Natural England Commissioned Report NECR088

Marine ecosystem services

Description of the ecosystem services provided by broad-scale habitats and features of conservation importance that are likely to be protected by Marine Protected Areas in the Marine Conservation Zone Project area

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

The aim of this literature review was to provide a baseline understanding of the marine ecosystem services that are provided by the broad-scale habitats and features of conservation importance that are likely to be protected by Marine Protected Areas in the Marine Conservation Zone Project area.

Coastal and marine ecosystems provide a variety of valuable economic services to human society. Examples include food production, flood protection and recreational and aesthetic benefits. There are various definitions of ecosystem services and methods for their classification, although all are related to the benefits that ecosystems provide for human society. By developing an understanding of ecosystem services, the implications for humans of changes to ecosystems can be assessed.

The Marine and Coastal Access Act (2009) requires the development of a network of Marine Protected Areas (MPAs) to protect marine species and habitats and to meet international and national commitments under the Marine and Coastal Access Act, the OSPAR Convention and the Convention of Biological Diversity.

This study was commissioned in order to contribute to the evidence base for the establishment of the MPA network by identifying how features within MPAs provide benefits to society. The findings will be used to:

- Develop the impact assessments for proposed Marine Conservation Zones (MCZs).
- Develop a baseline understanding of the economic importance of marine species, habitats and marine ecosystems.
- Input into further work to assess the social and economic value of marine ecosystems, in order to further develop and improve wider marine management advice.

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Further information
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Summary

The purpose of this research project is, through a literature review, "*to describe the ecosystem services provided by broad-scale habitats and features of conservation importance that are likely to be protected by Marine Protected Areas in the Marine Conservation Zone Project area*". Ecosystem services have been defined in many ways, but the common link between them is the emphasis placed upon the role played by ecosystems in enhancing or maintaining human wellbeing. The classification of ecosystem services used in this study has been adapted from a model developed through 'The Economics of Ecosystems and Biodiversity' (TEEB) project (Balmford and others 2008). The TEEB ecosystem service classification is based on a distinction between the beneficial ecological processes and the services experienced by humans. Since the ecosystem services are considered separately from their underpinning ecosystem processes, it eliminates the risk of double counting and facilitates effective economic valuation of ecosystem services.

The literature review was conducted using a systematic search method based on an agreed set of keywords that reflected the ecosystem services identified within the adapted TEEB classification. UK-specific peer-reviewed research was prioritised as the evidence base for this study, but where unavailable, alternative sources were used. The habitats and species likely to be protected in the Marine Conservation Zone Project area (known as 'marine features') were each reviewed in order to identify the beneficial ecosystem processes and services it provides. Each feature review has four main sections: 1) a summary of the beneficial ecosystem services the feature provides; 2) a summary of the ecological character of the marine feature; 3) a review of the beneficial ecosystem processes provided by the marine feature; and 4) a review of the beneficial ecosystem services provided by the marine feature.

Overall, the review found that the evidence base for the existence of beneficial ecosystem processes and services is inconsistent, with some features offering the potential for relatively strong conclusions regarding the beneficial ecosystem processes and services available, whereas others offered little or no evidence, making conclusions extremely tentative and potentially unreliable. Therefore when interpreting this report, it is important for the reader not to equate insufficient evidence with the provision of no beneficial ecosystem services. Of the evidence available, substantially more was related to habitats than species, with the evidence base stronger with respect to beneficial ecosystem processes than beneficial ecosystem services. In particular, a strong evidence base was identified for the beneficial ecosystem processes of primary and secondary production, larval/gamete supply, food web dynamics, formation of species habitat, and species diversification. Within the habitat reviews, commercial fisheries were the beneficial ecosystem service with the strongest evidence base. For individual species, the evidence base for beneficial ecosystem processes and services was very limited, with no evidence available at all for many species. As with the habitat evidence base, a majority of the evidence available for species-specific beneficial ecosystem services was focused upon commercial fisheries. All features were considered to provide spiritual, cultural, research and education benefits, although these were difficult to quantify.

Despite the limited evidence base, the report identifies that most marine features likely to be protected by the Marine Protected Areas in the Marine Conservation Zone Project area have both beneficial ecosystem processes and services, and therefore provide a clear link to aspects of human wellbeing.

Contents

1 Introduction

Purpose of the study

The purpose of this research project is, through a literature review, “to describe the ecosystem services provided by broad-scale habitats and features of conservation importance (as specified by EUNIS level 3) that will be protected by Marine Protected Areas in the Marine Conservation Zone Project area”. The need for this research arises from the Marine and Coastal Access Act (2009) which requires the development of a network of Marine Protected Areas (MPAs). The MPA network is vital to delivering the protection of important marine species and habitats and to meet our international and national commitments, specifically those outlined in the Marine and Coastal Access Act, the OSPAR Convention and the Convention of Biological Diversity. The network will consist of existing MPAs (European marine sites (Special Areas of Conservation, Special Protection Areas), Sites of Special Scientific Interest, and Ramsar sites) and new Marine Conservation Zones (MCZ). This study contributes to the evidence base for the establishment of the MPA network through identifying how features within MPAs provide benefits to society through the provision of ecosystem services.

The review is focused upon the species and habitats, collectively known as ‘marine features’ that are likely to be protected by the MPA network, excluding certain species identified in the Habitats Directive. Features to be protected within the MCZ Project area include broad-scale habitats and features of conservation importance. A full list of the marine features included in the study is presented in Appendix 1. The report begins with an introduction that outlines the purpose of the study and explains the classification of ecosystem services adopted in this report (section 1). This is followed by a detailed description of the method used to undertake the review (section 2). A summary of the results of the review is then presented and discussed, in particular, noting the quality of the evidence base for the report (section 3). The main body of the report consists of sections 4 to 54, each of which is a review of one of the marine features identified as likely to be protected through the MCZ project. The reviews are organised according to feature type: broadscale habitats (sections 4 to 16), habitats of conservation importance (sections 17 to 40), and species of conservation importance (sections 41 to 53). Section 54 consists of a list of features for which no information was found, all of which are species of conservation importance. Each feature review consists of four main sections: 1) a summary of the ecosystem services the feature provides; 2) a summary of the ecological character of the marine feature; 3) a review of the beneficial ecosystem processes provided by the marine feature; and 4) a review of the beneficial ecosystem services provided by the marine feature.

The work has been conducted by a partnership between the Centre for Conservation Ecology and Environmental Science (CCEES) of Bournemouth University and ABPmer, Southampton.

Ecosystem services

Coastal and marine ecosystems provide ecological functions that directly or indirectly translate to a variety of economic services of value to human society. For example, they support the production of food, climate regulation, flood protection, pollution sinks, and recreational and aesthetic benefits (Defra 2007; Remoundou 2009). Ecosystem services can be defined in a variety of ways, including “the benefits human populations derive, directly or indirectly, from ecosystem functions” (Costanza and others 1997), “the benefits people obtain from ecosystems” (MEA, 2003); “the direct and indirect contributions of ecosystems to human well-being” (Balmford and others 2008), and the “services provided by the natural environment that benefit people” (Defra 2007). The common link between the various definitions of ecosystem services is the emphasis placed upon the beneficial role played by ecosystems in enhancing or maintaining aspects of human well being and thereby human society.

Understanding ecosystem services allows the implications of changes in ecosystems to be assessed in terms of their impact on humans. Ecosystem change can arise from dynamic environmental conditions, modification in management practices, and development activity, all of which can change the benefits that society can derive from specific ecosystems. Ecosystem services therefore provide a convenient method to monitor the impacts of ecosystem change and can also be used to identify triggers for intervention in ecosystem management.

Classification of ecosystem services

There is considerable debate over how ecosystem services should be defined and classified, which reflects differing interpretations of how social benefits are linked with ecosystem functionality (Constanza 2008; Wallace 2007; Fisher and others 2008; Swedish Environmental Protection Agency 2008; Fisher and others 2009; Granek and others 2009). Several approaches to the measurement and classification of ecosystem services have been proposed (Costanza and others 1997; de Groot and others 2002; eftec 2006; Frid 2008). Each of these classification systems uses similar, but distinctive categories, which results in a lack of consistency and comparability between assessments. It has been suggested by Fisher and others (2009) that a single ecosystem service classification system will not be applicable in all circumstances and therefore a classification system should be tailored to meet the specific needs of a given assessment. In contrast, there have been calls to develop a single internationally standardized list of ecosystem services that can serve different purposes, but as yet, no such universal approach exists.

The most well-known and widely applied classification of ecosystems services was developed by the Millennium Ecosystem Assessment (MEA) (2003) which although useful for educational purposes, is not suited for economic valuation. The MEA firmly established the concept of ecosystem services as an approach for linking ecosystem function to human welfare within the marine environment (UNEP 2006a). It categorises ecosystem services as provisioning, regulating, cultural, or supporting (MEA 2003). The MEA ecosystem service classification has been complimented as being intuitive and highly useful as an educational and policy tool (Balmford and others 2008). However, it has been widely criticised as not 'fit for purpose' (Boyd and Banzhaf 2007) as it exhibits logical inconsistencies within and between categories, and mixes processes (means) and benefits (ends). It is therefore particularly prone to double counting (Haines-Young and Potschin 2007), and so unable to produce economically robust valuation of ecosystem services (Fisher and others 2009).

Following a review of ecosystem service classifications, this study does not use the MEA classification, but instead draws from a model developed through 'The Economics of Ecosystems and Biodiversity' (TEEB) project. The TEEB ecosystem service classification is based on a distinction between ecological processes and the benefits experienced by humans (Balmford and others 2008). It is therefore consistent with the framework developed by Fisher and others (2009), which similarly focuses on valuing the benefits to human wellbeing, and avoids the risk of double counting by separating such benefits from underlying ecosystem processes. The TEEB classification has three components (Balmford and others 2008):

- **Core ecosystem processes:** these describe the basic ecosystem processes supporting ecosystem functions.
- **Beneficial ecosystem processes:** these are the specific ecosystem processes that directly underpin benefits to people.
- **Beneficial ecosystem services:** these are the products of ecosystem processes that directly impact human wellbeing.

Figure 1 and Table 1 explain the ecosystem service classification used in this study, which is an adapted version of the TEEB classification. Adaptations were necessary to tailor the classification to the marine environment, as in general terms, the TEEB classification is more suited to terrestrial environments. Such adaptation of classification systems to suit specific applications is advocated for example by Fisher and others (2009). The adaptations were made in response to reflections following the application of the classification system during the review process and feedback from the Steering Group.

Specifically, the adaptations of the TEEB classification involved the replacement of certain terrestrial ecosystem processes with their marine equivalent (e.g. 'pollination' was replaced with 'larval / gamete supply'). A further refinement was the removal of any benefits not reliant upon active marine ecological processes or that were not relevant to this study. A focus on active processes has been adopted as the purpose of this study is to inform assessment of the potential benefits of MPAs. Therefore energy from oil and gas deposits has been removed as a potential beneficial ecosystem service as this service is not reliant upon contemporary ecological processes. Adaptations to the TEEB classification have resulted in the removal of categories including 'crops' (as this is considered to be a terrestrial consideration), and ‘aggregates’ (as this ecosystem service is not reliant upon contemporary ecological or geological processes). Other categories have been combined to simplify and promote clarity of classification. For example, ‘inspiration’ has been placed within the ‘aesthetic benefits’ category as there is ambiguity between these categories: an aesthetic benefit could be argued to also provide inspiration. Therefore the most effective mechanism to avoid double counting was to combine the categories.

Other categories, whilst initially appearing ambiguous, have been retained in order to maintain the consistency of the TEEB classification. For example, ‘fertiliser’ and ‘feed’ are included in the category of ‘food’ even though they provide inputs to plant and animal rearing practices (rather than food for humans directly). A number of beneficial ecosystem services are cross-cutting and cannot be allocated a single category. For example, ‘employment’ and ‘economic wellbeing’ are likely outcomes of any beneficial ecosystem service, making it difficult to categorise them as separate benefits.

Several beneficial ecosystem services are assumed to be universally provided by all habitats. These are ‘larval / gamete supply’, ‘biological control’, ‘food web dynamics’, ‘species diversification’, and ‘genetic diversification’. Where sufficient information was identified, these beneficial ecosystem services are included in the relevant feature reviews and in Tables 2 to 4. In addition, two beneficial ecosystem services are assumed to be provided by all features (both habitats and species), namely ‘spiritual / cultural wellbeing’, and ‘research and education’. These benefits do not appear in each feature review, except where particularly important, but do appear in Tables 2 to 4.

Figure 1. Ecosystem service classification used in this study (adapted from Balmford and others 2008)

CORE ECOSYSTEM PROCESSES
Production
Decomposition
Nutrient cycling
Hydrological processes
Ecological interactions
Evolutionary processes
Water cycling

BENEFICIAL ECOSYSTEM PROCESSES
Primary production
Secondary production
Larval/Gamete supply
Biological control
Food web dynamics
Species diversification
Genetic diversification
Waste assimilation
Erosion control
Formation of species habitat
Formation of physical barriers
Formation of pleasant scenery
Climate regulation
Air quality regulation
Biogeochemical cycling
Water cycling (regulation)
Water purification (quality)

BENEFICIAL ECOSYSTEM SERVICES	
Fisheries	Food
Other wild harvesting	
Aquaculture	
Fertiliser / Feed	
Salt	Raw materials
Ornamental materials (shells)	
Biofuels	Energy
Medicines	Physical wellbeing
Natural hazard protection	
Environmental Resilience	
Regulation of pollution	
Tourism	Psychological/ Social wellbeing
Recreation / Sport	
Spiritual/cultural wellbeing	
Aesthetic benefits	
Nature watching	
Aquaria	
Research and Education	Knowledge

Table 1. Definition of the classification system applied to the ecosystem services provided by Marine Features (adapted from Balmford and others 2008)

CORE ECOSYSTEM PROCESSES	
Production	Production of plant and animal biomass.
Decomposition	Reduction of the body of a formerly living organism into simpler forms of matter.
Nutrient cycling	Cycle by which a chemical element or molecule moves through both biotic and abiotic compartments of ecosystems (e.g. nitrogen cycle, phosphorus cycle, carbon cycle).
Water cycling	Cycle of water through both biotic and abiotic compartments of ecosystems.
Hydrological processes	Processes through which the context is formed for a habitat or species, including currents and salinity.
Ecological interactions	Inter- and intra-specific interactions between organisms (including predation, competition, and parasitism).
Evolutionary processes	Genetically-based processes by which life forms change and develop over generations (including evolution, speciation, adaptation).
BENEFICIAL ECOSYSTEM PROCESSES	
Primary production	Production of plant biomass.
Secondary production	Production of animal biomass.
Larval/Gamete supply	Transport of larvae and gametes.
Biological control	Inter- and intra-specific interactions resulting in reduced abundance of species that are pests, diseases or invasives in a particular ecosystem.
Food web dynamics	The interaction between species related to food consumption.
Formation of species habitat	Formation of the physical properties of the habitats necessary for the survival of species.
Species diversification	The production of genetic diversity across species.
Genetic diversification	The production of genetic diversity within species.
Waste assimilation	Removal of contaminants from the ecosystem (including through biological processes such as decomposition or bioaccumulation).
Erosion control	Control of the processes leading to erosion.
Formation of physical barriers	Formation of structures that attenuate the energy of (or block) water or wind flow, e.g. coast protection.
Formation of pleasant scenery	Formation of seascapes that are attractive to people.
Climate regulation	Modulation of regional/local climate (e.g., of temperature, or rainfall).
Water quality regulation	Removal of contaminants from water flowing through an ecosystem.
Biogeochemical cycling	The modification of matter through biogeochemical processes.
Water cycling (regulation)	Regulation of the timing of water flow through an ecosystem, e.g. flood defence.
Water purification (quality):	Removal of contaminants from water flowing through an ecosystem (inc. through physical processes such as filtration or biological processes such as decomposition or assimilation).
BENEFICIAL ECOSYSTEM SERVICES	
Food	From capture fisheries, wild sources, and for fertilizer and feed (for plants and animals).
Raw materials	Salt and ornamental materials.
Energy	Biofuels (e.g. from algae).
Physical wellbeing	From harvested, cultivated and synthetic medicines, natural hazard protection, regulation of pollution, and from providing environmental resilience. Environmental resilience includes services that reduce the harmful impacts of climate change.
Psychological / Social wellbeing	From tourism, recreation, sport, spiritual, cultural, aesthetic, nature watching, and aquaria.
Knowledge	From research of the natural world and education about the natural world.

2 Method

The beneficial ecosystem processes and services supported by marine features were identified through a review of published research and expert opinion. A three-tier approach was used, as follows:

- **Peer-reviewed literature search**. Sources that have been academically peer-reviewed prior to publication were considered to be the most reliable form of evidence. Since not all peer-reviewed research databases contain the same literature, multiple databases were searched in order to ensure full coverage of the published evidence. The databases searched were: CAB Abstracts, Scopus, Science Direct, and Web of Knowledge. A separate Boolean search of each database was undertaken for every marine feature using an agreed set of keywords. The keywords were developed in partnership with the Steering Group and Natural England specialists and reflected the ecosystem service classification framework used in this study. The keywords were refined throughout the study in order to ensure, as far as possible, that all relevant papers were identified. The keywords used are presented in Appendix 2. Where the peer-review search identified insufficient sources to draw any meaningful conclusions about the ecosystem services provided by a marine feature, a grey literature search was conducted. Similarly, where there was a doubt that the peer-reviewed literature did not reflect the full range of ecosystem services provided by a marine feature, a grey literature search was also undertaken. This resulted in a grey literature search being conducted for all marine features.

- **Grey literature search**. Grey literature refers to research that is in the public domain, but which has not been formally peer-reviewed. This typically includes conference proceedings, reports, dissertations, websites, and presentations. Grey literature is inherently less reliable as it has not been peer-reviewed and therefore has limited quality assurance. Grey literature is notoriously difficult to search as it is not concentrated in specific databases (unlike peer-reviewed research). Therefore, in order to search the grey literature, specialist search engines were used. Following trials to identify the most efficient way of finding relevant sources, Google Scholar was used as the primary search engine to identify 'leads' which lead to specific sources. In addition, specific organisational websites were searched which were likely to host relevant sources, including Natural England, JNCC, MarLIN, OSPAR Commission, World Wildlife Fund, and Wildlife Trusts. Where insufficient sources were identified in the grey literature from which to identify clear evidence for the ecosystem services provided by marine features, it was concluded that a research gap existed and expert opinion was sought.

- **Expert opinion**. Expert opinion is the least reliable form of evidence included in this study as it has no quality assurance being neither published nor peer-reviewed. Expert opinion was sought in order to fill the research gap presented by the absence of any peer-reviewed or grey literature. Expert opinion was generally obtained from specialists within the research partnership or through contact with external specialists. A list of experts contacted is presented in Appendix 3.

Evidence directly related to the UK was prioritised in the searches, but where this was not available or limited in scope, research from comparable temperate environments was sought. Unless stated otherwise, all studies referred to in the reviews are from the UK. Certain marine features were grouped for convenience of searching. For example, high, moderate and low energy intertidal rock habitats were group-searched as 'intertidal rock'. However, where there was evidence of a distinction between the different energy levels of the marine feature, this was clearly stated in the review.

Each feature review consists of four main sections. The first is a summary of the beneficial ecosystem services the feature provides, derived from the detailed review. This summary section includes a diagram illustrating the relationship between the core ecosystem processes, beneficial ecosystem processes, and beneficial ecosystem services which have been identified for each marine feature. The diagram shows the core ecosystem processes (listed in the blue column) upon which the beneficial ecosystem processes (listed in the green column) depend and then lists the beneficial ecosystem services (yellow column) which result from these underlying processes. The various lines shown on these diagrams represent the links between core ecosystem processes, beneficial processes and beneficial services, which have been identified through undertaking the review of literature. For example, where a line is drawn between the beneficial process ‘formation of species habitat’ and the beneficial ecosystem service ‘environmental resilience’, this means that evidence will have been found within the literature that this processes underpins this specific beneficial ecosystem service. The meaning of the different line styles in relation to the source of evidence is explained in each figure. The second section of the review is a summary of the ecological character of the marine feature. This was sourced from existing published accounts where possible; particularly Natural England feature descriptions and OSPAR definitions. The third section is the detailed synthesis of the beneficial ecosystem processes provided by the marine feature, derived from the literature review. Finally, the fourth section is the synthesis of the beneficial ecosystem services provided by the marine feature.

It is important that the reader assesses the applicability of the evidence presented in this report for the purpose for which the reader wishes to use the evidence.   Within each feature review, the text and summary diagram make clear which evidence is peer-reviewed, which is sourced from the grey literature, and which is based upon expert opinion. Tables 2 to 4 summarise the source and therefore the quality of the evidence base used for the review for each marine feature.

Given that there is overlap between some habitat classifications and that all species exist within the context of a habitat, there is some repetition of evidence amongst a limited number of feature reviews. This reflects the shared evidence base between certain habitats and species. It also reflects the assumption that this document will not be read cover to cover and that any evidence presented in one section may need to be repeated elsewhere to ensure that it is not missed by the reader. Finally, to assist the reader further, a glossary of some key scientific terms has been included in Appendix 4.

3 Discussion

This section of the report provides a summary of the evidence base available for each feature review and discusses the implications of the evidence quality for the reliability of the reviews. A simple greyscale classification scheme is used to summarise the quality of the evidence within each feature review, as illustrated in Tables 2 to 4. For each feature, the tables indicate whether or not any evidence was found to support the existence of both beneficial ecosystem processes and beneficial ecosystem services. Where an evidence base exists, the quality of the evidence is indicated in the tables using a colour coding scheme. Black represents peer-reviewed evidence, which is the most reliable evidence. Dark grey denotes evidence from the grey literature; whilst pale grey indicates evidence sourced from expert opinion or from overseas, which is the least reliable evidence. Hatching denotes cases in which beneficial ecosystem services have been assumed to exist, regardless of the presence or absence of an evidence base.

The summary of results presented in Tables 2 to 4, makes it clear that the evidence base is inconsistent, with some features offering the potential for relatively strong conclusions regarding the beneficial ecosystem processes and services they offer, whereas others have little or no evidence, making conclusions extremely tentative and potentially unreliable. However, when interpreting this report, it is important not to equate insufficient evidence with insignificant ecosystem value. The reader is therefore recommended to consider the evidence base described in the report, along with the conclusions presented on the current knowledge of the ecosystem services that the features provide.

The tables illustrate that substantially more evidence of beneficial ecosystem processes and beneficial ecosystem services is available for habitats than for species. Tables 2 and 3 also illustrate that the evidence base for habitats is generally greater with respect to beneficial ecosystem processes than beneficial ecosystem services. A particularly strong evidence base is available related to the beneficial ecosystem processes of primary and secondary production, larval/gamete supply, food web dynamics, formation of species habitat, and species diversification. Although this pattern potentially reflects the tendency in scientific research to study how a habitat or species functions rather than how it could be used, it represents a significant challenge for the study of ecosystem services. Within the habitat reviews, commercial fisheries are the beneficial ecosystem service with the strongest evidence base.

Table 4 demonstrates clearly that for specific marine species, the evidence base for beneficial ecosystem processes and services is very limited, with no evidence available at all for many of the species. Where evidence exists that relates to beneficial ecosystem processes, in general it is focused upon food web dynamics. As with the habitat evidence base, the bulk of the evidence available for species-specific beneficial ecosystem services is focused upon commercial fisheries.

In Tables 2 to 4, it is notable that expert opinion is more prevalent in the identification of beneficial ecosystem services than beneficial ecosystem processes. This reflects the relatively weak evidence base related to beneficial ecosystem services. More specifically, it reflects a lack of published research into how marine features are used for activities that do not include the commercial exploitation of fish. The tables collectively suggest a clear lack of evidence and therefore significant research gaps related to the beneficial ecosystem services of ‘environmental resilience’, ‘sport and recreation’, ‘tourism’, and ‘nature watching’ (see Table 1 for a definition of these beneficial ecosystem services).

Table 2. Evidence base for broadscale habitats

Key

- Peer-reviewed literature
- Grey literature
- Expert opinion
- Assumed beneficial services

	Intertidal rock	Intertidal coarse sediment	Intertidal sand, muddy sand and mixed sediments	Intertidal mud	Coastal saltmarshes	Intertidal sediments dominated by aquatic	Intertidal biogenic reefs	Infralittoral rock	Circalittoral rock	Subtidal sediment	Subtidal macrophyte-dominated sediment	Subtidal biogenic reefs	Deep-sea bed
Beneficial Ecosystem Processes													
Primary production	P	E	P	P	G	E	G	G	G	P	P	E	P
Secondary production	P			P	G	P	G		G	G	P	G	P
Larval/Gamete supply		P	P	P	P		E	G	G	P	G		
Biological control													
Food web dynamics	G	E	P	P	P	E	E	G		P	P	P	P
Species diversification	P			G			G	P	G	P		P	E
Genetic diversification													P
Waste assimilation													
Erosion control		P	P	P	P	E	E			P	E		
Formation of species habitat	G	P	P		P	E	P	G	G	P	G	G	
Formation of physical barriers					P			E	E				
Formation of pleasant scenery													
Climate regulation	G			P	P							E	P
Water quality regulation													
Biogeochemical cycling	P		P	P	P	P	G			P	G	P	P
Water cycling													
Water purification (quality)					P	P	E					P	
Beneficial Ecosystem Services													
Fisheries	E	E	E	P	P	P	G	P	E	G	P	P	P
Other wild harvesting	P		E			P						G	
Aquaculture							G					P	
Fertiliser / Feed					P	P	G				P		
Salt													
Ornamental materials (shells)													
Biofuels													
Medicines													
Natural hazard protection		E	E		P		G				E	P	
Environmental Resilience	P					P	E	E		P	E	E	
Regulation of pollution				P	P	E				P	G		
Tourism					P								
Recreation / Sport	E		E		P				E				
Spiritual/cultural wellbeing	A	A	A	A	A	A	A	A	A	A	A	A	A
Aesthetic benefits													
Nature watching				E	P	E							
Aquaria												E	
Research and Education	A	A	A	A	A	A	A	A	A	A	A	A	A

Table 3. Evidence base for habitats of conservation importance

Key

- Peer-reviewed literature
- Grey literature
- Expert opinion
- Assumed beneficial services

	Saline lagoons	Submarine Structures made by leaking gases	Submerged or partially submerged sea caves	Blue Mussel beds	Cold water coral reefs	Coral gardens	Estuarine rocky habitats	File Shell beds	Fragile sponge and anthozoan communities	Intertidal underboulder communities	Intertidal chalk communities	Maerl beds	Horse Mussel beds	Mud habitats in deep water
Beneficial Ecosystem Processes														
Primary production												Peer-reviewed		
Secondary production				Expert	Grey							Expert	Peer-reviewed	
Larval/Gamete supply	Peer-reviewed									Grey		Expert		
Biological control														
Food web dynamics		Expert	Expert	Expert				Peer-reviewed	Peer-reviewed			Peer-reviewed	Peer-reviewed	Grey
Species diversification	Peer-reviewed	Expert	Peer-reviewed	Expert	Grey	Peer-reviewed	Expert	Peer-reviewed	Peer-reviewed	Grey	Expert	Peer-reviewed	Peer-reviewed	Expert
Genetic diversification														
Waste assimilation														Expert
Erosion control				Expert				Peer-reviewed		Expert				
Formation of species habitat	Peer-reviewed	Peer-reviewed	Expert	Expert	Grey	Peer-reviewed	Grey	Peer-reviewed	Peer-reviewed	Grey	Peer-reviewed	Peer-reviewed	Peer-reviewed	Grey
Formation of physical barriers					Peer-reviewed					Expert				
Formation of pleasant scenery														
Climate regulation		Peer-reviewed												Grey
Water quality regulation														
Biogeochemical cycling	Peer-reviewed	Expert		Expert	Expert			Peer-reviewed				Expert		Grey
Water cycling														
Water purification (quality)				Peer-reviewed										
Beneficial Ecosystem Services														
Fisheries	Expert	Expert		Grey	Expert	Expert	Expert	Peer-reviewed				Peer-reviewed	Expert	Expert
Other wild harvesting									Peer-reviewed	Grey				
Aquaculture	Peer-reviewed			Grey										
Fertiliser / Feed				Grey								Expert		
Salt														
Ornamental materials (shells)						Peer-reviewed						Expert		
Biofuels														
Medicines													Peer-reviewed	
Natural hazard protection				Expert			Expert	Expert		Expert				
Environmental Resilience														Expert
Regulation of pollution				Expert										
Tourism	Expert		Expert											
Recreation / Sport			Expert											
Spiritual/cultural wellbeing	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed
Aesthetic benefits														
Nature watching	Expert						Expert		Peer-reviewed					
Aquaria														
Research and Education	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed

Table 3. Evidence base for habitats of conservation importance (continued)

Key

- Peer-reviewed literature
- Grey literature
- Expert opinion
- Assumed beneficial services

	Deep-sea sponge aggregations	Seapens and burrowing megafauna	Native oyster (*Ostrea edulis*) beds	Peat and clay exposures	*Sabellaria* Reefs	Seagrass beds	Sheltered muddy gravels	Subtidal chalk	Subtidal sands and gravels	Tide swept channels
Beneficial Ecosystem Processes										
Primary production						Expert				
Secondary production	Expert									Peer-reviewed
Larval/Gamete supply						Expert				
Biological control						Expert				
Food web dynamics		Grey	Expert		Grey	Peer-reviewed	Grey		Grey	
Species diversification	Expert	Grey		Grey	Peer-reviewed	Peer-reviewed	Grey	Grey	Grey	Grey
Genetic diversification						Expert				
Waste assimilation							Expert		Grey	
Erosion control			Expert			Expert				
Formation of species habitat	Grey	Peer-reviewed	Expert	Grey	Peer-reviewed	Expert	Grey	Grey	Grey	
Formation of physical barriers						Expert				
Formation of pleasant scenery										
Climate regulation	Expert	Grey	Expert				Expert			
Water quality regulation										
Biogeochemical cycling	Expert	Grey	Expert			Grey	Expert		Expert	
Water cycling										
Water purification (quality)			Expert			Grey				
Beneficial Ecosystem Services										
Fisheries	Expert	Grey	Peer-reviewed			Peer-reviewed	Grey		Grey	
Other wild harvesting							Grey		Grey	
Aquaculture						Peer-reviewed				
Fertiliser / Feed						Expert				
Salt										
Ornamental materials (shells)										
Biofuels										
Medicines	Expert									
Natural hazard protection			Expert			Grey				
Environmental Resilience	Expert		Expert				Expert		Expert	
Regulation of pollution						Grey	Expert		Expert	
Tourism						Grey				
Recreation / Sport										
Spiritual/cultural wellbeing	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed
Aesthetic benefits										
Nature watching		Expert				Grey				
Aquaria										
Research and Education	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed

Table 4. Evidence base for species of conservation importance

Key

- Peer-reviewed literature
- Grey literature
- Expert opinion
- Assumed beneficial services

	Sea-fan anemone *Amphianthus dohrnii*	Stalked jellyfish *Haliclystus auricula*	Stalked jellyfish *Lucernariopsis*	Stalked jellyfish *Lucernariopsis*	Starlet sea anemone *Nematostella vectensis*	Sunset cup coral *Leptopsammia pruvoti*	Timid burrowing anemone *Edwardsia timida*	Lagoon sandworm *Armandia cirrhosa*	Tentacled lagoon-worm *Alkmaria romijni*	Amphipod shrimp *Gitanopsis bispinosa*	Gooseneck barnacle *Mitella pollicipes*	Lagoon sand shrimp *Gammarus insensibilis*	Spiny lobster *Palinurus elephas*	Defolin's lagoon snail *Caecum armoricum*
Beneficial Ecosystem Processes														
Primary production													Peer-reviewed literature	
Secondary production											Peer-reviewed literature			
Larval/Gamete supply														
Biological control														
Food web dynamics	Expert opinion				Peer-reviewed literature						Peer-reviewed literature			
Species diversification														
Genetic diversification														
Waste assimilation														
Erosion control														
Formation of species habitat						Grey literature					Peer-reviewed literature			
Formation of physical barriers														
Formation of pleasant scenery														
Climate regulation														
Water quality regulation														
Biogeochemical cycling														
Water cycling														
Water purification (quality)														
Beneficial Ecosystem Services														
Fisheries											Peer-reviewed literature		Peer-reviewed literature	
Other wild harvesting														
Aquaculture														
Fertiliser / Feed														
Salt														
Ornamental materials (shells)														
Biofuels														
Medicines														
Natural hazard protection														
Environmental Resilience														
Regulation of pollution														
Tourism														
Recreation / Sport						Peer-reviewed literature								
Spiritual/cultural wellbeing	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services
Aesthetic benefits														
Nature watching						Peer-reviewed literature								
Aquaria														
Research and Education	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services

Table 4. Evidence base for species of conservation importance (continued)

Key

- Peer-reviewed literature (black)
- Grey literature (dark grey)
- Expert opinion (light grey)
- Assumed beneficial services (hatched)

	Fan mussel *Atrina pectinata*	Lagoon sea slug *Tenellia adspersa*	Ocean quahog *Arctica islandica*	Pink Sea-fan *Eunicella verrucosa*	Tall sea pen *Funiculina quadrangularis*	Couch's goby *Gobius couchi*	European eel *Anguilla anguilla*	Giant goby *Gobius cobitis*	Long snouted seahorse *Hippocampus guttulatus*	Short snouted seahorse *H. hippocampus*	Smelt *Osmerus eperlanus*	Undulate ray *Raja undulata*	Bearded red seaweed *Anotrichium barbatum*	Burgundy maërl *Cruoria cruoriaeformis*
Beneficial Ecosystem Processes														
Primary production														
Secondary production			Expert				Peer-reviewed							
Larval/Gamete supply							Peer-reviewed		Peer-reviewed	Peer-reviewed				
Biological control														
Food web dynamics			Grey			Expert	Peer-reviewed	Expert	Peer-reviewed	Peer-reviewed	Peer-reviewed	Expert		
Species diversification	Expert													
Genetic diversification														
Waste assimilation														
Erosion control														
Formation of species habitat	Expert													
Formation of physical barriers														
Formation of pleasant scenery														
Climate regulation														
Water quality regulation														
Biogeochemical cycling														
Water cycling														
Water purification (quality)														
Beneficial Ecosystem Services														
Fisheries	Expert		Peer-reviewed				Peer-reviewed				Peer-reviewed	Expert		
Other wild harvesting														
Aquaculture							Peer-reviewed							
Fertiliser / Feed														
Salt														
Ornamental materials (shells)	Expert													
Biofuels														
Medicines														
Natural hazard protection														
Environmental Resilience								Expert						
Regulation of pollution														
Tourism														
Recreation / Sport							Expert	Expert			Peer-reviewed			
Spiritual/cultural wellbeing	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed
Aesthetic benefits														
Nature watching						Expert			Expert	Expert				
Aquaria														
Research and Education	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed	Assumed

Table 4. Evidence base for species of conservation importance (continued)

Key

- Peer-reviewed literature
- Grey literature
- Expert opinion
- Assumed beneficial services

	Common maërl *Phymatolithon calcareum*	Coral maërl *Lithothamnion corallioides*	Grateloup's little-lobed weed *Grateloupia*	Peacock's tail *Padina pavonica*
Beneficial Ecosystem Processes				
Primary production				
Secondary production				
Larval/Gamete supply				
Biological control				
Food web dynamics				
Species diversification				
Genetic diversification				
Waste assimilation				
Erosion control				
Formation of species habitat				
Formation of physical barriers				
Formation of pleasant scenery				
Climate regulation				Expert opinion
Water quality regulation				
Biogeochemical cycling				
Water cycling				
Water purification (quality)				
Beneficial Ecosystem Services				
Fisheries				
Other wild harvesting				
Aquaculture				Expert opinion
Fertiliser / Feed				Expert opinion
Salt				
Ornamental materials (shells)				
Biofuels				
Medicines				Expert opinion
Natural hazard protection				
Environmental Resilience				
Regulation of pollution				
Tourism				
Recreation / Sport				
Spiritual/cultural wellbeing	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services
Aesthetic benefits				
Nature watching				
Aquaria				
Research and Education	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services	Assumed beneficial services

4 Intertidal Rock

Note: this section combines the EUNIS level 3 habitats of high energy intertidal rock, moderate energy intertidal rock, and low energy intertidal rock (EUNIS CODES A1.1, A1.2 and A1.3).

