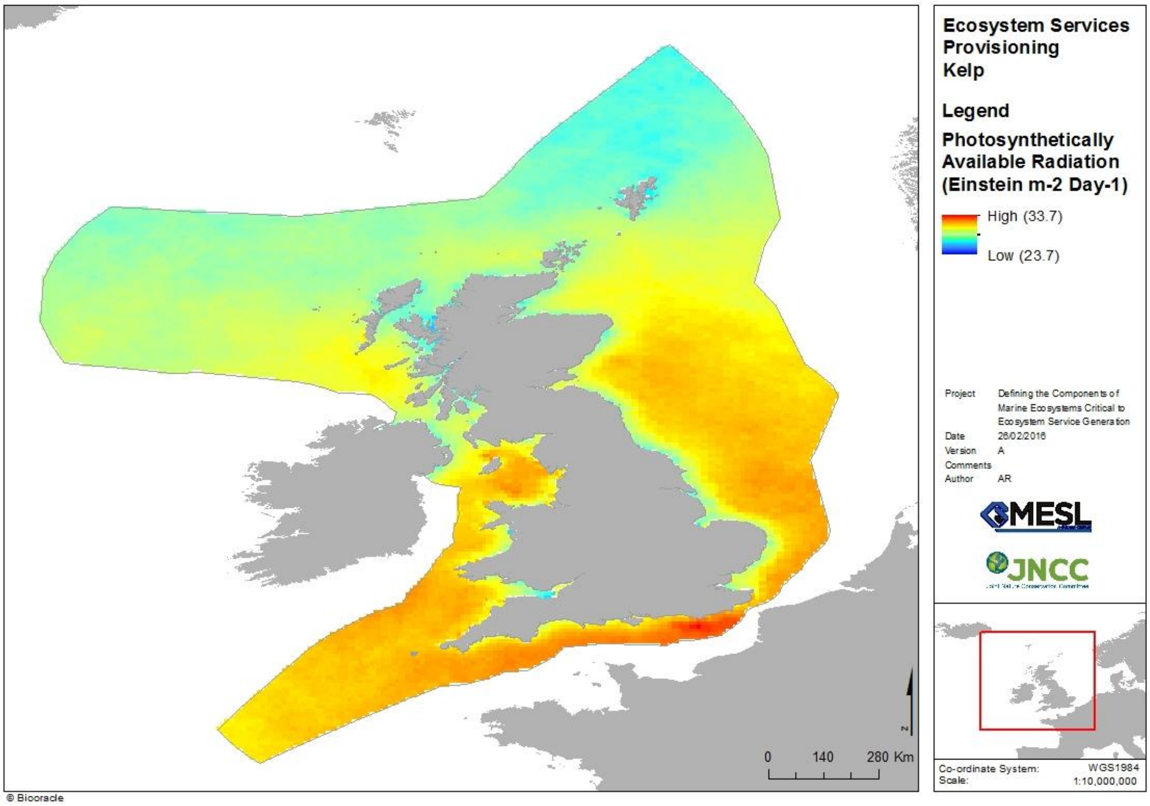


Figure 6. Light availability, mapped as photosynthetically available radiation according to Bio-ORACLE data. Kelp require light to photosynthesise (Luning 1990) and are therefore more likely to prosper in areas where greater photosynthetically available radiation is present.

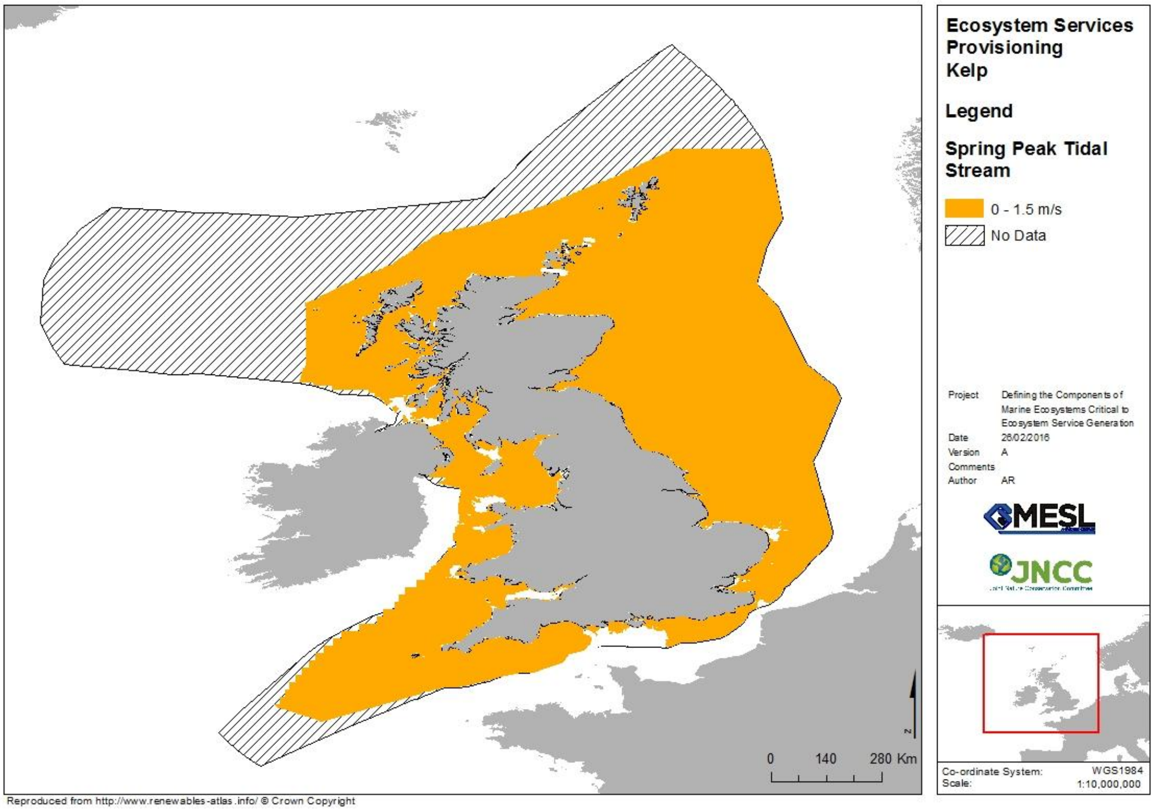


Figure 7. Tidal current, mapped according to POLCOMS (ABPmer) data. *L. hyperborea* distribution is limited to weak to moderately strong tidal currents of up to 3 knots (1.5m/sec.) (Tyler-Walters 2007).

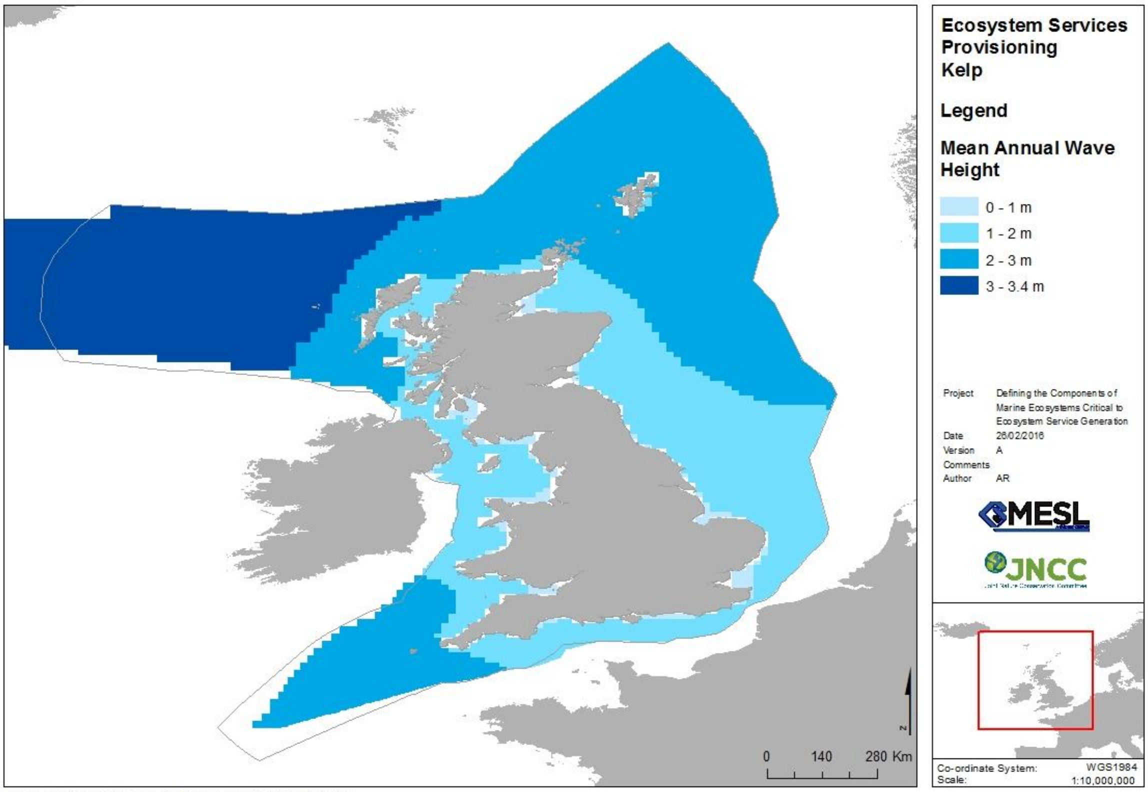


Figure 8. Wave action, mapped according to POLCOMS/ABPmer data. *L. hyperborea* has been reported absent from sheltered areas and also from areas of extreme wave action (Tyler-Walters 2007).

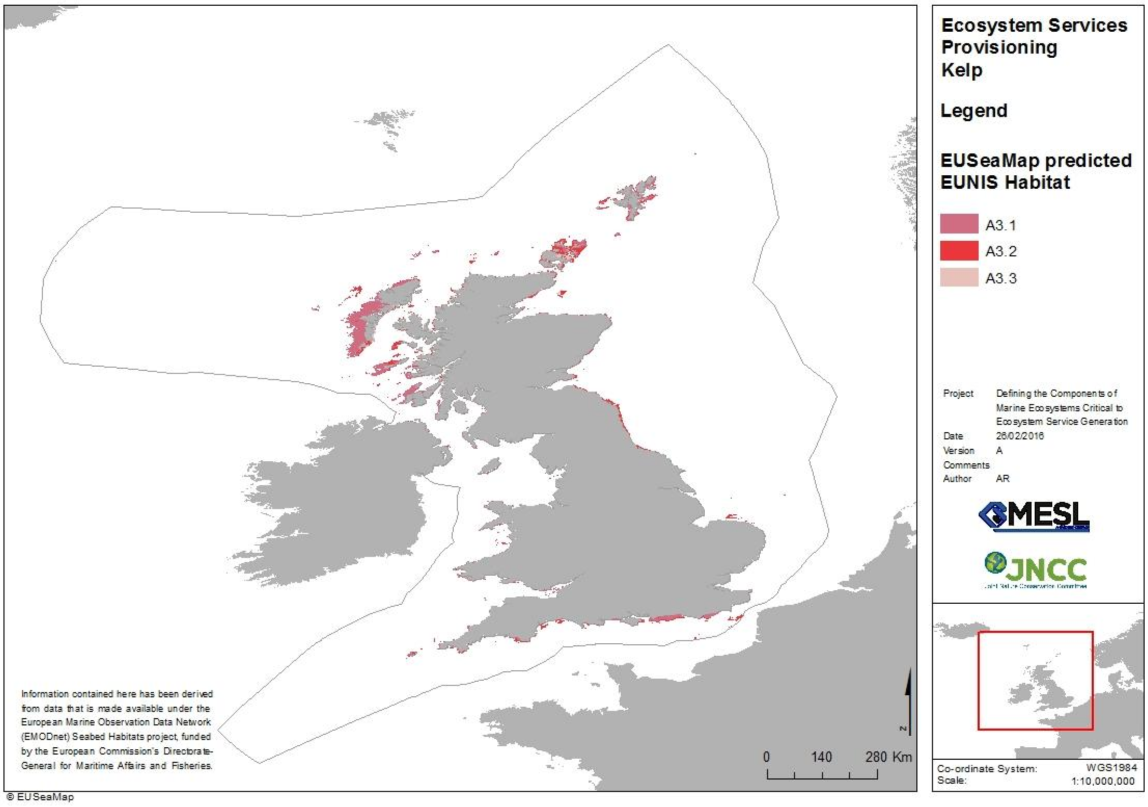


Figure 9. Preferred habitat type, mapped according to EUSeaMap data. Kelp requires hard substrate to grow on (Kain 1971); considering light availability and energy level, kelp habitat is generally restricted to the biotopes A3.1 (high energy infralittoral rock), A3.2 (moderate energy infralittoral rock) and A3.3 (low energy infralittoral rock).

Yesson *et al* (2015) used a similar set of environmental variables to compute predictive habitat suitability maps for common seaweeds of the British Isles. The predictive model identified an area of almost 50,000km^2 within the British Isles to be suitable for *L. hyperborea*, which was limited to 16,000km^2 when only areas of hard substrata were considered. However, the spatial detail of predictive models is generally limited by the spatial resolution of the underlying data. They further do not take into account biotic components such as grazing and predation, and therefore can over-estimate the actual range of the species distribution and the related ecosystem services it delivers.

As is the case for many other provisioning services, the delivery of ecosystem services by kelp is strongly tied to its actual occurrence and abundance, regardless of the various ecosystem components which affect ecosystem service delivery. The ecosystem components which affect service delivery should in theory match with mapped kelp distribution, yet in practice this is not an exact match, likely due to errors in predictive/modelled data, and localised environmental conditions. It is therefore proposed that the most effective and accurate way to map the ecosystem service delivery potential associated with *L. hyperborea* is to map the species distribution by plotting its known spatial extent.

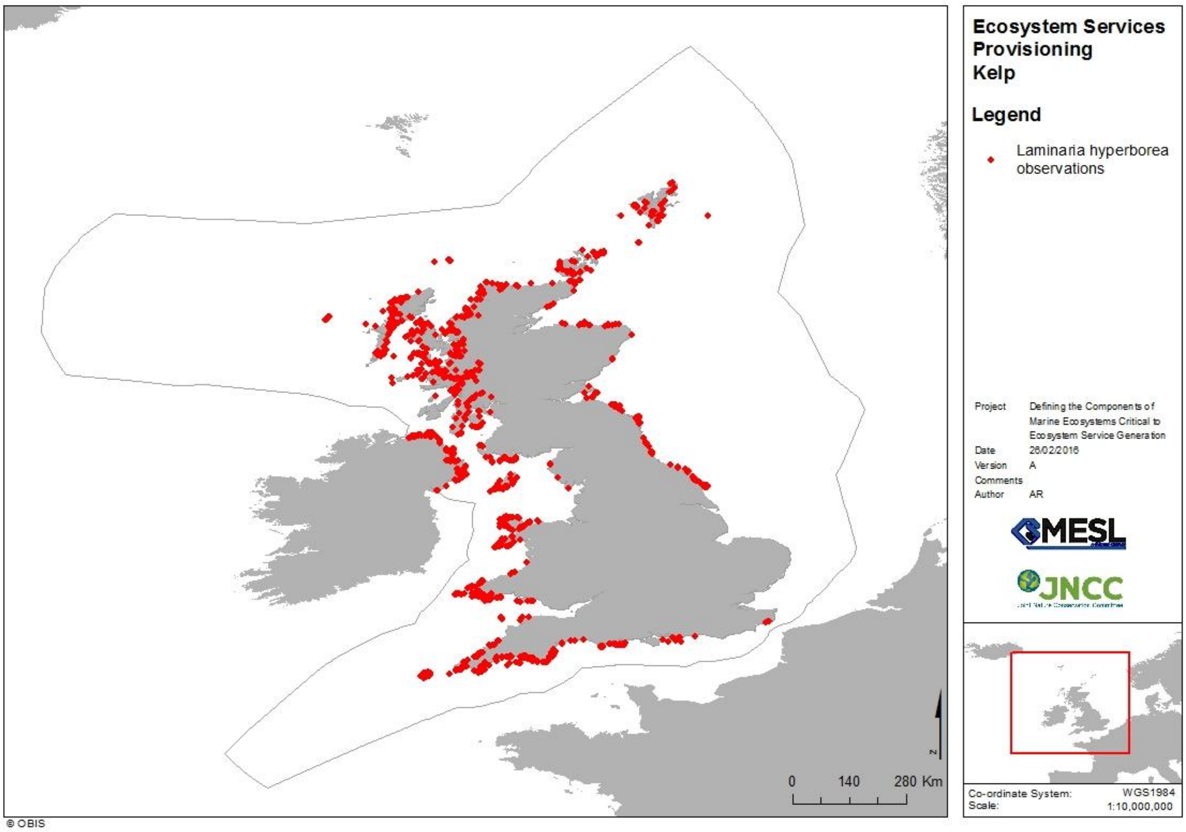


Figure 10. The distribution of *L. hyperborea* in the UK, mapped according to OBIS data, indicating the extent of potential provisioning ecosystem services associated with this species.