Summary

Figure 2 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for intertidal rock habitats. This review encompasses high energy, moderate energy and low energy intertidal rock. **The beneficial ecosystem processes identified were primary and secondary production, larval / gamete supply, food web dynamics, formation of species habitat, species diversification, climate regulation and biogeochemical cycling. The beneficial ecosystem services identified were fisheries, other wild harvesting, environmental resilience, and sport/recreation.**

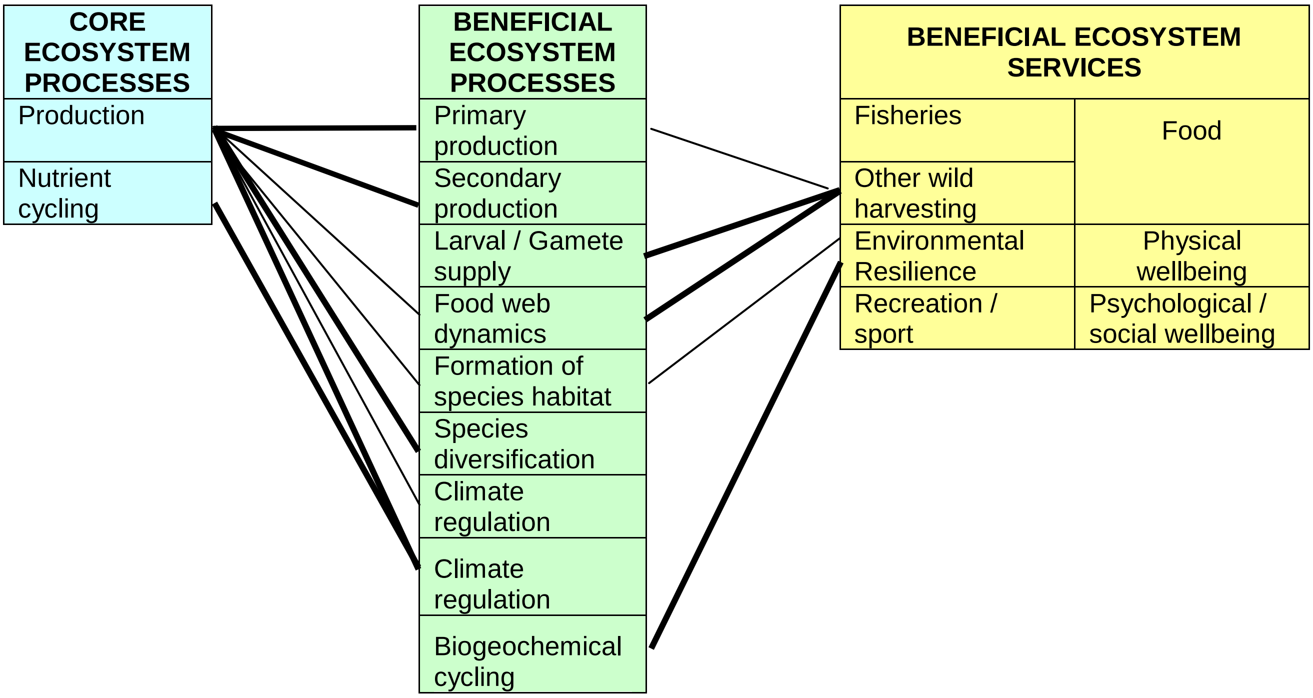

Figure 2 Marine ES Framework: Intertidal rock (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Intertidal rock is widespread around the UK. It is generally colonised by algae in wave-sheltered conditions and is increasingly colonised by limpets, barnacles and mussels as wave-exposure increases. In all cases there is a distinct zonation of species down the shore which principally reflects the degree of immersion and emersion by the tide. Biogeographic differences are also apparent with the littoral rock areas of south-west England tending to be richer in species than similar rocky habitats in the north and east (UK BAP 2010). The specific communities that occur vary according to a number of factors, including rock type, topographical features, outcrops from sediment and rock pools on the shore, exposure to wave action, temperature changes and turbidity (JNCC 2010).

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

Macroalgae on exposed intertidal rock produce large amounts of dissolved carbon which is taken up by bacteria and some larger invertebrates. Only about 10% of primary production is consumed directly, with grazers feeding mainly on microbial film on the rock surface (Jones, Hiscock and Connor 2000). Much of the dissolved organic carbon is removed by the sea which then enters other marine subtidal zones (Jones, Hiscock and Connor 2000).

Biomass Production: Secondary

Temperate rocky shores have been found to hold up to 14 times more secondary biomass than sedimentary shores (Ricciardi and Bourget 1999), which suggests that intertidal rock provides a particularly rich source of secondary biomass in the UK. Wave exposure is one of the best predictors for the biomass of suspension-feeding macroinvertebrates on temperate intertidal rock (Ricciardi and Bourget 1999). This is due to the effect of wave action on food supply for suspension feeders, as more exposed shores have increased food supply from particulate organic matter.

Larval / Gamete Supply

Juvenile fish use rocky shores as a nursery ground as many rocky shore species have a planktonic larval dispersal phase (Hill, Burrows and Hawkins 1998). Sheltered rock with mussel beds possibly favour species that reproduce with cocoons, brood their young or disperse as juveniles rather than as larvae because of the high rate of suspension feeding (Jones, Hiscock and Connor 2000).

Food Web Dynamics

Macroinvertebrates are an essential link between high trophic levels (e.g. fish, birds) and low trophic levels (e.g. algae) on intertidal rock habitat. Plaice (*Pleuronectes platessa*), Oystercatchers (*Haematopus ostralegus*) and Eider ducks (*Somaeria mollissima*) were found to predate on the horse mussel (*Modiolus modiolus*) (Ricciardi and Bourget 1999; Jones, Hiscock and Connor 2000). In addition, Corkwing wrasse (*Crenilabrus melopys*) was found to rely heavily on the intertidal habitat (Jones, Hiscock and Connor 2000). Both top-down and bottom-up trophic processes are therefore important regulators of rocky intertidal community dynamics, for example, controlling zonation of species on the shore that will impact upon primary production (Paine 1969; Menge 2000).

Formation of Species habitat

Rock pools and crevices provide protection for organisms from waves and desiccation (Baker and Crothers 1987; Jones, Hiscock and Connor 2000). They also provide shelter for invertebrate species such as crabs, near-shore fishes, shrimps and anemones. Rocky shores offer a wide range of refuges for intertidal fish communities where they can shelter during low tide, partly through supporting epifauna communities (Lalli and Parsons, 1997). Macroalgae increase the space available for attachment and protection from waves and heat as well as being an important food source. Mussels found on sheltered shores bind substratum and provide habitat for common species (Jones, Hiscock and Connor 2000). In more general terms, the UK intertidal rock resource is significant because it exists at the meeting point between northern and southern species distributions (Hill, Burrows and Hawkins 1998), and therefore provides habitat for a wide range of species.

Species Diversification

Intertidal rock sites are generally of high biodiversity as they can encompass a wide range of habitat types over a narrow spatial scale (Hill, Burrows and Hawkins 1998). In general, on exposed and sheltered rock, species diversity increases towards the lower shore. On exposed rock, mussels (*Mytilus edulis*) and barnacles (*Semibalanus balanoides*) and *Chthamalus* spp. typically dominate, occasionally with fucoids or red seaweed. Cracks, crevices and rock pools increase species richness and abundance of species (Baker and Crothers 1987). Keystone species on intertidal rock include barnacles (*S. balanoides*), mussels (*M.*

edulis), limpets (*Patella vulgata*) and fucoids (*Fucus vesiculosus, Fucus spiralis* and *Fucus serratus*). Sheltered intertidal areas have a dense fucoid algae cover (*F. spiralis*, *F. vesiculosus, F. serratus, Ascophyllum nodosum*). During the summer, ephemeral green and red seaweeds dominate intertidal rock (Jones, Hiscock and Connor 2000).

Climate regulation

Evidence from Portugal suggests that the net primary production rate exceeds net respiration rate on microbial biofilms, meaning that intertidal rock habitats contribute to carbon dioxide (CO_2) sequestration (Magalhaes and others 2003). CO_2 fluxes due to calcification can contribute to atmospheric CO_2; for example, calcification in the barnacles *Elminius modestus* and *Chthamalus montagui* contributes to around 40% of the species' total CO_2 production.

Biogeochemical cycling

Nitrate is removed from coastal waters by microbial biofilm on intertidal rock (Magalhaes and others 2003).

Review of Beneficial Ecosystem Services

Fisheries

Intertidal rock habitats are important sources of larval plankton upon which commercially important fish species feed, including mussels and larval fish of plaice and mackerel (expert opinion).

Other Wild Harvesting

Several rocky shore species are commercially exploited by man including: kelp, seaweed, edible crabs, mussels and winkles (Hill, Burrows and Hawkins 1998)

Environmental Resilience

Intertidal rock provides a natural form of protection from erosion by reducing the wave energy that reaches the shore. This is a long-term benefit as rocky shores are resistant to modification and so persist through time (Anthony 2008). In ecological terms, intertidal rock communities have a robust capacity to recover naturally from anthropogenic impacts due to arrival of propagules from unaffected areas (Hill, Burrows and Hawkins 1998).

Recreation / Sport

Rock pools are particularly important habitats of intertidal rock that attract visitors to the marine environment. In the correct conditions, intertidal rock can also generate surf breaks.

Research

Intertidal rocky shores are a classic focus for research with a wealth of historical data regarding many aspects of ecology (Connell 1961; Paine 1969). Such baseline data is extremely useful for exploring the impacts of environmental change (Hawkins and others, 2009). Rocky intertidal zones have been an active area of research because communities are well-defined and accessible, and so can be easily and efficiently surveyed (Petraitis and others 2008; Hill and others 1998).

5 Intertidal Coarse Sediment (EUNIS code A2.1)

Summary

Figure 3 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for intertidal coarse sediment. **The beneficial ecosystem processes identified were secondary production, larval/gamete supply, food web dynamics, formation of species habitat, and erosion control. The beneficial ecosystem services identified were fisheries and natural hazard protection.**

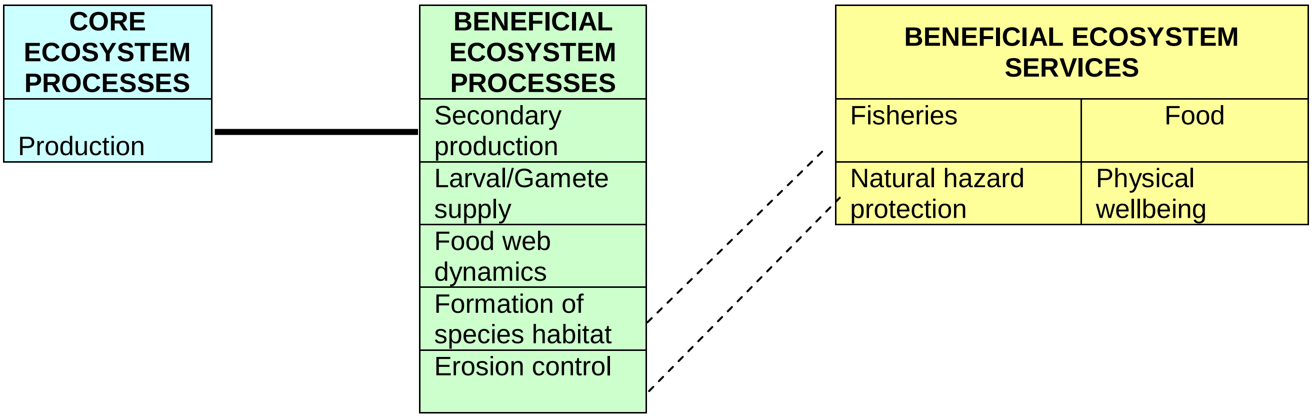

Figure 3 Marine ES Framework: Intertidal coarse sediment (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Intertidal coarse sediments include shores of pebbles, cobbles and gravel, sometimes with varying amounts of coarse sand. The sediment is highly mobile and subject to high degrees of drying between tides. As a result, few species are able to survive in this environment. Beaches of mobile cobbles and pebbles tend to be devoid of macroinfauna, while gravelly shores may support limited numbers of crustaceans. Intertidal coarse sediments are found along relatively exposed open shores, where wave action prevents finer sediments from settling. Coarse sediments may also be present on the upper parts of shores where there are more stable, sandy biotopes on the lower and mid shore (Connor 2004 and others).

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

Copepods that feed mostly on diatoms play an important role in transferring energy from primary producers to higher trophic levels (expert opinion).

Larval/Gamete supply

Burd and others (2008) and papers therein report higher rates of larval settlement on intertidal coarse sediments for both Dungeness crabs (*Cancer productus*) and Manilla clam (*Ruditapes philippinarum*). Furthermore, Jackson and others (2007) show that horseshoe crabs favour spawning sites with coarse sediment.

Food web dynamics

Intertidal coarse sediment provides feeding sites for wading birds at the strandline, but to a lesser extent than intertidal mud or intertidal sediment dominated by aquatic angiosperms (expert opinion).

Formation of species habitat

The relative mean particle size of coarse sediment habitats has an effect on the grazing efficiency of harpacticoid copepods, creating variation in the favoured habitat for these species. For example, De Troch and others (2006) note that the copepods *Paramphiascella fulvofasciata* and *Nitokra spinipes* in the Westerschelde Estuary (SW Netherlands) favour grazing on a substrate of large mean particle size. The strong negative effect of fine grains on the grazer's efficiency is thought to be explained by the resulting differences in the structure (and accessibility) of the diatom biofilm (De Troch and others, 2006). Burd and others (2008) suggest that coarse sediment is important for certain, mainly subtidal, biota. Levings and Thom (1994) found that in Canada coarse sediment habitats are crucial for shellfish species, especially those harvested recreationally and commercially. Similarly, larval settlement of Dungeness crabs (*Cancer productus*) and manila clams (*Ruditapes philippinarum*) tend to be higher in areas of shell hash or gravel (Dumbauld and others 1993 cited in Burd and others 2008).

Erosion control

Coarse sediment plays a significant role in beach protection. Chesil Beach, Dorset, UK is an example of an intertidal coarse sediment feature that provides a significant barrier to coastal erosion. Removing sediment from coastal barriers results in beach erosion, potentially placing coastal settlements and other social infrastructure at risk (Bishop and others 2006).

Review of Beneficial Ecosystem Services

Expert opinion suggested two beneficial ecosystem services arising from coarse intertidal sediments. The first is that fish scavenge in coarse sediment intertidal areas, and therefore this habitat has a beneficial ecosystem service related to both commercial and recreational fisheries. Secondly, it could also be assumed that the process of erosion control provides a direct benefit to natural hazard protection through enhanced coastal protection.

6 Intertidal sand, muddy sand and mixed sediments

Note: this review includes intertidal sand and muddy sand, intertidal mud, and intertidal mixed sediments (EUNIS codes A2.2 and A2.4).

Summary

Figure 4 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for intertidal sand, muddy sand and mixed sediment. **The beneficial ecosystem processes identified were primary and secondary production, larval/gamete supply, food web dynamics, formation of species habitat, species diversification, biogeochemical cycling, climate regulation, and erosion control. The beneficial ecosystem services identified were fisheries, other wild harvesting, sport/recreation, natural hazard protection and nature watching.**

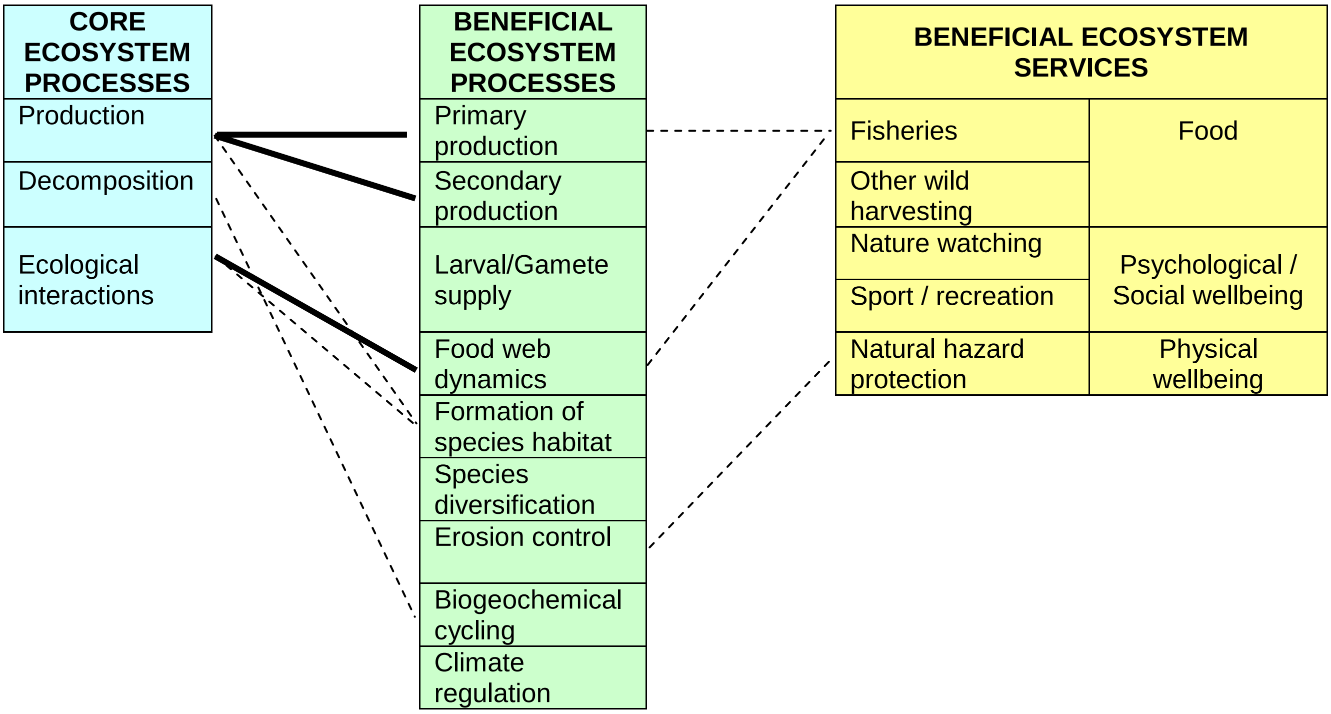

Figure 4 Marine ES Framework: Intertidal sand, muddy sediment and mixed sediment (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Intertidal sediment is found widely in the UK, forming features such as beaches, sand flats, and intertidal mudflats. It occurs principally in estuaries, in adjacent coastal areas, sheltered marine bays and semi-enclosed areas and is the most dominant estuarine habitat by area. Notable examples include The Wash, Burry Inlet, Morecambe Bay, the Solway, Moray and Cromarty Firths, and Strangford Lough. Beaches comprised of mostly sandy sediment develop in more exposed locations. Intertidal sediment communities vary according to sediment type, mobility, and the salinity of the overlying water. Mobile gravels and sands tend to be highly impoverished, whereas sheltered areas with mixed sediments can support very rich communities.

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

Muddy sediments exhibit high rates of primary productivity (Leach 1970) and tend to have higher microphytobenthic biomass than sandy sediments (Macintyre and others 1996; Lucas and others 2003). However, primary productivity can be equally high in sandy sediments during low tide exposure (Barranguet and others 1998).

Biomass Production: Secondary

Fundamental ecosystem processes including nutrient cycling are evident in this habitat. Dissolved organic carbon is supplied through the breakdown of organisms, exudation and excretion as well as by hydrolysis of particulate carbon (expert opinion).

Larval / Gamete supply

Intertidal sand, muddy sand and mixed sediments are important for spawning and nursery grounds (Fortes 2002). For example, sheltered sandflats are important nursery sites for plaice (Jones, Hiscock and Connor 2000).

Food Web Dynamics

Microphytobenthos are supported between sand grains on intertidal sand (Underwood and Paterson, 2003). Large algal mats of *Enteromorpha* spp. and *Ulva* spp. may also form. Copepods form a major part of the resident meiofaunal population in these shallow sediments, playing an important role in transferring energy from primary producers (i.e. plants) to top trophic levels (De Troch and others, 2006). Intertidal mud and sand flats are important areas for shorebirds and some wildfowl during the low water period and for diving ducks and fish during the high water period (Evans and others 1998). The shrimp *Crangon crangon* is predated by plaice when they settle on sand.

Polychaete worms are dominant predators in sand substratum. Sole (*Solea solea*) and gadoids often visit sandy, and mixed sediment (Jones, Hiscock and Connor 2000). Sandflats are frequented by sea bass and flounder as feeding grounds to predate on polychaetes and crustaceans, while migratory species like salmon and shad pass through sandflat areas en route to other wetland habitats (Jones, Hiscock and Connor 2000). Shorebirds when migrating from breeding to wintering grounds are important predators on sandflats in north-west Europe (UK sites include the Wash, Morecombe Bay, Poole Harbour and the Solent) (Jones, Hiscock and Connor 2000).

Formation of Species habitat

These soft-bottom environments create complex microhabitats supporting abundant populations of microphytobenthos (Underwood and Paterson 2003) and offer protection from predators or desiccation or other rapidly changing parameters (St-Onge and Miron 2007). Soft-substrate sediment has an increased proportion of infauna in comparison with epifauna which is more abundant on rocky intertidal areas (Lalli and Parsons 1997).

Species diversification

Estuarine soft sediments support a diverse group of microscopic and macroscopic organisms (De Troch and others 2006). Communities in sandflats tend to be poor in species richness but the species that are present tend to exist in high abundance (Jones, Hiscock and Connor 2000). Mixed sediment may offer favourable habitat to different benthic organisms and therefore a higher number of species. In general, it appears that species diversity and density decreases with an increase in sediment grain size. Muddy sand supports communities of polychaetes and bivalves, including the lugworm (*Arenicola marina)*, the cockle (*Cerastoderma edule)* and the Baltic tellin (*Macoma balthica)* and may also have eelgrass (*Zostera noltii)* (Jones, Hiscock and Connor 2000).

Biogeochemical cycling and climate regulation

Sulphate reduction has been reported as the most important process leading to a reflux of carbon dioxide into the water column (Al-Raei and others 2009). Active sulphur cycling was found to be more dynamic in sandy sediments than in muddy sediments, with potential turnover rates of sulphur in this zone in the order of hours to minutes. Climate regulatory processes are facilitated by the degradation potential and organic conversion rates in porous sand (De Beer and others 2005).

Erosion control

Muddy shores are important for coastal protection acting as buffers against incoming wave energy (Fortes 2002). Soft-sediment intertidal habitats are involved in sediment stabilisation which creates greater resistance to erosion (Underwood and Paterson 2003).

Review of Beneficial Ecosystem Services

Expert opinion suggests that intertidal sediments provide habitat for various fish species, including flounder, bass, and plaice, which contributes to commercial and recreational fisheries benefits. Wild harvesting of shellfish also occurs in these intertidal areas, as does bait digging (recreation / sport) and nature watching (bird watching). The erosion control process of this habitat may also contribute to natural hazard protection.

7 Intertidal mud (EUNIS code A2.3)

Summary

Figure 5 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for intertidal mud. **The beneficial ecosystem processes identified were primary and secondary production, larval/gamete supply, food web dynamics, formation of species habitat, species diversification, erosion control, climate regulation and biogeochemical cycling. The beneficial ecosystem services identified were fisheries, other wild harvesting, regulation of pollution, nature watching and natural hazard protection.**

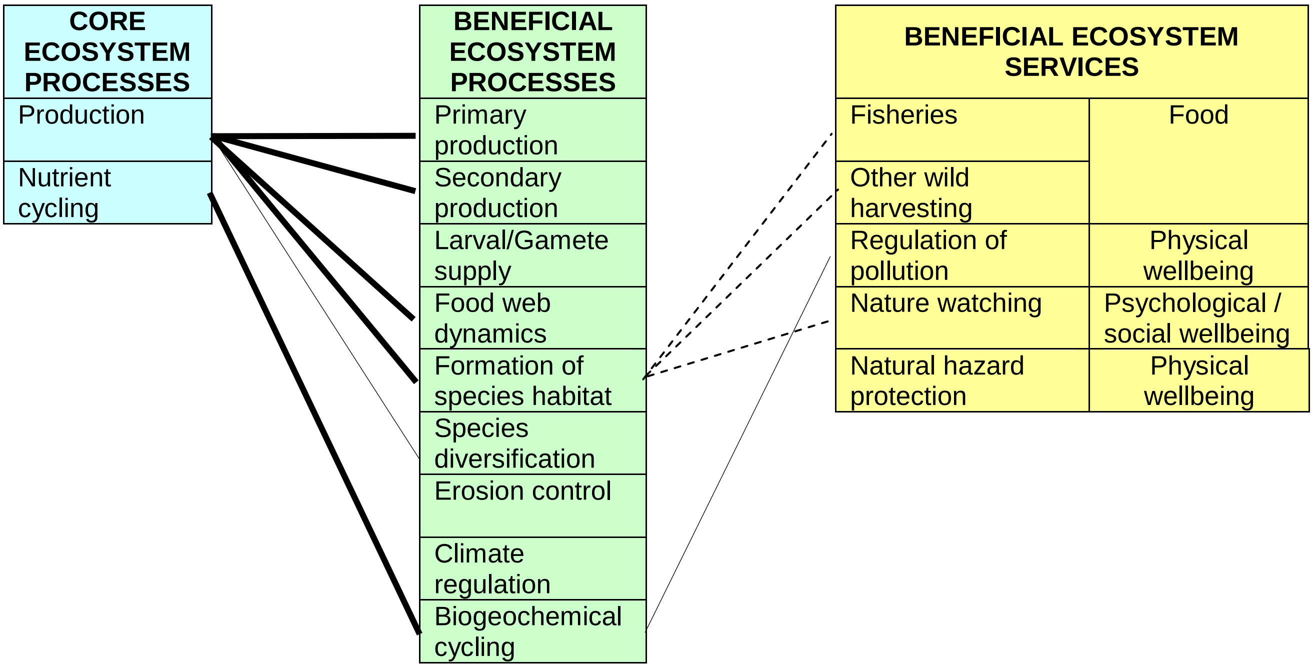

Figure 5 Marine ES Framework: Intertidal mud (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Mudflats are soft-sediment intertidal habitats created by the deposition of fine sediments in low energy coastal environments, particularly estuaries and other sheltered areas. The sediment consists mostly of silts and clays with a high organic content. Towards the mouths of estuaries where salinity and wave energy are higher, the proportion of sand increases. Mudflats occur principally in estuaries, adjacent coastal areas, sheltered marine bays and semi-enclosed areas. Mudflats are widespread in the UK and are highly productive, characterized by high abundance but low species diversity.

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

Guarini and others (2000) suggest that the role of biofilm at the air-mud interface is crucial to primary production on mudflats. During day-time this biofilm sustains all production. The film is made up of microalgae, mainly diatoms (Guarini and others 2000; Herlory and others 2005). The biomass of benthic microalgae often exceeds that of the phytoplankton in the overlying waters (MacIntyre and others 1996). Studies quantifying abundance and productivity of benthic microalgae are lacking but typically abundance of microphytobenthos within the upper 5mm to 10 mm of the sediment surface varies from about 105 cells cm^3 to 107 cells cm^3 depending on location, season, and sediment properties (MacIntyre and others 1995).

Biomass Production: Secondary

This highly productive ecosystem is a very important feeding ground for wading birds that prey on macroinvertebrates as it is a primary feeding ground that is available all year round (Bale and others 2007).

Larval/Gamete supply

Duquesne and others (2005) and references therein state that intertidal mud is an important area for juvenile fish such as plaice (Jones, Hiscock and Connor 2000).