The final map shown in Figure 10 illustrates the known distribution of the kelp species *Laminaria hyperborea*, and hence the spatial pattern and extent of where the associated provisioning ecosystem services are likely to occur. The species is widespread in the infralittoral zone around most of the UK's coastline, except for the east of England, where lack of hard substrate inhibits its growth (Yesson *et al* 2015).

A limiting factor when mapping this service is the point data representing species occurrences as this cannot be used directly for calculations of coverage or biomass, thus inhibiting quantitative assessments and economic valuation. The mapped kelp distribution will also be reflective of survey effort, so will be an under-estimate of its actual occurrence. Attempts were made during this research to enhance the distribution data by using EUNIS biotopes which contain kelp as a proxy for presence, but suitable resolution to EUNIS Level 4/5 is not available for this habitat type.

Some degree of correlation between the component data layers and the species distribution is evident, meaning that the layers could be used to develop a model for kelp distribution to fill in the gaps in sampling effort. Such a model might also be able to estimate biomass. However, the overriding component affecting the distribution in the case of kelp is suitable substrate to attach to, and the EUSeaMap layer used to model this is itself based on modelling. The uncertainties in this data would therefore carry across to any model based on it.

5.2.2 Maintenance and regulation services – Bioremediation of hydrocarbons by microorganisms

The bioremediation of pollutants, hydrocarbons in particular, is an important ecosystem service in the maintenance and regulation category. Pollutant contamination of the marine environment is widespread, with some of the most detrimental pollutants including nutrients, pesticides, heavy metals and hydrocarbons (Kennish 1996). Almost any chemical substance introduced into the marine environment will eventually be attacked by adapted microorganisms, which excrete enzymes capable of breaking them down into simpler molecules, which are then taken up by these microorganisms and metabolised for energy (Zilinskas 1998; Boopathy 2000; Dubey & Roy 2003; Baker *et al* 2014).

As hydrocarbons occur naturally in the marine environment, a diverse community of marine microorganisms have developed the capability of degrading hydrocarbons (Atlas & Hazen 2011). Biodegrading microorganisms have been widely used as biological treatment system for various applications include *inter alia,* rehabilitation of contaminated water and soils, cleaning up oil spills, chemical spills and toxic industrial effluents (Boopathy 2000; Atlas & Hazen 2011). For example, oil-degrading microorganisms that are indigenous to the Gulf of Mexico played a significant role in reducing the overall environmental impact of the British Petroleum (BP) Deepwater Horizon oil spill in the Gulf in 2010 (Atlas & Hazen 2011).

It has been estimated that annually more than two million tons of petroleum reach the seas as a result of run-off from land, offshore oil exploitation, discharge of ballast water, and accidents (Hassanshahian & Cappello 2013). Crude oil is a heterogeneous, hydrophobic mixture of saturates, aromatics, asphaltenes and resins (Boopathy *et al* 2012). As many of these hydrophobic compounds are less dense than seawater, they form sheens on the ocean surface (Atlas & Hazen 2011). Approximately 60% of the estimated 780 million litres of crude oil released in the Deepwater Horizon oil spill ultimately reached the water surface, where the observed oil sheen covered up to 180,000km^2 (Atlas & Hazen 2011).

Biodegrading microorganisms are ubiquitous in the marine realm (Atlas & Hazen 2011). Key components influencing rates of oil biodegradation are thought to be the chemical and physical properties of the oil, environmental components of the water column (e.g. nutrient availability, oxygen availability, temperature), and the composition of the resident microbial community (Zilinskas 1998; Atlas & Hazen 2011).

Table 13 summarises the abiotic and biotic components and processes that could potentially affect ecosystem service delivery of biodegrading microorganisms within the UK EEZ, and the corresponding spatial data to be used for mapping this regulation and maintenance service. Confidence in each data layer is assessed in full in Appendix 5. Full references and details of source data layers are presented in Electronic Appendix 2.

Maps of each ecosystem component produced are based upon the data outlined in Table 13 and are presented in Figures 11-16.

Table 13. Biotic and abiotic components affecting ecosystem service delivery of biodegrading microorganisms, with associated spatial datasets. Please see Electronic Appendix 2 for full reference of each data source, data resolution and scale, and Appendices 5 and 6 for details of the confidence assessment.

Component/ Process	Rationale	Data layer	Data source	Confidence in data layer
Temperature	Temperature affects enzymatic activity of biodegrading microorganisms, with rates typically decreasing with decreasing temperature. However, biodegradation occurs at a temperature range of 0 - 80°C (Atlas & Hazen 2011).	Mean Sea Surface Temperature (°C) (Figure 11)	Bio-ORACLE	Low
Oxygen	Molecular oxygen is required during the oxidation of hydrocarbons by oxygenase enzymes. However, oxygen is hardly ever a limiting factor in biodegradation in the water column (Hassanshahian & Cappello 2013).	Dissolved oxygen (ml/l) (Figure 12)	Bio-ORACLE	Low
pH	Most heterotrophic bacteria favour a near neutral pH. In marine waters, pH is usually stable around close to neutral and is not considered a limiting factor for biodegradation in surface waters (Hassanshahian & Cappello 2013).	pH (Figure 13)	Bio-ORACLE	Low
Wave action	Wave action disperses hydrocarbons in the water column, enhancing biodegradation rates by spreading the pollutants over a wider area, making them more accessible to microorganisms (Santas & Santas 2000)	Annual mean wave height (Figure 14)	POLCOMS, ABPmer	Medium
Nitrate	Nutrient availability is the main limiting component in bioremediation (Hassanshahian & Cappello 2013). Upper and lower limits of nutrient availability for bioremediation have not been established; microorganisms are likely to be present in a range of nutrient conditions, although are expected to produce a greater level of service in areas which contain a higher availability of essential nutrients (Hassanshahian & Cappello 2013).	Nitrate (μmol/l) (Figure 15)	Bio-ORACLE	Low
Phosphate	Nutrient availability is the main limiting component in bioremediation (Hassanshahian & Cappello 2013). Upper and lower limits of nutrient availability for bioremediation have not been established; microorganisms are likely to be present in a range of nutrient conditions, although are expected to produce a greater level of service in areas which contain a higher availability of essential nutrients (Hassanshahian & Cappello 2013).	Phosphate (μmol/l) (Figure 16)	Bio-ORACLE	Low

Component/ Process	Rationale	Data layer	Data source	Confidence in data layer
Iron	Nutrient availability is the limiting component in bioremediation (Hassanshahian & Cappello 2013). Upper and lower limits of nutrient availability for bioremediation have not been established; microorganisms are likely to be present in a range of nutrient conditions, although are expected to produce a greater level of service in areas which contain a higher availability of essential nutrients (Hassanshahian & Cappello 2013).	Iron (µmol/l)	Not available	

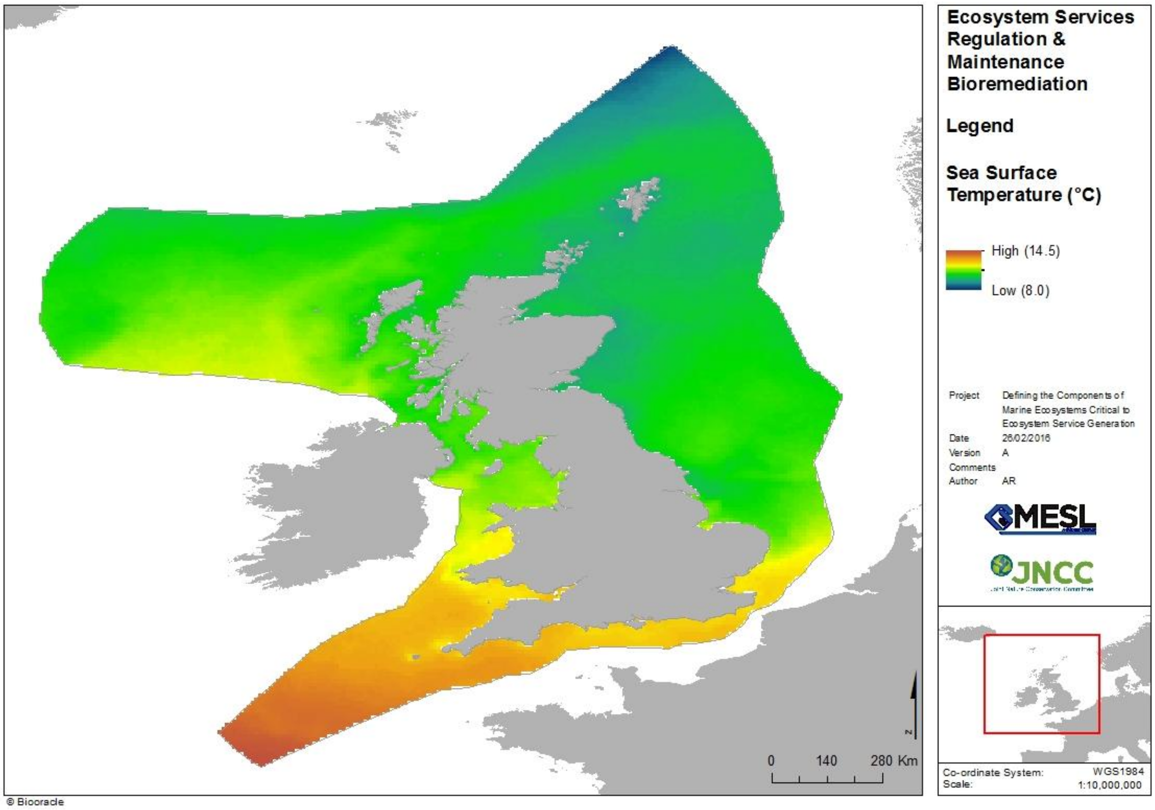


Figure 11. Sea surface temperature mapped according to Bio-ORACLE data. Sea surface temperature has a direct influence on microorganism metabolic rate; greater levels of bioremediation are likely to occur in warmer waters (Atlas & Hazen 2011; Hassanshahian & Cappello 2013).

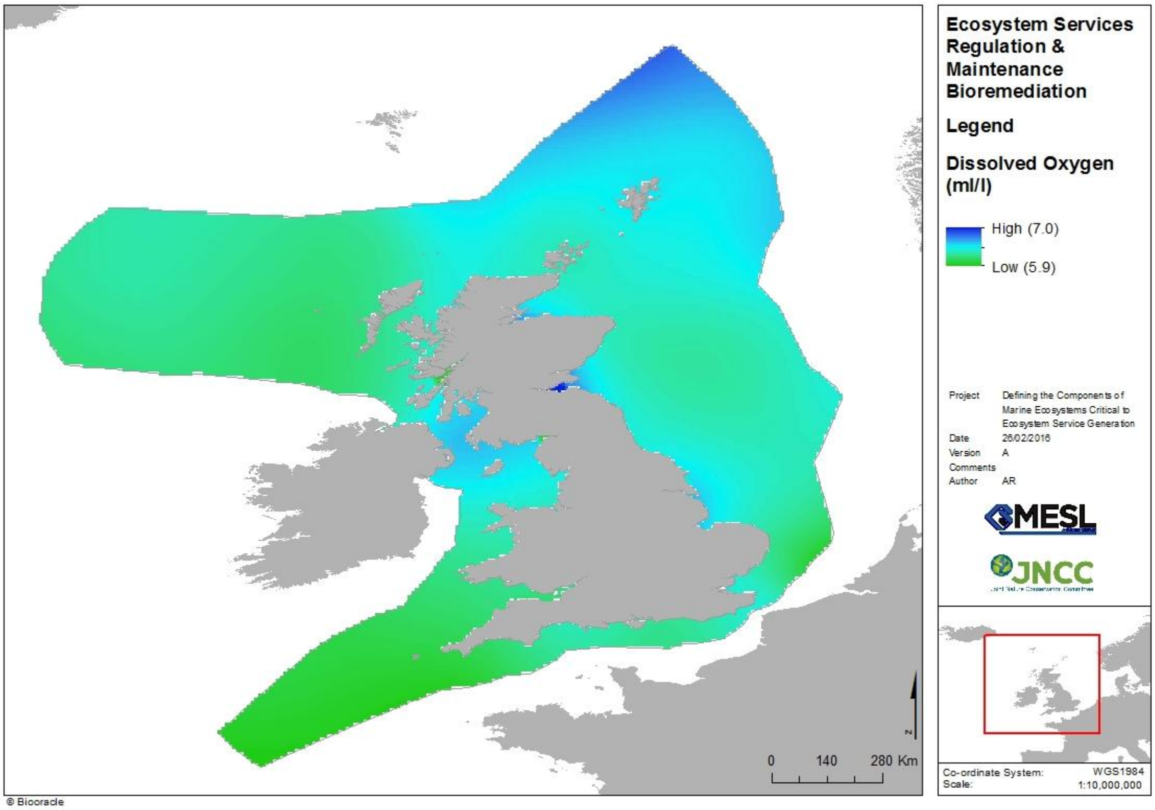


Figure 12. Dissolved oxygen mapped according to Bio-ORACLE data. Oxygen is required by microorganisms during the bioremediation process, thus this service is more likely to occur in well oxygenated areas (Hassanshahian & Cappello 2013).

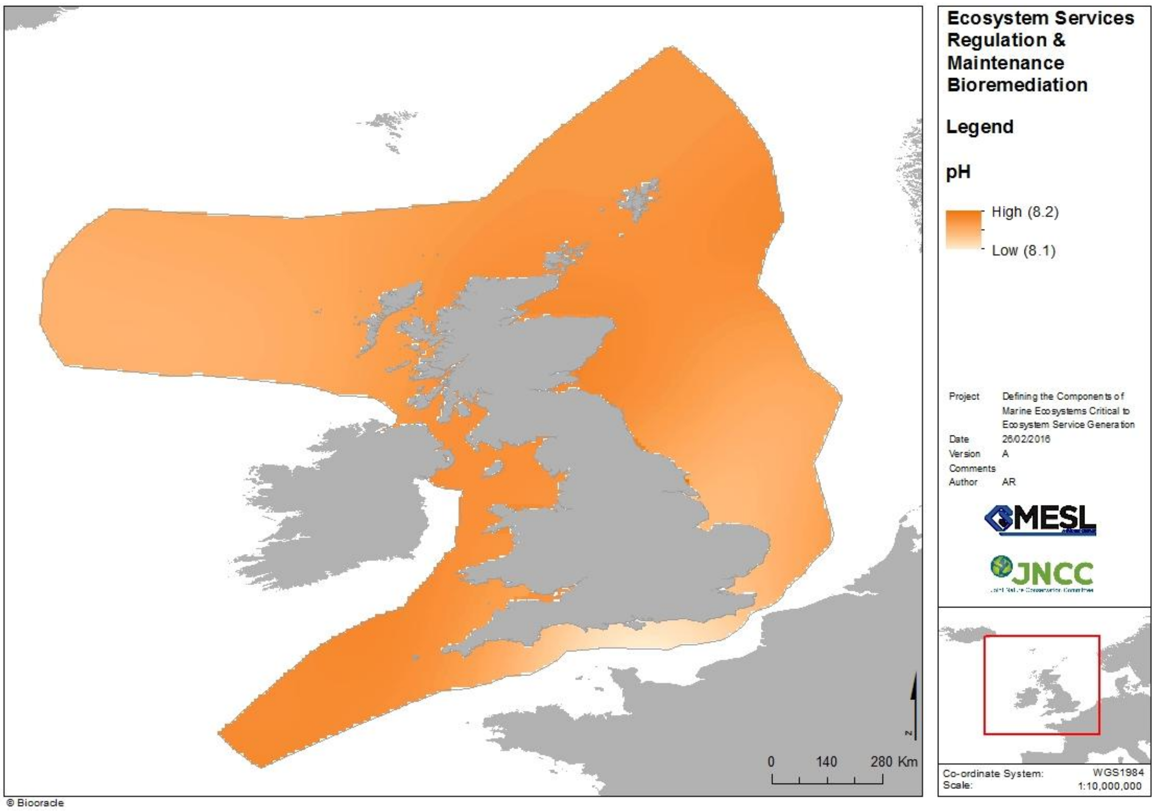


Figure 13. Sea water pH mapped according to Bio-ORACLE data. pH affects heterotrophic bacteria which favour a near neutral value; bioremediation is thus more likely to occur in areas with a pH close to 7 (Hassanshahian & Cappello 2013).