Food Web Dynamics

The most important predators on intertidal mudflats are sole (*Solea solea)*, dab (*Limanda limanda*), flounder (*Platichthys flesus)* and plaice (*Pleuronectes platessa)* which feed on polychaetes, young bivalves and siphons. This habitat is used by migrating birds for feeding, in particular brent geese, shelduck, pintail, oystercatcher, ringed plover, grey plover, bar-tailed and black-tailed godwits, curlew, redshank, knot, dunlin and sanderling (Jones, Hiscock and Connor 2000).

Formation of Species habitat

The shores of estuaries with large tidal ranges are generally characterised by accumulations of mud that form intertidal mudflats and banks, which are important sites for wading birds (Bale and others, 2007).

Species Diversification

Intertidal mud is not usually associated with species rich communities but there are often very high abundances of those species present (Jones, Hiscock and Connor 2000).

Erosion control

The shores of macro-tidal estuaries, characterised by mud accumulations, help protect coastal margins from erosion by dissipating wave and current energy (Bale and others 2007a; Kirby and Kirby 2008).

Climate regulation

Carbon burial rates within intertidal mud are influenced by sediment accumulation and production and the rate of biomass decomposition, therefore greater levels of sediment area allow for increased carbon burial (Chmura and others 2003). This makes intertidal mudflats desirable areas for carbon storage in comparison with freshwater wetlands/peatland areas where sedimentation rates are slower (Andrews and others 2006).

Biogeochemical cycling

Benthic microalgae play significant roles in biogeochemical reactivity (MacIntyre and others 1996).

Review of Beneficial Ecosystem Services

Fisheries

Intertidal mud provides habitat for fish of commercial importance (Humphreys and others 2007).

Regulation of Pollution

A considerable quantity of cadmium is stored in sediment by *Spartina anglica* (cord grass) growing in intertidal mud (Hubner and others 2010).

Others

Expert opinion suggests that intertidal mud is an extremely important habitat for bird watching (Nature Watching) and as a location for bait digging to support recreational fishing (Other wild harvesting). The erosion control function of intertidal mud may also contribute to Natural hazard protection.

8 Coastal saltmarshes and saline reedbeds (EUNIS code A2.5)

Summary

Figure 6 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for coastal saltmarshes and saline reedbeds. **The beneficial ecosystem processes identified were primary and secondary production, larval/gamete supply, food web dynamics, formation of species habitat, erosion control, formation of physical barriers, climate regulation, biogeochemical cycling and water purification. The beneficial ecosystem services identified were fisheries, fertiliser/feed, natural hazard protection, environmental resilience, regulation of pollution, tourism and nature watching.**

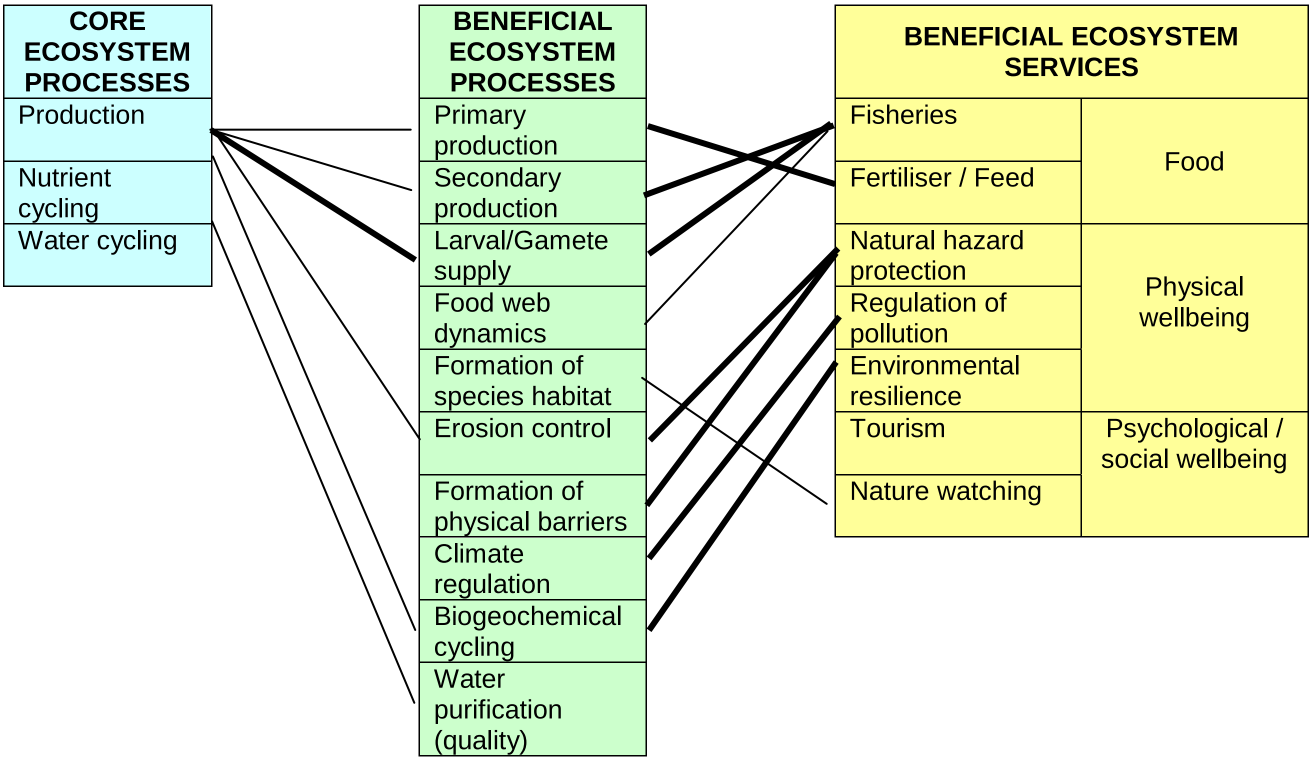

Figure 6 Marine ES Framework: Coastal saltmarshes and saline reedbeds (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Coastal saltmarshes in the UK (known as 'merse' in Scotland) comprise the upper vegetated portions of intertidal mudflats, lying approximately between mean high water neap tides and mean high water spring tides. These habitats are usually restricted to comparatively sheltered locations in five main physiographic situations: estuaries, saline lagoons, behind barrier islands, at the heads of sea lochs, and on beach plains. Development of saltmarsh vegetation is dependent upon the presence of intertidal mudflats. Saltmarsh vegetation consists of a limited number of salt tolerant species adapted to regular immersion by the tides. Saltmarshes are an important resource for wading birds and wildfowl. They act as high tide refuges for birds feeding on adjacent mudflats, as breeding sites for waders, gulls and terns and as a source of food for passerine birds particularly in autumn and winter (Maddock 2008).

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

Saltmarshes are generally considered to be one of the most productive ecosystems in the world, rivalling that of intensive agriculture (Niering and Warren 1980; Hopkinson and Giblin 2008; Peterson and others 2008). The rich substratum between stems of halophytic angiosperms (which dominate marshes) is ideal for microbial development. The economic value of productivity of marshes has been estimated in 1997 at £9,900/ha/yr (Aspden and others 2004).

Biomass Production: Secondary

These habitats are well known for their high productivity and providing resources to support secondary production in coastal and near-shore waters (McKinney and others 2009). It has been estimated that forty percent of cordgrass production is exported from saltmarshes, supplying other marine habitats with fixed carbon and nutrients (Pennings and Bertness 2001).

Larval/Gamete supply

Many birds, juvenile fish, crustaceans and molluscs use marshes as nurseries (Pennings and Bertness 2001). Kallasvuo and others (2010) suggest that reed habitats are hot spots for zooplankton prey in the coastal ecosystem. During spring, the reed-covered shores of an archipelago area of the northern Baltic Sea had 10 times higher densities of copepods and cladocerans, which are the preferred prey of larval pike (*Esox lucius*) compared with other shores. The only place where larval pike were found was the reed belt habitat. The reed belts according to this study were the best habitat for larval pike in the coastal area of the northern Baltic Sea (Kallasvuo and others 2010).

Food Web Dynamics

The availability of nutrients to plants is increased by the transfer of nutrient-rich particulate matter from the water column to the soil by sessile filter feeders. As more larvae settle there is an increase in cordgrass growth, which in turn benefits mussel populations as they can crawl up the stems to escape suffocation by burial in the mud substrate. Detritus from stems is also an important part of the mussel's diet. When vascular plants die the plant matter is broken down by microbes, invertebrate detritivores, deposit and filter feeders (Pennings and Bertness 2001). Bivalves, shrimp and killifish predate on invertebrates which are in turn prey for fish. Birds predate on fish and crustaceans. Insects are the most abundant herbivores in marshes, whilst otters and ungulates graze on vegetative matter, and herbivorous beetles graze on clonal turf (Pennings and Bertness 2001).

Formation of Species habitat

Saltmarsh is an important habitat and refuge from predators and physical stress for a wide range of species (Peterson and others 2008). In the North Kent Marshes Environmentally Sensitive Area, coastal marshes support large breeding populations of lapwing (*Vanellus vanellus*) and red shank (*Tringa tetanus*) (Milsom and others 2002). Findings from a habitat assessment study by McKinney and others (2009) in Narragansett Bay (New England, USA) demonstrated that even if small wetlands with saltmarshes are present in highly urbanized coastal locations they can still provide wildlife habitat value (McKinney and others 2009). Coastal salt marshes in the Wadden Sea area are used by hare (*Lepus europaeus*), brent geese (*Branta bernicla*), barnacle geese (*Branta leucopsis*), red shank (*Tringa tetanus*), breeding bearded tits (*Panurus biarmicus*), sedge warbler (*Acrocephalus schoenobaenus*) and avocet (*Recurvirostra avosetta*) (Bakker and others 1997).

Erosion control

Wave action on land causes erosion. Salt marshes act to shelter coasts from this erosion (Pennings and Bertness 2001). Filamentous algae, cyanobacteria and macrophyte roots strengthen sediment, further supporting erosion control (Aspden and others 2004).

Formation of physical barriers

Saltmarshes are known to accumulate sediment and organic matter at a rate that compensates for sea level rise (Morris 2007 and references therein). This is an important ecological service considering the threat of sea level change with future climate change. Morris (2007) promotes use of saltmarshes in flood defence solutions for the purpose of increasing sedimentation and dissipating wave energy.

Climate regulation

Wetlands represent the largest component of the global terrestrial organic carbon inventory. Carbon burial in saline wetlands is thus potentially an important sink for CO_2 (Chmura and others 2003).

Biogeochemical cycling

Microbial assemblages carry out nitrogen and carbon fixation services. In the lower sediment layers anaerobic bacteria reduce sulphate to sulphide (Aspden and others 2004). Cyanobacteria in the sediment are involved in nitrogen fixation, therefore they are critical to nutrient turnover of many low nutrient areas (Aspden and others 2004).

Water purification (quality)

Coastal saltmarsh vegetation is involved in the regulation of water purity through the take up of excess inorganic nutrients such as nitrates and phosphates, therefore reducing the potential for eutrophication (Peterson and others 2008).

Review of Beneficial Ecosystem Services

Fisheries

Saltmarshes are nursery areas for commercial fisheries. For example, juvenile sea bass use saltmarshes for feeding areas, ingesting great quantities of live and detritic organic matter (Pennings and Bertness 2001; Laffaille and others 2000; LeFeuvre and others 2003).

Fertilizer / Feed

In the past, saltmarshes have been cut for hay-making but more recently they are being used for livestock grazing (Bakker and others 1997; Bouchard and others 2003).

Natural hazard protection

Saltmarsh environments in a variety of physical settings can significantly increase attenuation of incident waves compared to unvegetated sand/mudflats. This is especially relevant with the increased risk of sea level rise and an increase in storm frequency (Moller 2006).

Environmental resilience

Saltmarshes are significant carbon sinks, proving carbon storage at approximately 10 times the rate observed in temperate forests and 50 times the rate observed in tropical forests per unit area (IUCN, 2009). This has prompted the IUCN (2009) to state that saltmarshes are “critical components to include in future carbon management discussions and strategies”.

Regulation of pollution

Saltmarshes are able to regulate pollution. A study by Kay and others (2005) in Clacton, Essex, UK, showed a reduction of over 97% in the flux and concentrations of faecal organism indicators following the construction of a flood defence wall that created a marshland area. Faecal organism indicator concentrations in the water and in the marsh were similar to those found in sewage treatment works after secondary treatment and UV treatment (Kay and others 2005).

With respect to heavy metals, Coehlo and others (2009) found that all saltmarsh plants of the Ria de Aveiro, in Northwest Portugal, had accumulated mercury in their root system. Similarly, Hung and Chmura (2006) found that the saltmarshes in the Bay of Fundy, Canada accumulated mercury in their sediments and over time became robust stores of mercury. The authors suggested that this would be maintained under scenarios of future sea-level rise, as the high sediment deposition rates were considered likely to ensure that vertical growth of these marshes will keep pace with rising sea-level (Hung and Chmura, 2006). Saltmarshes have also been noted to extract uranium from the surrounding water, with the estimated global uranium sink in salt marshes being fifty times more than the sink represented by the entire ocean (Church 1996). Furthermore, it has been recorded that saltmarsh cord grass *Spartina anglica* stores significant quantities of cadmium in Poole Harbour (Hubner and others 2010).

Tourism and nature watching

Saltmarsh areas have been designated as nature reserves or national parks in certain places (Bakker and others 1997), making them ideal places for tourism and nature watching (Bakker and others 1997).

9 Intertidal sediments dominated by aquatic angiosperms (EUNIS code A2.6)

Note: Seagrass beds are reviewed separately in this document (see section 36).

Summary

Figure 7 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for intertidal sediment dominated by angiosperms. **The beneficial ecosystem processes identified were primary and secondary production, larval/gamete supply, food web dynamics, formation of species habitat, erosion control, biogeochemical cycling and water purification. The main beneficial ecosystem services identified were fisheries, other wild harvesting, fertilizer/feed, environmental resilience, regulation of pollution and nature watching.**

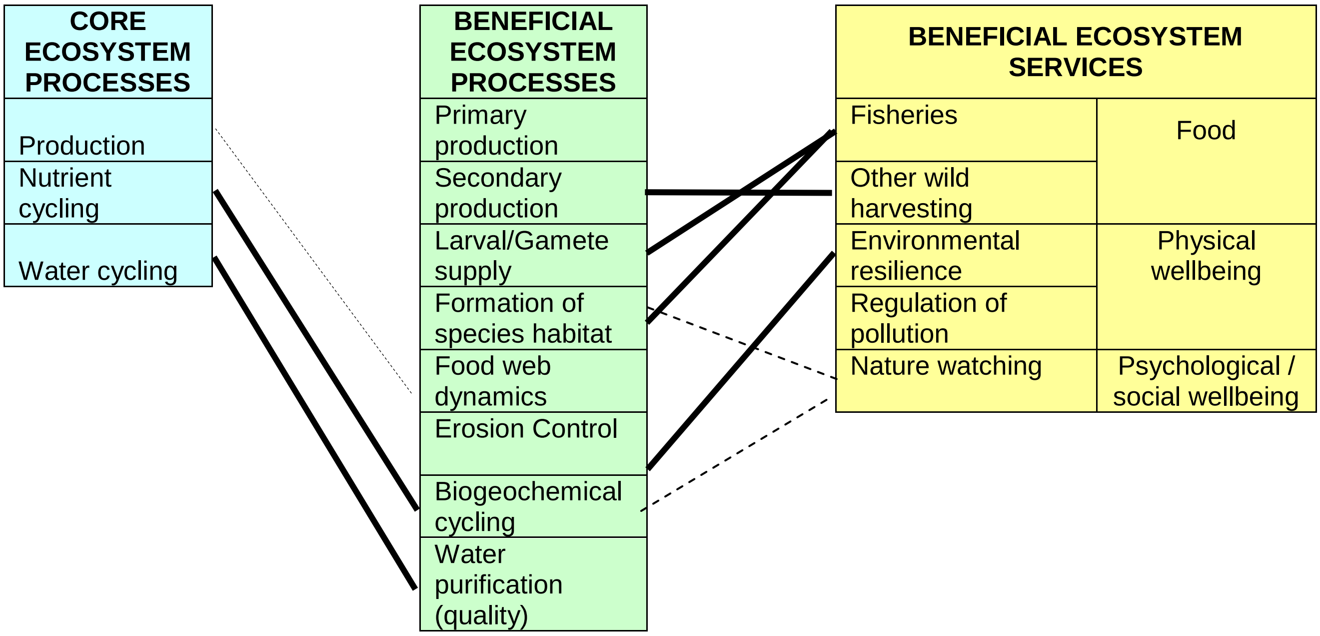

Figure 7 Marine ES Framework: Intertidal sediment dominated by aquatic angiosperms (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Seagrasses are unique in being the only truly marine flowering plants, or angiosperms (Heminga and Duarte, 2000). Typically seagrass is found on sheltered sandy or muddy substrata down to 4m, but can occur to a maximum depth of about 10m around UK waters (Davison and Hughes, 1998; Nielsen and others. 2002). There are four confirmed species of seagrass found in UK waters: two species of tassel weed *Ruppia maritima* and the rarer *Ruppia spiralis* and two species of eelgrass, *Zostera noltii*, (dwarf eelgrass) and *Zostera marina* (common eelgrass). Intertidal areas with angiosperms correspond to the seagrass species *Zostera noltii* (Foden and Brazier 2007).

Eelgrass beds are a Biodiversity Action Plan priority habitat and an OSPAR threatened habitat (OSPAR, 2008). Although seagrass beds are not listed as an Annex I habitat under the European Community (EC) Habitats Directive they are a recognized component of several of these habitats, namely ‘Lagoons’, ‘Estuaries’, ‘Large shallow inlets and bays’, ‘Intertidal mud and sand banks’ and ‘Sandbanks covered by sea water at all times’. It is also listed as a ‘scarce’ nationally important marine feature (Lieberknecht, 2004).

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

Z. noltii is an important primary producer in Atlantic coastal systems, providing the majority of primary production to the detritus food chain (Massa and others 2009).

Biomass Production: Secondary

Eelgrass (*Zostera* spp.) provides food for overwintering wildfowl, particularly Brent geese and wigeon (Davison and Hughes 1998; Tubbs 1999; Percival and Evans 2008). Grazing wildfowl can consume a high proportion of the available standing stock of *Zostera*. Portig and others (1994) found that in Strangford Lough, 65% of the estimated biomass (~1100 tonnes fresh weight) of *Zostera* was consumed by grazing wildfowl during the winter months and that up to 80% was disturbed by their feeding activity. Small crustaceans and crabs consume seagrass tissue (Hemminga and Duarte 2000).

Food web dynamics

Primary and secondary production provides food for grazing wildfowl species such as Brent geese and also wading birds (expert opinion).

Formation of Species Habitat

Polte and others (2005) found *Z. noltii* to be an important refuge for marine animals in the intertidal zone in the northern Wadden Sea. Higher abundance and production of the following species were found in vegetated flats compared with bare sand flats: juvenile shore crabs (*Carcinus maenas* L.), brown shrimps (*Crangon crangon* L.) and common gobies (*Pomatoschistus microps* Krøyer) (Polte and others 2005). It has also been noted that seagrass serves as a nursery site for juvenile crabs and fish (Massa and others 2009).

Erosion Control

The dissipation of wave and tidal current energy by seagrasses in intertidal and shallow subtidal zones, gives it an important function in preventing coastal erosion. This is further enhanced by the sediment stability created by the binding effect of the roots / rhizomes (Terradoos and Borum 2004).

Biogeochemical (Nutrient) Recycling

Seagrasses and associated algae are able to absorb inorganic nutrients through both roots and leaves. The acquisition of nutrients from the water column allows seagrass to compete with phytoplankton for the inorganic nutrients that support the primary production of coastal ecosystems which has a beneficial effect on water quality (expert opinion).

Water Purification (Quality)

The ability of seagrass to take up inorganic nutrients benefits water quality by helping to reduce the risk of eutrophication (Terradoos and Borum 2004). The balance is a fine one however, as seagrass is highly sensitive to nutrient levels. Excessive nutrient levels can adversely affect seagrass in a number of ways: it can inhibit cell growth in the plant; plants can become smothered by algae inhibiting photosynthetic growth; and algal blooms in the water column that result from nutrient imbalance can inhibit available light for photosynthesis (Terradoos and Borum 2004).

Review of Beneficial Ecosystem Services

Fisheries

Intertidal sediments dominated by aquatic angiosperms provides habitat for commercial fisheries including nursery sites (Massa and others 2009).

Other Wild Harvesting

Cockle harvesting by both hand-picking and by suction dredging has been undertaken in the vicinity of *Zostera* beds in the UK. In the USA, shellfish harvesting for clam, blue crab and scallop has each been associated with seagrass (Fonesca and others 1998). Lugworm (*Arenicola marina*) and catworm (*Nephtys hombergi)* are both associated with seagrass habitat and harvested commercially for bait, an activity that occurs particularly on intertidal seagrass habitat (South East of England Biodiversity Forum 2008).

Environmental resilience

As with other intertidal areas, areas dominated by aquatic angiosperms are significant carbon sinks, proving carbon storage at approximately 10 times the rate observed in temperate forests and 50 times the rate observed in tropical forests per unit area (IUCN 2009). These areas are therefore important for future strategies to address to climate change.

Nature watching

Zostera beds, because of their association with grazing wildfowl and waders, make them important for nature watching. Snorkelling and (to a lesser extent) diving occurs in seagrass beds, such as at Bembridge on the Isle of Wight where the seagrass offers a rich and diverse seabed to explore in very shallow water (expert opinion). This activity may also have tourism and sport/recreation beneficial ecosystem services.

Regulation of Pollution

Seagrass beds aid pollution prevention through their water purification role. They have a filtration role in coastal waters, trapping particles indirectly through the filter feeding activity of the organisms that they host and directly through the capture of suspended particles to the mucus-covered leaf surfaces. In so doing they improve water transparency and quality (Terradoos and Borum 2004).

10 Intertidal Biogenic Reefs (EUNIS code A2.7)

Note: *Sabellaria* reefs, also considered to form biogenic reefs, are reviewed separately in this document (section 35).

Summary

Figure 8 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for intertidal biogenic reefs. **The beneficial ecosystem processes identified were primary and secondary production, larval/gamete supply, food web dynamics, formation of species habitat, species diversification, erosion control, biogeochemical cycling, and water purification. The beneficial ecosystem services identified were fisheries, aquaculture, fertilizer/food, natural hazard protection and environmental resilience.**

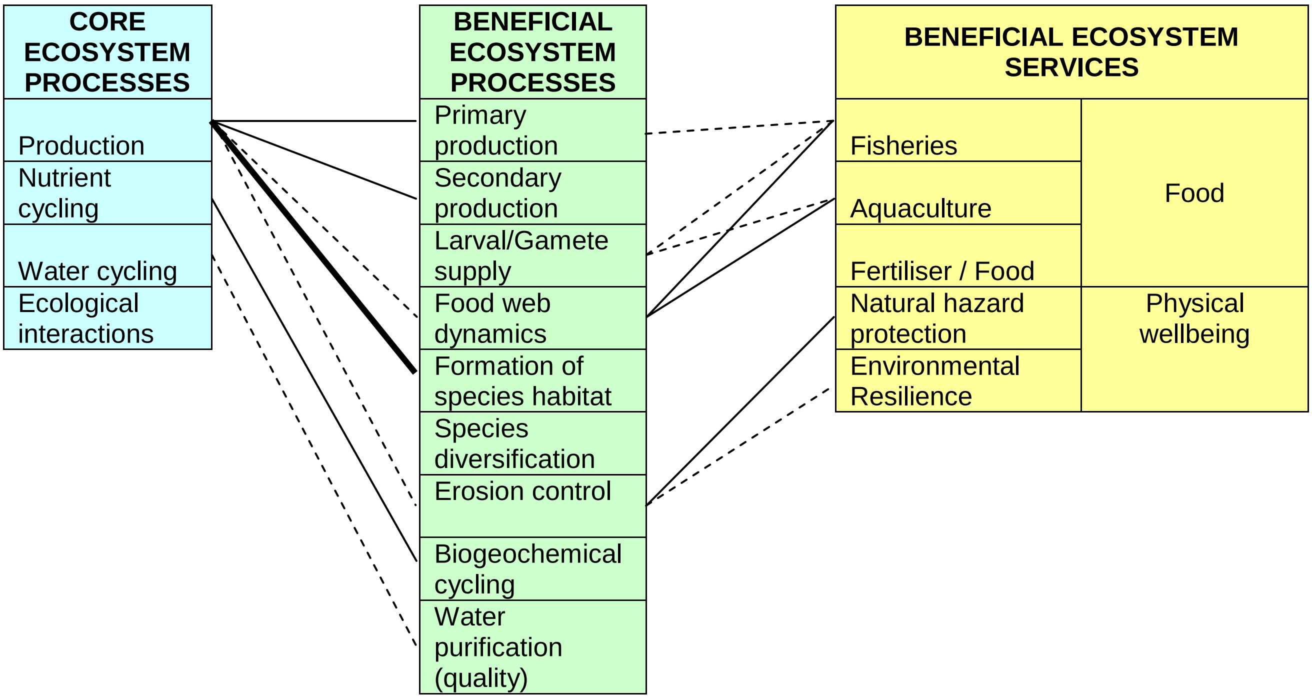

Figure 8 Marine ES Framework: Intertidal Biogenic reefs (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Intertidal biogenic reefs are formed primarily by two invertebrate species; *Sabellaria alveolata,* the honeycomb worm and *Mytilus edulis*, the blue mussel. Another polychaete worm *Sabellaria spinulosa* can be found in intertidal areas but this is rare. However *Lanice cochilega* also forms reefs in intertidal areas although there are gaps in the knowledge about this polychaete's reef-building properties in intertidal areas (Rabaut and others 2009). Biogenic reefs, usually up to 50cm thick, are mainly found on the bottom third of the shore but may reach mean high water of neap tides and extend into shallow subtidal areas. Older biogenic reefs may increase the biodiversity and stability of what would otherwise be sand-abraded rocks and boulders. Sheet-like reefs may restrict drainage of the shore, creating rockpools where there would otherwise be none (Maddock 2008). In Britain, the most numerous and extensive biogenic reef areas occur on the Cumbrian coast, particularly between Morecambe Bay and the Solway Estuary and at Dubmill Point. Reefs are also found in Cardigan Bay and in the Bristol Channel, including the coasts of south Wales, north Devon, Somerset and Avon.

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

The polychaete species *S. alveolata* forms biogenic reefs most commonly in intertidal areas but occasionally in subtidal areas (De Grave and Whitaker 1997; Lancaster and Savage 2008). In the Mont-Saint-Michel Bay area, France, the *S. alveolata* reef structures are the largest in Europe and are characterized by a high productivity, with an overall production of about 4600 tonnes per km^2 per year (fresh weight) (LeLoup and others 2008). Mussel reefs are highly significant in terms of enriched biodeposits, which provide nutrition for a wide range of deposit-feeding invertebrates over a vast area including surrounding tidal flats (Holt and others 1998).

Biomass Production: Secondary

Mytilus edulis beds provide habitat for a diverse range of associated species (see Species diversification below). The mussel species itself is responsible for most of the secondary production within a mussel bed community.

Larval/Gamete supply

Juvenile bivalves are known to settle on polychaete tubes as they provide attachment surfaces (Bolam and Fernandes 2003). In a study by Rabaut and others (2009) on a Belgian intertidal nursery area, the density distribution of the flatfish species plaice (*Pleuronectes platessa*), was significantly explained by the presence of reefs built by the polychaete *Lanica conchilega*. The Mont-Saint-Michel Bay area, is one of the main nurseries of the English Channel coast for many fish species of commercial interest such as sea bass (*Dicentrarchus labrax*), whiting (*Merlangius merlangius*), flatfishes (common sole *Solea solea* and plaice *P. platessa*), and clupeids (European pilchard *Sardina pilchardus*, Atlantic herring *Clupea harengus* and European sprat *Sprattus sprattus*) (LeLoup and others 2008).

Food Web Dynamics

The space between polychaete tubes serves as a refuge from epibenthic predators and from physiological stress (Woodin 1978; Bolam and Fernandes 2002). In a study by Rabaut and others (2007) polychaetes and amphipods were found to constitute the highest numbers of predatory species positively associated with *Lanice conchilega*.

Dubois and others (2003) identified the important trophic role of *S. alveolata* reefs in Mont-Saint-Michel Bay (France) ecosystem as a primary consumer of phytoplankton through filtering large volumes of water. They calculated that the *S. alveolata* reefs filter approximately 396,500 m3 of seawater during the 13 hours each day that the reefs are immersed. Holt and others (1998) suggest that the filter feeding of biogenic reefs is such that they affect energy flow over a much wider area than the reef itself.

Mussel beds are an important food source for birds. For example, Nehls and Thiel (1993, cited in Tyler-Walters, 2008) suggests that removal or exploitation of mussel beds in the Wadden Sea may remove crucial winter food reserves for birds such as Eider ducks and oystercatchers. Knot, turnstones, sandpipers, herring gulls, crows and scoters also feed on mussels (Nehls and Thiel 1993, cited in Tyler-Walters, 2008). It has been reported by Baird and Milne (1981) that bird predation accounted for a total of 72% of the annual *Mytilus* production in Scotland (Holt and others 1998). Juvenile shellfish, fish, crab, starfish and flatfish predate on *Mytilus edulis* reefs (LeLoup and others, 2008; Cranfield and others 2003; Holt and others 1998).

Formation of Species habitat

Biogenic structures provide hard substrate for colonization by benthic vertebrates and invertebrates (Dubois and others 2006 2007). In general, *Sabellaria* reefs increase the habitat complexity (heterogeneity) of the surrounding environment and provide microhabitats for other organisms in crevices and cavities (Hill and others 2010 and references therein). *S. alveolata* reefs in the UK also provide attachment for seaweed communities (Hill and others 1998 and references therein). *S. alveolata* can stabilise mobile sediment, enabling seabed species to establish communities (Holt and others 1998; Jones and others 2000) and can bind unstable rocky ground restricting drainage, which creates rock pool refuges for prawns, blennies and hermit crabs (Lancaster and Savage 2008).

Mytilus reefs (intertidal) are not considered to have a rich associated fauna but as they are generally the only hard substrate in an area, they generally increase the heterogeneity of the habitat (Holt and others 1998). In areas of soft sediment *Mytilus edulis* provide an area of hard substrata (Hill and others 2010 and references therein) and create biogenic structurally complex habitats that provide refuge for a range of flora and fauna not observed on surrounding sediments (Hill and others 2010 and references therein).

Species Diversification

Although *S. alveolata* reefs increase habitat complexity and form local hotspots of biodiversity (Ayata and others 2009; Dubois and others 2009), the overall influence of these structures on marine diversity is still debated (Hill and others 2010 and references therein). Older reefs may have more diverse associated communities than younger ones and several studies have found that the highest levels of diversity are associated with degraded reef (Hill and others 2010 and references therein). This is because gaps and cavities in the reef provide shelter for a range of crevice dwellers. Sediment retained within the reef structures provide a suitable habitat for interstitial species (Hill and others 2010 and references therein). Sheets of *S. alveolata* appear to enhance algal diversity, apparently by providing barriers to limpet grazing (Cunningham and others 1984).

In the bay of Mont-Saint Michel, (France), reefs are being increasingly colonised by oysters (*Crassostrea gigas*) from local aquaculture (Dubois and others 2006). These reefs are the only hard substrate available for oysters apart from artificial aquaculture structures. The biogenic reefs provide a complex habitat for macrofauna and exhibit high levels of biodiversity that contrast with the surrounding low diversity, soft bottom environments (Dubois and others 2007). Biogenic reefs with oysters are found to have higher species diversity than those without, as oyster shells create habitats and refuges for numerous sessile species such as barnacles (*Elminius modestus*), the ascidian *Ascidiella aspersa*, and the polychaete *Pomatoceros lamarckii* (Dubois and others 2006).

Biogeochemical cycling

In a study in Quebec, Canada, Mermillod-Blondin and others (2003) found the presence of biogenic structures produced by benthic invertebrates strongly affects biogeochemical processes as benthic invertebrates play a key role in organic matter processing and nutrient cycling at the water–sediment interface (Mermillod-Blondin and others 2003).

Water purification (quality)

Biogenic reefs may be viewed as significant biological filters thereby contributing to improved water quality (Dubois and others 2006). Forster and Graf (1995) explain that *L. conchilega* acts as a pump, exchanging burrow water with the overlying water (Rabaut and others 2007). The purification function can continue under high sediment loads as *S. alveolata* is adapted to turbid systems (Cayocca and others, 2008).

Erosion Control

In general, mussel beds play an important role in the sediment dynamics of coastal systems as they collect sediment and are able to respond to changes in sea level (OSPAR 2008). For example, in *M. edulis* beds in Maine, USA, Commito and others (2004) found increased sediment deposition rates within the mussel beds compared to the surrounding soft-sediment substratum, and concluded that altered transport rates of sediment are important mechanisms by which mussels act as ecosystem engineers to modify soft-bottom habitats.

Review of Beneficial Ecosystem Services

Fisheries

Biogenic reefs provide habitat for species that can be exploited for commercial fishing, such as temperate rocky reef fish (Gunderson and Vetter 2006) and other species including plaice, dab, flounder. In The Wash, several thousand tonnes of mussels are commercially dredged annually for consumption and for angling bait (Holt and others 1998), although British mussel production is relatively small comprising only 5% of total European production (Tyler-Walters 2008 and references therein). The commercial development of natural beds is hampered by sporadic and unpredictable recruitment, although wild mussel fisheries are found in tidal flats of The Wash, Morecambe Bay, Solway and Dornoch Firths in Scotland (Tyler-Walters, 2008 and references therein).

Aquaculture

There has been a move away from exploitation of wild mussel stocks to commercial cultivation in the UK (Tyler-Walters 2008 and references therein). The west coast of Scotland in particular has developed a valuable mussel industry since the 1970s. In Scotland, raft-and-line cultivation of mussels also takes place (Holt and others 1998). The pink shrimp (*Pandalus montagui)* feeds on *Mytilus* and is an economically important aquaculture species itself (Holt and others 1998).

Fertiliser/Feed

Mussels are harvested for bait (Tyler-Walters 2008 and references therein).

Natural Hazard Protection

Reefs provide protection for coasts by attenuating wave energy (McManus 2001).

Environmental resilience

The resilience of biogenic reefs to wave energy is arguably an implicit characteristic of all biogenic reefs (Riding 2002). *Mytilus* reefs have a strong stabilizing effect on the sediment and therefore serve to counter erosive wave action (Holt and others 1998).

11 Infralittoral Rock

Note: This review includes High energy infralittoral rock, Moderate energy infralittoral rock, Low energy infralittoral rock (EUNIS codes A3.1 to A3.3).

Summary

Figure 9 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for infralittoral rock. In this review infralittoral rock covers high energy, moderate energy and low energy infralittoral rock. **The beneficial ecosystem processes identified were primary production, larval/gamete supply, food web dynamics, formation of species habitat, species diversification and formation of a physical barrier. The beneficial ecosystem services identified were fisheries and environmental resilience.**

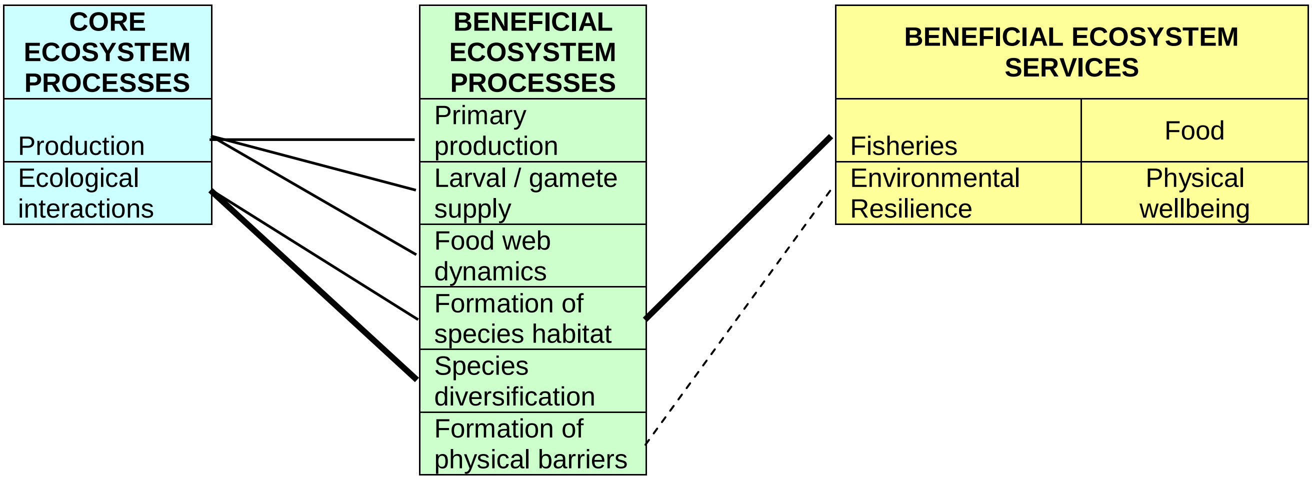

Figure 9 Marine ES Framework: Infralittoral Rock (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Infralittoral rock is found in shallow and subtidal areas characterised by macroalgal communities. These areas tend to be immediately adjacent to the shore, fringing islands, headlands, open coast and rocky inlets such as rias and sea lochs. Species zonation is defined by the light exposure at the water depth of the rock. Well-lit areas are dominated by kelp forests and foliose red algae. Wave action and tidal currents are the two other major influences on community structure in shallower water. The nature of the rock is significant in terms of habitat provision. Unbroken bedrock has little habitat diversity, whereas a surface cut by gullies and crevices and overlain by boulders provides much more variety and localised areas of shelter. The water surrounding sublittoral rock is an important habitat for larger animals such as seals, cetaceans and seabirds. Cetaceans found in these waters include the harbour porpoise (*Phocoena phocoena*) and bottlenose dolphin (*Tursiops truncatus)* (UK Biodiversity Partnership 2010).

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

Kelp plants associated with this habitat are the principal primary producers. From the zone of high water to the depth of light penetration, kelp produces nearly 75% of the overall fixed carbon (Jones, Hiscock and Connor 2000).

Larval/Gamete Supply

It is probable that all the species that are present in kelp as adults utilize kelp as a nursery area when juveniles (expert opinion).

Food Web Dynamics

Studies in the Mediterranean have provided evidence to suggest that changes in fishing pressure can result in a shift in food web dynamics in infralittoral rock ecosystems (Pinnegar and Polunin 2004).

Formation of Species Habitat

Infralittoral rock supports kelp (*Laminaria hyperborea)* communities (to a depth of 45m) and associated foliose seaweeds and animals. Within the kelp are a wide variety of habitats colonized by other species. Sheltered infralittoral rock has a different species of kelp *(Saccharina latissima)* which attracts urchins and chitons that graze heavily on *S. latissima* (Jones, Hiscock and Connor 2000). Holdfasts provide a sheltered refuge and some meiofauna may burrow into the kelp itself (Jones, Hiscock and Connor 2000). Predators such as lobsters (*Homarus gammarus)* and the wolf fish (*Anarhichas lupus)* hunt in kelp forests.

Species Diversification

Infralittoral rock is extremely rich in faunal species due to the range of habitats provided by kelp communities within the subtidal zone. Floral diversity is also high with colonisation taking place on kelp or on the surrounding substratum. In sheltered infralittoral rock areas, high grazing pressure from urchins and chitons results in poorly developed seaweed communities (Jones, Hiscock and Connor 2000).

Formation of Physical Barrier

The rock and kelp form a physical barrier that can reduce incident wave energy (expert opinion).

Review of Beneficial Ecosystem Services

Fisheries

Expert opinion suggests that infralittoral rock is a suitable habitat for inshore commercial fisheries species, particularly lobster and crab.

Environmental resilience

Although no information could be found on the resilience of UK infralittoral ecosystems, results from Pinnegar and Polunin (2004) indicate that all aspects of the infralittoral rocky zone could recover to within 1% of baseline values within 20 years after a disturbance.

12 Circalittoral Rock

Note: This review includes High energy circalittoral rock, Moderate energy circalittoral rock, Low energy circalittoral rock (EUNIS codes A4.1 to A4.3).

Summary

Figure 10 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for circalittoral rock. In this review circalittoral rock covers high energy, moderate energy and low energy circalittoral rock. **The beneficial ecosystem processes identified from the supporting evidence were primary and secondary production, larval/gamete supply, formation of habitats, species diversification and formation of physical barriers. The beneficial ecosystem services identified were fisheries and recreation/sport.**

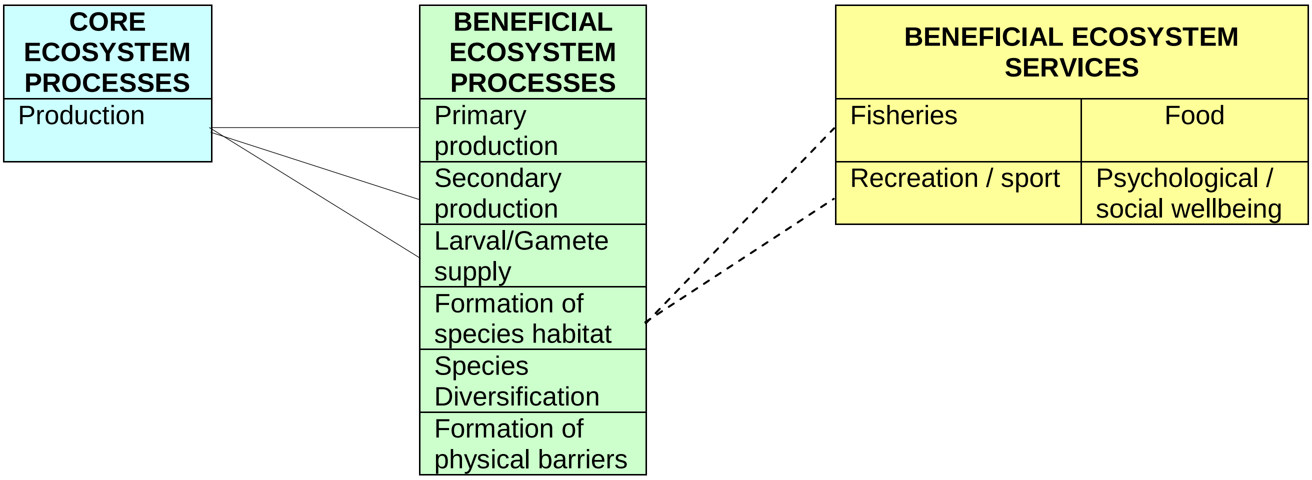

Figure 10 Marine ES Framework: Circalittoral Rock (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Circalittoral areas are subtidal rock areas dominated by animal communities. They are typically found in deep water or in shallow water with limited light penetration. Offshore, rocky sublittoral habitats may be present as submerged reefs, pinnacles and ledges, and are often surrounded by areas of soft sediment (UK Biodiversity Partnership 2010). In the upper circalittoral, sparse foliose algae can be found, but in the lower circalittoral there is no foliose algae. Species found here include ascidians, sponges, sea anemones and hydroids: the typical colonisers of the rock surfaces. In deeper water there tend to be few hydrozoans and bryozans, but abundant numbers of the sea anemone (*Protanthea simplex)*. The water surrounding sublittoral rock is an important habitat for larger animals such as seals, cetaceans and seabirds.

Review of Beneficial Ecosystem Processes

Biomass Productivity: Primary

Primary production within circalittoral communities is largely generated from phytoplankton within the surrounding water mass, where it is made available to pelagic and benthic organisms at higher trophic levels (Jones, Hiscock and Connor 2000).

Biomass Productivity: Secondary

Circalittoral communities are important secondary producers through growth of epibiotic organisms including sponges and tunicates (Jones, Hiscock and Connor 2000).

Larval/Gamete Supply

Most larvae of species found on circalittoral rock become part of the planktonic mass. However, hydroid larvae settle on the rock as do juvenile jellyfish. Juvenile fish find refuge amongst dense turf made up of sessile species (Jones, Hiscock and Connor 2000).

Formation of Species habitat

Exposed circalittoral rock occurs very widely around the UK coast and provides a firm substrate for attachment (Jones, Hiscock and Connor 2000).

Species Diversification

Circalittoral rock supports a diverse array of species (Jones, Hiscock and Connor 2000). Cebrian and others (2000) examined the species richness of a circalittoral rock ecosystem and observed a reduction in algal cover and an increase in suspension feeders with increasing depth. Polychaetes, sponges, cnidarians and bryozoans were also found to form a diverse community within this habitat (Cebrian and others, 2000). Fauna of exposed circalittoral rock is dominated by low-lying faunal crusts, cushions and turfs but also includes soft coral (*Alcyonium digitatum)* communities, which can be the dominant community species in some biotopes (Jones, Hiscock and Connor 2000).

As exposure to wave energy decreases the community changes to become dominated by taller forms, including sea fans and soft corals (Jones, Hiscock and Connor 2000). Sheltered circalittoral rock differs from exposed rock in that there is a number of mobile turf species that do not need to be attached because of the low energy nature of the habitat. These mobile species include decapod crustaceans, gastropod molluscs, and echinoderms. Organisms that are attached but still mobile include the starfish and sea urchins. Circalittoral rock areas tend to be dominated by encrusting algae (*Aglaozonia*, *Pseudolithoderma extensum*), with larger solitary ascidians (*Ascidia* spp., *Ascidiella* spp., *Corella parallelogramma* and *Ciona intestinalis*) often prominent (Jones, Hiscock and Connor 2000).

Formation of Physical Barrier

Circalittoral rock can form a physical barrier that reduces incident wave energy (expert opinion).

Review of Beneficial Ecosystem Services

Fisheries

Circalittoral rock is an important location for commercial inshore fishing activity, particularly crab and lobster (expert opinion).

Recreation / sport

It is also a potential location for SCUBA diving and angling due to the high concentration of animal life (expert opinion).

13 Subtidal sediment

Note: this review includes Subtidal coarse sediment, Subtidal sand, Subtidal mud, and Subtidal mixed sediments (EUNIS codes A5.1 to A5.4).

Summary

Figure 11 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for subtidal sediment. In this review subtidal sediment covers sand, mud, coarse and mixed sediment. **The beneficial ecosystem processes identified were primary and secondary production, larval/gamete supply, food web dynamics, formation of species habitat, species diversification, erosion control and biogeochemical cycling. The beneficial ecosystem services identified were fisheries, environmental resilience, and regulation of pollution.**

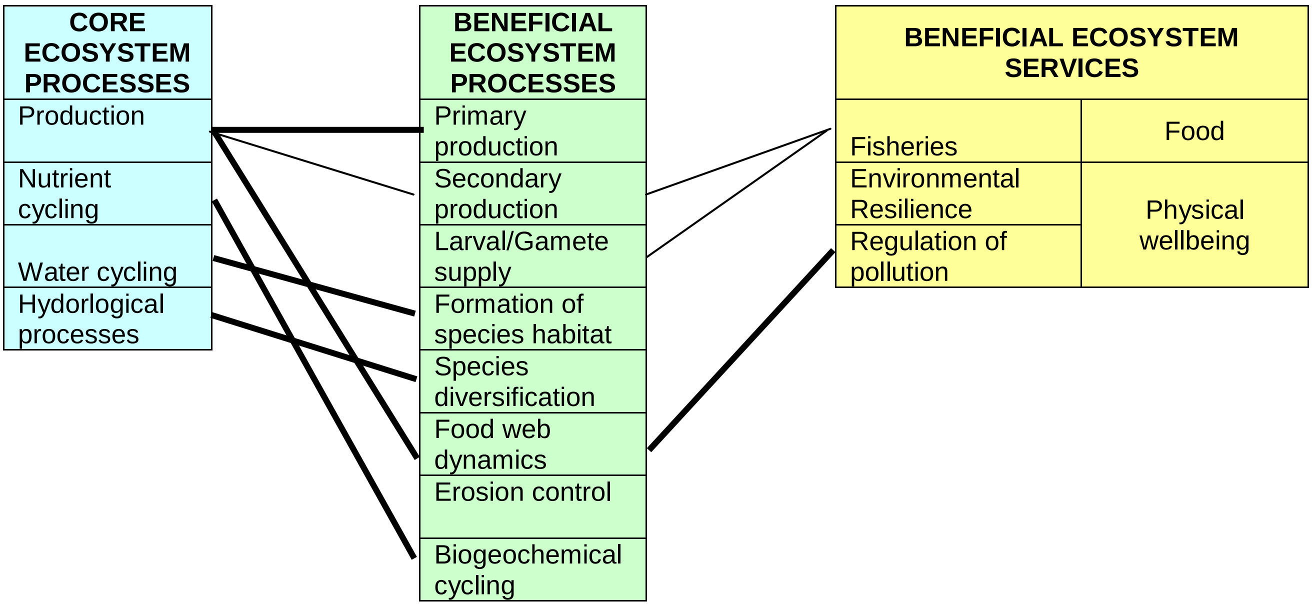

Figure 11 Marine ES Framework Subtidal sediment (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

The most common habitats found below the level of the lowest low tide around the coast of the United Kingdom consist of subtidal sand and gravel. Those found to the west of the UK (English Channel and Irish Sea) are largely shell derived, whereas those from the North Sea are largely rock derived. Sublittoral sand and gravel occurs in a wide variety of environments, from sheltered (sea lochs, enclosed bays and estuaries) to highly exposed conditions (open coast). The particle structure of these habitats ranges from mainly sand, through various combinations of sand and gravel, to mainly gravel.

Sand and gravel habitats exposed to variable salinity in the mid- and upper regions of estuaries, or exposed to strong tidal currents or wave action, are associated with low species diversity. Subtidal sediment is inhabited by robust fauna specific to this habitat such as small polychaetes, small or rapidly burrowing bivalves and amphipods. Epifauna tends to be dominated by mobile predatory species. Upper estuarine mobile sands, subject to very low fluctuating salinity, are species poor. This habitat is characterised by mysids (*Neomysis integer*) and amphipods. However, subtidal sediment found in sheltered or deeper water is one of the most diverse habitats with bivalves, polychaetes, amphipods, sessile and mobile epifauna (UK Biodiversity Partnership 2010).

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

A significant proportion of primary production sinks to the sea floor and is assimilated into the subtidal sediment (Jensen and others 2003). No direct estimates are available for primary production for this ecosystem in the UK. However, research has indicated that a degree of primary production in this ecosystem is dependent on the assimilation of organic material, which occurs following algal blooms (Denis and Desroy 2008).

Biomass Production: Secondary

A large proportion of the biomass of subtidal gravel and sand sediment is represented by epifauna with high abundance of the starfish (*Asterias rubens)* and brittlestar (*Ophiura albida)*. The large numbers of sandeel (*Ammodytes* spp.) present attract birds such as puffin, razorbill, guillemot and terns (Jones, Hiscock and Connor 2000). This habitat type is an important area for crab species including hermit crabs (*Pagurus bernhardus)*, the swimming crab (*Liocarcinus depurator)* and the edible crab (*Cancer pagurus)* (Jones, Hiscock and Connor 2000).

Larval/Gamete supply

The benthic communities typical of subtidal sediment ecosystems do not commonly have planktonic larval stages but release young at an early stage of adult life (Boeckner and others 2009). Recruitment of polychaetes and crustaceans is known to be impacted by a number of factors including the sediment grain size, organic and chemical content, porosity and contour of subtidal sediment ecosystems (Bishop and others 2006; Boeckner and others 2009). Subtidal gravel and sand sediments are often important as nursery areas for fish such as plaice (*Pleuronectes platessa)* (Jones, Hiscock and Connor 2000).

Food Web Dynamics

The large numbers of sandeel (*Ammodytes* spp.) present in sandy sediment attract sea birds such as puffin, razorbill, guillemot and terns. This habitat type is an important area for crabs and other epifauna, in particular echinoderms. Hermit crabs (*Pagurus bernhardus)*, the swimming crab (*Liocarcinus depurator)* and the edible crab (*Cancer pagurus)* feed on prey in this habitat (Jones, Hiscock and Connor 2000).

Formation of Species habitat

The spatial distribution of species within and upon subtidal sediments is significantly influenced by particle size distribution, organic content and chemical composition. These may ultimately be determined by the magnitude of tidal flows, currents, storms and other events (Denis and Desroy 2008). Polychaetes such as *Lanice conchilega* can provide additional structure to otherwise soft sediment subtidal habitats (Van Hoey and others 2008). Strong currents in the environment of subtidal sand can be too harsh for vegetation to establish but in more sheltered areas sugar kelp (*Saccharina latissima)* may grow which will maintain a microphytobenthic (diatom) community. Mobile sandbanks are colonised by infaunal/epifaunal small crustaceans, polychaetes and molluscs adapted to this dynamic environment; such species include *Nephtys cirrosa* and *Micropthalmus similis* (Jones, Hiscock and Connor 2000).

Species Diversification

Within inshore subtidal sediments, species diversification occurs over a gradient of sediment size forming different communities based on the dominant species. A study on the English Channel identified a number of different communities including the *Abra alba* community in fine to medium sands, and *Ophelia borealis* and *Amphioxus lanceolatus* in the medium grain size range (Denis and Desroy 2008). The dominant species in English Channel subtidal sediment communities included *Lanice conchilega, Nephtys cirrosa, Nephtys hombergii, Sigalion mathildae, Fabulina fabula, Hinia reticulata* and *Donax vittatus.* Denis and Desroy (2008) suggest that macrofaunal abundance is lower in offshore subtidal communities, but exhibits high species richness. In meiofaunal communities, nematodes and harpaticoid copepods are of highest abundance in fine and muddy subtidal sediments (Boeckner and others 2009).

On subtidal sandbanks, the density of individuals and species richness is often highest in the coarsest grade of sand owing to the abundance of interstitial polychaetes (Jones, Hiscock and Connor 2000). Generally, macrobenthic diversity and species richness of mobile sandbanks is lower than adjacent sea bed areas (Jones, Hiscock and Connor 2000). In subtidal sandbank communities there is a large proportion of opportunistic species such as *Chaetozone setosa.* Meiofauna are an important part of subtidal sandbank fauna (Jones, Hiscock and Connor 2000).

Erosion control

The presence of microalgae in subtidal sediment ecosystems plays a role in stabilisation of the habitat which in turn can reduce incident wave energy and reduce erosion (Ziervogel and Forster 2006).

Biogeochemical cycling

Marine sediments, through the processes that occur in their upper layers, have an important role in the global cycling of many elements, including carbon and nitrogen (Burdige 2006 and references therein). For example, the balance between carbon preservation and remineralization in marine sediments represents a key link between carbon cycling in the oceans, atmosphere, and land (Burdige 2006 and references therein). Similarly, nitrification occurring in marine sediments is an important component of the global nitrogen cycle and may play a role in regulating oceanic nitrogen (Burdige 2006 and references therein).

At a local scale, nitrogen and phosphorus remineralization provide a significant contribution to the nutrients required by primary producers in the water column (Burdige 2006 and references therein). Depending upon local sedimentation processes, marine sediments may provide either temporary or permanent sinks for pollutants, particularly toxic metals (Burdige 2006 and references therein). In deep-sea sediments, local trace metal remineralization may play a role in the growth and genesis of manganese nodules (Burdige 2006 and references therein).

Others

Algal blooms can have detrimental impacts on subtidal sediment communities as a result of increased accumulation of alga-derived mucilage e.g. from *Phaeocystis* blooms as indicated in the English Channel (Denis and Desroy 2008).

Review of Beneficial Ecosystem Services

Fisheries

As subtidal sediment is an important nursery area for many species, it can be assumed that it is also an important area for commercial fisheries. In a benthic invertebrate and fish community survey in the North Sea, Calloway and others (2002) found subtidal sediment to be an important parameter in determining the major divisions between communities, which may be reflected in fishery activity. This habitat can provide important nursery grounds for juvenile commercial species such as flatfishes and bass. Offshore, sand and gravel habitats support internationally important fish and shellfish fisheries (UK Biodiversity Partnership 2010).

Environmental resilience

Subtidal sedimentary habitats are more resilient than other habitats as they can be easily affected by wave and tidal displacement of sediment. Recovery of habitats following a disturbance is dependent on physical, chemical and biological processes and can be a more rapid process than in other areas (Bishop and others 2006).

Regulation of pollution

Although there was no direct evidence of subtidal sediment habitats being used in regulation of pollution in the UK, research in the Mediterranean and Baltic Seas has indicated that nematode species present in subtidal sediment habitats can be good indicators of environmental conditions (Gheskiere and others 2005). Other studies carried out in the Irish Sea around Sellafield have suggested that muddy subtidal sediment habitats act as sinks for radionuclides released from the Sellafield plant, with the potential for resuspension from the sediment as a result of wave and tidal processes (Finnegan and others 2009).

14 Subtidal macrophyte dominated sediment (EUNIS codes A5.5)

Note: This habitat includes features that are summarised here, but reviewed separately in more detail including Subtidal Sediments (13), Saline lagoons (17), Maerl beds (28) and Seagrass beds (36).

Summary

Figure 12 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for subtidal macrophyte dominated sediment. This review covers subtidal sediments, saline lagoons, maerl beds and seagrass beds. **The beneficial ecosystem processes identified were primary and secondary production, food web dynamics, larval/gamete supply, formation of species habitat, erosion control, biogeochemical cycling and water purification. The beneficial ecosystem services identified were fisheries, fertiliser/feed, natural hazard protection, regulation of pollution, climate regulation, tourism, and nature watching.**

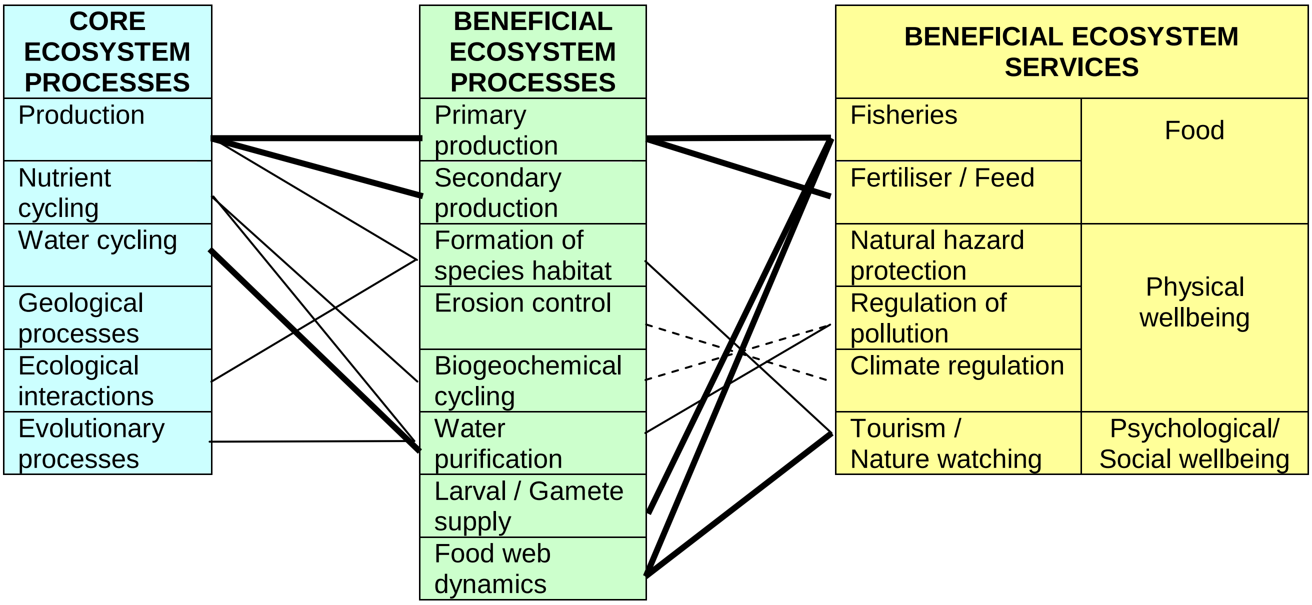

Figure 12 Marine ES Framework: Subtidal macrophyte-dominated sediment (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence

Introduction

This complex habitat includes maerl beds, seaweed dominated mixed sediments including kelps such as *Saccharina latissima* and filamentous/foliose red and green algae, seagrass beds and lagoonal angiosperm communities. These communities develop in a range of habitats from exposed open coasts to lagoons and are found in a variety of sediment types and salinity regimes. These habitats are particularly prevalent along the south and west coast of the British Isles (JNCC 2010).

Seagrasses are unique in being the only truly marine flowering plants or angiosperms (Heminga and Duarte 2008). Typically seagrass is found on sheltered sandy or muddy substrata down to 4m but can occur to a maximum depth of 10m in UK waters (Davison and Hughes 1998; Nielsen and others 2002). Sublittoral and lagoonal species of seagrass found in UK waters are tassel weed (*Ruppia maritima)* and the rarer (*Ruppia spiralis)* and eelgrass (*Zostera marina)* (common eelgrass). Eelgrass beds are a Biodiversity Action Plan (BAP) priority habitat and an OSPAR threatened habitat (OSPAR 2008). Although seagrass beds are not listed as an Annex I habitat under the Habitats Directive they are a recognized component of several Annex I habitats, namely ‘Lagoons’, ‘Estuaries’, ‘Large shallow inlets and bays’, ‘Intertidal mud and sand banks' and 'Sandbanks covered by sea water at all times'. It is also listed as a 'scarce' nationally important marine feature (Lieberknecht 2004).

Maerl is the collective term for several species of calcified red seaweed, which in their free living form and under favourable conditions can create extensive maerl beds. Maerl beds are often formed in association with sand and gravel and can constitute both live and dead maerl thalli (Kamenos, Moore and Hall-Spencer 2003). Maerl habitats exhibit a high heterogeneity compared to the surrounding substrata (Hall-Spencer and others 2003; Kamenos, Moore and Hall-Spencer 2003). Maerl beds typically develop where there is some tidal flow and are found off the southern and western coasts of the British Isles, but are particularly well developed around the Scottish islands and in sea loch narrows, around Orkney, and in the south in the Fal Estuary.

In soft sediment habitats the predominant kelp species is *Saccharina latissima* (formerly *Laminaria saccharina*). This species is often attached to stones or shells on a sandy or muddy seabed and can attain lengths of 2-3 metres. Associated with this kelp species are red and green algae (*Ceramium* and *Ulva* spp.). Most studies of kelp beds (*Laminariales* spp.) have been carried out on rocky substrate where they can be some of the most highly diverse and productive inshore ecosystems (Duggins and others 1989).

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

Eelgrass species have high rates of primary production. Decomposing organic matter provides detritus for lower trophic levels (Jones, Hiscock and Connor 2000). No estimates of the rate of primary biomass production from seagrass beds in the UK have been sourced to date. However, in the Mediterranean Sea, the seagrass *Posidonia oceanic*a, together with microphytobenthos, was responsible for primary production values of 169-300 g C per square metre per year (Danovaro and others 2002). Martin and others (2006) estimated the net primary production of natural *L. corallioides* populations (within Maerl) in shallow waters of the Bay of Brest (France) to be 10–600 g C per square metre per year (Martin and others 2006). Kelp net production varies between 1000-2000 g C per square metre per year and can be the most productive of all marine macrophytes (Mann and Chapman 1975).

Biomass Production: Secondary

Eelgrass (*Zostera* spp.) provides food for grazing for overwintering wildfowl, particularly Brent geese and wigeon (Davison and Hughes 1998; Tubbs 1999). Grazing wildfowl can consume a high proportion of the available standing stock of *Zostera*. Portig and others (1994) found that in Strangford Lough, 65% of the estimated biomass (~1100 tonnes fresh weight) of *Zostera* was consumed by grazing wildfowl during the winter months. Small crustaceans and crabs consume seagrass tissue whereas direct grazing by fish species is relatively uncommon among finfish (Hemminga and Duarte 2000).

Kelp plants contribute significantly to the dissolved organic matter in coastal waters (Duggins and others 1989). On subtidal rocky habitats filter-feeders use kelp-derived detritus as their main source of organic carbon and nitrogen. Kelp-derived detritus represented more than 65% of POM (particulate organic matter), being consistently high all year round and during both high and low tides (Bustamante and Branch 1996).