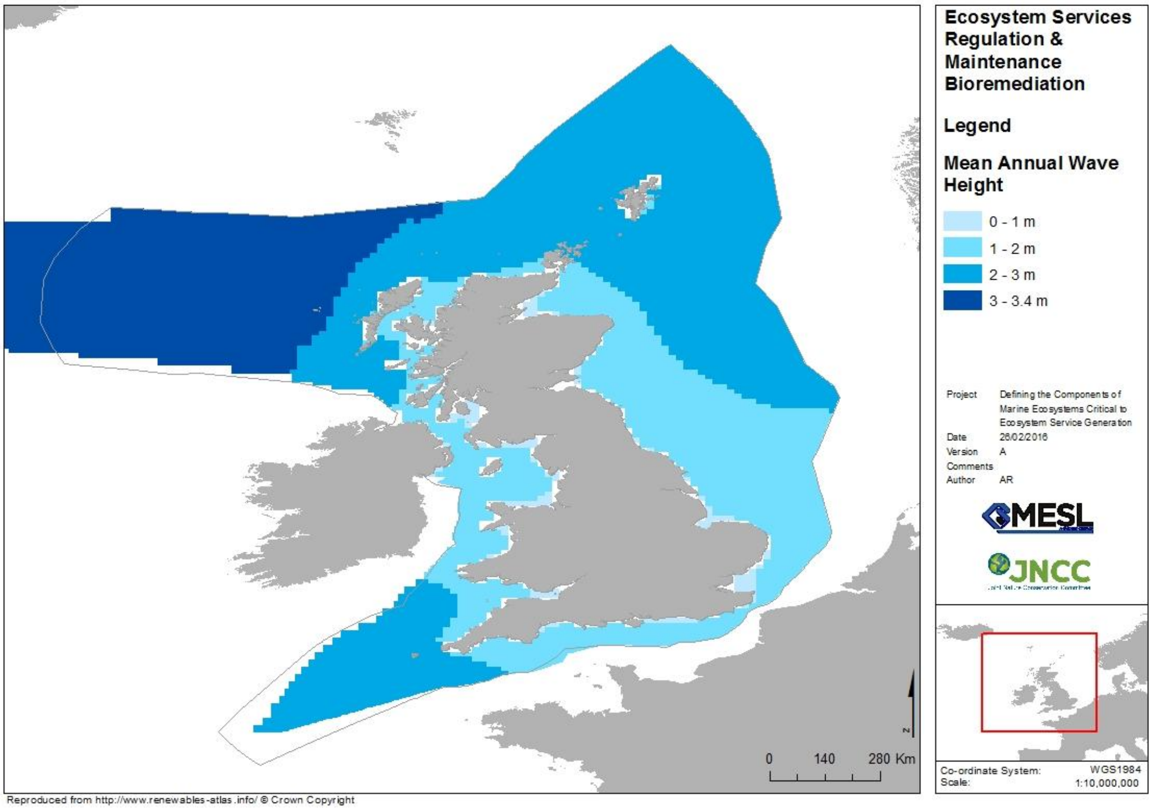


Figure 14. Wave mapped according to POLCOMS/ABPmer data. Bioremediation rates may be increased in areas of higher mean annual wave height (Santas & Santas 2000).

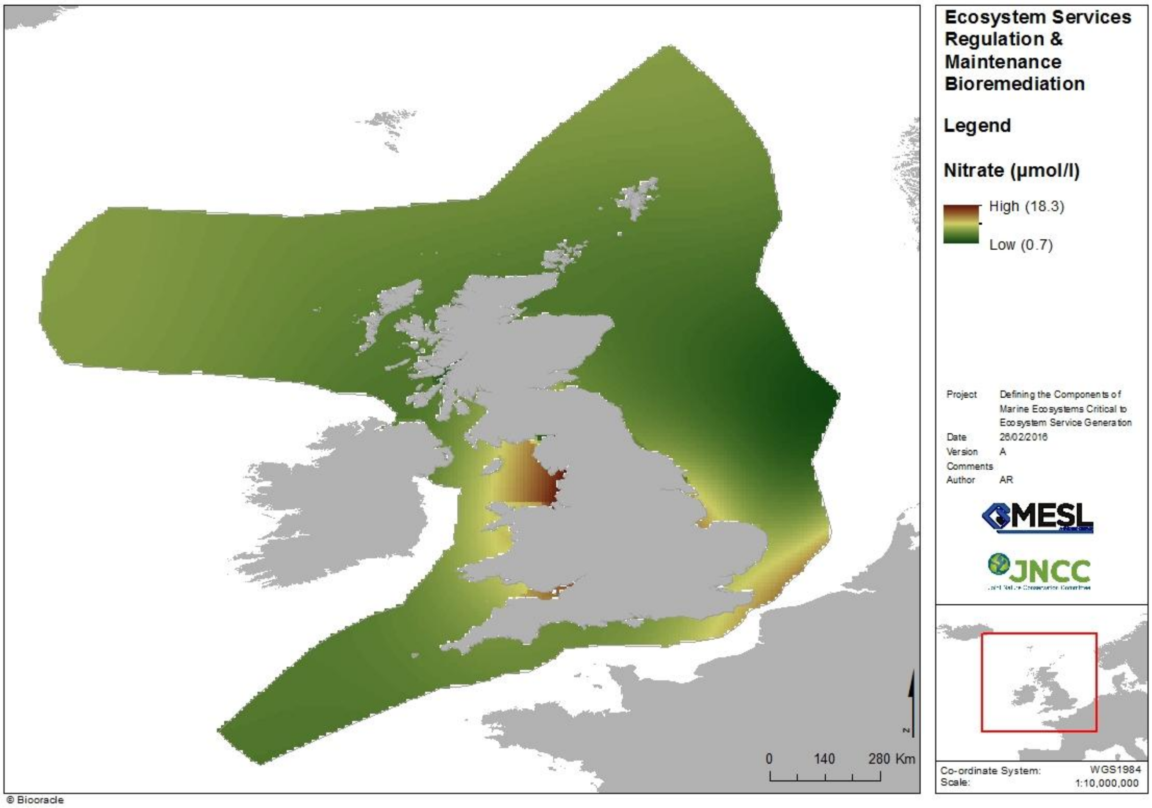


Figure 15. Concentration of nitrate mapped according to Bio-ORACLE data. Nutrient availability is important in determining the rate of bioremediation; higher concentrations are likely to promote greater remediation (Hassanshahian & Cappello 2013).

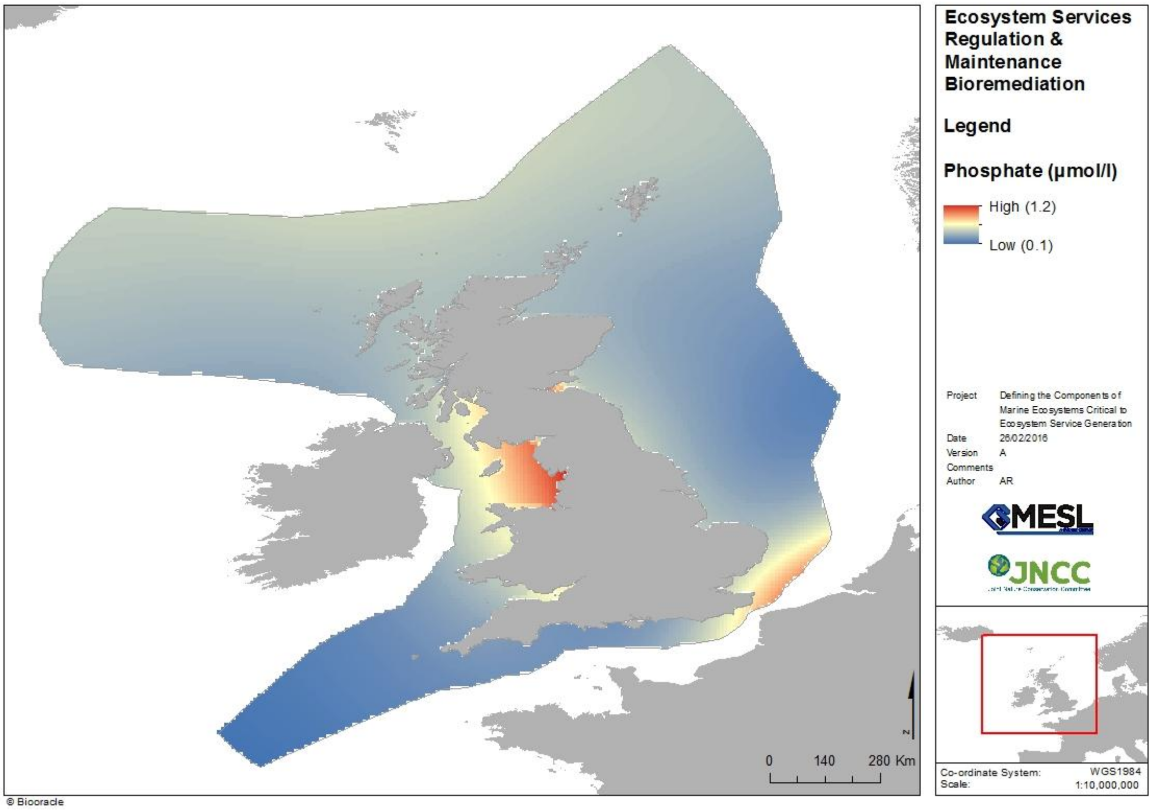


Figure 16. Concentration of phosphate mapped according to Bio-ORACLE data. Nutrient availability is important in determining the rate of bioremediation; higher concentrations are likely to promote greater remediation (Hassanshahian & Cappello 2013).

Biodegradation rates have been reported to decrease at colder temperatures, presumably due to a decrease in the microorganisms' metabolic rate (Hassanshahian & Cappello 2013). It is noteworthy that temperature also influences the physical characteristics and composition of hydrocarbons. At lower temperatures oil viscosity increases, the volatility of the lower chain hydrocarbons decreases and solubility decreases, all having negative effects on biodegradation rates (Atlas & Hazen 2011; Hassanshahian & Cappello 2013).

Oxygen is one of the most important requirements for microbial biodegradation of hydrocarbons, as it is required during the oxidation of polluting substances by oxygenase enzymes (Atlas & Hazen 2011; Hassanshahian & Cappello 2013). However, oxygen is rarely a limiting component in the biodegradation of marine oil spills, on or near the surface of the ocean, and does not appear to be a limiting component within surface waters of the UK EEZ (Figure 12). Anaerobic biodegradation is also known to occur, although its ecological significance is described as negligible (Hassanshahian & Cappello 2013).

Extreme pH values affect a microbe's enzyme activity and thereby its ability to degrade hydrocarbons (Hassanshahian & Cappello 2013). In marine surface waters, pH is shown to be relatively stable and does not seem to have an important effect on biodegradation rates (Hassanshahian & Cappello 2013). In salt marshes however, pH maybe as low as 5.0, and thus may slow the rate of biodegradation in these habitats (Hassanshahian & Cappello 2013). The pH in surface waters of the UK EEZ ranges between 8.1 and 8.2 (Figure 13) and is not considered to be a limiting factor on the spatial distribution of bioremediation ecosystem services (however, it is shown as a layer for which suitable quality data was freely available, thus was included in the mapping process).

As most components of crude oil are hydrophobic in nature, biodegradation by microorganisms takes place at the hydrocarbon-water interface. The surface-area-to-volume ratio of the pollutants has a direct effect on the surface area exposed to the biodegrading microorganisms, thus significantly influencing biodegradation rates (Atlas & Hazen 2011). The surface area to volume ratio of hydrocarbons may be influenced by wave energy spreading and breaking down droplets into smaller units (Santas & Santas 2000).

When excess carbon, in the form of hydrocarbon, is added to the water column due to an oil spill, nutrients necessary to support microbial growth such as nitrates, phosphates and iron quickly become a limiting factor for biodegradation rates (Atlas & Hazen 2011; Hassanshahian & Cappello 2013). Marine ecosystems are often deficient in these nutrients as they are also consumed by non-oil degrading microorganisms such as phytoplankton (Hassanshahian and Cappello 2013). Low concentrations of nutrients are available throughout the UK EEZ (Figures 15 & 16). Bioremediation of resident hydrocarbon-degrading microorganisms is therefore often enhanced by the addition of fertilisers containing nitrogen nutrients (Atlas & Hazen 2011), and indeed the addition of fertilisers to the marine environment to stimulate microorganism activity is a recognised oil spill remediation practice (Boopathy 2000; Atlas & Hazen 2011). Iron and other trace metals are also important for microbial growth, and the lack of iron in clear offshore waters is thought to be a limiting factor of bioremediation rates (Hassanshahian & Cappello 2013). However, no data layer for iron concentrations in UK marine waters could be sourced for this report (see Section 5.4).

Considering the ubiquity of biodegrading microorganisms in the marine environment (Atlas & Hazen 2011; Coulon *et al* 2006; Beolchini *et al* 2010), the quick adaptation of microbial communities to changes in the environment (Zilinskas 1998), and the lack of immediately limiting biotic or abiotic components in the water column, it can be concluded that bioremediation of hydrocarbons by microorganism has the potential to occur within the entire marine system of the UK to some degree, as shown in Figure 17. However, the rate of bioremediation will vary due to the factors discussed above. Using these factors to model potential bioremediation rate would be a possible future development of this work.

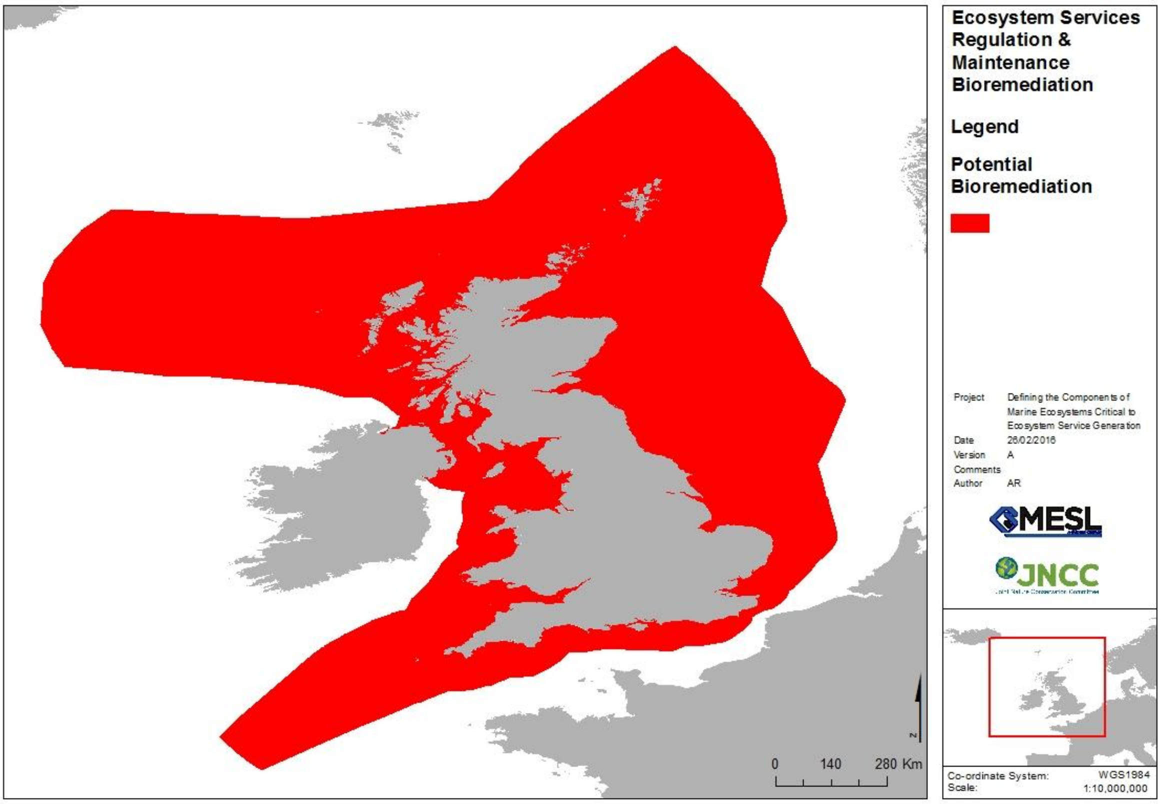


Figure 17. The distribution of potential bioremediation by microorganism ecosystem services in the UK, based on the ubiquitous distribution of microorganisms capable of hydrocarbon degradation.

5.2.3 Cultural services – Physical use of seascapes: delivery of 'good' experiential diving experiences

Physical and experiential use of the natural marine environment is an important cultural ecosystem service and recreational scuba (**s**elf-**c**ontained **u**nderwater **b**reathing **a**pparatus) diving in the UK is carried out by a number of organisations. While exact statistics are not available, the British Sub-Aqua Club (BSAC) estimates the total 'UK sports diving population' to be in the order of 200,000. UK coastal and offshore waters provide a variety of interesting features to the scuba diving community, such as wrecks, caves and reefs, as well as charismatic species.

Very little research is available on the needs and values of scuba divers in relation to the marine environment, and hence on the abiotic and biotic components affecting the delivery of this ecosystem service to the diving community. From a physiological point of view, recreational scuba diving using compressed air is limited to a water depth of approximately 50m (Schwerzmann & Seiler 2001). Beyond this depth nitrogen narcosis reduces the diver´s cognitive function, while oxygen toxicity impairs respiration beyond 60-70m (Schwerzmann & Seiler 2001). Technical diving apparatus and different air mixes do allow divers to descend to greater depths, however for the purposes of this study it has been assumed that 50m is the maximum depth that can be reached by most recreational divers.

Compared to popular diving destinations in warm, calm and clear tropical waters, scuba diving in the UK is generally characterised by relatively low visibility and temperatures, strong currents, cold winds and potentially rough seas (Dive Site Directory 2008). While exposure to currents and surge created by intense wave activity can lower visibility and, potentially, cause a diver to expend greater amounts of energy than experienced under calm conditions, these components are extremely variable, and are therefore not considered suitable to be used in the delineation of this ecosystem service. However, areas where currents generally exceed a certain threshold considered safe for diving (for the purpose of this study considered to be 2m/s based on expert judgement of the report team) have been identified as unsuitable dive destinations.

Within the possible depth range (5-50m), areas characterised by hard substrate (i.e. infralittoral and circalittoral rock, EUNIS biotope classifications A3.1 – A3.3 and A4.1 – A4.3), as well as stony and biogenic reef habitat (Annex I reef habitat), are considered areas of interest for scuba diving. Sandy or muddy areas have been excluded due to the potential for low visibility or potential lack of features of diving interest. The designation and existence of conservation areas may further enhance biodiversity and biomass of certain species, and has been found to be highly valued by recreational divers in the UK (Kenter *et al* 2013).

Table 14 summarises the biotic and abiotic ecosystem components and processes considered influential in the delivery of good recreational diving experiences, in both coastal and offshore waters of the UK.

The table also summarises the data layers needed to map the component or process and the source material used in the creation of the maps. Confidence in each data layer is assessed in full in Appendix 5. Full references and details of source data layers are presented in Electronic Appendix 2.

Maps that have been produced for each ecosystem component or process are based on the data that is outlined in Table 14 and are presented in Figures 18-22.

Table 14. Biotic and abiotic components affecting ecosystem service delivery for scuba divers. Please see Electronic Appendix 2 for full reference of each data source and data resolution and scale, and Appendices 5 and 6 for details of the confidence assessment.

Component/ process	Rationale	Data layer	Data source	Confidence in data layer
Depth/ pressure	Nitrogen narcosis reduces diver's cognitive function, limiting safe recreational diving to 40-50m depth (Schwerzmann & Seiler 2001). Water depths <5m are considered too shallow.	Areas where water depth ranges from -5m to -50m (Figure 18)	EMODnet DTM	Medium
Tidal currents	Strong currents may inhibit diving in an area and/or affect safety.	Modelled current speeds - the threshold for unsafe currents was chosen to be spring peak tidal flows >2m/s (Figure 20)	POLCOMS, ABPmer	Medium
Biodiversity/ Seabed habitat	Hard substrate or reefs are preferred destinations for diving activity (Kenter *et al* 2015).	EUNIS classes considered suitable: A3.1, A3.2, A3.3, A3.7, A4.1, A4.2, A4.3, A4.7 (Figure 19)	EUSeaMap	Medium
Existence of reefs	Reefs act as biodiversity hotspots and are generally considered to be areas of interest for divers (Kenter *et al* 2015).	Annex I Reefs (Figure 21)	JNCC - Composite Map of Annex I Reef in UK Waters	Not applicable

Component/ process	Rationale	Data layer	Data source	Confidence in data layer
Conservation	Certain conservation zones include species, habitats, seabed features of interest to recreational divers as they are likely to enhance faunal biodiversity and biomass (Kenter *et al* 2013).	Review of OSPAR MPAs, NCMPAs, SACs, MCZs. Only areas protecting features or species considered interesting to recreational divers are considered. Areas protecting birds, cliffs, estuaries, *etc*, were excluded; a decision based on expert opinion (Figure 22)	JNCC - Marine Protected Areas in the UK	Not applicable
Wrecks	Wrecks provide cultural heritage value. They have a high scenic value, act as artificial reefs and aggregate fish (Kenter *et al* 2013).	Buffered point or polygon shapefile of popular wreck locations	UK Admiralty Wrecks Database **– restricted** UK & Ireland wreck map - **not digitised**	

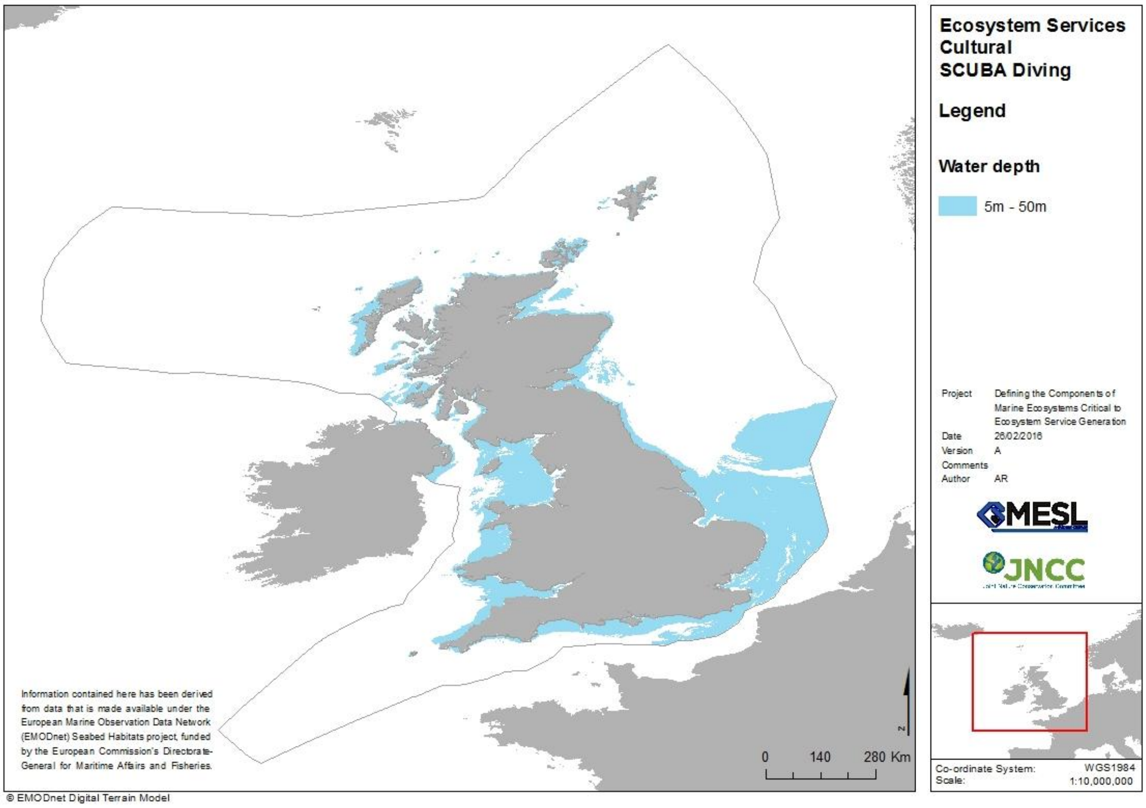


Figure 18. Water depth mapped according to EMODnet DTM data. The limit for recreational diving is generally considered to be no more than 50m without specialised equipment.

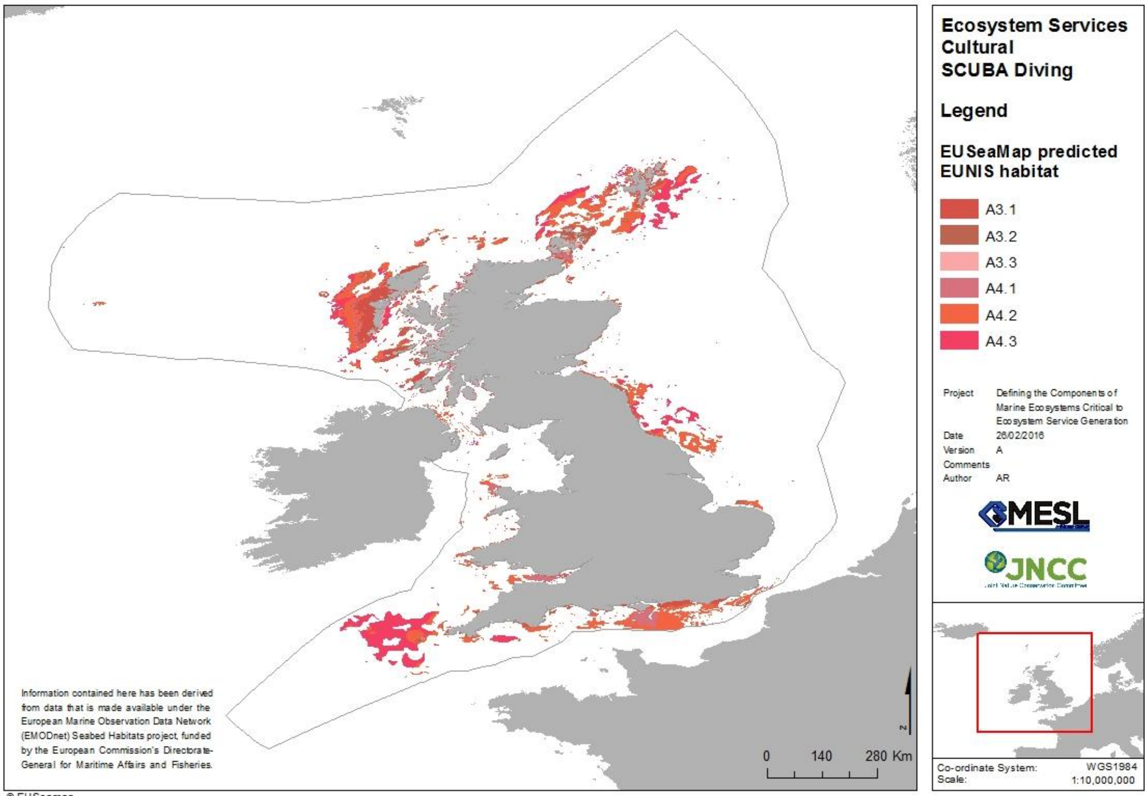


Figure 19. Habitat type (EUNIS biotopes) mapped according to EUSeaMap data. Habitats identified as interesting in terms of diving experiences include A3.1 (high energy infralittoral rock), A3.2 (moderate energy infralittoral rock), A3.3 (low energy infralittoral rock), A4.1 (high energy circalittoral rock), A4.2 (moderate energy circalittoral rock), and A4.3 (low energy circalittoral rock).

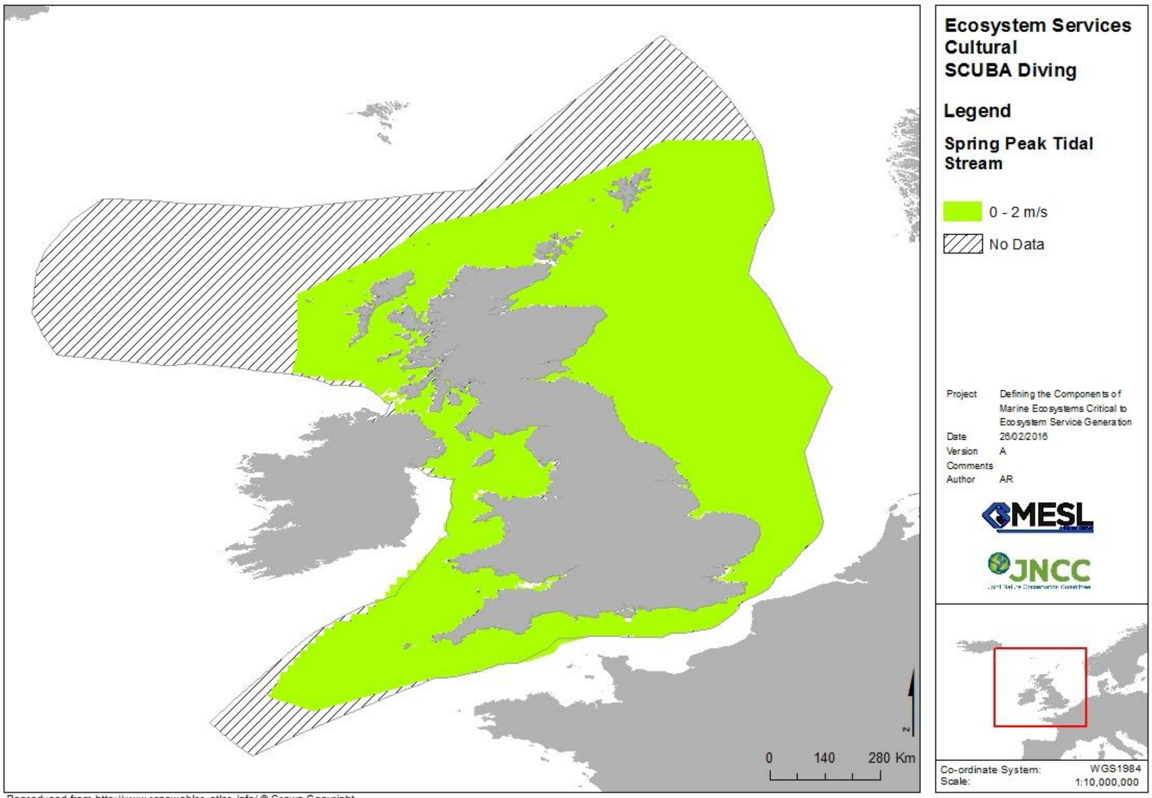


Figure 20. Tidal currents mapped according to POLCOMS data. Areas with typically strong currents are likely to prohibit diving activity (above 2m/s), such as the Bristol Channel, parts of the Orkney Islands, and around Anglesey.