Food Web Dynamics

Wildfowl such as Brent and Canada geese graze eelgrass, particularly on *Zostera noltii*. It has been reported that in the UK, eelgrass cover in September was reduced by 60-100% and by 5-10% from mid-October to mid-January suggesting heavy reliance on eelgrass by bird species (Jones, Hiscock and Connor 2000). Grall and others (2006) identified that the major primary food sources in maerl beds in the Bay of Brest, France originated from micro and macro algae growing on the maerl thalli, together with sedimentary particulate organic matter originating from the water column. The maerl community was characterised by the co-existence of a large number of feeding strategies (including filter feeders, deposit feeders, micrograzers and macroalgae grazers), a strong overlap in food sources, and a high degree of food web complexity. From primary producers to predators, the benthic food web of maerl covered more than three trophic levels. The structural complexity of live maerl beds enhances the array of prey items available for predators such as juvenile fish. For example, Kamenos and others (2004a) concluded that juvenile gadoids were using maerls beds in Scotland as nursery areas sustained, in part, by the abundant food biomass of the live maerl matrix.

In a study of algal and faunal assemblages on soft sediments (Hily and others 1992) interactions between flora and fauna were either direct, e.g. grazing and spatial competition, or indirect, with most of the substrata occupied by macrophytes being shells of dead bivalves and gastropods. Moreover attachment of algae was largely dependent on population dynamics of shell species living in the area. The high frequency of storms during the year was found to be the main feature that disturbs both flora and epifauna. As a consequence, in the most disturbed area, the macrophytes found were opportunistic species (*Polysiphonia fibrillosa* and *Polysiphonia urceolata*). In areas where the assemblage was unstructured, a fact which prevented the development of the herbivorous species, the animal assemblage was then dominated by suspension feeders (*Ficulina ficus* and *Phallusia marnmillata*) which competed for space with the macrophytes. In the least disturbed area, the herbivorous species dominated the fauna assemblage while the flora assemblage had a high level of organization.

The fauna/flora interactions also provided positive and negative impacts upon the populations. Grazing by herbivores reduced algal biomass but enhanced its production. Persistence of algal cover increased the biomass and diversity of herbivores and associated carnivores. Suspension feeders and algae were in competition for occupation of space, but algae provided detritus exploited by the suspension feeders during the winter periods (Hily and others 1992).

Larval/Gamete Supply

The cuttlefish (*Sepia officinalis)* lives in *Z. marina* and lays its eggs amongst the eelgrass (Jones, Hiscock and Connor 2000). Kelp biotopes, with their enormous numbers of species, high biomass and high rates of productivity are important nursery areas for a diverse range of species. It is likely that juvenile forms of all the animals that are present as adults in the kelp bed make use of the habitat as a nursery area (Rinde and others 1992).

Formation of Species Habitat

Z. marina provides shelter or substratum for a wide range of species. Eelgrass rhizomes help stabilize sediment, therefore possibly increasing species diversity and higher densities of individuals than surrounding bare sediment. Leaves and rhizomes provide attachment substrata for epibenthic species (Jones, Hiscock and Connor 2000).

The three-dimensional structure of maerl forms structurally complex and heterogeneous habitats which provide a wide range of niches for infaunal and epifaunal organisms which increase the habitat complexity further (Hall-Spencer and others 2003; Bordehore and others 2003; Ordines and others 2009). Maerl grounds in Scotland have been found to act as nursery areas for several juvenile invertebrate and vertebrate species, including commercially targeted species such as queen scallop (*Aequipecten opercularis*) (Kamenos and others 2004b) and gadoids (Kamenos and others 2004a). Although mainly on hard rocky substrates, one of the characteristic features of kelp beds throughout the world is the patchwork of different species and groups of species that occur within the biotopes (UK Marine SACs Project).

Erosion Control

The dissipation of wave and tidal current energy by seagrasses in the intertidal and shallow subtidal zones gives them an important function in preventing or reducing coastal erosion. This is further enhanced by the sediment stability created by the binding effect of the roots / rhizomes (Terradoos and Borum 2004).

Biogeochemical (Nutrient) Recycling

Seagrasses and associated algae are able to absorb inorganic nutrients through both roots and leaves. The acquisition of nutrients from the water column allows seagrasses to compete with phytoplankton for the inorganic nutrients that support the primary production of coastal ecosystems, which has a beneficial effect on water quality. Maerl beds act as active traps for sestonic particles (particulate matter suspended in the water column comprising of organic and/or inorganic material) and are sites of high organic matter remineralisation (Martin and others 2006).

Water Purification (Quality)

The ability of seagrass to take up inorganic nutrients benefits water quality by helping to reduce the risk of eutrophication (Terradoos and Borum 2004). The balance is a fine one however as seagrass is highly sensitive to excessive nutrient levels (Davison and Hughes 1998; Burkholder 1992).

Species Diversification

This habitat hosts numerous species, including the polychaetes *Pygospio elegans* and *Arenicola marina*, the mud amphipod *Corophium volutator* and the bivalves *Cerastoderma edule*, *Macoma balthica* and *Scrobicularia plana,* which characterise the infaunal community of *Z. noltii* (usually found on lower estuaries and sheltered coastal muddy sands) (Jones and others 2000). Epifaunal species include the mud snail *Hydrobia ulvae*, the shore crab *Carcinus maenas* and the green alga *Enteromorpha* sp. (Jones and others 2000). Fish species that can be found include: wrasse, gobies, and the pipefish species *Syngnathus typhle* and *Entelurus aequoreus* (Jones and others 2000). The mud snail *Hydrobia ulvae* and the hydroid *Laomedea angulata* can be found on the leaves as can various species of algae (Jones and others 2000). Two species of stalked jellyfish of conservation importance, *Haliclystus auricula* and *Lucernariopsis campanulata,* can be found on seagrass leaves in open coast (Jones and others 2000).

Others

There is no direct evidence at present for the following, but a link has been highlighted based on expert understanding of ecological processes to larval/gamete supply, biological control, and species diversification.

Review of Beneficial Ecosystem Services

Fisheries

Sepia officionalis (cuttlefish) have a known association with seagrass habitat in the UK (Connor and others 2004). A cuttle fishery operates in the vicinity of the Cowes Outer Harbour Seagrass bed from April to August (ABPmer 2009). In the USA, shellfish harvesting for clam, and blue crab and scallop have all been associated with seagrass (Fonesca, Kenworthy and Theyer 1998).

Northern European maerl beds typically occur in shallow waters (< 32m) with high rates of water exchange. These conditions support the growth of an abundance of epifaunal and infaunal bivalves including scallops (*Aequipecten* spp., *Pecten* spp.), razor clams (*Ensis* spp.) and clams (*Dosinia* spp., *Tapes* spp.) making maerl habitats attractive to fishers. The habitat complexity and emergent biota of maerl beds has been shown to significantly reduce mortality in juvenile Atlantic cod (Lindholm and others 1999 cited in Hall-Spencer and others 2003).

Fertiliser

The nutrient content of seagrass has resulted in its use in agriculture, albeit rare and mainly overseas. Eelgrass is used as both animal feed for pigs, rabbits and hens and as a soil fertilizer (Terradoos and Borum 2004; Hemminga and Duarte 2000). Agricultural use in a number of countries has reduced over recent years because of bans on harvesting of seagrass. Maerl is dredged industrially as a source of soil conditioner (Grall and Hall-Spencer 2003 cited in Kamenos and others 2004c).

Natural Hazard Protection

There are benefits provided from erosion control which reduces exposure to natural hazard (expert opinion).

Tourism/Nature watching

Zostera beds, because of their association with grazing wildfowl and waders, are important for nature watching and a focus for scientific research. Snorkelling and (to a lesser extent) diving in seagrass occurs at suitable sites, as at Bembridge on the Isle of Wight where the seagrass exists in very shallow water.

Regulation of Pollution

Seagrass beds aid the regulation of pollution through its take up of inorganic nutrients. They have a filtration role in coastal waters, trapping particles indirectly through the filter feeding activity of the organisms they host and directly through capture of suspended particles to the mucus-covered leaf surfaces. In so doing they improve water transparency and quality (Terradoos and Borum 2004).

Climate regulation

There is evidence to suggest that eelgrass beds provide a natural coastal carbon sink (IUCN 2009).

15 Subtidal Biogenic Reefs (EUNIS codes A5.6)

Note: *Sabellaria spinulosa* can be found in intertidal areas but primarily is associated with the subtidal. There may also be some relevant material within the Intertidal biogenic reef chapter of this review (10).

Summary

Figure 13 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for Subtidal Biogenic Reefs. **The beneficial ecosystem processes identified were secondary production, larval/gamete supply, formation of species habitat, food web dynamics, species diversification, biogeochemical cycling, climate regulation and water purification. The beneficial ecosystem services identified were fisheries, other wild harvesting, aquaculture, natural hazard protection, environmental resilience and aquaria.**

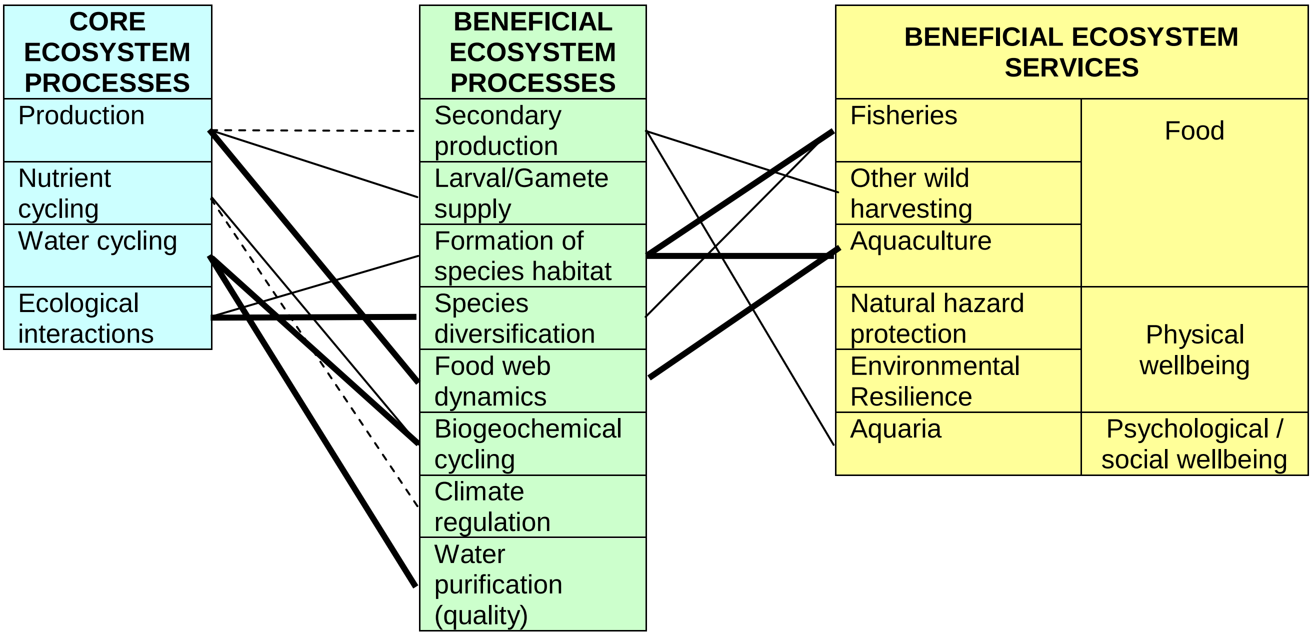

Figure 13 Marine ES Framework: Subtidal Biogenic Reefs (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Three principal subtidal biogenic reef-building species have been focused upon in this review: *Modiolus modiolus, Sabellaria spinulosa* and *Serpula vermicularis* (Holt and others 1998). However *Lanice cochilega* also forms reefs in subtidal areas and although there are gaps in the knowledge about this polychaete (Rabuat 2010; Rabaut and others 2009) this species has also been included in this review.

The horse mussel *M. modiolus* forms dense beds at depths of 5-70 m in fully saline, often moderately tide-swept areas off northern and western parts of the British Isles. It is a widespread and common species. True beds forming a distinctive biotope are more limited than the species distribution and are not known south of the Humber and Severn estuaries. Beds have been found from Shetland, Orkney, the Hebrides and other parts of western Scotland, the Ards Peninsula, Strangford Lough, off the Isle of Man, off north-west Anglesey and north of the Lleyn Peninsula. Dense beds of young horse mussel do occur in the Bristol Channel but do not often survive to adulthood. Occasional beds occur off the North Sea coast, between Berwickshire and the Humber.

S. spinulosa is a small tube-building polychaete worm that through aggregation builds subtidal reefs. *S. spinulosa* acts to stabilise cobble, pebble and gravel habitats, providing a consolidated habitat for epibenthic species. Even though they are fragile structures, they are solid and can reach massive consolidations at least several centimetres thick, raised above the surrounding seabed, and can persist for many years. As such, they provide a biogenic habitat that allows establishment of many other associated species. The *S. spinulosa* reef habitats of greatest nature conservation significance are those which occur on predominantly sediment or mixed sediment areas (Maddock 2008).

S. vermicularis is a marine worm which makes a hard, calcareous tube 4-5 mm in diameter and up to 150 mm long. The worms can be solitary in most places, but when found in aggregations they form into clumps or 'reefs' up to 1 m across. This species is found in sheltered sites worldwide (except for polar seas) but reef formations have been reported from very few locations. In the UK, these reefs have only been found in Loch Creran, and the Linne Mhuirich arm of Loch Sween; both sea lochs on the west mainland coast of Scotland. The reefs in Loch Sween are now reported to be dead. Small *S. vermicularis* reefs have also been found in two loughs on the west coast of Ireland, but the best developed reefs in the world are in Loch Creran (Maddock 2008).

Review of Beneficial Ecosystem Processes

Biomass Production: Secondary

Modiolus is the largest contributor to secondary benthic production (Holt and others 1998). Biodeposition in the form of faeces and pseudofaeces is one of the main mechanisms by which organic matter and other nutrients are made available for deposit and suspension feeders, channelling organic matter between plankton and benthos (Holt and others 1998).

Larval/Gamete Supply

Wilson (1976) showed that *S. spinulosa* larvae are strongly stimulated to settle by adults or newly settled juveniles of *S. spinulosa*. It is suspected that juvenile survival is greatly enhanced by settling between the mass of *Modiolus* byssus threads in established beds (Jones, Hiscock and Connor 2000).

Formation of Species Habitat

Biogenic structures built by ecosystem engineers such as bivalves and polychaetes provide hard substrate for crevice colonization by benthic vertebrates and invertebrates (Dubois and others 2006).

Modiolus beds are found on a range of substrata, from cobbles through to muddy gravels and sands, where they tend to have a stabilising effect, due to the production of byssal threads (OSPAR 2008). *Modiolus* has been recognized as a keystone engineer constructing very stable reefs (Queen's University Belfast 2004). Both living and dead *Modiolus* shells form the bed framework in single or multiple layers. The resulting reefs support a wide range of epifaunal and infaunal organisms. Witman (1980) for example observed eight times as much organism biomass inside *Modiolus* beds compared to outside. Furthermore, the rate at which mussel beds fix nutrients from the seawater is 2-3 times higher than comparable locations without mussels, which means that mussel beds are able to support a rich and diverse benthic community in the mussel and mussel mud matrix (Inglis and others 2000).

The *S. spinulosa* reef habitats of greatest nature conservation significance are those which occur on predominantly sediment or mixed sediment areas. These enable a range of epibenthic species with their associated fauna and a specialised 'crevice` infauna, which would not otherwise be found in the area, to become established (Maddock 2008). *S. spinulosa,* widely distributed around the British Isles, is found mainly in the subtidal zone. This species stabilises mobile sediment (Holt and others 1998) which allows a diverse epifaunal and infaunal species not found in other habitats to establish communities in a multitude of niches (JNCC 2010). Some of the structures built by these species can be a metre deep and hundreds of metres across (Lancaster and Savage 2008). They bind unstable rocky scar ground, restricting drainage, which creates rock pool refuges for prawns, blennies and hermit crabs (Lancaster and Savage 2008).

S. vermicularis is a subtidal reef-forming worm that provides substratum for a wide variety of other species including sessile sponges, ascidians, hydroids, other tube worms, bryozoans, bivalves, the tunicate (*Pyura microcosmos)* and the anemone *(Metridium senile)*. In shallow water the red alga *(Phycodrys rubens)* may be found*.* Mobile organisms include: crustaceans, sea urchins (*Echinus esculentus* and *Psammechinus miliaris),* brittle star *(Ophiothrix fragilis),* the starfish *(Asteris rubens),* and the whelk *(Buccinum undatum) (*Holt and others 1998).

The effect of *L. conchilega* on the macrobenthic community and sediment characteristics of its habitat was evaluated by Rabaut and others (2007) in the Belgian area of the North Sea. The effect of the protruding tubes resulted in the retention of fine sediment particles, while the increased coarse fraction was assumed to reflect a dynamic population build-up. This study suggested that *L. conchilega* expand the niche of several species without forming its own association. In addition, Rabaut and others (2009) found that the density distribution of the flatfish species plaice (*Pleuronectes platessa*) was significantly explained by the presence of reefs built by the polychaete *L. conchilega*.

Food Web Dynamics

Modiolus modiolus reefs play an important ecological role in energy transfer, from pelagic to benthic systems and between trophic levels within the reef itself (Navarro and Thompson 1996). *Modiolus* reefs are highly productive and in high densities the suspension feeding of *M. modiolus* can remove and store large amounts of suspended material. *S. spinulosa* probably provides an important food source for the pink shrimp (*Panadalus montagui)* (Jones, Hiscock and Connor 2000). There is evidence to suggest that the total density of macrobenthic fauna is significantly augmented by the presence of *L. conchilega* (Zuhlke 2001) and other polychaete tube patches (Woodin 1978; Bolam and Fernandes 2003). A study by Rebaut and others (2007) found that polychaetes and amphipods constitute the highest numbers of predatory species positively associated with *L. conchilega*.

Species diversification

Communities associated with *M. modiolus* are generally known to be extremely rich; for example 270 invertebrate species have been found associated with *Modiolus* off the north east of the Isle of Man (OSPAR 2008 and references therein). Similarly, *S. spinulosa* appears to have a rich associated infauna and epifauna (Holt and others 1998). *S. spinulosa* reefs are home to crevice dwelling animals including the porcelain crab (*Pisidia longicornis)* and the polychaete worm species *Scoloplos armiger* and *Lumbrineris gracilis* (Hill and others 1998 and references therein). Larger gaps in the reef structure may be inhabited by large crabs and lobster as well as the queen scallop *Aequipecten opercularis* (Hill and others 1998 and references therein).

On *S. spinulosa* reefs in the Bristol Channel, Hill and others (2010) and references therein reported an 80% increase in biodiversity associated with reef areas compared to the surrounding sand substratum, however Hill and others (2010) noted that the surrounding sand environment was particularly species-poor. Cooper and others (2007) showed that some benthic macro-invertebrate communities off Great Yarmouth support higher species numbers and greater abundances of individuals compared to other areas, which may have been due, in part, to the presence of *S. spinulosa* reefs.

The epifauna of *Modiolus* reefs is dominated by a wide diversity of suspension feeding animals such as sponges (for example *Halichondria panacea*), hydroids (such as *Sertularia* spp.), bryozoans and ophiuroids (in particular *Ophiothrix fragilis*). These contribute to energy transfer (Witman 1980; Sanderson 2008; Comely 1978), as do hydroids, red seaweeds, solitary ascidians, and bivalves such as *Aequipecten opercularis* and *Chlamys varia* (OSPAR 2008). Brown and Seed (1977) recorded 90 invertebrate taxa associated with *Modiolus* clumps in Strangford Lough. OSPAR (2008 and references therein) found 270 invertebrate taxa associated with *Modiolus* reef areas to the north east of the Isle of Man, and suggested that this was likely to be an underestimate, particularly in terms of sponges and infauna. Because of the abundant epifauna and infauna *Modiolus* beds have been considered to support one of the most diverse sublittoral communities in north-west Europe (Holt and others 1998).

S. vermicularis reefs have a very rich and diverse epifauna and large mobile fauna. Cryptic fauna may also be very diverse. The tunicate *Pyura microcosmus* appears to be limited mostly to this habitat (Holt and others 1998). In addition, *L conchilega* is known to have positive effects on the distribution and abundance of infaunal species diversity in subtidal areas (Rabaut and others 2009).

Biogeochemical cycling

Mermillod-Blondin and others (2003) found that in Quebec, Canada the presence of biogenic structures produced by benthic invertebrates strongly affects biogeochemical processes. They note that in aquatic ecosystems, benthic invertebrates play a key role in organic matter processing and nutrient cycling at the water–sediment interface (Mermillod-Blondin and others 2003). The calcareous shells and skeletons produced by many biogenic reef builders become biogenic sediments after breakdown by bacteria and algae, which contributes to biogeochemical precipitation of calcareous mud (Holt and others 1998).

Climate regulation

In general terms, subtidal biogenic reefs play a major role in the global carbon cycle and act as a major store of carbon (expert opinion).

Water purification

Reefs filter large volumes of water (Dubois and others 2006). Forster and Graf (1995) found increased oxygen concentrations in the sediment along the whole length of the tube and suggested that *L. conchilega* acts as a piston, exchanging burrow water with the overlying water (Rabaut and others 2007). It is estimated that an area of mussel bed the same size as a tennis court (400,000 mussels) can filter the equivalent of four Olympic sized swimming pools of seawater per day. These 'living' reefs are important are they fix and process nutrients from the seawater into the benthic environment.

Review of Beneficial Ecosystem Services

Fisheries and bait

Biogenic reefs provide habitat for shellfish and fish, such as temperate rocky reef fish (Gunderson and Vetter 2006), which are exploited by the fishing industry. The close association between *S. spinulosa* and the pink shrimp *Pandalus montagui* has led to intensive fishing of these reefs, for example the Morecambe Bay fisheries, the Thames Estuary pink shrimp fishery and in the Wadden Sea (Holt and others 1998). There have also been small scale *M. modiolus* (horse mussel) fisheries in Scotland. The mussels are also used for fishing bait (Jones, Hiscock and Connor 2000).

The possible role of *Modiolus* reef communities in providing a nursery refuge for commercial fisheries and shellfisheries species is occasionally mentioned in the literature but does not appear to have been investigated. Dense growths of bushy hydroids and bryozoans could conceivably provide an important settling area for spat of bivalves such as the scallops *Pecten maximus* and *Aequipecten opercularis*, adults of which are often abundant in nearby areas (OSPAR 2008).

Other wild harvesting

Scallop and queen scallop dredging is carried out in locations of *M. modiolus* reefs (Holt and others 1998) for example off the south east coast of the Isle of Man.

Aquaculture

There is a commercial mussel fishery in the Wash, UK (Eastern Sea Fisheries Joint Committee, 2010). Foveaux Strait, between South Island and Stewart Island, New Zealand, has been the site of a major oyster fishery for *Ostrea chilensis* since 1867. Oysters were an abundant part of the biogenic reef fauna and important in reef structure (Cranfield and others 1999).

Natural Hazard Protection

Reefs provide protection for coasts through reduction of incoming wave energy (McManus 2001). Wave–resilience is a characteristic of hard biogenic reefs they reduce wave energy reaching the coast (Riding 2002). *Mytilus* reefs have a strong stabilizing effect on the sediment and structures can last for many years (Holt and others 1998).

Environmental Resilience

The Byssus threads secreted by *M. modiolus* have an important stabilising effect on the seabed, binding together living *M. modiolus*, dead shell, and sediments (expert opinion).

Aquaria

In Loch Creran, Scotland, divers hand pick *S. vermicularis* for commercial aquaria (Holt and others 1998).

16 Deep-sea bed (EUNIS codes A6)

Note: This habitat includes the following additional features reviewed separately ‘ submarine structures made by leaking gases’ (18); cold water coral reefs (21); and deep sea sponge aggregations (31).

Summary

Figure 14 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for Deep-sea beds. **The main ecosystem processes identified were primary and secondary production, food web dynamics, species diversification, genetic diversification, climate regulation and biogeochemical cycling. The beneficial ecosystem services identified were fisheries and research and education.**

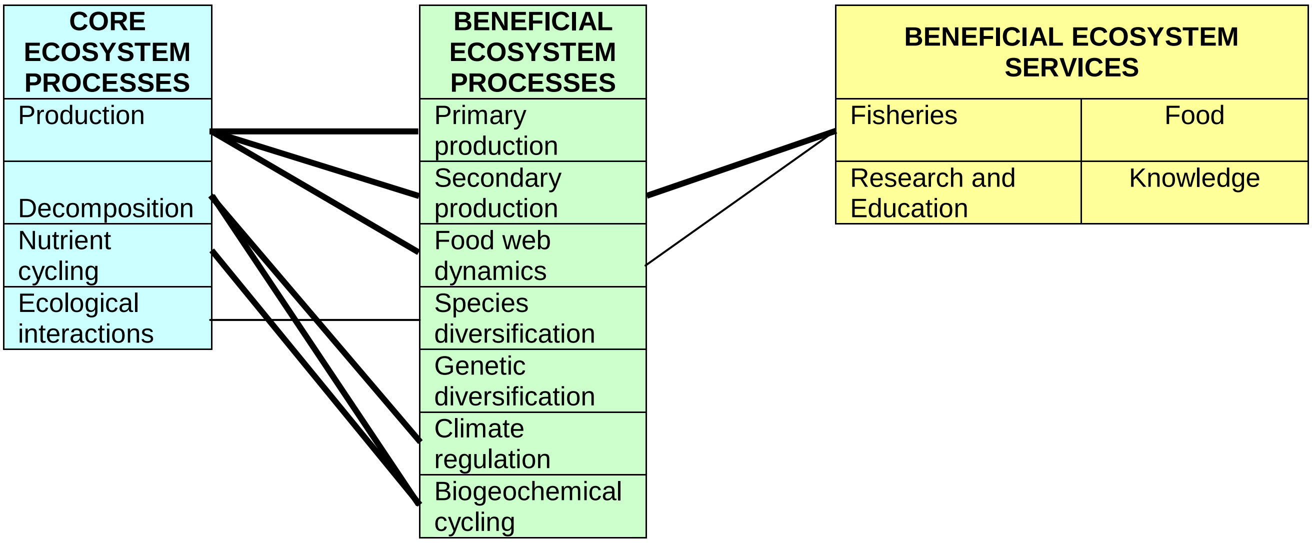

Figure 14 Marine ES Framework: Deep-sea bed (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

The deep-sea bed is defined as the area beyond the continental shelf break (Smith and Hughes 2008) and is typically at a depth greater than 200m. Deep sea sediment covers 65% of the Earth’s surface and is therefore of a much more extensive scale than the other habitats in this document, reflected in its designation as a EUNIS Level 2 habitat. The deep-sea bed contains a mix of physical features, including areas of both sediment and hard substrates and biogenic reefs (e.g. *Lophelia pertusa* reefs). In UK territorial waters the “deep sea” includes part of the Wyville Thomson Ridge, the Atlantic North-West Approaches, Rockall Trough and Faroe-Shetland Channel, together with a small region in the Western English Channel, Celtic Sea and Southwest Approaches. Water depths range from approximately 200 m at the shelf break to 2500 m in the northern Rockall Trough, and > 3000 m in the Iceland Basin at the western extremity of Region 8. Offshore areas of relatively shallow topography include the summits of the Anton Dohrn and Rosemary Bank seamounts (500–600 m) and the broad expanse of the Rockall Bank, much of which is less than 500 m deep. The areas to the north and west of Scotland were the scene of some of the pioneering oceanographic surveys of the 19th century and played an important role in the birth of deep-sea science (Gage and Tyler 1991). Additional survey work or research activity has been conducted since the mid-1970s (reviewed in Hughes and others 2003; Davies and others 2006).

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

Sunlight does not penetrate to deep-sea beds and therefore primary production in this habitat does not originate from photosynthesis. Instead, primary production depends upon the assimilation of sulphates, carbonates and other chemical compounds through chemolithoautotrophy (Jorgensen & Boetius 2007). Although not restricted to hydrothermal vents, it has been noted that chemolithoautotrophs that inhabit hydrothermal vents are some of the most productive primary producers globally (Jorgensen and Boetius 2007). Alternatively, primary production occurs higher in the ocean and organisms then fall to the sea bed as particulate organic matter (Jorgensen and Boetius 2007). No direct measurements of primary production are available for this habitat. Chemosynthetic primary producers are also found at cold-seeps, a more recently discovered cold equivalent of the hydrothermal vents, which produce hydrocarbons (Jorgensen and Boetius 2007).

Biomass Production: Secondary

The microbial community and the symbiotic macrofauna of hydrothermal vents and cold-seeps are the key components of secondary production, however, the processes that lead to secondary production are poorly understood (Jorgensen and Boetius 2007).

Food Web Dynamics

The deep-sea bed has few trophic levels and often relies on primary production that is external to the system. Available energy resources are also increasingly supplemented by fisheries discards, which create carrion for benthic scavengers (Ramsay and others 1997). Studies of the Porcupine Abyssal Plain show that deep-sea communities are far more dynamic than once believed. Population explosions of some invertebrate species are thought to have been triggered by increases in the quantity of food reaching the sea-bed, which has been linked to climate variability (Hughes and Hughes 2010).

Species diversification

The sea bed itself is not thought to be associated with high species diversity but has errant megafauna dominated by echinoderms and to a lesser extent decapoda, or bottom-dwelling fish (Van Dover 2000). At the top of seamounts, corals, sea pens, sponges, and brachiopods flourish (Van Dover 2000). Pelagic and benthopelagic fish species are found at seamounts as are gorgonian sea fans and there is often significant endemism in seamount fauna (Rogers 1994).

Genetic diversification

Novel and uncultured bacterial lineages dominate deep-sea beds (Jorgensen and Boetius 2007). Deep-sea genetic diversity is being exploited by the new blue biotechnology industry (Pfannkuche and others 2009).

Climate regulation

The deep-sea bed acts as an unrivalled reservoir (up to 30%) for sequestration of CO_2 (Pfannkuche and others 2009). Gas and climate regulation provided by the deep sea includes the maintenance of the chemical composition of the atmosphere and the oceans, for example via the “biological pump”, which transports carbon absorbed during photosynthesis into the deep seas. Methanotrophic microbes in the ocean floor and waters control almost all of the oceanic methane emission (Reeburgh 2007).

Biogeochemical cycling

Deep-sea beds have a profound involvement in global biogeochemical processes and nutrient regeneration, which in turn sustain primary and secondary oceanic production (Pfannkuche and others 2009). At the deep-sea bed there is considerable sedimentation of organic matter. In addition, chemical energy is released and converted into organic matter around hydrothermal vents and cold-seeps (Jorgensen and Boetius 2007). Bioturbation is the process of nutrient cycling in deep-sea beds and creates a much more of a productive layer immediately around the beds in comparison with deep-sea pelagic habitats (Jorgensen and Boetius 2007). Waste absorption and detoxification are important processes, as marine organisms store, bury and transform waste materials through assimilation and chemical transformation (Solan and others 2004).

Review of Beneficial Ecosystem Services

Fisheries

Increasing attention is being paid to deep-sea demersal fish because commercial stocks elsewhere are diminishing (Merrett and Haedrich 1997). Fisheries that are currently exploited in UK territorial waters include the black scabbard fish (*Aphanopus carbo);* birdbeak dogfish (*Deania calceus),* orange roughy *(Hoplostethus atlanticus)*; rabbit fish Chimaeridae, blue ling (*Molva dypterygia*); roundnose grenadier (*Coryphaenoides rupestris)* and anglerfish (*Lophius piscatorius)* (Large and others 2004).

Research and education

Deep-sea beds provide the potential to learn about mutation rates in slow growth microorganisms using energy sources that are alternatives to photosynthesis. Following the release of information and data after the discovery of deep-sea hydrothermal vents after 1977, new interest was triggered in this previously neglected ocean habitat (Van Dover 2000; Jorgensen & Boetius 2007). Cabled or stand alone observatories networked at the seafloor offer unique opportunities to study at this depth (Pfannkuche and others 2009).