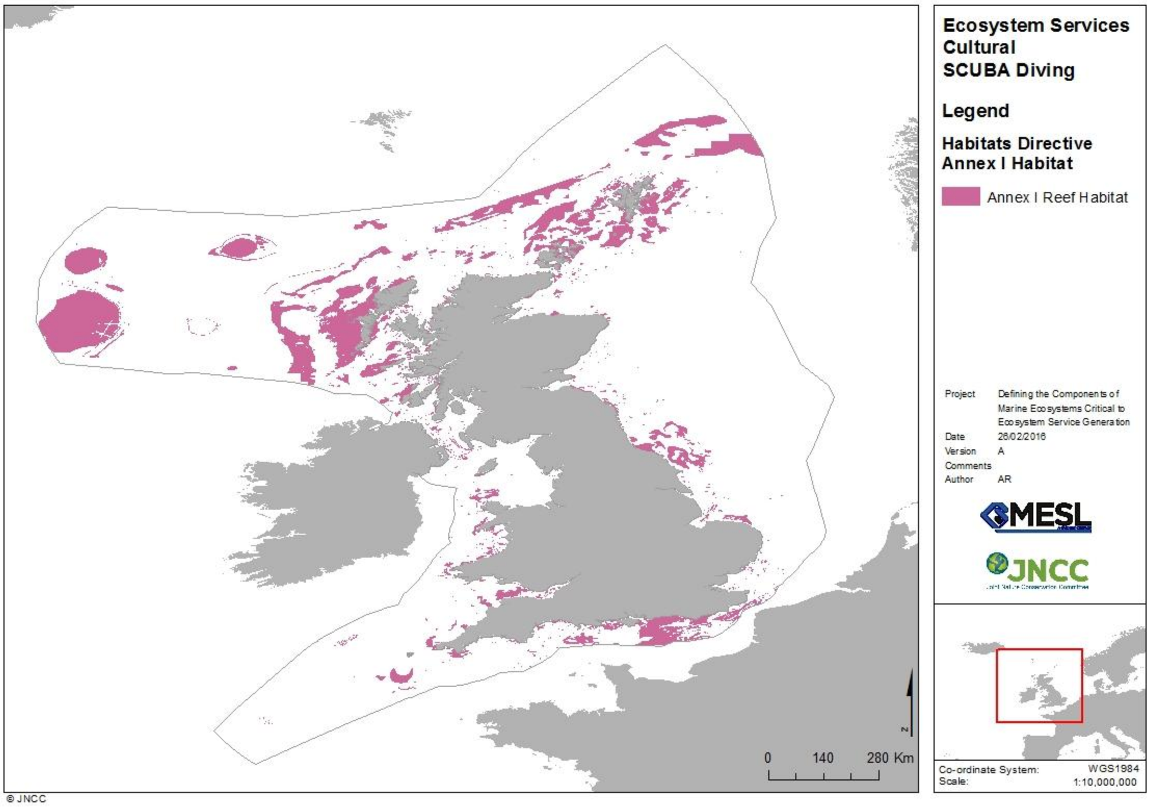


Figure 21. Presence of Annex I reef habitat mapped according to JNCC data. Both biogenic reef structures (those constructed by living organisms) and geogenic (constructed from abiotic features) as defined by the EU Habitats Directive (Council Directive 92/43/EEC) are included.

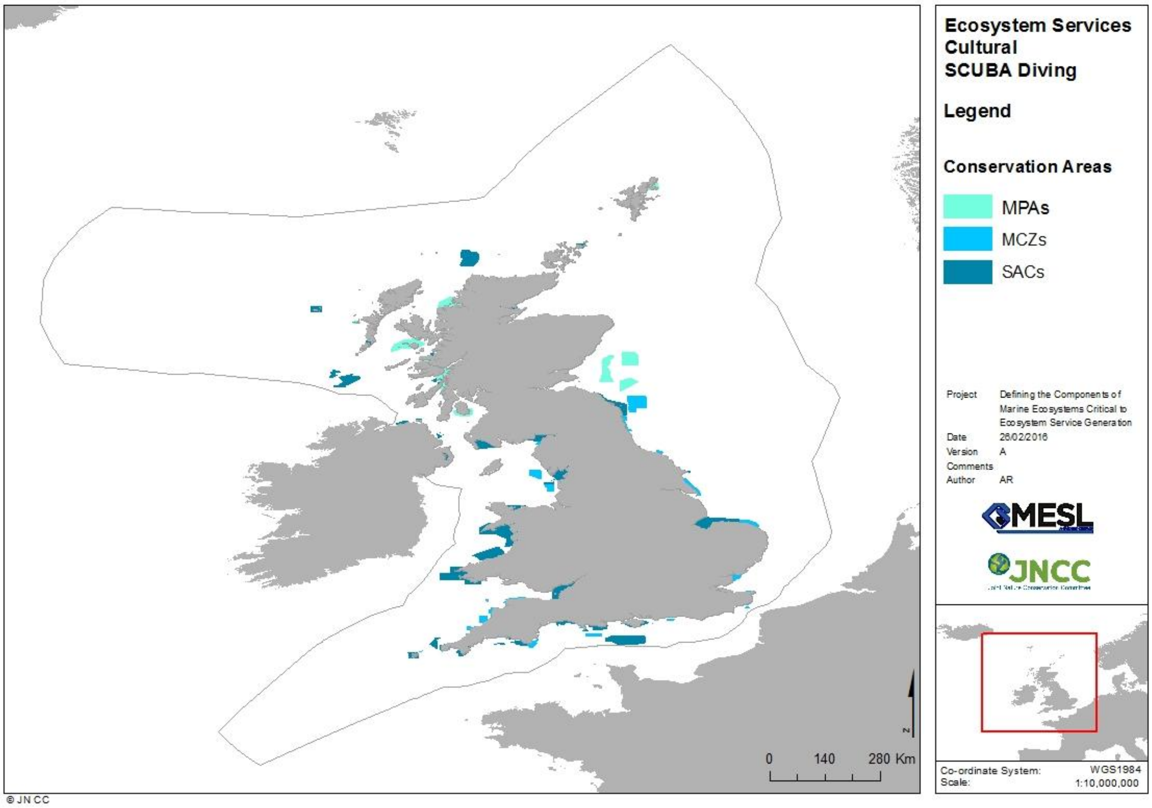


Figure 22. Presence of marine conservation areas (only those designated to conserve features of relevance to 'good' diving experiences') mapped according to JNCC data. Certain conservation zones include species, habitats and seabed features of interest to recreational divers (Kenter *et al* 2013).

A combined map was produced by overlaying data layers for the components and processes which are considered to offer ‘good’ recreational diving sites (i.e. Annex I reef habitat, infralittoral and circalittoral rock habitat and the selected conservation areas), and by restricting (“clipping”) these areas to include only areas of depths (5-50m) and tidal currents (<2m/s) considered suitable for diving. The resulting map (Figure 23) shows the potential for ‘good’ diving experiences in the UK marine environment.

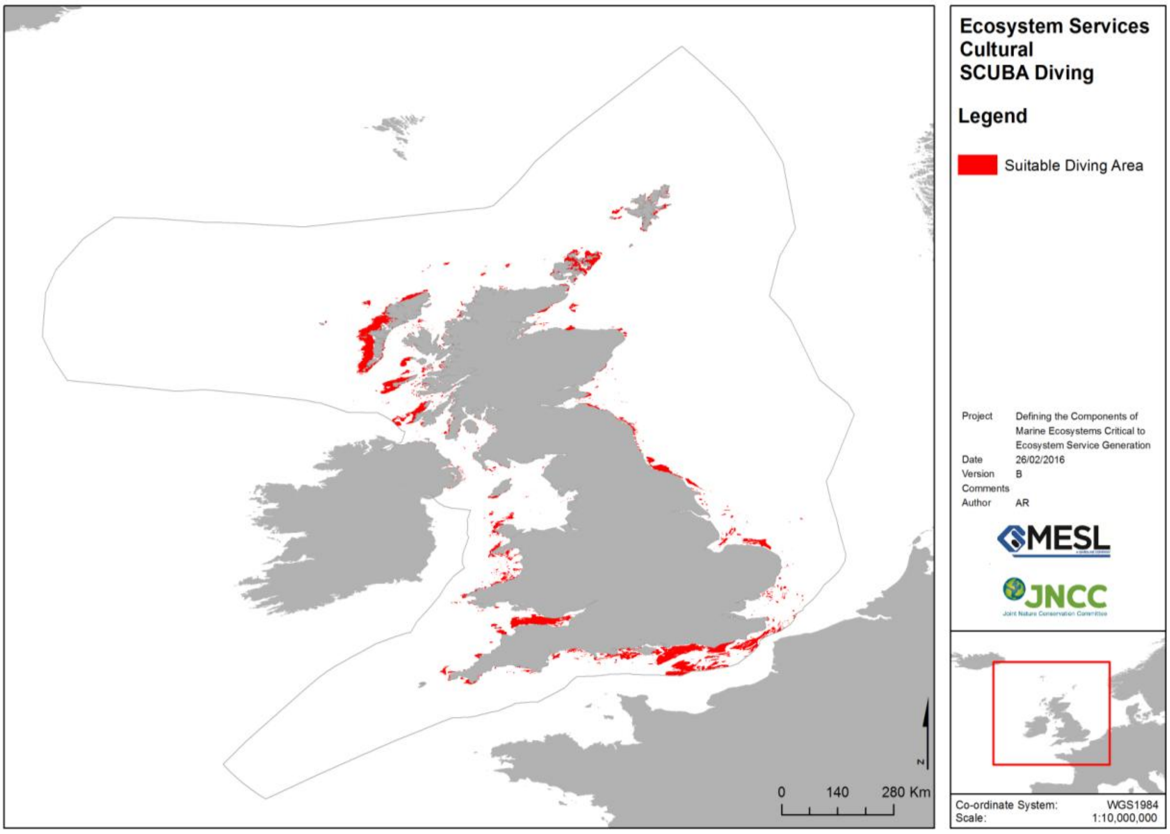


Figure 23. The distribution of potentially ‘good’ diving experiences in the UK as a cultural ecosystem service, based on the combined information presented in Figures 18-22.

Figure 23 demonstrates that most of the UK coastline and larger estuaries provide areas of interest for scuba divers.

The accuracy of the mapped areas could be enhanced by including popular dive locations; however such data was not available for this report in digitised format. Water quality, visibility or water turbidity are also likely to affect the dive experience; but are temporally extremely variable and their inclusion into static maps delineating general ecosystem service delivery was not deemed to be representative at a UK-scale.

5.3 Data Confidence Assessment

The distribution data set for *Laminaria hyperborea* scored the highest confidence assessment value, reflecting the high data quality of direct field observations for this species. Low resolution interpolated data such as nutrient and oxygen concentrations derived from Bio-Oracle scored the lowest confidence values, while satellite-derived data, modelled seabed habitats and modelled oceanographic data (tidal currents and wave action) were rated as medium confidence (see Appendix 5 for full confidence scores for each layer).

It is noteworthy that these confidence values do not always have direct implications for the final maps produced in the scope of this report. For example, the map illustrating the potential provisioning service delivered by kelp is based on the species distribution data only (high confidence), while the bioremediation map is based on multiple layers of varying confidence, with no overarching informative layer. In this instance the use of higher resolution water column data might better resolve variations of nutrient distribution, for example, but would be unlikely to have changed the overall outcome that bioremediation is a ubiquitous ecosystem service within the UK marine environment.

Data layers informing the cultural ecosystem service map were based on relatively recent information of 'moderately adequate spatial resolution' (see confidence assessment, Appendix 5), and thus were all classified as medium confidence.

5.4 Mapping Limitations and Constraints

The maps of potential ecosystem service delivery presented in this report are subject to a number of limitations, caveats and constraints as a result of the various datasets that were used.

The results presented reflect the limited time and resources that have been made available for this report, and the outputs presented are based only on the data collected as part of the literature review and data mining exercise. Additional data sources with a higher confidence level could be sourced if more resources were available. An example of datasets which would help to improve the quality of the deliverables and confidence of the outputs are identified in Table 15.

Table 15. Additional unavailable datasets identified that could be included in this study. See Electronic Appendix 2 for full details and references for each layer.

Component	Rationale	Data Layer	Source (if applicable)	Why not included in present study
Provisioning Ecosystem Services				
Modelled nutrient \vailability,	Higher resolution and seasonal information on nutrient (N, P) concentration would resolve small scale variations of nutrient availability, especially in coastal environments (Fe not deemed as critical for macrophytes). Information on seasonality of nutrient availability could also be useful.	Modelled Nitrate and Phosphate concentration	NERCPOL ocean biogeochemistry non-assimilative hindcast (1967–2004)	Further processing needed
Distribution of competitors and predators (grazers)	*L. hyperborea* distribution is influenced by predation (e.g. sea urchin grazing) and competition with other seaweed species (Yesson *et al* 2015).	Distribution data of competing or grazing species influencing *L. hyperborea* distribution	Species distribution data from OBIS or the National Biodiversity Network	Only point data available, not usable for spatial analyses in this report
Modelled current speed	High resolution, 3D information on regional currents to better map kelp exposure to energy at the seabed, and to better understand gamete dispersal and supply (Brennan *et al* 2014).	Modelled Northward and Eastward Velocities	NERCPOL Ocean physics non-assimilative hindcast (1960–2004)	Further processing needed

Component	Rationale	Data Layer	Source (if applicable)	Why not included in present study
Seabed habitat	The EUSeaMap predicted habitat used in this study lacked sufficient detail to accurately map kelp biotopes along the UK coastline. Full coverage of EUNIS Level 5 classes would be ideal.	Currently not existent. More systematic surveys are needed to meet this requirement	Currently not existent	Currently not existent
Regulation & Maintenance Ecosystem Services				
Modelled nutrient availability	Higher resolution, full coverage information of nutrient (N, P, Fe) concentration would much better resolve small scale variations of nutrient availability, especially around the coastline. Information on seasonality of nutrient availability could also be useful.	Modelled Nitrate, Phosphate and Iron concentration	NERCPOL ocean biogeochemistry non-assimilative hindcast (1967–2004). Layers on Iron concentration currently not available	Further processing needed; Information on Iron not available
Distribution and biomass of hydrocarbon degrading micro-organisms	Information on distribution and biomass of hydrocarbon degrading microorganisms could potentially be used to simulate bioremediation rates in the event of hydrocarbon release.	Currently not existent	Currently not existent	Currently not existent
Cultural Ecosystem Services				
Wreck sites	Inclusion of popular wreck sites would significantly improve the map of potential diving areas. Wrecks provide cultural heritage value. They have a high scenic value, act as artificial reefs and aggregate fish (Kenter *et al* 2013).	Buffered point or polygon shapefile of popular wreck locations	UK Admiralty Wrecks Database; UK & Ireland wreck map	Restricted data sets, only point data available, not usable for spatial analyses in this report
Distribution of charismatic species	Existence of certain charismatic species enhance the dive experience (Kenter *et al* 2013).	Distribution data of selected charismatic species	Species distribution data from OBIS or the National Biodiversity Network (NBN)	Only point data available, not usable for spatial analyses in this report

6 Conclusions

Ecosystem service consideration in current and future policy legislation has been reviewed to give context to the report; whilst ecosystem services are considered in current policy at varying scales, there is scope for further integration and consideration of ecosystem services in decision making and assessment. Area-based planning approaches to marine policy (Marine Spatial Planning, Marine Protected Areas, fisheries closures, Marine Licensing, EIAs *etc*) may be influenced by better understanding of ecosystem service delivery potential.

Although more recent policy and legislative instruments make reference to ecosystem services and related terms (i.e. natural resources), they are not specific about how ecosystem services should be considered in the delivery of the instrument in question. A key step towards the useful application of ecosystem services in decision making is a common understanding of how service delivery should be considered to help inform stakeholders and regulators. At a more local and regional level, maps representing potential delivery of ecosystem services (derived from data layers indicating critical elements which carry a medium-high level of confidence assessment) can be overlaid to identify conflicts but also synergies.

This report also explored how ecosystem service delivery is influenced by various ecosystem components and processes. It indicates which are deemed critical and are of particular relevance in ecosystem service delivery, and as such should be given special attention when future management plans or policy implementations are considered. The maps produced serve to test the method and the outputs may be useful in informing management or impact assessment decisions. The information presented is well informed by the literature review, and confidence in the identification of ecosystem components is relatively high, although expert judgement has been used to augment data in certain instances. Should additional data become available in the future it could be incorporated into the mapping process, thus the confidence of the outputs could likely be improved.

The three ecosystem services mapped for this report produced three different results in terms of spatial delineation of service delivery. For the provisioning service it was found that the production of a map based on environmental parameters would over-estimate the spatial extent of kelp, which is ultimately tied to its actual distribution; the environmental data layers collated for other components thus became ultimately irrelevant in the production of the final map which is based on species distribution data only. This layer is high in confidence, although the data is restricted by survey effort to identify *Laminaria hyperborea* distribution, and not all locations in which this species exists have been mapped. The distribution of kelp both horizontally along the UK coastline and vertically within the water column is influenced by interactions with competing seaweeds and grazing sea urchins (Tyler-Walters 2007; Yesson *et al* 2015). Consideration of such biotic factors and their inclusion in a mapping framework could potentially improve future management efforts and lead to more informed mapping outputs.

The bioremediation map is relatively generic and based on data layers demonstrating ubiquitous microorganism distribution, as the environmental conditions in the UK marine environment lie within the range tolerated by the microorganisms that break down hydrocarbons.

The mapping approach produced the most spatially delineated results for the cultural services map, in showing areas likely to provide good diving experiences. This was largely due to multiple data layers that were available, availability of specific thresholds to map (e.g. recreational diving not likely to occur below 50m, unsuitable environmental conditions *etc*), and because the service was not tied to a specific species. This is a key consideration in the mapping method and a potential issue for wider mapping of other ecosystem services which are based on the presence/absence of particular species or groups of species.

The results of the mapping exercise indicate that the method applied may be used to produce detailed maps of potential ecosystem service delivery in the UK, although the scale of results does depend on the level and resolution of input data and the extent to which the spatial scale of service delivery is tied to a particular environmental feature.

A lack of specific data on ecological thresholds for individual ecosystem components that contribute to ecosystem service delivery was identified during the report. For example, it was noted that bioremediation is potentially delivered as an ecosystem service across the whole of the UK marine environment. Bioremediation will occur under any level of nutrient availability, although the scale of the service delivered will vary depending on the localised concentrations of nutrients available. The production of heat maps to identify areas of the marine environment where natural bioremediation would be likely to occur on a greater scale would be the next logical progression from the work completed as part of this report, or indeed ecosystem service mapping from a ‘demand’ focus, factoring in known activities and resultant pressures (such as oil production and the release of hydrocarbons).

As this report aims to focus on the delivery of ecosystem services from a ‘supply’ point of view, the ‘demand’ driven components, such as distance to port, competing uses (e.g. military practice area, commercial fishing and shipping activity, submarine cables, oil and gas exploration, windfarms), and the potential legal constraints are not included in the analyses. Essentially, the maps do not consider the anthropogenic realisation of the ecosystem services mapped, and take no account of the practicality of the realisation of these services. In the future, data on anthropogenic activity might prove useful to further delineate areas where selected ecosystem processes are likely to be delivered and where this delivery may be realised.

It is worth noting that the generation of realistic, two-dimensional static maps that capture ecosystem service delivery based on three-dimensional, complex and dynamic processes is challenging to implement. For example, hydrodynamic models coupled with virtual particle tracer studies would be needed to inform on dynamic processes such as spawning patterns and larval dispersal. Future efforts could concentrate on integrating three-dimensional hydrodynamic and process-based models into the mapping framework, ultimately enhancing the understanding of environmental processes driving spatial patterns of ecosystem service delivery.

The literature review has shown that there is a large variability in the understanding of ecosystem services depending on the type (e.g. cultural) or level of exploitation (less information relating to potentially ‘novel’ uses of the marine area) being considered. The broad scale information used in the mapping exercise has shown the applicability of the method. However, the resolution of the data may make the application of potential ecosystem service delivery maps to specific decision-making scenarios (e.g. at marine plan scale or for report-specific decisions) less useful, unless finer resolution data are available for the specific area and ecosystem services in question. The robustness of the approach is also dependent on accurate identification of critical elements for ecosystem service delivery and the level of confidence in the data layers

The scope for additional research has been identified throughout this report. The deliverables presented set a good base for continuing research within this field and serve as a test of the methods applied, although they also highlight the current gaps in knowledge and the potential for future improvements.

7 References

ABPmer. (2015) Marine Planning in the UK: Making a Difference? ABPmer White Paper, ABPmer, Southampton. 13pp.

Alonso, I., Weston, K., Gregg, R. & Morecroft, M. (2012) Carbon storage by habitat–Review of the evidence of the impacts of management decisions and condition on carbon stores and sources. Natural England Research Reports, Number NERR043.

Álvarez-Romero, J.G., Wilkinson, S.N., Pressey, R.L., Ban, N.C., Kool, J. & Brodie, J. (2014) Modeling catchment nutrients and sediment loads to inform regional management of water quality in coastal-marine ecosystems: A comparison of two approaches. Journal of Environmental Management, 146, 164-178.

Armsworth, P.R. (2002) Recruitment limitation, population regulation, and larval connectivity in reef fish metapopulations. Ecology 83: 1092–1104.
Atkins, J., Banks, E., Burdon, D., Greenhill, L., Hastings, E. & Potts, T. (2013) An analysis of methodologies for defining ecosystem services in the marine environment. *JNCC Report No. 491*. JNCC, Peterborough.

Atlas, R.M. & Hazen, T.C. (2011) Oil biodegradation and bioremediation: a tale of the two worst spills in US history. *Environmental science & technology*, *45* (16), 6709-6715.

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C. & Silliman, B.R. (2011) The value of estuarine and coastal ecosystem services. Ecological Monographs, 81 (2), pp 169-183.

Basford, D., Eleftheriou, A. & Raffaelli, D. (1990) The Infauna and Epifauna of the Northern North Sea. Netherlands Journal of Sea Research, 25 (1/2), 165-173.

Beaumont, N.J., Austen, M.C., Mangi, S.C. & Townsend, M. (2008) Economic valuation for the conservation of marine biodiversity. Marine Pollution Bulletin vol 56 (3) pp 386-396.

Beck, M.W., Heck, K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Halpern, B., Hays, C.G., Hoshino, K., Minello, T.J. & Orth, R.J. (2001) The identification, Conservation and Management of Estuarine and Marine Nurseries for fish and Invertebrates. BioScience 51 (8) 633-641.

Beher, J., Possingham, H.P., Hoobin, S., Dougall, C. & Klein, C. (2016) Prioritising catchment management reports to improve marine water quality. Environmental Science and Policy, 59, 35-43.

Bianchi, C.N. & Morri, C. (2000) Marine Biodiversity of the Mediterranean Sea: Situation, Problems and Prospects for Future Research. Marine Pollution Bulletin, 40 (5), 367-376.

Birkett, D.A., Maggs, C.A., Dring, M.J. & Boaden, P.J.S. (1998) Infralittoral Reef Biotopes with Kelp Species (volume VII). An overview of dynamic and sensitivity characteristics for conservation management of marine SACs. Scottish Association of Marine Science (UK Marine SACs Report). 174 pages.

Bolam, S.G., Barrio-Frojan, C.R.S. & Eggleton, J.D. (2010) Macrofaunal Production along UK Continental Shelf, Journal of Sea Research 64 166–179.

Boopathy, R. (2000) Factors limiting bioremediation technologies. *Bioresource technology*, *74* (1), 63-67.

Brennan, G., Kregting, L., Beatty, G.E., Cole, C., Elsäßer, B., Savidge, G. & Provan, J. (2014) Understanding macroalgal dispersal in a complex hydrodynamic environment: a combined population genetic and physical modelling approach. Journal of The Royal Society Interface, 11 (95), 20140197.

Brown, E., Colling, A., Park, D., Phillips, J., Rothery, D. & Wright, J. (2002) Seawater: Its composition, properties and behaviour. Butterworth-Heinemann, Oxford.

Brown, E., Colling, A., Park, D., Phillips, J., Rothery, D., Wright, J. (2002b) Waves, tides and shallow-water processes. Butterworth-Heinemann, Oxford.

Callaway, R., Shinn, A.P., Grenfell, S.E., Bron, J.E., Burnell, G., Cook, E.J., Crumlish, M., Culloty, S., Davidson, K., Ellis, R.P., Flynn, K.J., Fox, C., Green, D.M., Hays, G.C., Hughes, A.D., Johnston, E., Lowe, C.D., Lupatsch, I., Malham, S., Mendzil, A.F., Nickell, T., Pickerell, T., Rowley, A.F., Stanley, M.S., Tocher, D.R., Turnbull, J.F., Webb, G., Wootton, E. & Shields, R.J (2012) Review of climate change impacts on marine aquaculture in the UK and Ireland. Aquatic Conserv: Mar. Freshw. Ecosyst. 22; 389-421.

Cappello, S., Calogero, R., Santisi, S., Genovese, M., Denaro, R., Genovese, L., Giuliano, L., Mancini, G. & Yakimov, M.M. (2015) Bioremediation of oil polluted marine sediments: a bio-engineering treatment. International microbiology 18: 127-134.

Casey, M., Dietl, G.P., Post, D.M. & Briggs, D.E.G. (2014) The impact of eutrophication and commercial fishing on molluscan communities in Long Island Sound, USA. Biological Conservation 170, 137-144.

Chamberlain, J., Fernandes, T.F., Read, P., Nickell, T.D. & Davies, I.M. (2001) Impacts of biodeposits from suspended mussel (*Mytilus edulis* L.) culture on the surrounding surficial sediments, ICES Journal of Marine Science, 58: 411–416.

Chung, I.K., Beardall, J., Mehta, S., Sahoo, D. & Stojkovic, S. (2011) Using marine macroalgae for carbon sequestration: a critical appraisal. Journal of Applied Phycology 23.5: 877-886.

Codd, G. (2000), Cyanobacterial toxins, the perception of water quality, and the prioritisation of eutrophication control, Ecological Engineering, Volume 16, Issue 1, 51-60.

Cognetti, G., Sarà, M. & Magazzù, G. (2001) Biologia marina. First edition. Editorial Ariel S.A., Barcelona.

Cole, J. & McGlade, J. (1998) Clupeoid population variability, the environment and satellite imagery in coastal upwelling systems. Reviews in Fish Biology and Fisheries 8, 445-471.

Cooper, K.M., Curtis, M., Wan Hussin, W.M.R., Barrio Frojan, C.R.S., Defew, E.C., Nye, V. & Paterson, D.M. (2011) Implications of dredging induced changes in sediment particle size composition for the structure and function of marine benthic macrofaunal communities. Marine Pollution Bulletin*,* 62, 2087–2094.

Corbett, D.R. (2010) Resuspension and estuarine nutrient cycling: insights from the Neuse River Estuary. Biogeosciences, 7 (10), 3289-3300.

Cusson, M. & Bourget, E. (2005) Global patterns of macroinvertebrate production in marine benthic habitats, Marine Ecology Progress Series, Vol. 297: 1–14.

Dayton, P.K. (1985) “Ecology of Kelp Communities”. *Annual Review of Ecology and Systematics* 16. Annual Reviews: 215–45.

Devlin, M.J., Barry, J., Mills, D.K., Gowen, R.J., Foden, J., Sivyer, D. & Tett, P. (2008) Relationship between suspended particulate material, light attenuation and Secchi depth in UK marine waters. Estuarine, Coastal and Shelf Science, 79, 429-439.

Diaz, R.J. & Rosenberg, R. (1995) Marine benthic hypoxia: A review of its ecological effects and the behavioural Reponses of benthic macrofauna. Oceanography and Marine Biology: An Annual Review. 33, 245-303.

Diaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., Larigauderie, A., Adhikan, J.R., Arico, S., Baldi, A., Bartuska, A., Baste, I.A., Belgin, A., Brondizio, E., Chan, K.M.A., Figueroa, V.E., Duraiappah, A., Fischer, M., Hill, R., Koeta, T., Leadley, P., Lyver, P., Mace, G.M., Martin-Lopez, B., Okumura, M., Pacheco, D., Pascual, U., Perez, E.S., Reyers, B., Roth, E., Saito, O., Scholes, R.J., Sharma, N., Tallis, H., Thaman, R., Watson, R., Yahara, T., Hamid, Z.A., Akosim, C., Al-Hafedh, Y., Allahverdiyev, R., Amankwah, E., Asah, S.T., Asfaw, Z., Bartus, G., Brooks, A.L., Caillaux, J., Dalle, G., Darnaedi, D., Driver, A., Erpul, G., Escobar-Eyzaguirre, P., Failler, P., Fouda, A.M.M., Fu, B., Gundimeda, H., Hashimoro, S., Homer, F., Lavorel, S., Lichtenstien, G., Mala, W.A., Mandivenyi, W., Matczak, P., Mbizvo, C., Mehrdadi, M., Metzger, J.P., Mikissa, J.B., Moller, H., Mooney, H.A., Mumby, P., Nagenra, H., Nesshover, C., Oteng-Yeboah, A.A., Pataki, G., Roue, M., Rubis, J., Schultz, M., Smith, P., Sumaila, R., Takeuchi, K., Thomas, S., Verma, M., Yeo-Change, Y. & Zlatanova, D. (2015) The IPBES Conceptual Framework — connecting nature and people. Current Opinion in Environmental Sustainability, 14, 1-16.

Dive Site Directory. (2008) SCUBA Diving in the UK. [online] Available: http://www.divesitedirectory.co.uk/uk.html. [Accessed 16/03/16].

Duarte, C.M., Middelburg, J.J. & Caraco, N. (2005) Major role of marine vegetation on the oceanic carbon cycle. Biogeosciences, 2 (1), 1-8.

Dubey, S.K. & Roy, U. (2003) Review: Biodegradation of tributyltin (organotins) by marine bacteria. Appl. Organomental. Chem. 2003: 17: 3- 8.

Eckman, J.E., Duggins, D.O. & Sewell, A.T. (1989) The ecology of Understory kelp environments: Effects of kelps on flow and particle transport near the bottom. Journal of Experimental Marine Biology, 129 173-187.

Edwards, M. & Watson, L. (2011) Cultivating Laminaria digitata. *Aquaculture explained*, *26*, 72.

European Environment Agency (EEA). (2015) State of Europe’s Seas. European Environment Agency, Copenhagen. EEA Report No 2/2015, ISSN 1977 8449.

Forster R.M. & Dring M.J. (1994) Influence of blue light on the photosynthetic capacity of marine plants from different taxonomic, ecological and morphological groups. European Journal of Phycology, 29:1, 21-27.

Galil, B.S. (2009) Control and eradication of invasive aquatic invertebrates. Biodiversity Conservation and Habitat Management-Volume II: 331.

Galparsoro, I., Borja, A. & Uyarra, M.C. (2014) Mapping ecosystem services provided by benthic habitats in the European North Atlantic Ocean. *Frontiers in Marine Science*, *1* (23), 1-14.

Gattuso, J.P., Pichon, M. & Frankignoulle, M. (1995) Biological control of air-sea CO2 fluxes: effect of photosynthetic and calcifying marine organisms and ecosystems. Marine Ecology Progress Series 1-3.

Gaylord, B., Reed, D.C., Raimondi, P.T. & Washburn, L. (2006) Macroalgal spore dispersal in coastal environments: Mechanistic insights revealed by theory and experiments. Ecological Monographs, 76 (4), 2006 pp 481-502.

Glibert, P.M., Allen, J.I., Bouwman, A.F., Brown, C.W., Flynn, K.J., Lewitus, A.J. & Madden, C.J. (2010) Modeling of HABs and eutrophication: status, advances, challenges. Journal of Marine System vol 83, issue 3-4 pp 262-275.

Haines-Young, R. & Potschin, M. (2013) Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012. EEA Framework Contract No. EEA/IEA/09/003.

Hassanshahian, M. & Cappello, S. (2013) Crude Oil Biodegradation in the Marine Environments. *Chamy R. Biodegradation-Engineering and Technology, InTech* (2013): 101-135.