17 Saline lagoons

Summary

Figure 15 shows the core ecosystem processes and beneficial ecosystem processes and services that have been identified for saline lagoons. **The main ecosystem processes identified were larval/gamete supply, formation of species habitat, species diversification and biogeochemical cycling. The main services identified were fisheries, aquaculture, tourism, and nature watching.**

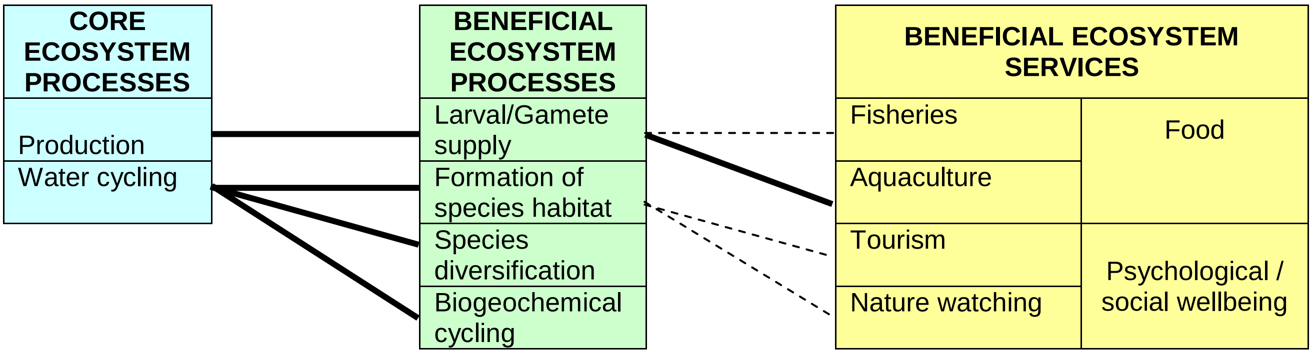

Figure 15 Marine ES Framework: Saline lagoons (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicate oversees evidence or expert evidence)

Introduction

Lagoons are essentially natural or artificial bodies of saline water partially separated from the adjacent sea that retain a proportion of their seawater at low tide and may develop as brackish, fully saline or hyper-saline water bodies (UK Biodiversity Partnership 2010). Lagoons can contain a variety of substrata, often soft sediments, which may support tasselweeds and stoneworts as well as filamentous green and brown algae. They provide important habitat for waterfowl, marshland birds and seabirds and are protected as a 'priority habitat type' under Annex 1 of the EC Habitats Directive (Johnson and others 2007) and as a BAP priority habitat. The flora and invertebrate fauna present can be divided into three main components: those that are essentially freshwater in origin, those that are marine/brackish species and those that are more specialist lagoonal species. There are several different types of lagoons, including those separated from the adjacent sea by a barrier of sand or shingle ('typical lagoons'), those arising as ponded waters in depressions on soft sedimentary shores, and those separated by a rocky sill or artificial construction such as a sea wall. The salinity of the systems is determined by various levels of freshwater input from ground or surface waters. The degree of separation and the nature of the material separating the lagoon from the sea are the basis for distinguishing several different physiographic types of lagoon (this section is adapted from UK Biodiversity Partnership 2010).

Review of Beneficial Ecosystem Processes

Larval/Gamete supply

These environments play a key role in spawning grounds for fish and shellfish (Deborde and others 2008).

Formation of Species habitat

Saline lagoons form a habitat for a variety of species, including the following low mobility species of conservation importance: *Gammarus insensibilis, Armandia cirrhosa, Nematostella vectensis, Alkmaria romijni, Caecum armoricum, Paludinella littorina, Tenellia adspersa and Victorella pavida*. Their significance as a habitat has resulted in their designation as a 'priority habitat type' under Annex 1 of the EC Habitats Directive (Johnson and others 2007).

Species Diversification

Currently nine lagoonal animals and two lagoonal plants of the 40 known lagoonal species are protected under schedules 5 and 8 of the Wildlife and Countryside Act, 1981 and comprise some of Britain's rarest species (Johnson and others 2007). UK saline lagoons usually support both estuarine and brackish specialist macrofauna and flora (Barnes 2008 and references therein).

Biogeochemical cycling

The sediment in lagoons becomes the sink for biogeochemical nutrient cycles because water depth is low and the intertidal zone is extended (Deborde and others 2008).

Review of Beneficial Ecosystem Services

Fisheries

Saline lagoons are exploited for fisheries such as the pikeperch (*Sander lucioperca*) fishery in the Baltic Sea, Germany (Groger and others 2007).

Aquaculture

Saline lagoons have been extensively exploited for aquaculture, for example Arachon Bay, France which is a major centre for oyster farming (Castel and Lasserre 2004; Deborde and others 2008).

Nature watching / Tourism

Saline lagoons have been extensively used for tourism and nature watching purposes, particularly bird watching (Deborde and others 2008). Some lagoonal areas attract nature watchers requiring overnight stays and therefore create a tourism benefit (expert opinion).

18 Submarine structures made by leaking gases

Summary

Figure 16 shows the relevant core ecosystem processes and beneficial ecosystem processes and services that have been identified for submarine structures made by leaking gases. **The main beneficial ecosystem processes identified were food web dynamics, species diversification, formation of species habitat, biogeochemical cycling and climate regulation. The only beneficial ecosystem service identified was fisheries.**

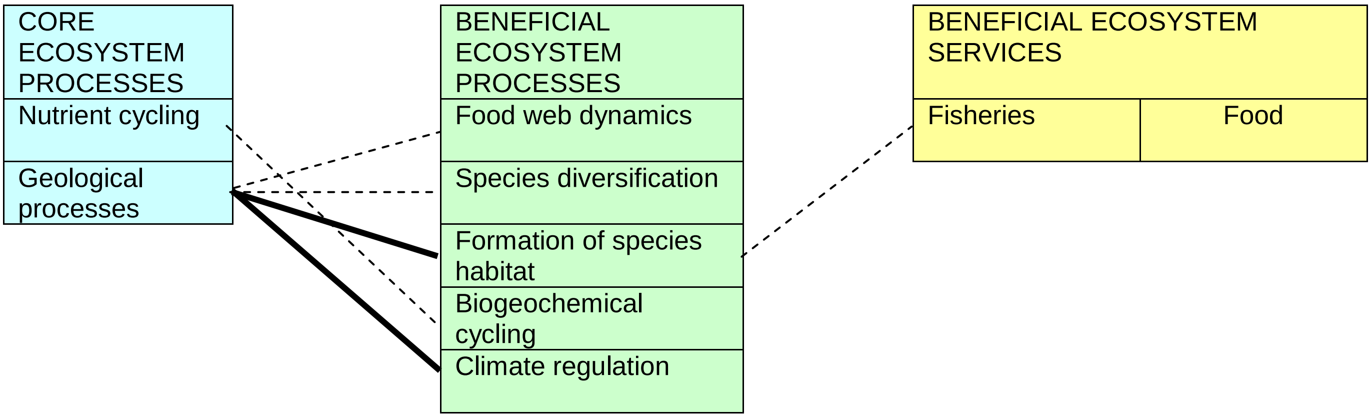

Figure 16 Marine ES Framework: Submarine structures made by leaking gas (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

This habitat is defined as "spectacular submarine complex structures, consisting of rocks, pavements and pillars up to 4 m high. These formations are due to the aggregation of sandstone by a carbonate cement resulting from microbial oxidation of gas emissions, mainly methane. The formations are interspersed with gas vents that intermittently release gas" (Johnston and others 2002). This habitat has a restricted distribution in European waters due, in part, to its relationship to sources of shallow gas. No examples of this habitat have been identified in UK inshore waters (Johnston and others 2002), however a variation of this habitat type does occur in UK offshore waters, in the form of blocks and 'pavements' found in association with gas seep depressions (pockmarks) in the seabed, formed by the expulsion of shallow gas. These pockmarks are found in the Fladen and Witch Grounds in the northern North Sea and parts of the Irish Sea (JNCC 2010). This habitat is included in Annex I of the Habitats Directive.

Review of Beneficial Ecosystem Processes

Food Web Dynamics

In general, the supply of methane at cold water seeps (areas where waters enriched with methane are forced upwards through sediments) leads to dense microbial communities. Methane oxidation facilitates the formation of carbonates and in many places generates extremely high concentrations of hydrogen sulphide. Increased food supply, availability of hard substratum and high levels of methane and sulphide supplied to bacteria provide the basis for the complex ecosystems found at these sites (Levin 2005).

Species Diversification

Jensen and others (1992) stated that the submarine landscape of carbonate-cemented rocks (the 'bubbling reefs') in the northern Kattegat (the area between eastern Denmark and Sweden), support a diverse ecosystem ranging from bacteria to macroalgae and anthozoans with many animals living within the rocks in holes bored by sponges, polychaetes and bivalves.

Formation of species habitat

In general, the carbonate formations that comprise this habitat shelter a highly diversified ecosystem with brightly coloured species (European Commission, 2003). The carbonate structures found in the pockmarks located in UK offshore waters provide a habitat for marine fauna usually associated with rocky reefs, such as anemones and squat lobsters (Dando and others 1991). These features also appear to provide shelter for fish species including hagfish, haddock, wolf fish, cod and small red fish (Dando and others 1991).

Biogeochemical cycling

The carbonate structures that form this habitat also support chemosynthetic organisms (organisms that convert carbon molecules and nutrients into organic matter using inorganic molecules or methane as a source of energy instead of sunlight) which feed off the methane seeping from beneath the sea floor and its by-product hydrogen sulphide (Judd and others 1997). The results of Jensen and others (1992) who studied the shallow water 'bubbling reef' habitat in the northern Kattegat off the Danish coast, found maximum aerobic methane oxidation rates of 4.2-45.6 per decimeter $(dm)^3$ per day. The rock surfaces and epifauna around the gas seeps were also sites of methane-oxidising activity. Jensen and others (1992) stated that since gas venting occurs over several square kilometres of the sea floor in the Kattegat, it is likely to make a significant local contribution to the cycling of elements in the sediment and the water column.

Climate regulation

As a source of methane, gas seeps provide both positive and negative feedback to global warming and global cooling, thereby playing a role in climate regulation (Judd and others 1997). Based on published seabed flux rates and models of loss to solution in the water column, Judd and others (1997) provided an estimated contribution to atmospheric methane from natural gas seeps on the UK continental shelves of 0.12-3.5 Terragrammes (Tg) of methane per year. In the context of the total atmospheric methane budget of 535 Tg per year (Houghton and others 1996) this represents about 0.7 to 0.02 % of the total methane source. However the impact from this released methane on climate is currently unclear.

Review of Beneficial Ecosystem Services

There is no direct evidence at present for beneficial ecosystem services but expert opinion suggests that submarine structures made by leaking gas provide shelter for species such as haddock and cod and so benefit commercial fisheries.

19 Submerged or partially submerged sea caves

Summary

Figure 17 shows the relevant core ecosystem processes and beneficial ecosystem processes and services that have been identified for submerged or partially submerged sea caves. **The beneficial ecosystem processes identified were food web dynamics, species diversification, and formation of species habitat. The main beneficial ecosystem services identified were recreation/sport, and tourism.**

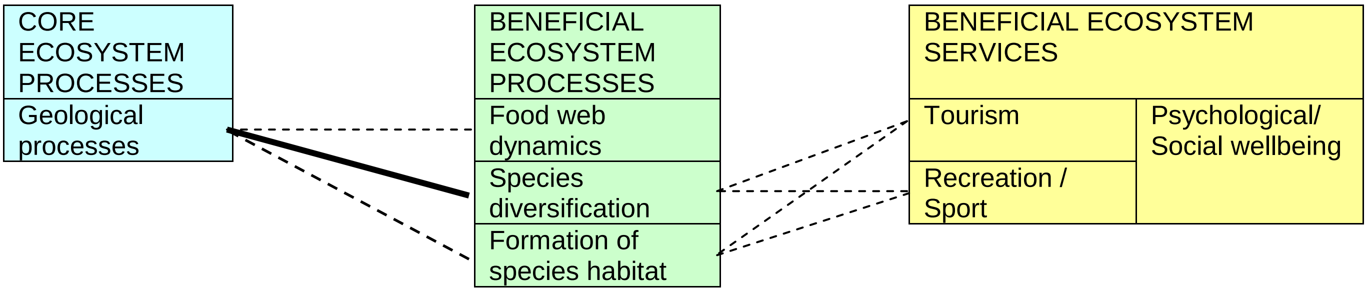

Figure 17 Marine ES Framework: Submerged and partially submerged sea caves (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

This habitat includes submerged sea caves and partially submerged caves which are only exposed to the sea at high tide. Caves vary in size from a few metres to more extensive systems which may extend hundreds of metres into the rock. Vertical and overhanging rock faces within the tunnels or caverns provide the principal marine habitat (JNCC 2010). Although sea caves are distributed throughout rocky coastlines in Europe they are a relatively scarce habitat and are included in Annex I of the Habitats Directive. The UK has the most varied and extensive sea caves on the Atlantic coast of Europe where they are widely distributed in inshore waters (JNCC 2010). Sea cave communities vary considerably depending on their structure, extent of the cave system, the degree of submergence, their exposure to sand scour and wave surge and their geology (JNCC 2010).

Review of Beneficial Ecosystem Processes

Food web dynamics

Bussotti and Guidetti (2009) stated that Mediterranean sea caves in south east Italy may provide additional resources for fish in terms of food availability and refuge against predators, compared to rocky reefs without caves. Particular species that inhabit Mediterranean sea caves appear to play an important ecological role in the maintenance of the benthic communities within the caves. For example, the fish species *Apogon imberbis* (Cardinal Fish) which Bussoti and Guidetti (2009) recorded inside the sea caves studied in south east Italy, feed on small crustaceans outside the cave at night, then defecate during the daytime when they move back into the caves, hence transferring organic matter into the caves. Similarly, the mysid shrimp (*Hemimysis speluncola*) found in marine caves within the northern Mediterranean, feed outside the cave at night then import organic matter into the nutrient deficient (oligotrophic) cave ecosystem during the day by providing cave consumers with their faecal pellets or by being preyed on by resident carnivores. Hence, *H. speluncola* which typically form large swarms, play an important role in the energy budget of the cave ecosystems (Bianchi 2007 and references therein).

Species diversification

Much of the research regarding sea caves has been undertaken in the Mediterranean region. The extent to which the findings of this can be applied to the UK is unclear. Several studies in the Mediterranean have shown that due to their particular environmental conditions (e.g. light gradients and water confinement), submerged and semi-submerged marine caves host a rich and diversified biota (e.g. Harmelin and others 1985; Harmelin and Vacelet 1997; Chevaldonne and Lejeusne 2003; Marti and others 2004). Todaro and others (2006) studied the meiofauna (animals between 50-500µm) of a semi-submerged sea cave on the southern Italian coastline and found that, although the meiofauna of the cave was not particularly abundant, it was notable for its diversification, with at least 12 phyla (major taxonomic groups) represented as well as species new to the Mediterranean Sea. The authors concluded that, as previously shown for macrofauna (larger sized biota), the marine caves were a hotspot for biodiversity and endemism.

One location with studied sea caves in the UK is in the Torbay area, which has extensive limestone sea caves. Marine cave fauna in Torbay is exceptionally diverse. For example, Berry Head has a unique and extensive solutional limestone cave system that extends well beyond daylight and the influence of wave action. Species identified in sea caves around Torbay include the carpet coral (*Hoplangia durotrix*), pink seafingers (*Alcyonium hibernicum*), Devonshire cup coral (*Caryophyllia smithii*), sponge (*Dercitus bucklandi*), anthozoans (*Edwardsiella carnea* and *Epizoanthus couchi*), burrowing anemones (*Cerianthus lloydii* and *Edwardsia claparedii*) and the squat lobster (*Galathea nexa*) (Torbay Coast and Countryside Trust 2006). Similarly, Bell (2002) recorded thirty one species of sponge inhabiting a semi-submerged sea cave at Lough Hyne Marine Nature Reserve in County Cork, Ireland.

Formation of species habitat

In the Mediterranean, there are long stretches of rocky coast characterised by the presence of many submarine caves. In some regions marine caves may extend for hundreds of metres, enlarging rocky reefs by increasing the availability of suitable rocky surface per length unit of coastline for both benthic (living on or in the seabed) and nektonic (actively swimming aquatic organisms) assemblages and by offering special environments with respect to ecological conditions (e.g. light, water motion) (Bussotti and Guidetti 2009 and references therein). In the UK, sea caves are generally less extensive. Bussotti and Guidetti (2009) noted that Mediterranean sea caves in south east Italy may provide additional resources for fish in terms of food availability and refuge against predators (including for juveniles of some commercially valuable species e.g. groupers) compared to rocky reefs without caves. The extent to which this is likely to apply to the UK is unclear.

Review of Beneficial Ecosystem Services

Recreation / Sport

Many sea caves can only be accessed by SCUBA diving and thus attract sport divers (Torado and others 2006).

Tourism

In locations globally (e.g. Thailand, USA, Sardinia, Malta), and in the UK, many tourism companies advertise excursions to visit sea caves, for example via boat and kayak.

20 Blue Mussel beds

Note: Blue mussel (*Mytilus edulis*) beds can form 'reef' structures, referred to as biogenic reefs. The beneficial ecosystem processes and services provided by biogenic reefs are considered elsewhere in this document as inter-tidal biogenic reefs (10) and sub-tidal biogenic reefs (15).

Summary

Figure 18 shows the relevant core ecosystem processes and beneficial ecosystem processes and services that have been identified for blue mussel beds. **The main beneficial ecosystem processes were secondary production, food web dynamics, species diversification, erosion control, formation of species habitat, biogeochemical cycling and water purification. Beneficial ecosystem services identified were fisheries, aquaculture, fertiliser/feed, natural hazard protection, and regulation of pollution.**

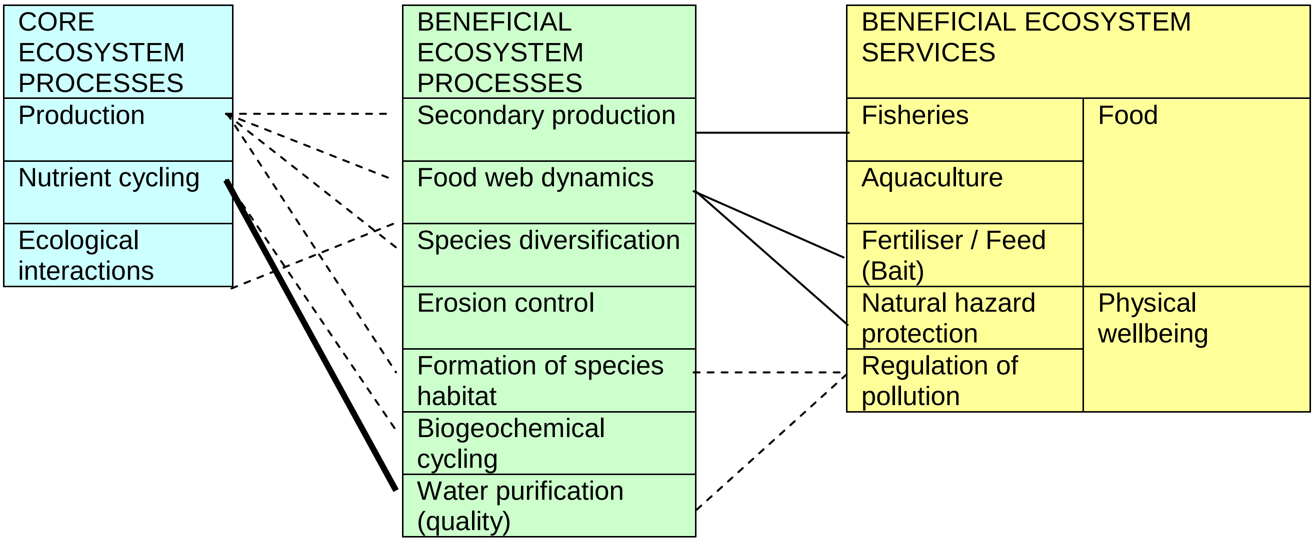

Figure 18 Marine ES Framework: Blue mussel beds (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Mytilus edulis (blue or common mussel) beds are composed of layers of living and dead mussels occurring at high densities, bound together by the byssus threads secreted by the mussels (OSPAR 2008). The three main components are a physical matrix of living and dead shells; a bottom layer of accumulated sediments, mussel faeces and pseudofaeces (suspended particles unsuitable for food which are expelled without having passed through the digestive system), organic detritus and shell debris; and an assemblage of associated flora and fauna (OSPAR 2008). On shores comprised of sediment (as opposed to rock), *Mytilus edulis* beds occur principally on mid and lower shore mixed substrata (mainly cobbles and pebbles on muddy sediments) but also on sands and muds (OSPAR 2008).

Review of Beneficial Ecosystem Processes

Biomass production: secondary

Although *Mytilus edulis* beds provide habitat for a diverse range of associated species (see species diversification below), the mussel species itself is responsible for most of the secondary production within the mussel bed community.

Food Web Dynamics

Mussel beds are an important food source for birds. For example, Nehls and Thiel (1993 cited in Tyler-Walters 2008) suggest that the removal or exploitation of mussel beds in the Wadden Sea may remove crucial food reserves for birds such as eider duck and oystercatchers whilst Holt and others (2008 cited in Tyler-Walters 2008) noted that low mussel numbers in the Dutch Wadden Sea in 1990 resulted in the death or migration of eider and oystercatchers seeking alternative prey.

Species diversification

Several studies conducted on sedimentary coasts of the North Sea have found that macrofaunal species richness is higher in *M. edulis* beds compared to surrounding sediment flats (Buschbaum and others 2009). Buschbaum and others (2009) examined mussel beds in four locations around the globe and concluded that whilst in general *M. edulis* beds enhance habitat heterogeneity and species diversity at an ecosystem level, their effects on associated species are site specific. For example, whilst *M. edulis* beds in the Wadden Sea (North Sea) had markedly higher species numbers and diversity compared to the surrounding sediment, this was not the case in mussel beds in other locations (e.g. southern Australia and the East China Sea). The spatial variation in species diversity associated with blue mussel beds is supported by results from Commito and others (2004) who found that *M. edulis* beds in Maine, USA, had significantly fewer macrofauna species in the mussel beds compared to surrounding bare sediment.

Erosion control

In general, mussel beds play an important role in the sediment dynamics of coastal systems as they collect sediment and are able to keep up with sea level rise (OSPAR 2008). For example, in *M. edulis* beds in Maine, USA, Commito and others (2004) found increased sediment deposition rates within the mussel beds compared to the surrounding soft-sediment substratum. Commito and others (2004) concluded that altered transport rates of sediment are important mechanisms by which mussels act as ecosystem engineers to modify soft-bottom habitats.

Formation of species habitat

In areas of soft sediment, *M. edulis* provide an area of hard substrata (Dittman 1990 cited in Hill and others 2010) and create biogenic structurally complex habitats that provide refuge for a range of flora and fauna not observed on surrounding sediments (e.g. Ragnarsson and Raffaelli 1999 cited in Hill and others 2010). Buschbaum and others (2009) describe how mussel beds, including *M. edulis* beds in the Wadden Sea (North Sea), generally enhance habitat heterogeneity and species diversity (see below) at the ecosystem level.

Biogeochemical Cycling and Water Purification

M. edulis are filter-feeders and hence increase the turnover of nutrients and organic carbon by transferring phytoplanktonic primary production in the water column to secondary production (Tyler-Walters 2008 and references therein). Bologna and others (2005) investigated the role of *Mytilus edulis* beds in the cycling of nutrients between the water column and bottom sediments in Barnegat Bay, USA. The authors calculated that the high density of *M. edulis* (175,000 individuals/m^2) that sometimes settled in eelgrass beds in the Bay, had maximum filtration rates of over 15m^3 water per m^2 per day, a filtration rate that significantly reduced the concentration of phytoplankton in the water column and which may in turn have impeded the development of the summer algae bloom which often occurred within the bay.

Review of Beneficial Ecosystem Services

Fisheries

Mussels are harvested for food, although British mussel production is relatively small, comprising only 5% of total European Community production. The commercial development of natural beds is hampered by sporadic and unpredictable recruitment (Edwards 1997 cited in Tyler-Walters 2008). Wild mussel fisheries are found in tidal flats of The Wash, Morecambe Bay, Lyme Bay, and Solway and Dornoch Firths in Scotland (Edwards 1997 cited in Tyler-Walters 2008).

Aquaculture

There has been a move away from exploitation of wild stocks to cultivation in Britain (Edwards 1997 cited in Tyler-Walters 2008). The west coast of Scotland in particular has developed a valuable mussel industry since the 1970s, producing over 1000 tonnes of mussels in 1991 (Edwards 1997 cited in Tyler-Walters 2008).

Fertiliser/Food

Mussels are harvested for bait (Edwards 1997 cited in Tyler-Walters 2008).

Others

It is thought that blue mussel beds provide some degree of natural hazard protection, through their role in erosion control and sediment dynamics. It is also thought that blue mussel beds have a role in the regulation of pollution through their role in nutrient cycling and water purification.

21 Cold Water Coral Reefs

Note: Since cold water coral reefs are found on the deep sea bed, please also see the Deep sea bed review (16). It may also be useful to examine the Coral Gardens review (22).

Summary

Figure 19 shows the relevant core ecosystem processes and beneficial ecosystem processes and services that have been identified for cold water coral reefs. **The main beneficial processes identified were secondary production, species diversification, formation of species habitat and physical barriers, and biogeochemical cycling. The only beneficial ecosystem service identified was fisheries.**

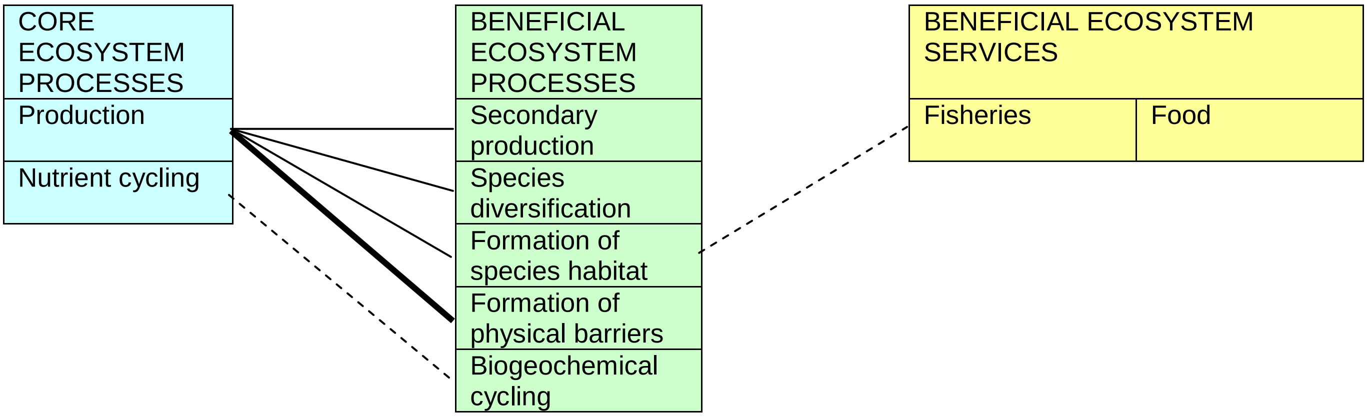

Figure 19 Marine ES Framework: Cold water coral reefs (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Cold water coral reefs include the reef-building deep water coral *Lophelia pertusa* and other coral species such as *Madrepora oculata* (Hill and others 2010). The majority of records of *L. pertusa* reefs occur in the north-east Atlantic within a depth range of 200 to over 2000m (UK Biodiversity Partnership 2010). *Lophelia* reef colonies are estimated to be several hundred years old. Some deep water *Lophellia* reefs have been estimated to be as much as 40,000 years old (Wilson 1979). Such cold water biogenic reefs are able to support over 1300 species, a number comparable in biodiversity to that of a tropical reef ecosystem (Roberts and others 2006).

Review of Beneficial Ecosystem Processes

Biomass Production: Secondary

The reef-forming coral *Madrepora oculata* often occurs amongst *L. pertusa* reefs which trap sediment and create carbonate-rich deposits to form isolated habitats of high benthic biomass (UK Biodiversity Partnership online).

Species diversification

The biological diversity of cold water coral reef communities can be three times as high as the surrounding soft sediment (UK Biodiversity Partnership 2010). For example, studies of the biodiversity of cold water coral reefs indicate increased megafaunal diversity occurs ‘on-reef’ compared to ‘off-reef’ (Jonsson and others 2004). Studies of species diversity within samples of reef habitat show high diversities associated with the coral framework (Jensen and Frederiksen 1992 cited in Roberts and others 2008). Roberts and others (2006) reported that over 1,300 species have been identified as being associated with *Lophelia pertusa* reefs in the north east Atlantic, whilst Van Soest and others (2007) found that the cold water reefs to the west of Ireland supported 191 species of sponge. Roberts and others (2008) compared diversity between different ‘macrohabitats’ (mud, sand, cobbles, coral rubble, coldwater coral framework and rock) on the Hatton Bank (part of the Rockall plateau) in the north-east Atlantic. Their results showed that diversity varied between the macrohabitats with the richest communities associated with the coral and rocky macrohabitats. Coral macrohabitats (both coral rubble and coral framework) were characterised by abundant suspension-feeding taxa.

Formation of species habitat

Similar to warm water coral reefs, cold water coral reefs create complex three dimensional structures providing space and refuge for a diverse community of organisms (Hill and others 2010 and references therein). Cold water *L. pertusa* reefs are thought to act as both breeding grounds for commercially targeted fish species and provide hunting territory for predatory demersal fish species (UK Biodiversity Partnership 2010).

Formation of physical barriers

Similar to warm water coral reefs, *Lophelia pertusa* reefs create structural habitats that alter local hydrology (Davies and others 2009 cited in Henry and others 2009). For example, on the Mingulay Reef Complex (MRC) of *Lophelia* reefs, located in the Sea of Hebrides off the west coast of Scotland, current speeds and turbidity are spatially structured (i.e. differ between the top and the base of the reef) due to the interplay between reef topography and local hydrography (Davies and others 2009 cited in Henry and others 2009).

Biogeochemical Cycling

Carbon and nutrient cycling processes in cold water coral reefs are less well understood compared to well studied tropical coral reef systems (Wild and others. 2009). Initial estimates indicate that cold-water coral reefs can be a regionally important contributor to the calcium carbonate budget and account for over 1% of the global calcium carbonate production (Lindberg and Mienert 2005 cited in Wehrmann and others 2009). Wehrmann and others (2009) showed that cold water coral reef ecosystems strongly influence biogeochemical processes in adjacent coral-bearing sediments. These authors concluded that organic carbon turnover in the two cold water reefs investigated (Rost and Traenadjupet reefs, on the mid-Norwegian shelf) occurred in the cold water coral reef surface framework (consisting of living and dead coral thickets and coral rubble) and in the underlying carbonate-rich, coral fragment-bearing sediments.

Review of Beneficial Ecosystem Services

Commercial fisheries

Although no functional relationships have been demonstrated to date, cold water *L. pertusa* reefs are presumed to act as breeding grounds for commercially targeted fish species and provide hunting territory for predatory demersal fish species (UK Biodiversity Partnership 2008) and hence, based on expert opinion, cold water reefs are considered likely to provide beneficial ecosystem services for commercial fisheries.

22 Coral Gardens

Note: It may also be useful to examine the Cold water coral review (21) and Deep sea bed (16).