Heinze, C., Meyer, S., Goris, N., Anderson, L., Steinfeldt, R., Chang, N. & Bakker, D.C. (2015) The ocean carbon sink-impacts, vulnerabilities and challenges. Earth System Dynamics, 6 (1), 327.

Hiscock, K., Marshall, C., Sewell, J. & Hawkins, S.J. (2006) The structure and functioning of marine ecosystems: an environmental protection and management perspective. English Nature Research Reports, No 699.

Hiscock, K., Southward, A., Tittley, I. & Hawkins, S. (2004) Effects of changing temperature on benthic marine life in Britain and Ireland, Aquatic Conserv: Mar. Freshw. Ecosyst. 14: 333–362.

HM Government. (2011) UK Marine Policy Statement. Available online: www.gov.uk/government/publications/uk-marine-policy-statement [Accessed 07/03/16]

Hunt, J.C.R. (2005) Inland and coastal flooding: development in prediction and prevention. Phil. Trans. R. Soc A 363, 1475-1491.

JNCC. (2014) Evidence Quality Assurance Policy. JNCC, Peterborough. 16pp.

Jobstvogt, N., Watson, V. & Kenter, J.O. (2014) Looking below the surface: The cultural ecosystem service values of UK marine protected areas (MPAs). Ecosystem services vol 10 pp 97-110.

Jones, W.R. (1998) Practical applications of marine bioremediation. Current Opinion in Biotechnology vol 9 (3) pp 300-304.

Kain, J.M. (1971) Synopsis of biological data on *Laminaria hyperborea*. FAO Fisheries Synopsis, no. 87.

Karr, J.R. & Dudley, D.R. (1981) Ecological perspective on water quality goals. Environmental Management, 5 (1), 55-68.

Katsanevakis, S., Wallentinus, I., Zenetos, A., Leppakoski, E., Cinar, M.E., Ozturk, B., Grabowski, M., Golani, D. & Cardoso, C. (2014) Impacts of invasive alien marine species on ecosystem services and biodiversity: a pan-European review. Aquatic Invasions, 9.4: 391-423.

Keeler, B.L., Polasky, S., Brauman, K.A., Johnson, K.A., Finlay, J.C., O'Neill, A., Kovacs, K. & Dalzell, B. (2012) "Linking water quality and well-being for improved assessment and valuation of ecosystem services." Proceedings of the National Academy of Sciences109, No. 45: 18619-18624.

Kennish, M.J. (1996) *Practical handbook of estuarine and marine pollution*. Vol. 10. CRC press.

Kenter, J.O., Bryce, R., Davies, A., Jobstvogt, N., Watson, V., Ranger, S., Solandt, J.L., Duncan, C., Christie, M., Crump, H., Irvine, K.N., Pinard, M. & Reed, M.S. (2013) The value of potential marine protected areas in the UK to divers and sea anglers. UNEP-WCMC, Cambridge, UK.

Kilburn, R., Murray, A.G., Hall, M., Bruno, D.W., Cockerill, D. & Raynard, R.S. (2012) Analysis of a company's production data to describe the epidemiology and persistence of pancreas disease in Atlantic salmon (*Salmo salar* L.) farms off Western Scotland. Aquaculture 368-369, 89-94.

Lalli, C.M. & Parsons, T.R. (2006) Biological Oceanography An Introduction. Oxford: Elsevier Butterworth-Heinemann.

Laurila-Pant, M., Lehikoinen, A., Uusitalo, L. & Venesjarvi, R. (2015) How to value biodiversity in environmental management? Ecological Indicators, 55, 1-11.

Lee, K., Park, S.R. & Young, K.K. (2007) Effects of irradiance, temperature, and nutrients on growth dynamics of seagrasses: a review. Journal of Experimental Marine Biology and Ecology 350, pp 144-175.

Lee, S.C. & Bruno, J.F. (2009) Propagule supply controls grazer community structure and primary production in a benthic marine ecosystem. Proceedings of the National Academy of Sciences of the United States of America vol 106 No 17 pp 7052-7057.

Lenormand, T. (2002) Gene flow and the limits to natural selection. Trends in Ecology & Evolution vol 17 issue 4 pp 183-189.

Little, C. & Kitching, J.A. (1996) The Biology of Rocky Shores. Oxford University Press: Oxford.

Lohrer, A.M., Chiaroni, L.D., Hewitt, J.E. & Thrush, S.F. (2008) Biogenic Disturbance Determines Invasion Success in a Subtidal Soft-sediment System. Ecology 89.5: 1299–1307.

Lüning, K. (1980) Critical levels of light and temperature regulating the gametogenesis of three Laminaria species (Phaeophyceae). Journal of Phycology, 16, 1-15.

Mace, G.M., Hails, R.S., Cryle, P., Harlow, J. & Clarke, S.J. (2015) "REVIEW: Towards a Risk Register for Natural Capital." Journal of Applied Ecology 52, 641–53.

Maes, J., Teller, A., Erhard, M., Liquete, C., Braat, L., Berry, P. & Paracchini, M.L. (2013) Mapping and Assessment of Ecosystems and their Services. *An analytical framework for ecosystem assessments under action*, *5*, 1-58.

Manabe, S. & Stouffer, R.J. (1995) Simulation of abrupt climate change induced by freshwater input to the North Atlantic Ocean. Nature, 378, 165-167.

Masselink, G. & Hughes, M.G. (2003) Introduction to Coastal Processes & Geomorphology. Hodder Arnold, London.

McHugh, D.J. (2003) *A guide to the seaweed industry*. Rome, Italy: Food and Agriculture Organization of the United Nations.

McKew, B.A., Coulon, F., Yakimov, M.M., Denaro, R., Genovese, M., Smith, C.J., Osborn, A.M., Timmis, K.N. & McGenity, T.J. (2007) Efficacy of intervention strategies for bioremediation of crude oil in marine systems and effects on indigenous hydrocarbonoclastic bacteria. Environmental Microbiology 9 (6) 1562-1571.

Medcalf, K., Small, N., Finch, C. & Parker, J. (2012) Spatial framework for assessing evidence needs for operational ecosystem approaches. *JNCC Report No. 469*. JNCC, Peterborough.

Medcalf, K., Small, N., Finch, C., Williams, J., Blair, T., Haines-Young, R., Potschin, M. & Parker, J. (2014) Further development of a spatial framework for mapping ecosystem services. *JNCC Report No. 514*. JNCC, Peterborough.

Millennium Ecosystem Assessment. (2005) Ecosystems and Human Well-being. Island Press, Washington, DC.

Mork, M. (1996) The effect of kelp in wave damping. Sarsia 80: 323-327.

Munn, C.B. (2004) Marine Microbiology - Ecology & Applications. Garland Science / BIOS Scientific Publishers, Oxon.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautski, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. & Troell, M. (2000) Effect of aquaculture on world fish supplies. Nature 405, 1017-1024.

Norderhaug, K.M. & Christie, H. (2011) Secondary production in a *Laminaria hyperborea* kelp forest and variation according to wave exposure. Estuarine, Coastal Shelf Science. 95 135-144.

Nybakken, J.W. (2001) Marine Biology: an ecological approach. 5th edition. Benjamin Cummings, San Francisco.

Paerl, H.W., Hall, N.S. & Calandrino, E.S. (2011) Controlling harmful cyanobacterial blooms in a world experiencing anthropogenic and climatic-induced change. Science of the Total Environment, 409 (10), 1739-1745.

Palmer, M.A., Allan, J.D. & Butman, C.A. (1996) Dispersal as a regional process affecting the local dynamics of marine and stream benthic invertebrates. Trends in Ecology & Evolution, vol 11 issue 8 pp 322-326.

Pinsky, M.L., Palumbi, S.R., Andrefouet, S. & Purkis, S.J (2012) Open and closed seascapes: where does habitat patchiness create population with high fractions of self recruitment? Ecological Applications vol 22 issue 4 pp 1257-1267.

Pretterebner, K., Riedel, B., Zuschin, M. & Stachowitsch, M. (2012) Hermit crabs and their symbionts: Reactions to artificially induced anoxia on a sublittoral sediment bottom, Journal of Experimental Marine Biology and Ecology 411, 23–33.

Quian, P-Y. (1999) Larval settlement of polychaetes. Hydrobiologia. 402 239-253.

Raaymakers, S. (2007) Possible Effects of Climate Change on the Spread of Invasive Marine Species and Implications for Maritime Industries. WMU Journal of Maritime Affairs, Vol. 6, No.2, 235–240.

Reichwaldt, E.S. & Ghadouani, A. (2012) Effects of rainfall patterns on toxic cyanobacterial blooms in a changing climate: between simplistic scenarios and complex dynamics. Water Research, 46 (5), 1372-1393.

Romero, J., Pérez, M., Mateo, M.A. & Sala, E. (1994) The below ground organs of the Mediterranean seagrass *Posidonia oceanica* as a biogeochemical sink. Aquatic Botany, 47, 13-19.

Ruiz-Frau, A., Hinz, H., Edwards-Jones, G. & Kaiser, M.J. (2013) Spatially explicit economic assessment of cultural ecosystem services: Non-extractive recreational uses of the coastal environment related to marine biodiversity. Marine Policy vol 38 pp 90-98.

Ruocco, A.C., Nicholls, R.J., Haigh, I.D. & Wadey, M.P. (2011) Reconstructing coastal flood occurrence combining sea level and media sources: a case study of the Solent, UK, since 1935. Nat Hazards 59:1773-1796.

Sakultantimetha, A., Keenan, H.E., Dyer, M., Beattie, T.K., Bangkedphol, S. & Songsasen, A. (2009) Isolation of tributyltin-degrading bacteria *Citrobacter braakii* and *Enterobacter cloacae* from butyltin-polluted sediment. Journal of ASTM International, 6 (6).

Santas, R. & Santas, P. (2000) Effects of wave action on the bioremediation of crude oil saturated hydrocarbons. *Marine Pollution Bulletin*,*40* (5), 434-439.

Schwerzmann, M. & Seiler, C. (2001) Recreational scuba diving, patent foramen ovale and their associated risks. Swiss medical weekly, 131 (25-26), 365-374.

Seiderer, L.J. & Newell, R.C. (1999) Analysis of the relationship between sediment composition and benthic community structure in coastal deposits: Implications for marine aggregate dredging, ICES Journal of Marine Science, 56, 757–765.

Seitz, R.D., Wennhage, H., Bergstrom, U., Lipcius, R. & Ysebaert, T. (2013) Ecological value of coastal habitats for commercially and ecologically important species. ICES Journal of Marine Science.

Sharples, J., Ellis, J.R., Nolan, G. & Scott, B.E. (2013) Fishing and the oceanography of a stratified shelf sea. Progress in Oceanography 117 (2013) 130-190.

Shawky, Y., Nada, A.M. & Abdelhaleem, F.S. (2013) Environmental and hydraulic design of thermal power plants outfalls Case study: Banha Thermal Power Plant, Egypt. Ain Shams Engineering Journal, 4 (3), 333-342.

Sheppard Brennand, H., Soars, N., Dowrjanyn, S.A., Davis, A.R. & Byrne, M. (2010) Impact of Ocean Warming and Ocean Acidification on Larval Development and Calcification in the Sea Urchin *Tripneustes gratilla*. PLOS ONE, 5 (6).

Siegel, D.A., Mitarai, S., Costello, C.J., Gaines, S.D., Kendall, B.E., Warner, R.R. & Winters, K.B. (2008), The stochastic nature of larval connectivity among nearshore marine populations. PNAS, 105 8974-8974.

Sunda, W.G. & Shertzer, K.W. (2012) Modelling ecosystem disruptive algal blooms: positive feedback mechanisms. Marine Ecology Progress Series, 447, 31-47.

Swannell, R.P., Lee, K. & McDonagh, M. (1996) Field Evaluations of Marine Oil Spill Bioremediation. Microbiological Reviews, June 1996 p 342-365.

Taylor, A.H. (1995) North–south shifts of the Gulf Stream and their climatic connection with the abundance of zooplankton in the UK and its surrounding seas. ICES Journal of Marine Science: Journal du Conseil, 52 (3-4), 711-721.

TEEB. (2010) The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations. Edited by Pushpam Kumar. Earthscan, London and Washington.

Tuhkanen, H., Piirsalu, E.P., Nommann, T., Karloseva, A., Nommann, S., Czajkowski, M. & Hanley, N. (2016) Valuing the benefits of improved marine environmental quality under multiple stressors. Science of the Total Environment, 551-552, 367-375.

Tyler-Walters, H. (2007) *Laminaria hyperborea* Tangle or cuvie. In Tyler-Walters, H. & Hiscock, K. (eds) *Marine Life Information Network: Biology and Sensitivity Key Information Reviews*, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: http://www.marlin.ac.uk/species/detail/1309.

UK National Ecosystem Assessment. (2011) The UK National Ecosystem Assessment Technical Report. UNEP-WCMC, Cambridge.

Ungaro, F., Hafner, K., Zasada, I. & Piorr, A. (2016) Mapping cultural ecosystem services: Connecting visual landscape quality to cost estimations for enhanced services provision. Land Use Policy, 54, 399-412.

Van den Belt, M. & Costanza, R. (2012) Ecological economics of estuarine and coasts. In Wolanski, E. & McLusky, D.S. (eds) Treatise on Estuarine and Coastal Science, Vol. 12, Waltham, MA: Academic Press, 525.

Van den Hoek, C. (1982) The distribution of benthic marine algae in relation to the temperature regulation of their life histories. Biological Journal of the Linnaean Society, 18, 81-144.

Van der Heijden, L.H. & Kamenos, N.A. (2015), Calculating the global contribution of coralline algae to carbon burial. Biogeosciences Discussions, 12 (10), 7845-7877.

Wadey, M.P., Nicholls, R.J. & Haigh, I. (2013) Understanding a coastal flood event: the 10th March 2008 storm surge event in the Solent, UK. Natural Hazards vol 67 (2) pp829-854.

Ware, J.R., Smith, S.V. & Reaka-Kudla, M.L. (1992) Coral reefs: sources or sinks of atmospheric CO2? Coral reefs 11.3: 127-130.

Wernberg, T. & Goldberg, N. (2008) Short-term temporal dynamics of algal species in a subtidal kelp bed in relation to changes in environmental conditions and canopy biomass. Estuarine, Coastal and Shelf Science. 76 265-272.

Wilkinson, S.B., Zheng, W., Allen, J.R., Fielding, N.J., Wanstall, V.C., Russell, G. & Hawkins, S.J. (1996) Water quality improvements in Liverpool docks: the role of filter feeders in algal and nutrient dynamics. Marine Ecology, 17 (1-3), 197-211.

Worm, B., Barbier, E.B., Beaumont, N., Duffy, E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J. & Watson, R. (2006) Impacts of Biodiversity Loss on Ocean Ecosystem Services. Science, 314, 787-790.

Yesson, C., Bush, L.E., Davies, A.J., Maggs, C.A. & Brodie, J. (2015) Large brown seaweeds of the British Isles: evidence of changes in abundance over four decades. *Estuarine, Coastal and Shelf Science*, *155*, 167-175.

Zhao, Y.J., Zeng, L., Zhang, A.L. & Wu, Y.H. (2015) Response of current, temperature, and algae growth to thermal discharge in tidal environment. Ecological Modelling, 318, 283-292.

Zilinskas, R.A. (1998) Bioremediation in the Marine Environment. In *Advances in Bioprocess Engineering* (pp. 209-227). Springer Netherlands.