Summary

Figure 20 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Processes and Services (Figure 1) that have been identified for coral gardens. **The beneficial ecosystem processes that were identified were species diversification and formation of species habitat. The beneficial ecosystem services identified were fisheries and ornamental materials.**

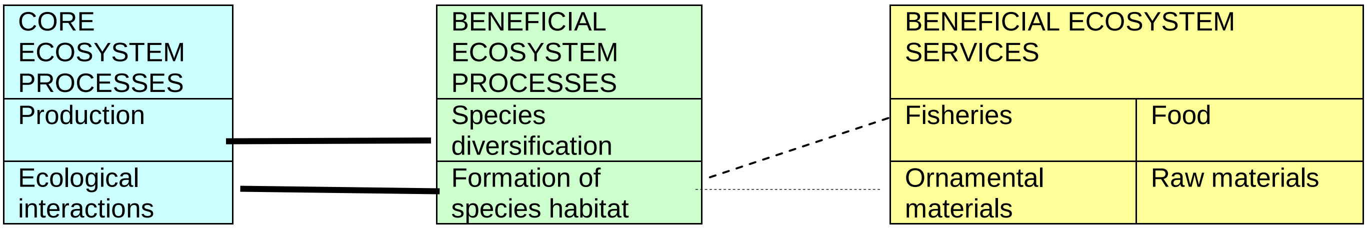

Figure 20 Marine ES Framework: Coral Gardens (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

A coral garden is a relatively dense aggregation of colonies or individuals of one or more coral species (OSPAR 2008). Coral gardens can occur on a wide range of soft and hard seabed substrata that tend to determine the species present. For example, soft-bottom coral gardens may be dominated by solitary scleractinians (stony corals), sea pens or certain types of bamboo corals, whereas hard-bottom coral gardens are often found to be dominated by gorgonians, stylasterids (lace corals or hydrocorals), and/or black corals (OSPAR 2008 and references therein). A precise description of the coral garden habitat as it occurs in relation to different substrates, depths and regions is yet to be developed (OSPAR 2008). However, OSPAR (2008) does state that the current habitat definition is distinct from deeper-water habitats where colonial stony reef building corals dominate.

Review of Beneficial Ecosystem Processes

Species diversification

The biological diversity of coral garden communities is typically high and often contains several species of coral, relatively large numbers of sponge species (OSPAR 2008) and other commonly associated fauna including basket stars (*Gorgonocephalus*), brittle stars, crinoids, molluscs, crustaceans and deep-water fish (Krieger and Wing 2002).

Formation of species habitat

Although coral gardens are understood to be distinct from deeper water coral habitats, some of the beneficial ecosystem processes from these latter habitats may also apply although there is a low level of confidence about whether they apply. Cold-water gorgonians are known to host several symbiotic species, underlining the importance of these corals as major habitat formers and providers (OSPAR 2008). Studies have also shown that deep water corals provide important refuge habitat for fish and invertebrates, including commercially targeted species. Stone (2006) reported that 85% of the economically important fish species observed in surveys of Aleutian Island (Alaska) cold water coral habitats (at depths between 27 and 363m depth) were associated with corals and other sedentary structure-providing invertebrates.

Review of Beneficial Ecosystem Services

Fisheries

Given the beneficial ecosystem services that deep-water corals provide for commercial fisheries, it is presumed that the same beneficial ecosystem services arise from shallower coral gardens. However, there is low confidence in this presumption.

Ornamental materials

It is known that many species of coral are traded worldwide and while the majority of these are shallow-water coral species from tropical regions, some species of cold water corals, including species included in this review, have been harvested for jewellery.

23 Estuarine Rocky Habitats

Note: Some occurrences of estuarine rocky habitats may also fall within the habitats of Intertidal rock (4), ‘Tideswept channels’ (40) and Intertidal underboulder communities (26) and hence information may overlap with these review sections.

Summary

Figure 21 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Processes and Services (Figure 1) that have been identified for estuarine rocky habitats. **The main beneficial ecosystem processes identified were the formation of species habitat and consequent support of species diversification. It is also assumed that estuarine rocky habitats form of physical barriers providing erosion control and form pleasant scenery. It is possible these habitats provide benefits to fisheries, natural hazard protection and nature watching**.

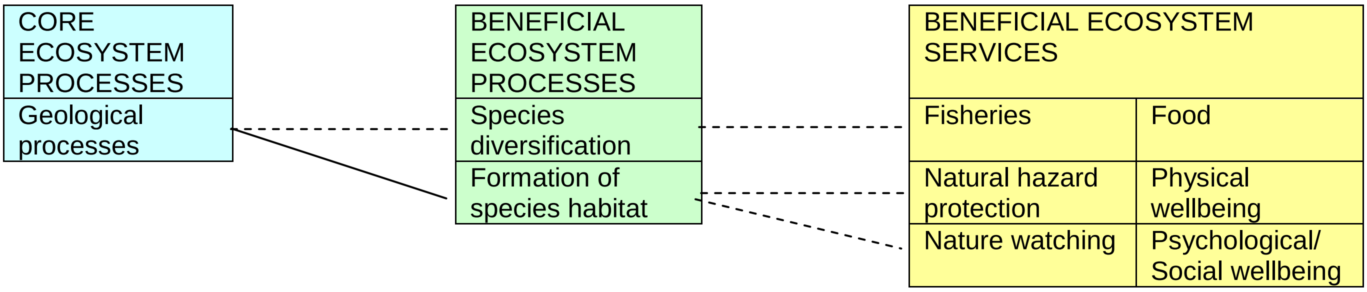

Figure 21 Marine ES Framework: Estuarine Rocky Habitats (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

This habitat encompasses rocky habitats in estuaries, extending from the supralittoral to the subtidal circalittoral. Estuarine rocky habitats incorporate substrata types such as bedrock and stable boulders. Generally rias, fjords and fjards are the most relevant types of inlet for rocky estuarine habitats (UK Biodiversity Partnership 2008). Rocky habitat is a comparatively uncommon feature in estuaries in the UK (UK Biodiversity Partnership 2008). Rocky habitats in estuaries are typically located in low wave energy environments with reduced salinity and experience accelerated tidal streams with increased turbidity and siltation (UK Biodiversity Partnership 2008).

Review of Beneficial Ecosystem Processes

Species Diversification

Rocky habitats in estuaries make a significant contribution to the overall diversity of estuaries by providing attachment for a wide range of algal species (Hill and others 2010). Subtidal rocky estuarine habitats are often subject to increased tidal streams and support a wide range of filter feeding encrusting organisms (Hill and others 2010). Estuarine rocky habitats are also an important component of the nursery grounds for fish which occur within the rich and sheltered waters of estuaries (UK Biodiversity Partnership 2008).

Formation of species habitat

The topography of estuarine rocky shores varies from flat and gently sloping to rugged reefs and large boulders, the latter of which provide many microhabitats (UK Biodiversity Partnership 2008).

Review of Beneficial Ecosystem Services

Although no direct evidence was available, it is likely that estuarine rocky habitats provide nursery grounds for commercial fish species. Estuarine rocky habitats are also likely to provide some degree of natural hazard protection through the formation of physical barriers and a likely role in erosion control. Finally, these locations attract people to undertake nature watching, including activities such as rock-pooling.

24 File Shell Beds

Summary

Figure 22 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Processes and Services (Figure 1) that have been identified for file shell beds. **The beneficial ecosystem processes identified were food web dynamics, provision of species habitat, species diversification, erosion control and biogeochemical cycling. The beneficial ecosystem services identified were fisheries and natural hazard protection.**

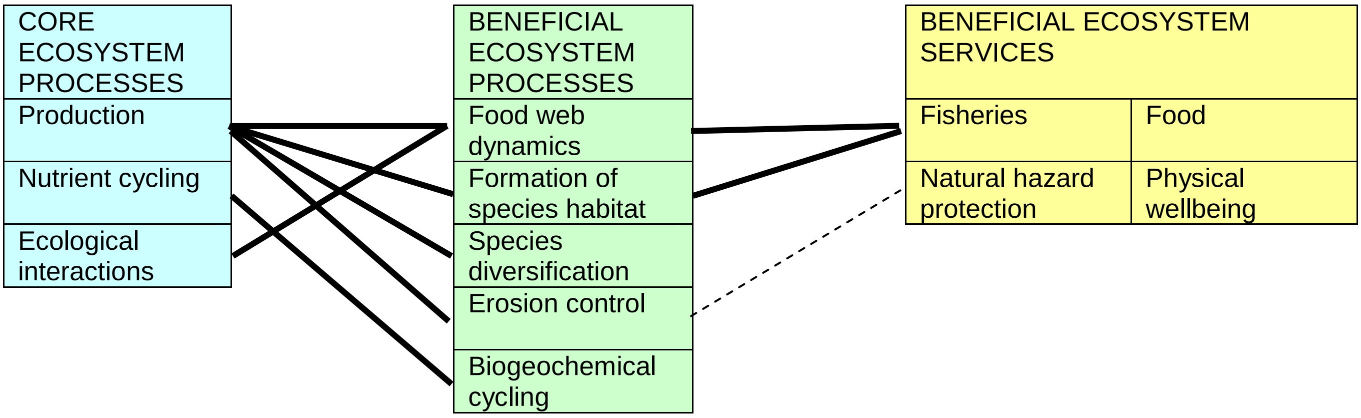

Figure 22 Marine ES Framework: File Shell beds (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

File shell beds are composed of only one species in the UK (*Limaria hians),* otherwise known as the gaping file shell or flame shell. File shells in the UK are found from low water to about a 100 m depth on coarse sand, gravel, broken shells and stones (Tyler-Walters 2008). File shells form 'nests' that are responsible for consolidation of sediments and provision of substratum for the attachment of a wide diversity of associated organisms. When undisturbed, file shell beds are very stable, and several beds are known to have existed for approximately 100 years. In some areas, such as tidal sea lochs, beds form continuous reefs standing 10-20 cm high and several hectares in extent (Hill and others 2010 and references therein). File shell beds are not necessarily classified as biogenic reefs (Holt and others 1998), and have not been considered as such in this review, although it has been argued that some file shell beds do fulfil all the criteria to qualify as biogenic reefs (Hall-Spencer and Moore 2000).

Review of Beneficial Ecosystem Processes

Food Web Dynamics

File shell beds support species with differing feeding strategies (detrivores, deposit feeders, scavengers and predators) and are likely to provide a locally important food source for predators such as crabs and some fish. Hall-Spencer and Moore (2000) reported juvenile cod feeding on *L. hians* reefs at Creag Gobhain, Loch Fyne. Hall-Spencer and Moore (2000) observed shoals of juvenile cod (*Gadus morhua)* feeding on the surface of *Limaria* reefs in Loch Fyne, Scotland. In summary, food webs dynamics are supported both by the structural presence of the shells themselves (i.e. production of shells) and by providing prey through ecological predator-prey interactions.

Formation of species habitat and species diversification

File shells can build extensive 'nests' made of shell, stones, debris and maerl (when present) interlaced by several hundred byssus threads and lined with mucus, mud and faeces (Hall-Spencer and Moore 2000).

Where there are dense populations of file shells the nests coalesce into a carpet or reef (Tyler-Walters 2008 and references therein). These nests provide substratum for the attachment of a wide diversity of invertebrates, and refuges for mobile animals, while the nests themselves support burrowing fauna and scavengers (Tyler-Walters 2008). For example, Hall-Spencer and Moore (2000) reported that six file shell nests in one site in Loch Fyne, Scotland supported 19 species of macroflora and 265 species of invertebrate macrofauna. File shell beds may also provide habitat for juveniles of commercially important fish species. For example, Minchin (1995) reported that file shell beds in Mulroy Bay, County Donegal provided substratum for kelp, which in turn provided cover for young cod (*Gadus morhua*) and saithe (*Pollachius virens*). When the reef was destroyed by Tributyl Tin (TBT) contamination, the kelp and juvenile fish were lost.

Other species characteristically found with file shell beds are hydroids (*Sertularia* spp.), small bivalves (*Mysella bidentata*), barnacles (*Balanus crenatus*), epifaunal animals such as brittlestars (*Ophiothrix fr*agilis), nudibranchs, amphipods (*Gammaropsis* spp.) and a range of scavenging and predatory invertebrates such as small crabs (*Pisidia longicornis*), polychaetes (e.g. *Lepidonotus* spp.) and echinoderms (*Asterias rubens, Antedon bifida*) (Minchin 1995; Trigg and Moore, 2009). In some areas, consolidation of the sediment by file shell beds creates substratum for holdfasts of algal kelp species such as *Laminaria digitata* which are unable to anchor otherwise (Hall-Spencer and Moore 2000). The habitat is often shared with the maerl species *Lithothamnion glaciale* and *Phymatolithon calcareum*.

Erosion control

When file shells beds combine, the resulting carpet of nests covers and hence stabilizes the substratum. Minchin (1995) noted that when populations of *Limaria hians* declined in Mulroy Bay, County Donegal due to TBT contamination, the loss of the extensive byssal ‘carpet’ and associated kelp cover led to destabilization of the sediment and marked reductions in the abundance of non-mobile organisms living on, in or near the seabed.

Biogeochemical cycling

Dame (1996 cited in Tyler-Walters 2008) suggested that dense beds of bivalve suspension feeders increase the turnover of nutrients and organic carbon in estuarine (and presumably coastal) environments by effectively transferring pelagic phytoplanktonic primary production to secondary production in the sediments (pelagic-benthic coupling).

Review of Beneficial Ecosystem Services

Fisheries

File shell beds play a role in supporting commercial fisheries through providing a habitat and food source for juveniles of fishery species (e.g. Minchin 1995 and Hall-Spencer and Moore 2000).

Natural hazard protection

It is possible that the physical character of the file shell beds produce some level of natural hazard protection through reducing wave energy reaching coastal areas.

25 Fragile sponge and anthozoan communities on subtidal rocky habitats

Summary

Figure 23 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Processes and Services that have been identified for fragile sponge and anthozoan communities including the pink sea fan *Eunicella verrucosa,* Tall sea pen *Funiculina quadrangularis* and the sea fan anemone *Amphianthus dohrnii* which are component species of this habitat. **Beneficial ecosystem processes identified for the habitat were species diversification, formation of species habitat and food web dynamics. Beneficial ecosystem services identified were other wild harvesting and nature watching.** Many of these benefits could be directly attributed to *E. verrucosa*, however no such evidence was found for the Sea fan anemone *Amphianthus dohrnii.*

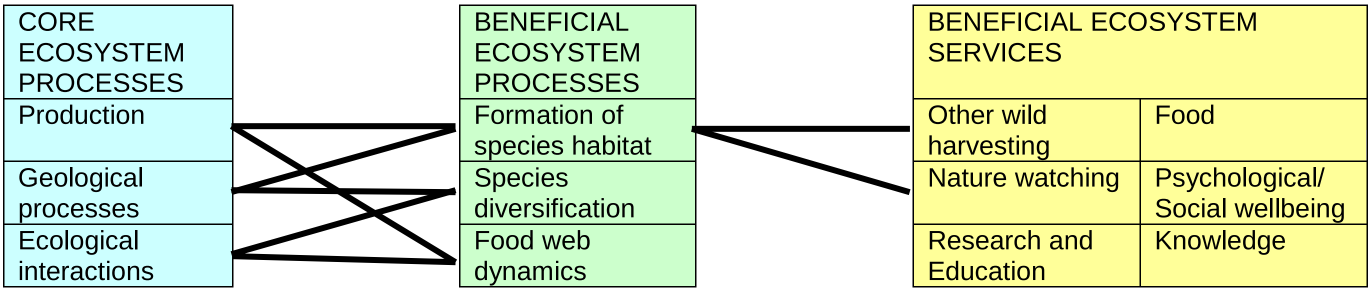

Figure 23 Marine ES Framework: Fragile sponge and anthozoan communities (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Areas of bedrock that are close to, but locally sheltered from, tide-swept or wave exposed areas are often dominated by large, slow growing animals, in particular branching sponges and seafans. A good supply of particulate material means these habitats are dominated by filter and suspension feeding organisms although the actual species present are likely to vary depending on the geographical location (Hill and others 2010). This habitat includes *Eunicella verrucosa* (Pink sea fan) and *Amphianthus dohrnii* (sea fan anemone), both features of conservation importance which are described below, as well as other species of hard coral such as the cup corals *Caryphyllia smithii* and *Leptopsammia pruvoti*. In addition, *A. dornhii* is nationally rare and a priority species under the UK BAP (Jackson 2008).

Review of Beneficial Ecosystem Processes

Species diversification and Formation of species habitat

Branching sponges of the genus *Axinella* are characteristic of this habitat and other sponge species such as *Cliona celata* may also be present (Connor and others 2004). The most common seafan species are *Eunicella verrucosa* and *Swiftia pallida* and other anthozoans such as *Alcyonium digitatum* and *Caryophyllia smithii* are also likely to be present. A species rich understory may develop, typically consisting of the hydroids *Nemertesia* spp., erect bryozoans including *Bugula* spp., *Pentapora foliacea* and *Alcyonidium diaphanum* and colonial ascidians such as *Clavelina lepadiformis* (Fish and Fish 1996).

Many of the species that characterise these communities add considerable physical complexity to the habitat. Three species, the Pink sea fan *Eunicella verrucosa*, the bryozoan *Pentapora fascialis* and the sponge *Axinella dissimilis,* contribute significantly to the physical structure and complexity of the habitat (Jackson and Hiscock 2008). The Northern sea fan *S. pallida*, which is found in this habitat in Scottish waters, provides habitat for the sea fan anemone *A. dohrnii* (Jackson, 2008). *A. dohrnii* is a small anemone found in sublittoral habitats below 15 m, where it attaches to the branches of the seafan species *E. verrucosa* (in England) and *S. pallida* (in Scotland) and other 'tubular' organisms such as *Tubularia indivisa* (Hill and others 2010; Jackson 2008).

In general, gorgonians are important habitat-forming species. Decreases in the average size of populations (e.g. through pathogen-related or thermal stress-related mortalities) may negatively affect habitat complexity, which may in turn have significant affects on local biodiversity (Cerrano and Bavestrello 2008 and references therein).

The Pink sea fan *Eunicella verrucosa* is a branching gorgonian (sea fan) found in subtidal areas where it can attach to bedrock, large boulders and artificial substrata and also to rocky outcrops associated with coarse sediment. It is most commonly found at depths of 10-100m, although it has been observed at shallower depths. *E. verrucosa* is nationally scarce and a priority species under the UK BAP (Hill and others 2010 and references therein). *E. verrucosa* increases habitat complexity, and provides an important habitat for a number of species which are found only on, or particularly in association with the Pink sea fan – these species are the sea fan anemone (*Amphianthus dohrnii)*, the sea slug (*Tritonia nilsodhneri)*, the 'poached egg shell' (*Simnia patula)*, and in recent years, the warm-water barnacle (*Solidobalanus fallax)*. Other species, including barnacles, bryozoans (sea mats) and ascidians (sea squirts) colonise damaged or partially dead sea fans (Hiscock and others 2006). A number of species use the habitat provided by *E. verrucosa* to attach their eggs, including the sea slug dogfish and cuttlefish (Hill and others 2010 and references therein).

Food web dynamics

The erect sponges *E. verrucosa* and *P. fascialis* which are found on slightly tide swept, moderately exposed circalittoral rock may have some importance for mobile predators and scavengers such as fish and crabs (Jackson and Hiscock 2008).

Review of Beneficial Ecosystem Services

Other wild harvesting

The sea urchin (*Echinus esculentus)* which may be associated with this habitat (and subtidal rock also) may be subject to exploitation for local consumption (of its roe) and the curio trade (Jackson and Hiscock 2008).

Tourism/Recreation/Nature watching

Species such as *E. verrucosa* attract divers to areas where they are found, such as Lyme Bay and Lundy (Rees and others 2010).

Research/Education

The Pink sea fan *E. v*errucosa has been the subject of research, relating to the impacts of fishing gear (for example the impacts of scallop dredging in Lyme Bay; impacts of static fishing gears (Eno and others 2001)) and the subject of both in situ and laboratory observations to examine the nature of a disease which has been observed to be affecting populations off Lundy Island in Devon (Hall-Spencer and others 2007). Institutions such as The Zoological Society of London (ZSL) and the National Marine Aquarium have undertaken research on the Pink sea fan. For example, the ZSL has conducted research into the captive breeding (i.e. the successful spawning, fertilisation and settlement of coral polyps) of pink sea fans to open up the possibility of re-stocking reefs with juvenile colonies as a potential conservation management strategy for this species (ZSL online). These institutions also highlight such projects to the public to increase awareness and understanding of this species. Several conservation organisations, including the Wildlife Trusts and the Marine Conservation Society, co-ordinate surveys (for example Seasearch) using volunteer divers to monitor the health of known populations of pink sea fans, and run marine awareness programmes to educate the public about such species (Tinsley 2005).

26 Intertidal underboulder communities

Summary

Figure 24 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Processes and Services (Figure 1) that have been identified from intertidal underboulder communities. **The main beneficial ecosystem processes identified were the formation of species habitat, species diversification, larval/gamete supply, the formation of physical barriers and erosion control. Beneficial ecosystem services identified were wild harvesting, and nature watching**.

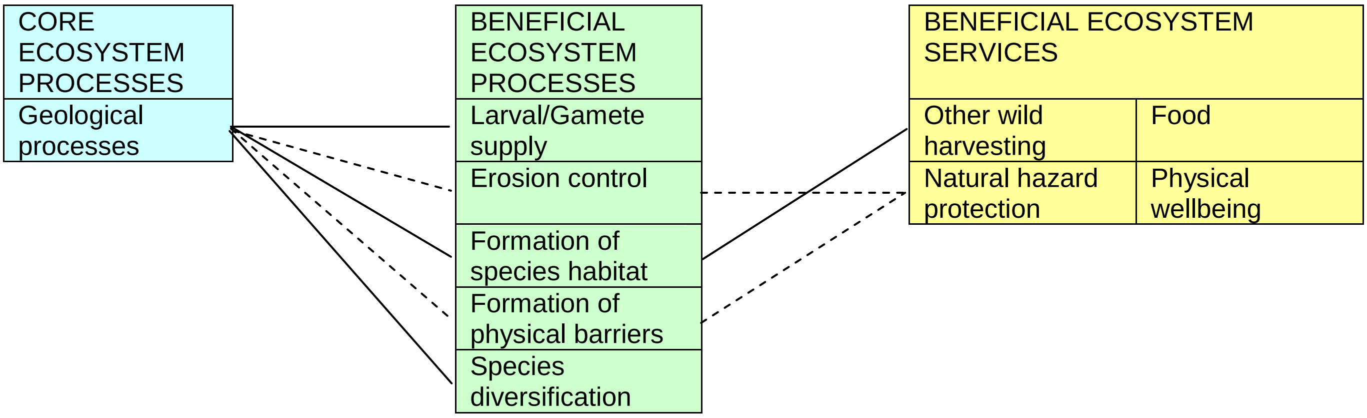

Figure 24 Marine ES Framework: Intertidal underboulder communities (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

This habitat is found from the mid-shore down to the extreme lower shore on moderately exposed to sheltered boulder shores, and encompasses areas of boulders (greater than 256 mm diameter) that support a diverse underboulder community (UK Biodiversity Partnership 2008). This habitat can occur on a variety of substrata (including bedrock, mixed rock and sediment or mud), but there needs to be a sufficient gap on the underside of the boulder to support an under-boulder community (UK Biodiversity Partnership 2008). Underboulder communities are entirely different from those communities present on the tops and sides of boulders (Hiscock 2000).

Review of Beneficial Ecosystem Processes

Formation of species habitat and consequent species diversification

The underboulder habitat, along with fissures, crevices and any interstitial spaces between adjacent boulders, forms a series of microhabitats that add greatly to the biodiversity of a shore. As the underboulder habitat provides shade, moisture and shelter it can sustain a diverse collection of animals which require these conditions to survive in an otherwise hostile environment, including a wide range of encrusting species that are not found on exposed surfaces (Hill and others 2010). In general the lower surfaces of boulders are dominated by sponges, bryozoans (seamats) and ascidians (sea squirts) (Motta and others 2003 cited in McArthur and others 2009). The richest underboulder communities develop in wave sheltered locations on stable boulders where the downward facing surfaces are clear of sediment and there is flowing water present, such as Strangford Lough and Menai Strait (Hiscock 2000). Underboulder areas may be important refuge areas for young crabs and juvenile lobsters and at low tide. This habitat also provides shelter from predators for species which are not an integral part of the underboulder community e.g. blennies (Hiscock 2000 and references therein). Le Hir and Hily (2003) showed that two microhabitats within the intertidal boulder fields of western Brittany, France (specifically sheltered cavities within piles of boulders and sheltered sediment protected by surrounding overhanging boulders) had the highest number of species and the greatest diversity.

Larval/gamete supply

Certain species such as gastropods (sea snails and sea slugs), fish and dog whelks, use the sheltered undersides of boulders to deposit egg masses, making this habitat important in reproduction and larval recruitment (Przeslawski and Davis 2007 cited in McArthur and others 2009).

Formation of physical barriers and consequent erosion control

The presence of boulders in the intertidal area can lead to local modification to wave exposure, current strength and levels of trapped organic matter in the areas surrounding the boulders (UK Biodiversity Partnership 2010). For example Motta and others (2003 cited in McArthur and others 2009) showed that sediments underneath boulders in intertidal boulder fields in New South Wales, Australia were affected by complex hydrodynamic conditions and incorporated a high percentage of organic matter, even in relatively coarse sediments such as gravel, where levels of organic material are often relatively low. Such alteration of the physical environment can result in an enhancement to the immediate biodiversity beyond the boulders themselves (UK Biodiversity Partnership 2010).

Review of Beneficial Ecosystem Services

Other wild harvesting

Boulder turning is undertaken by anglers for the collection of bait, mainly 'peeler' crabs (soft crabs which have moulted their shells) and shrimps. At a study site in the Mumbles Head, Swansea it was found that up to 90% of boulders along a transect could be overturned during a two week period and that some boulders may be turned 40-60 times during the summer (Sewell and Hiscock 2005 and references therein). In nearby locations (Mumbles and Oxwich) it was found that during periods of low tides at two study sites, 3,000 rocks were overturned (Sewell and Hiscock 2005 and references therein). Boulders are also turned for the collection of periwinkles for human consumption (UK Biodiversity Partnership 2010). In some parts of the UK, where large numbers of people may have relatively easy access to this habitat, these activities are considered to pose a threat to the under boulder communities if boulders are not replaced to their original position (Sewell and Hiscock 2005; UK Biodiversity Partnership 2010).

Others

Although there was no written evidence for these beneficial ecosystem services, it is known that intertidal underboulder communities are used for education, research, and nature watching. These activities take place in coastal areas with relatively easy access to the shore and generally involve overturning boulders to view the flora/fauna which lives underneath. Many organisations, such as the Wildlife Trusts and the Marine Life Information Network (MarLIN), co-ordinate such activities for educational and research purposes for schools, community groups and tourists. It is also likely that intertidal boulders provide some degree of natural hazard protection through the formation of physical barriers and erosion control.

27 Littoral chalk communities

Note: there is some overlap between this review and those of Intertidal rock (4) and Intertidal underboulder communities (26).

Summary

Figure 25 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Processes and Services (Figure 1) that have been identified from Littoral chalk communities. **The only beneficial ecosystem processes identified were species diversification and formation of species habitat. No evidence of beneficial ecosystem services was identified from the review literature.**

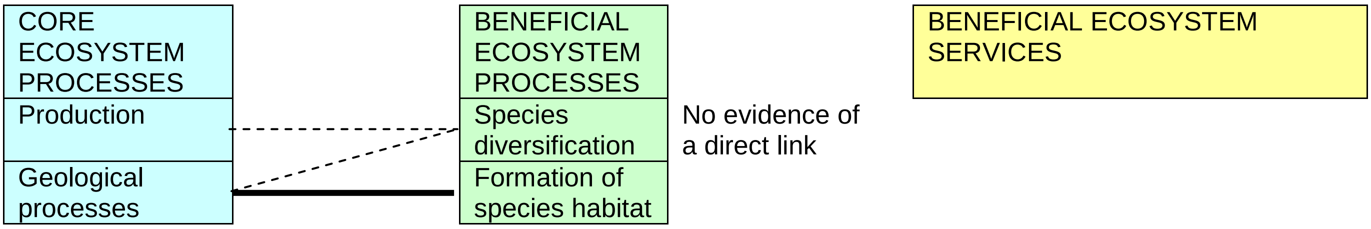

Figure 25 Marine ES Framework: Littoral chalk communities (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

The erosion of chalk exposures on the coast results in the formation of vertical cliffs and gently-sloping intertidal platforms that support a range of micro-habitats of biological importance and unique faunal communities (OSPAR 2008). Such coastal exposures of chalk are rare in Europe, with those occurring on the southern and eastern coasts of England accounting for the greatest proportion (57%) (OSPAR 2008). Littoral chalk communities are a UKBAP Priority Habitat, are on the OSPAR List of Threatened and/or Declining Species and Habitats, and Annex I of the Habitats Directive listed as submerged or partially submerged caves and reefs (Natural England, online).

Review of Beneficial Ecosystem Processes

Species diversification

Intertidal chalk shores, because of the porous nature of the substratum, support highly specialised communities that are not found in other habitats (Fowler and Tittley 1993), in particular benthic stages of certain planktonic algae. Species include *Apistonema* spp., *Pleurochrysis carterae, Chrysotila lamellosa* and *Thallochrysis litoralis*. The lower intertidal fringe may be characterised by a dense mat of green algae *Ulva* spp. (OSPAR 2008). Characteristic species in the littoral zone include the boring polychaete *Polydora ciliata* and several mobile species typical of UK rocky shores including *Littorina littorea*, *Gibbula cineraria*, *Porcellana platycheles* and *Patella* spp. (Connor and others 2004; Pinn and others 2008; George and Fincham 1989).

Formation of species habitat

Further down the shore, the rock-boring behaviour of piddocks, in particular *Pholas dactylus*, increases the topical complexity of the chalk thereby increasing species diversity (Pinn and others 2008).

Review of Beneficial Ecosystem Services

No direct beneficial ecosystem services were identified from any source.

28 Maerl beds

Note: This review includes the species Common maerl (*Phymatolithon calcareum*), Coral maerl (*Lithothamnion coralliodes*), Grateloup's little-lobed weed (*Grateloupia montagnei*) and Burgundy maerl paint weed (*Cruoria cruoreaeformis*).

Summary

Figure 26 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Services and Benefits (Figure 1) that have been identified for maerl beds. **The main beneficial ecosystem process were primary and secondary production, food web dynamics, species diversification, formation of species habitat, larval/gamete supply and biogeochemical cycling. Beneficial ecosystem services identified were fisheries, fertiliser/feed and ornamental materials. No evidence for beneficial processes or services for the red algae species *Dermocorynus montagnei* and *Cruoria cruoreaeformis,* which are strongly associated with maerl beds, was found**.

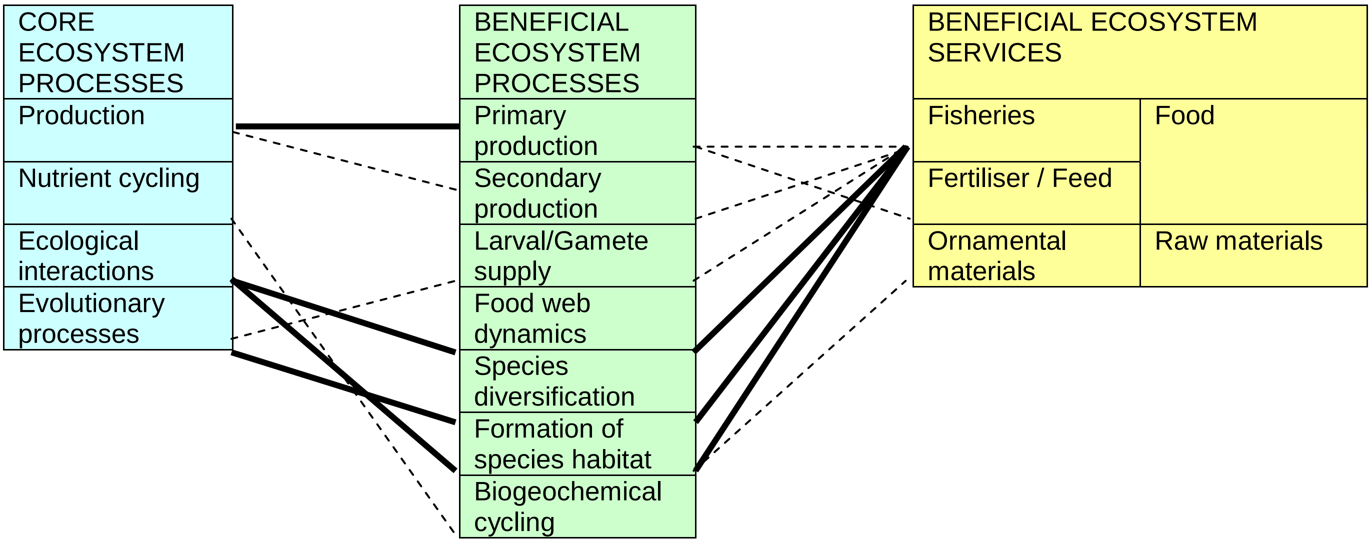

Figure 26 Marine ES Framework: Maerl beds including the features of conservation importance Phymatolithon calcareum and Lithothamnion corallioides. (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Maerl is the collective term for several species of calcified red seaweed, which in their free living form and under favourable conditions can create extensive maerl beds. Maerl beds are often formed in association with sand and gravel and can constitute both live and dead maerl thalli (Kamenos and others 2003). Maerl habitats exhibit a high heterogeneity compared to the surrounding substrata (Hall-Spencer and others 2003; Kamenos and others 2003). Maerl beds typically develop where there is some tidal flow and are found off the southern and western coasts of the British Isles, but are particularly well developed around the Scottish islands and in sea loch narrows, around Orkney, and in the south in the Fal Estuary.