8 Glossary of Ecosystem Component and Processes Definitions

Term	Definition
Abundance of bacteria/microbes	Abundance of bacteria/microbes in the environment
Abundance of Scavengers	Presence of any organism that feeds on dead organic material
Biodeposition	The process by which filter feeding organisms capture particulate matter from the water column and deposit into the sediments
Bioengineering	The creation, modification and maintenance of habitats (and microhabitats) by marine organisms
Biotic potential	Highest possible rate of population increase resulting from maximum rate of reproduction and minimum mortality
Bioturbation	Sediment re-working by marine fauna
Complexity of Life cycle	The number of developmental stages that an organism undergoes from birth to reproduction
Confinement of population/Dispersal capability	Level of isolation of a population/ability of an organism or population to colonise new habitat
Disease prevalence	Exposure of a biota or ecosystem to harmful diseases
Dissolved gases	Gases dissolved in a given volume of water at a given temperature and pressure
Dissolved/suspended organic matter	Floating or dissolved substances/particles derived from the breakdown of organisms and organic material
Disturbance recovery capacity	Capacity of recovery from any perturbation (either natural or anthropogenic) experienced by an ecosystem
Eutrophication	Process of excessively increasing the nutrient levels in the ocean through natural or artificial means
Freshwater input	Addition of freshwater from rivers or ground water to the marine environment
Grazing	Feeding on vegetation or sessile colonial animals by either consuming the whole food organism or by cropping all on part of the surface growth
Large scale weather events	Any event affecting ambient weather/climate on a synoptic scale, including but not limited to weather fronts, surface high-pressure systems, extratropical cyclones and El Niño-Southern Oscillations
Light attenuation	The penetration of light in the water column
Natural disturbance	Natural perturbation experienced by an ecosystem
Nutrient availability	The concentration of nutrients (predominantly nitrates and phosphates) in ambient seawater
Nutrient cycling	The exchanges of elements between the living and non-living components of an ecosystem
pH	Measure of seawater acidity
Population dynamics	The changes in the structure of a population over time, i.e. the changes in the relative numbers of individuals of particular ages, different sexes or different forms
Presence of bio-regulatory species	Presence of species which through their actions perform a regulatory function in the marine environment
Presence of carbonate/aragonite species	Calcifying marine organisms ranging from corals to coralline algae and many others
Presence of filter feeders	Presence of animals that obtain their food by filtering particles out of the water column
Presence of iconic species or species of conservation importance	Presence of iconic species or species of conservation status or public interest
Presence of invasive species	Presence of plant, animal or fungus that is not native to the specific region

Term	Definition
Presence of macroalgae	Photosynthetic nonvascular plants commonly found in the divisions Chlorophyta (green algae), Phaeophyta (brown algae) and Rhodophyta (red algae), commonly called seaweeds
Presence of predators/competitors	Presence of predating or competing species somehow affecting the ecosystem, food web, population dynamics, or a species' distribution
Presence of reefs	Rocky marine habitats or biological concretions that rise from the sea bed
Presence of seagrass	Collective name for marine flowering plants of the families Potamogetonaceae and Hydrocharitaceae
Presence of specialized hydrocarbon-degrading microbial consortia	Presence of microorganisms which are able to degrade hydrocarbons
Presence of TBT degraders	Presence of microorganisms which are able to degrade Tributyltin
Propagule supply	Supply of larvae, spores and/or regenerative body fragments
Recruitment	Entry of new individuals into a population by reproduction or emigration
Salinity	The total amount of dissolved material (salt) in seawater
Sea level	The average height of the sea where it meets the land
Seabed mobility	Movement of sediment on the seabed
Sediment type	Physical properties of seabed substrate (e.g. sediment grain size and sorting)
Stratification	Formation of distinct water masses with different physico-chemical properties (salinity, oxygen, density, temperature) preventing water mixing
Suspended sediment	Particles of sediment which have become elevated from the seabed and are being kept suspended by turbulence within the water column
Tidal flows	Water movement caused by tides
Water chemistry	The chemical and physical characteristics and composition of the water column
Water currents	Movement of water masses by forces other than tides (e.g. winds)
Water depth	Distance between water surface and sea bed
Water quality	The condition of sea water relative to the requirements of a species or ecosystem and to any human need or purpose
Water temperature	The ambient temperature of the seawater
Wave action	Frequency and physical properties (height and period) of waves

9 List of Acronyms

Acronym	Definition
AEOI	Adverse Effect on Integrity
BSAC	British Sub-Aqua Club
CBD	Convention on Biological Diversity
CICES	Common International Classification of Ecosystem Services
CITES	Convention on International Trade in Endangered Species
Defra	Department for Environment, Food and Rural Affairs
DTM	Digital Terrain Models
EC	European Commission
EEA	European Environment Agency
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EMODnet	European Marine Observation and Data Network
EQA	Evidence Quality Assurance
EU	European Union
EUNIS	European Nature Information System
GES	Good Environmental Status
HAB	Harmful Algal Bloom
HLMO	High Level Marine Objectives
HRA	Habitat Regulations Assessment
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IROPI	Imperative Reason of Overriding Public Interest
JNCC	Joint Nature Conservation Committee
MarLIN	Marine Life Information Network
MCAA	Marine and Coastal Access Act
MCZ	Marine Conservation Zone
MPA	Marine Protected Area
MPS	Marine Policy Statement
MS	Member State
MSFD	Marine Strategy Framework Directive
NBN	National Biodiversity Network
NNRP	National Natural Resources Policy
OBIS	Ocean Biogeographic Information System
OSPAR	Oslo-Paris Agreement
PISCES	Partnerships Involving Stakeholders in the Celtic Sea Ecosystem
POLCOMS	Proudman Oceanographic Laboratory Coastal Ocean Modelling System
RBMP	River Basin Management Plan
SAC	Special Area of Conservation
SCUBA	Self-Contained Under Water Breathing Apparatus
SEA	Strategic Environmental Assessment
TBT	Tributyltin
UNCLOS	United Nations Convention on the Law of the Sea
WCA	Wildlife and Countryside Act
WFD	Water Framework Directive

10 List of Appendices

Appendix 1 – Links to Policy and Legislative Instruments Applicable to the UK Marine Environment

- Marine Strategy Framework Directive: eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0056&from=EN
- Maritime Spatial Planning Directive: eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0089&from=GA
- Habitats Directive: eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31992L0043&qid=1458229606611&from=EN
- Birds Directive: eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0147&rid=1
- Water Framework Directive: eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF
- Environmental Impact Assessment (EIA) Directive: http://ec.europa.eu/environment/eia/pdf/EIA_Directive_informal.pdf
- Environment (Wales) Bill: http://www.senedd.assembly.wales/documents/s48648/Environment%20Wales%20Bill%20as%20passed.pdf . At the time of writing, the Bill has not received Royal Assent.
- Convention on Biological Diversity: www.cbd.int/doc/legal/cbd-en.pdf
- OSPAR: www.ospar.org/site/assets/files/1290/ospar_convention_e_updated_text_in_2007_no_revs.pdf
- Convention on the Conservation of Migratory Species of Wild Animals: www.cms.int/sites/default/files/instrument/CMS-text.en_.PDF
- UNCLOS: www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf
- Wildlife and Countryside Act: www.legislation.gov.uk/ukpga/1981/69/pdfs/ukpga_19810069_en.pdf
- Conservation of Seals Act: www.legislation.gov.uk/ukpga/1970/30/pdfs/ukpga_19700030_en.pdf
- Marine and Coastal Access Act: www.legislation.gov.uk/ukpga/2009/23/pdfs/ukpga_20090023_en.pdf
- Marine Scotland Act: www.legislation.gov.uk/asp/2010/5/pdfs/asp_20100005_en.pdf
- UK High Level Marine Objectives: www.gov.uk/government/uploads/system/uploads/attachment_data/file/182486/ourseas-2009update.pdf
- Safeguarding Our Seas:
- www.gov.uk/government/uploads/system/uploads/attachment_data/file/69321/pb6187-marine-stewardship-020425.pdf
- UK Marine Policy Statement: www.gov.uk/government/uploads/system/uploads/attachment_data/file/69322/pb3654-marine-policy-statement-110316.pdf
- East Inshore and East Offshore Marine Plans (2014) www.gov.uk/government/uploads/system/uploads/attachment_data/file/312496/east-plan.pdf
- Scotland's National Marine Plan: www.gov.scot/Resource/0047/00475466.pdf
- EU Biodiversity Strategy: ec.europa.eu/environment/nature/info/pubs/docs/brochures/2020%20Biod%20brochure%20final%20lowres.pdf

Appendix 2 – List of Keywords used as Search Terms

Abiotic
Abundance of biota
Accumulation
Acidity
Aesthetic
Aquaculture
Bacteria
Benthic
Bequest
Biodeposition
Biodiversity
Bioengineering
Biological driver
Biomass
Bio-regulatory species
Bioremediation
Biotic
Biotic potential
Bioturbation
Carbon sequestration
Chemical condition
Climate
Climate regulation
Climate variation
Cold water coral
Competitor
Conservation
Cultural
Currents
Decomposition
Depth
Disease control
Disease prevalence
Dispersal capability
Dissolved gasses
Dissolved organic matter
Dissolved oxygen
Disturbance recovery capacity
Diving
Ecosystem functioning
Ecosystem process
Ecosystem service
Education
Emblematic interactions
Energy
Entertainment
Environmental driver
Erosion prevention
Eutrophication
Existence
Fibres
Filter feeders
Filtration
Fisheries
Flood protection
Food availability
Food web
Freshwater input
Function
Gas flows
Gene pool
Genetic material
Grazing pressure
Habitat
Habitat provision
Heritage cultural
Heterogeneous habitats
Hydrocarbon
Hydrodynamic flow
Hypoxia
Intellectual & representational interactions
Invasive species
Kelp
Large-scale weather events
Life cycle
Light Attenuation
Liquid flows
Macroalgae
Macrofauna
Maintenance
Marine
Marine Protected Area
Mass flows
Mediation
Microbial activity
Microorganism
Natural capital
Natural disturbance
Natural variability
Natural variation
Nitrogen flux
Nursery populations and habitats
Nutrient
Nutrient availability
Nutrient cycling
Nutrient provision
Nutrition
Ocean acidification
Organic carbon
Organic matter
Pest control
pH
Physical & experiential interactions
Physical refugee
Policy
Pollination & seed dispersal
Pollutants
Population dynamics
Predator
Primary production
Propagule supply
Provisioning
Recruitment
Reef
Regulation
Salinity
Scientific
Sea level
Seabed mobility
Seagrass
Sediment retention
Sediment type
Spatial scale
Spiritual interactions
Stratification
Suspended organic matter
Suspended sediment
Symbolic interactions
TBT
Temperature
Tidal flows
Toxins
Turbidity
Ventilation & transpiration
Visibility
Waste
Water chemistry
Water currents
Water depth
Water quality
Water temperature
Wave action

Appendix 3 – List of Competent Bodies used for Grey Literature Search

Centre for Environment, Fisheries and Aquaculture Science (Cefas)
Department for Environment, Food & Rural Affairs (Defra)
European Marine Observation and Data Network (EMODnet)
Food and Agriculture Organisation of the United Nations (FAO)
Intergovernmental Panel on Climate Change (IPCC)
International Union for Conservation of Nature (IUCN)
Irish Sea Fisheries Board/Bord Iascaigh Mhara (BIM)
Joint Nature Conservation Committee (JNCC)
Marine Biological Association (MBA)
Marine Life Information Network (MarLIN)
Natural England (NE)
Natural Resources Wales (NRW)
Scottish Natural Heritage (SNH)
The Crown Estate
United Nations Environmental Programme World Conservation Monitoring Centre (UNEP-WCMC)

Appendix 4 – Data Layer Confidence Score Method

Each data layer utilised in the mapping of potential ecosystem service delivery is subject to a confidence assessment to assess the quality of the data shown using the proforma outlined below. Separate scores for age, resolution adequacy, method of acquisition and degree of ground-truthing are attributed to each layer, and the summed score used to assign overall confidence. Confidence scores for some categories are weighted where applicable to ensure that the most important influences on data confidence are accounted for sufficiently in the assessment (for example age is considered an important factor in data confidence, but to a lesser degree than resolution adequacy or method of acquisition, hence variability in the maximum scores achievable). Most confidence categories are objective, however some degree of expert judgement is applied when assigning a score to the resolution adequacy, which is a consideration of the extent to which the scale over which the component/process occurs is reflected in the data resolution. A conservative approach to assigning confidence to take the lowest possible score for combination datasets has been adopted where appropriate.

Score	Age (vintage) of data
0	Unknown age
1	Old (>10 years old)
2	Recent (5 to 10 yrs old)
3	Very recent (<5yrs old)

Score	Resolution adequacy of data
0	Unknown resolution adequacy
1	Low - data resolution is poor for component mapped
3	Moderate - data resolution is moderate for component mapped
6	High – data resolution is good for component mapped

Score	Method of Data Acquisition
0	Unknown methods of acquisition
1	Interpolated
2	Modelled
4	Remotely sensed
6	Field observations

Score	Extent of Ground-truthing (if applicable)
0	None or limited ground-truthing
2	Ground-truthing

Overall Score	Confidence Classification
12 - 17	High confidence
6 - 11	Medium confidence
0 - 5	Low confidence

Appendix 5 – Data Layer Confidence Assessment

CONFIDENCE MATRIX	Age				Resolution adequacy				Method of acquisition					Ground-truthing (if applicable)		Total Score	Confidence
	Unknown	Old (>10 years old)	Recent (5 to 10 yrs old)	Very recent (<5yrs old)	Unknown	Low - data resolution is poor for component mapped	Moderate - data resolution is moderate for component mapped	High – data resolution is good for component mapped	Unknown	Interpolated	Modelled	Remotely sensed	Field observations	Limited or no evident ground-truthing	Ground-truthing		
Score	0	1	2	3	0	1	3	6	0	1	2	4	6	0	2		
Provisioning – Kelp Data Layers																	
Laminaria hyperborea distribution		1						6					6			13	High
Temperature				3		1						4		0		8	Medium
Salinity				3		1				1				0		5	Low
Nitrate				3		1				1				0		5	Low
Phosphate				3		1				1				0		5	Low
Light attenuation				3		1						4				8	Medium
Tidal currents				3			3				2			0		8	Medium
Wave action				3			3				2			0		8	Medium
Seabed habitat			2				3				2				2	9	Medium
Regulation & Maintenance – Bioremediation Data Layers																	
Temperature				3		1				1				0		5	Medium
Oxygen				3		1				1				0		5	Low
pH				3		1				1				0		5	Low
Wave action				3			3				2			0		8	Medium
Nitrate				3		1				1				0		5	Low
Phosphate				3		1				1				0		5	Low
Cultural – Diving Data Layers																	
Depth/pressure				3			3					4		0		10	Medium
Tidal currents				3			3				2			0		8	Medium
Seabed habitat			2				3				2				2	9	Medium
Existence of reefs	not applicable																
Conservation	not applicable																

Appendix 6 – OBIS Database List

The OBIS data layer used to provide information on *Laminaria hyperborea* distribution is comprised of the following database records. Further details of records can be obtained from www.iobis.org.

Data source	Provider	Number of records
Norman and Florence Hammond records. Sea watch and coastal survey records	Cumbria Biodiversity Data Centre	35
Biodiversity of the North Sea - Helgoland	GEO-Tag der Artenvielfalt	1
DASSH Data Archive Centre Academic surveys	Marine Biological Association of the UK	27
DASSH Data Archive Centre expert sighting records	Marine Biological Association of the UK	1
DASSH Data Archive Centre volunteer sightings records	Marine Biological Association of the UK	4
Seasearch Marine Surveys	Marine Conservation Society	3949
Marine data from Natural Resources Wales (NRW) Technical Support (Research & Monitoring) Contracts, Wales	National Biodiversity Network Trust	144
Marine flora and fauna records from the North-east Atlantic	National Biodiversity Network Trust	6
Marine species data for Scottish waters held and managed by Scottish Natural Heritage, derived from benthic surveys 1993 to 2012	National Biodiversity Network Trust	749
Survey of North Wales and Pembrokeshire Tide Influenced Communities	National Biodiversity Network Trust	16
Yorkshire Naturalists Union Marine and Coastal Section Records	National Biodiversity Network Trust	17
Marine Data from Northern Ireland	National Museums of Northern Ireland; Ulster Museum Centre for Environmental Data and Recording	454
Marine Nature Conservation Review (MNCR) and associated benthic marine data held and managed by CCW	Natural Resources Wales	73
Marine species distributions in Irish coastal waters	Seasearch	401
Checklist of benthic marine algae and cyanobacteria of northern Portugal	University of A Coruña; Department of Animal, Plant and Ecological Biology	13
Monitoring of the intertidal biodiversity of rocky beaches with schools in Portugal 2005-2010	University of Porto Interdisciplinary Centre for Marine and Environmental Research (Porto)	1