There are at present three main species of coralline algae known to occur free-living in the waters around the UK, with a least a further six species known to contribute to deposits in certain areas. This review includes the four features of conservation importance *Phymatolithon calcareum*, *Lithothamnion corallioides, Dermocorynus montagnei and Cruoria cruoreaeformis* which are described further below:

P. calcareum is a non-jointed coralline red algae. It can occur attached to pebbles and other substrata in its crustose form, or as free-living rhodoliths which form maerl beds (Hill and others, 2010 and references therein). *L. corallioides* is a non-jointed coralline red algae known to exist in two forms; a crustose form that attaches to substrata such as pebbles, and as free-living rhodoliths, which can form extensive maerl beds.

In the UK *L. corallioides* is predominantly found in its free-living form (Hill and others 2010 and references therein). *Grateloupia montagnei* is an encrusting red algae found exclusively on small (5-10 mm) mobile pebbles and fragments of maerl in subtidal, shallow inlets and bays. *D. montagnei* is strongly associated with maerl beds and is often attached to maerl fragments and is considered rare (Hill and others 2010 and references therein). *C. cruoreaeformis* is an encrusting alga that forms crusts about 200 µm thick on live maerl and live crusts are bright red and appear velvety in texture. It is classified as rare (although it can be locally abundant in suitable habitats) and has only been recorded from maerl beds in the UK and, less frequently from gravel beds elsewhere (Hill and others 2010 and references therein).

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

Martin and others (2006) estimate the net primary production of natural *L. corallioides* populations in shallow waters of the Bay of Brest (France) to be 10–600 grams of carbon per square metre per year.

Biomass Production: Secondary

Maerl beds in the Mediterranean are generally known to increase local biomass and secondary production (Ordines and others 2009). Bordehore and others (2003) reported that well preserved Mediterranean maerl grounds support high macrobenthic secondary production.

Food Web Dynamics

Grall and others (2006) identified that the major primary food sources in maerl beds in the Bay of Brest, France originated from micro and macro algae growing on the maerl thalli together with sedimentary particulate organic matter originating from the water column. The maerl community was characterised by the co-existence of a large number of feeding strategies (including filter feeders, deposit feeders, micrograzers and macroalgae grazers), a strong overlap in food sources, and a high degree of complexity of the food web. From primary producers to predators, the benthic food web of maerl covered more than three trophic levels. The structural complexity of live maerl beds enhances the array of prey items available for predators such as juvenile fish. For example, Kamenos and others (2004b) concluded that juvenile cod and other gadoids were using maerls beds in Scotland as nursery areas sustained, in part, by the abundant food biomass of the live maerl matrix.

Formation of Species habitat

The three-dimensional structure of maerl forms complex and heterogeneous habitats which provide a wide range of niches for infaunal and epifaunal organisms which increase the habitat complexity further (Hall-Spencer and others 2003; Bordehore and others 2003; Ordines and others 2009). Maerl grounds in Scotland have been found to act as nursery areas, providing refuge and supporting higher juvenile densities and survival rates than surrounding habitats, for several invertebrate and vertebrate species including commercially targeted species such as queen scallop (*Aequipecten opercularis*, Kamenos and others 2004b) and gadoids (Kamenos and others 2004a).

Species Diversification

Due to its structural complexity and longevity, pristine live maerls grounds are highly biodiverse (Kamenos and others 2004c and references therein; Hall-Spencer and others 2003). For example, Sciberras and others (2009) recorded a total of 331 species (244 macroinvertebrates and 87 algae) in Maltese (Mediterranean) maerl beds whilst Grall and others (2006) identified 183 macrofaunal species from 15 grab samples taken from a maerl bed in the Bay of Brest, France.

Larval/Gamete supply

Maerl habitats in Europe provide brood-stock areas for bivalves and can enhance the recruitment of juvenile scallops (Thouzeau and Lehay 1988 cited in Hall-Spencer and others 2003). Juvenile *Aequipecten opercularis* are attracted to pristine live maerl by a series of chemical and physical cues and it is likely that the higher post-settlement recruitment (settlement out of the water column and recruitment to the adult population) to pristine live maerl, compared to gravel and rock substrata, is attributable to this stimulus (Kamenos and others 2004).

Biogeochemical (Nutrient) Recycling

Maerl beds act as active traps for sestonic particles (particulate matter suspended in the water column comprising of organic and/or inorganic material) and are sites of high organic matter remineralisation (Martin and others 2006).

Review of Beneficial Ecosystem Services

Fisheries

Northern European maerl beds typically occur in shallow waters (< 32m) with high rates of water exchange, conditions which support the growth of an abundance of epifaunal and infaunal bivalves including scallops (*Aequipecten* spp., *Pecten* spp.), razor clams (*Ensis* spp.) and clams (*Dosinia* spp., *Tapes* spp.) making these maerl habitats attractive to fishers. Pristine live maerl beds have been shown to act as nursery areas for commercial populations of queen scallops (*Aequipecten opercularis*) and other invertebrates such as the soft clam *Mya arenaria* during the phase in their life history between settlement and recruitment to the adult population (Kamenos and others 2004) and to provide structurally complex feeding areas for commercially important juvenile fish species such as Atlantic cod (*Gadus morhua*) (Hall-Spencer and others 2003; Kamenos and others 2004a).

The habitat complexity and emergent biota of maerl beds has been shown to significantly reduce mortality in juvenile Atlantic cod (Lindholm and others 1999 cited in Hall-Spencer and others 2003). Hence degradation of maerl habitat would be expected to damage commercial fisheries (Kamenos and others 2004c). Comparison of the population densities of the scallop species *A. opercularis* and *P. maximus* between maerl beds with different fishing histories (an unfished site where towed demersal gear had been banned since 1968 and a fished site with a forty year history of scallop dredging) showed that the densities of both scallop species were higher at the unfished site, where mature individuals of *P. maximus* predominated, whilst at the fished site no individuals of *P. maximus* aged over seven years were observed and *A. opercularis* was absent (Hall-Spencer and Moore 2000).

Fertiliser

Maerl is dredged industrially as a source of soil conditioner and as an organic alternative to lime. (Grall and Hall-Spencer 2003 cited in Kamenos and others 2004c)

Ornamental materials

Although there is no written evidence, it is known that Maerl is collected and used for ornamental purposes.

29 Horse mussel beds

Note: Horse mussel (*Modiolus modiolus*) beds can form 'reef' structures, referred to as biogenic reefs. The beneficial ecosystem processes and services provided by biogenic reefs in general are considered elsewhere in this document (reviews 10 and 15).

Summary

Figure 27 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Processes and Services that have been identified from Horse mussel beds. **The beneficial ecosystem processes identified were secondary production, food web dynamics, species diversification and formation of species habitat. Beneficial ecosystem services identified were fisheries, medicine and research and education**.

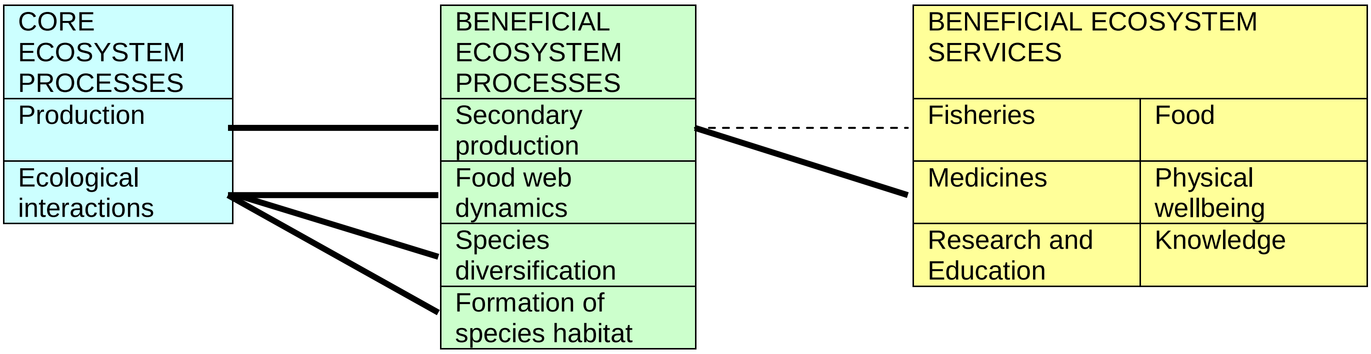

Figure 27 Marine ES Framework: Horse mussel Modiolus modiolus reefs (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

The horse mussel *Modiolus modiolus* forms dense beds, at depths up to 70m (but which may extend onto the lower shore), mostly in fully saline conditions and often in tide swept areas (OSPAR 2008). Although *M. modiolus* is a widespread and common species, horse mussel beds are more limited in their distribution, which ranges from the seas around Scandinavia and Iceland south to the Bay of Biscay (OSPAR 2008). In the United Kingdom, horse mussel beds are located along the southwest peninsular coast and the Irish Sea.

Review of Beneficial Ecosystem Processes

Biomass Production: Secondary

Wildish and Fader (1998 cited in Tyler-Walters 2007) reported that in the Bay of Fundy, horse mussel beds were able to feed on phytoplankton down to about 100m in depth and made a significant contribution to secondary benthic productivity.

Food web dynamics and Biogeochemical cycling

M. modiolus beds are highly productive and in high densities the suspension feeding of *M. modiolus* can remove and store large amounts of suspended material. *M. modiolus* beds play an important ecological role in energy transfer, from pelagic to benthic systems and between trophic levels within the reef itself (Navarro and Thompson 1996). The infaunal community that includes polychaete worms (e.g. *Lepidonotus squamata*) and small bivalves such as *Mysella bidentata* and *Nucula* spp. (Rees and others 2008) also plays an important role in the transfer of energy between trophic levels through feeding on the energy rich faeces and pseudofaeces produced by *M. modiolus* (Navarro and Thompson 1996).

Species diversification

Communities associated with *Modiolus modiolus* beds are diverse with a rich community of free living and sessile epifauna and predators and a rich and diverse community which seeks shelter in the crevices between the *Modiolus* shells and byssus threads and flourishes on its rich sediments (OSPAR 2008). The epifauna are dominated by a wide diversity of suspension feeding animals such as sponges (for example *Halichondria panace*a), hydroids (such as *Sertularia* spp.), bryozoans (seamats) and ophiuroids (brittlestars) (in particular the common brittlestar *Ophiothrix fragilis*) that also contribute to energy cycling (Witman 1980; Sanderson and others 2008; Comely 1978). Other associated fauna include hydroids, red seaweeds, solitary ascidians and bivalves such as *Aequipecten opercularis* (Queen scallop) and *Chlamys varia* (Variegated scallop) (OSPAR 2008). Brown and Seed (1977) recorded 90 invertebrate taxa associated with *Modiolus* clumps in Strangford Lough, with most of the major groups well represented. OSPAR (2008 and references therein) found 270 invertebrate taxa associated with *Modiolus modiolus* reef areas to the north east of the Isle of Man, and suggested that this was likely to be an underestimate, particularly in terms of sponges and infauna. Because of the abundant epifauna and infauna, *M. modiolus* beds have been considered to support one of the most diverse sublittoral communities in north-west Europe (Holt and others 1998).

Formation of species habitat

M. modiolus beds are found on a range of substrata, from cobbles through to muddy gravels and sands, where they tend to have a stabilising effect, due to the production of byssal threads (OSPAR 2008). Both living and dead *Modiolus modiolus* shells form the physical structure of the Horse mussel beds in single or multiple layers. The resulting reefs support a wide range of epifaunal and infaunal organisms as described above; Witman (1980) for example observed eight times as much organism biomass inside *Modiolus modiolus* beds compared to outside.

Review of Beneficial Ecosystem Services

Fisheries

The possible role of *M. modiolus* reef communities in providing a nursery refuge for commercial fisheries and shellfisheries species is occasionally mentioned in the literature but does not appear to have been investigated. Dense growths of bushy hydroids and bryozoans could conceivably provide an important settling area for spat of bivalves such as the scallops *Pecten maximus* and *Aequipecten opercularis*, adults of which are often abundant in nearby areas (OSPAR 2008). It has also been stated that it is likely that young Atlantic cod (*Gadus morhua*) utilise structurally complex habitats including *M. modiolus* beds for food and refuge (Hiscock and others 2006.

In The Wash, several thousand tonnes of *M. modiolus* are commercially dredged annually for consumption and for angling bait (Holt and others 1998), although British mussel production is relatively small comprising only 5% of total European production (Tyler-Walters 2008 and references therein). The commercial development of natural mussel beds is hampered by sporadic and unpredictable recruitment, although wild mussel fisheries are found in tidal flats of The Wash, Morecambe Bay, Solway and Dornoch Firths in Scotland (Tyler-Walters 2008 and references therein).

Medicine and research

Haug and others (2004) identified antibacterial activity in *M. modiolus* and concluded that *M. modiolus* was a promising source for identifying novel drug compounds.

30 Mud habitats in deep water

Note: This habitat may be considered to overlap with two broad scale habitats: Subtidal sediment (13) and Deep-sea bed (16), both of which are assessed separately in this review. However, evidence of beneficial ecosystem processes and services relating to this specific habitat of conservation importance is included below.

Summary

Figure 28 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Processes and Services (Figure 1) that have been identified from mud habitats in deep water. **The beneficial ecosystem processes identified were food web dynamics, species diversification, waste assimilation, formation of species habitat, biogeochemical cycling, and climate regulation. The beneficial ecosystem services identified were fisheries and environmental resilience.**

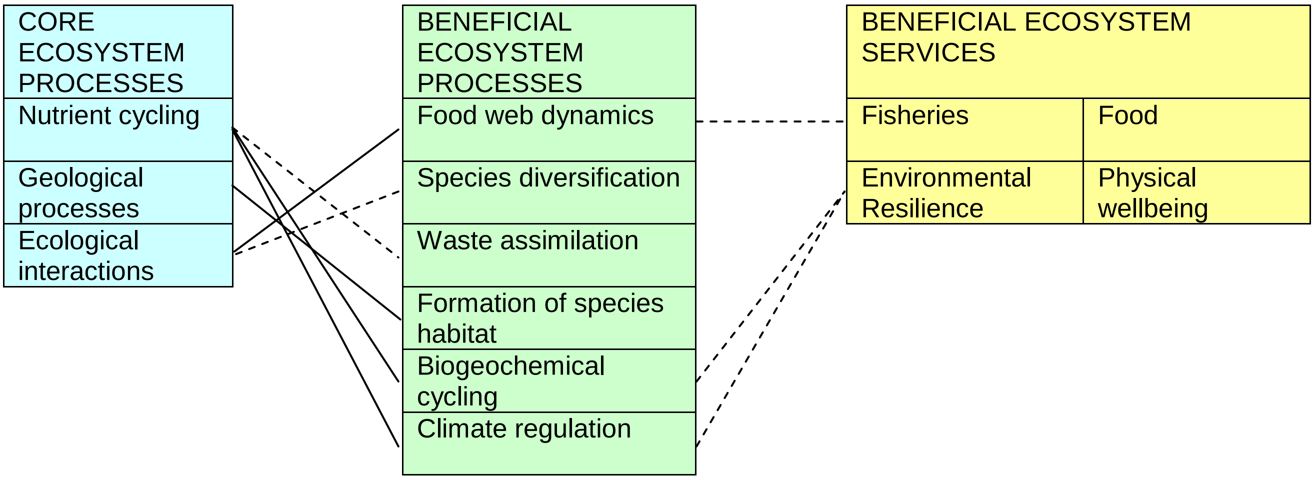

Figure 28 Marine ES Framework: Mud habitats in deep water (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Mud habitats in deep water (circalittoral muds) occur below 20-30m in many areas of the UK's marine environment, including marine inlets such as sea lochs (UK Biodiversity Partnership 2010). The relatively stable conditions associated with deep mud habitats often lead to the establishment of communities of burrowing crustaceans such as *Nephrops norvegicus* (Norway lobster) and can also support seapen populations. However, the ecosystem processes and services provided specifically by such 'seapen and burrowing megafaunal communities' are reviewed separately within this document (32).

Review of Beneficial Ecosystem Processes

Species diversification

Due to their depth and low-energy hydrographic regime, deep water mud habitats are very stable and often highly diverse (Hiscock and Marshall 2006). Fauna associated with these habitats include seapens and burrowing crustaceans (reviewed separately), scavengers such as the starfish (*Asterias rubens)*, hermit crab (*Pagurus bernhardus)* and the harbour crab (*Liocarcinus depurator)* and infaunal polchaetes and bivalves (UK Biodiversity Partnership 2010). In general, evidence suggests that the diversity of soft sediments increases from shallow areas to the deep sea (Paramour and Frid 2006 and references therein).

Formation of species habitat

The presence of benthic invertebrates increases habitat complexity through the creation of tubes and burrows (Paramour and Frid 2006 and references therein).

Biogeochemical cycling

The recycling of energy and nutrients in marine systems is performed mainly by microoganisms. In benthic habitats, the activities of microorganisms are enhanced by macroinvertebrates through their burrowing and burrow-irrigation activities (Paramour and Frid 2006 and references therein). Burrowing and burrow integration processes promote the return of mineralised nutrients to the overlying seawater at a faster rate than diffusion alone (Paramour and Frid 2006 and references therein). Offshore circalittoral muds are dominated by surface and subsurface invertebrate deposit feeders (which eat particles that have settled on the seabed) which support this function (Paramour and Frid 2006 and references therein). Paramour and Frid (2006) note that larger burrowing invertebrates in offshore circalittoral mud individually recycle more nutrients than the smaller individuals, and to a greater depth. Bioturbation is also important for oxygenating the upper layers of sediment (Hiscock and Marshall 2006).

Food Web Dynamics

In general, the benthic invertebrates of sediment habitats can be major dietary components of commercially targeted fish and shellfish species which feed on these organisms either as juveniles or adults (Snelgrove 1999). Amphipods, decapods, polchaetes and echinoderms dominate the diet of Atlantic cod, haddock, dab, plaice and sole (Paramour and Frid 2006 and references therein). The benthic (bottom dwelling) organisms of this habitat form an important part of the food chain and transfer organic carbon back into the pelagic realm (Snelgrove 1999).

Waste assimilation

Fauna residing in sediments, including mud, can influence the concentration and distribution of pollution, by pelletizing sediment as faeces or stabilising sediment through mucus excretion, animals within the sediment can increase or decrease the likelihood of sediment bound pollutants being resuspended and transported elsewhere (Snelgrove 1999). Vertical mixing of sediments by macrofauna (animals larger than 300μm) which move through or move sediment as they feed can influence the likelihood of pollutants being buried (Snelgrove 1999).

Climate regulation

Sedimentary fauna influence global carbon dioxide dynamics and hence global warming through their feeding and mixing activities (e.g. burrowing) which result in carbon metabolism and burial (Snelgrove 1999).

Review of Beneficial Ecosystem Services

Fisheries

In general, the food web dynamics of sedimentary habitats support commercially targeted fish and shellfish species (Snelgrove 1999). The principal fishery in mud habitats in deep water is for *Nephrops norvegicus*, although other crustaceans may also be targeted (UK Biodiversity Partnership 2010).

Environmental resilience

Although no direct evidence was available, it is likely that the climate regulation beneficial ecosystem processes associated with mud habitats in deep water contribute to climatic environmental resilience (expert opinion).

31 Deep-sea sponge aggregations

Note: It may be useful to examine the Deep-sea bed review (16) to supplement material in this review.

Summary

Figure 29 shows the Core Ecosystem Processes, Beneficial Ecosystem Processes and Services from deep-sea sponge aggregations that have been identified at the scoping stage of this review listed in Figure 1. **The beneficial ecosystem processes identified were secondary production, species diversification, formation of species habitat, biogeochemical cycling and climate regulation. The beneficial ecosystem services identified were fisheries, medicines and environmental resilience.**

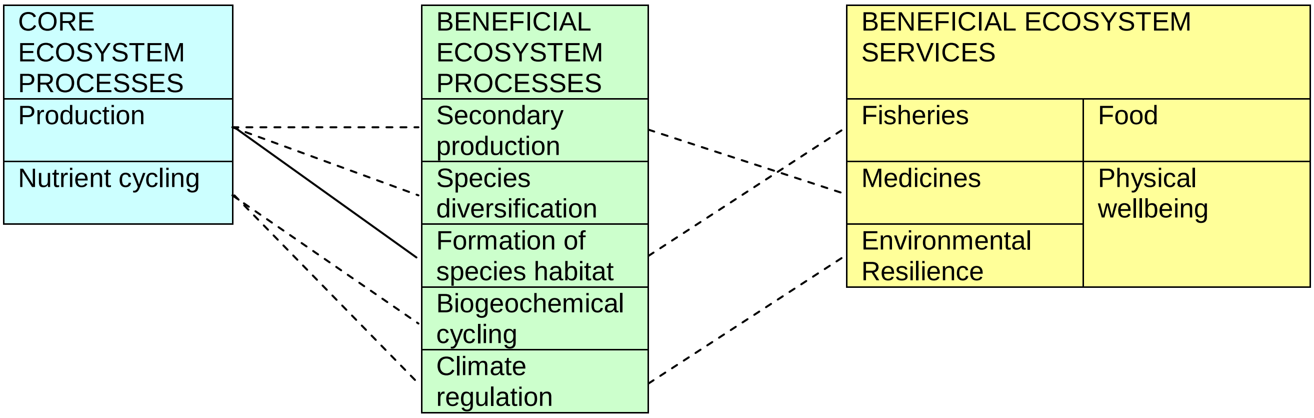

Figure 29 Marine ES Framework: Deep-sea sponge aggregations (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence).

Introduction

Deep sea sponge aggregations are known to occur between water depths of 250-1300m (Bett and Rice 1992 cited in OSPAR 2008) on soft substrata or hard substrata (such as boulders and cobbles which may lie on sediment). Dense aggregations of deep sea sponges are known to occur in various places in the Northeast Atlantic, in particular, close to the shelf break (250m to 500m depth) around the Faroe Islands (Klitgaard and Tendal 2001 cited in OSPAR 2008). Deep sea sponge aggregations are principally composed of sponges from two taxonomic classes: Hexactinellida and Demospongia. These two types of deep sea sponges are associated with different types of substratum; demosponges are found on reef/rocky substrate while hexactinellid sponges are found in open sediment (Smith and Hughes 2008).

Review of Beneficial Ecosystem Processes

Secondary production

Sponges make up more than 90% of the biomass in these deep sea habitats, excluding benthic fish (OSPAR 2008). Densities of sponge occurrence are difficult to quantify, but sponges in the class Hexactinellida have been reported at densities of 4-5 per m^2, whilst 'massive' growth forms of sponges from the class Demospongia have been reported at densities of 0.5-1 per m^2 (expert opinion cited in OSPAR 2008). The massive sponges that dominate some areas include *Geodia barretti*, *G.macandrewi*, and *Isops phlegraei*. All are widely distributed in the North East Atlantic and reach considerable sizes with body weights of more than 20 kg (Hougaard and others 1991; Klitgaard 1995; both cited in OSPAR 2008).

Species diversification

The diversity and abundance of sponges in some locations in the OSPAR Maritime Area rivals that of tropical reef systems. One study off the coast of northern Norway took grab samples from an area of less than 3 per m^2, yielding 4,000 sponge specimens belonging to 206 species (Konnecker 2002). Material from a sponge field in the northern North Sea and other locations had a comparable diversity and density of sponges (OSPAR 2008). In the North Atlantic, scientists have found nearly twice as many species near deep sea sponge fields as they found on the surrounding seabed (UNEP 2006b). The two main types of deep sea sponges, demosponges and hexactinellid sponges, have their own distinct fauna (Smith and Hughes 2008 and references therein).

Formation of species habitat

Deep sea sponges are keystone species which provide a habitat for many other invertebrates (Smith and Hughes 2008). Desmosponges provide substratum for other species while hexactinellid aggregations, which are found on open sediment, are linked to increased macrofaunal abundance and richness, particularly where they are surrounded by large deposits of sponge spicules (Smith and Hughes 2008 and references therein). The presence of spicules from dead sponges can alter the characteristics of surrounding muddy sediments, for example by stabilising soft sediments. In some areas this can amount to 3.5kg of pure siliceous spicule material per m^2 (Gubbay 2002). Sponges influence the density and species of other animals present. Encrusting sponges occupy space on hard substrata, denying space for other sessile species such as bryozoans (sea mats), while the internal architecture of sponges provide shelter to small epifauna and larger upright sponges provide an elevated perch, for example, for brittlestars (Konnecker 2002). Sponge aggregations also add a three dimensional structure to the seabed that provides habitat, hunting ground and refuge for many fish species, including commercially important fish species like redfish, cod and ling (UNEP 2006b).

Biogeochemical cycling and climate regulation

Epibenthic suspension feeders like sponges extract particles from the water column and, by expelling them as faeces or pseudofaeces, make them available for other benthic organisms (biodeposition). Pile and Young (2006) quantified the diet, rates of water processing and abundance of the deep-sea hexactinellid sponge *Sericolophus hawaiicus* (which forms dense beds of sponges in Hawaii between 360-460m deep). The authors found that these sponges were significant sinks for ultraplankton, processing water at rates of 7.9 $\pm$ 2.4 ml per sponge per second. The authors calculated that the large amount of water processed by these benthic suspension feeders resulted in the transfer of approximately 55 mg of carbon and 7.3 mg of nitrogen per day per m^2 of seabed from the water column to the benthos and concluded that *S. hawaiicus* could be included in the functional group of organisms that link the pelagic microbial food web to the benthos.

Witte and others (1997) calculated bulk biodeposition rates for the sponge community of between 7-10 mg per day per gram ash-free dry weight in the Norwegian and Greenland Sea. Combining the biodeposition rates with biomass data Witte and others (1997) estimated that the biodeposition rate for the sponge community of the deep Greenland and Norwegian Seas ranged between 0.5-2 mg of carbon per m^2 of seabed per day, which will contribute to climate regulation.

Review of Beneficial Ecosystem Services

Fisheries

Although no direct evidence was found, a low confidence link to fisheries can be assumed, based on the information that deep sea sponge bed habitats are utilised by commercially important fish species such as redfish, cod and ling (UNEP 2006b).

Medicines

Sponges have been found to contain many different chemical compounds in their tissues which act as a defence/deterrent to other encrusting organisms and many of which may have important pharmaceutical properties, especially as antibiotic and anti-cancer agents (Konnecker 2002). Hence sponges are collected as part of bioprospecting operations although the collection of large numbers of sponges for this purpose has been identified as a potential threat to this habitat (OSPAR 2008).

Environmental resilience

Although no direct evidence was available, it is likely that the climate regulation beneficial ecosystem processes associated with mud habitats in deep water contribute to climatic environmental resilience (expert opinion).

32 Seapens and burrowing megafauna

Summary

Figure 30 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Services and Benefits (Figure 1) that have been identified for seapens and burrowing megafauna. **The beneficial ecosystem processes identified were food web dynamics, the formation of species habitat, species diversification, biogeochemical recycling and climate regulation. The beneficial ecosystem services identified were fisheries, and nature watching.**

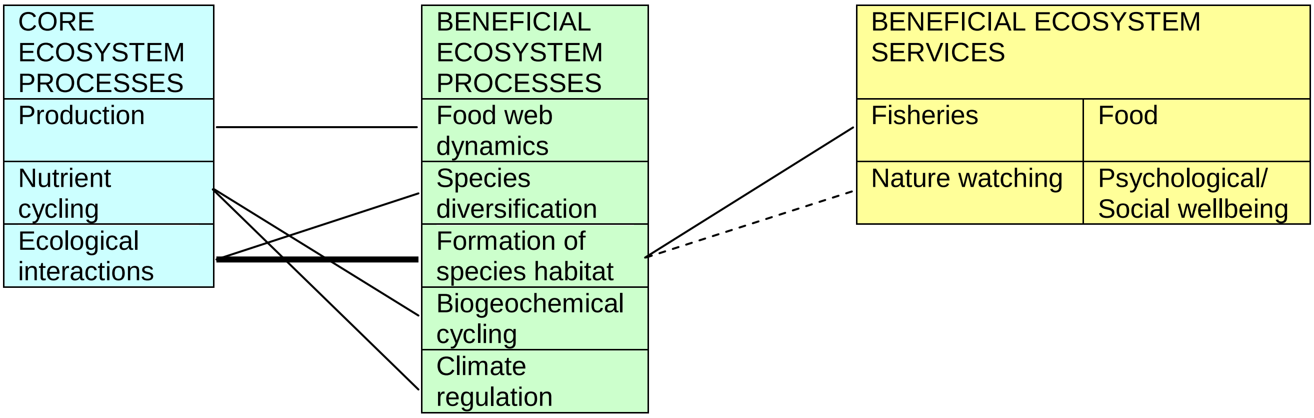

Figure 30 Marine ES Framework: Seapens and burrowing megafauna (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

The seapen and burrowing megafauna biotope occurs in areas of fine mud (which is often heavily burrowed) at water depths ranging from 15-200m or more. This habitat occurs extensively in sheltered basins of fjords, sea lochs, and in deeper offshore waters such as the North Sea and Irish Sea basins (OSPAR 2008). The habitat may include conspicuous populations of seapens, typically *Virgularia mirabilis* and *Pennatula phosphorea*. The burrowing crustaceans present may include *Nephrops norvegicus*, *Calocaris macandreae* or *Callianassa subterranea*. In deeper fiordic lochs, the tall seapen *Funiculina quadrangularis* may also be present (OSPAR 2008). This habitat includes the feature of conservation importance, the Tall sea pen (*Funiculina quadrangularis)*, a large elongate seapen that can reach over 2 m in length. *F. quadrangularis* is found in areas of fine muds from depths of 20 m to over 2000 m in sheltered, low energy environments such as sea lochs (Hill and others 2010 and references therein).

Review of Beneficial Ecosystem Processes

Food Web Dynamics

The benthic (bottom dwelling) organisms of this habitat form an important part of the food chain and transfer organic carbon back into the pelagic (open water) realm (Snelgrove 1999). *Nephrops norvegicus* is known to be eaten by a variety of bottom-feeding fish including haddock, cod, skate and dogfish (Jones, Hiscock and Connor 2000). Burrowing shrimps and echiuran worms are also found in the stomachs of bottom feeding fish (Hill 2008).

Formation of species habitat

The activities of large burrowing megafauna associated with this habitat produce prominent burrows and mounds on the surface of fine mud sediment ‘plains’ (UK Biodiversity Partnership 2010) and contribute to the displacement and mixing of sediment particles through bioturbation. The burrows produced by megafaunal species may provide shelter for a variety of small benthic animals, especially if the structures are long-lasting or permanent. The construction and ventilation of burrows may enable smaller organisms (macrofauna) to inhabit otherwise uninhabitable sediment through making the sediment less compact, increasing oxygenation and enhancing food supply (by stimulating bacterial growth) (Hughes 1998). In the UK, certain organisms have been recorded in association with sea pens. For example, the crustacean *Astacilla longicornis* and the brittle star *Asteronyx loveni* have been found on the sea pen *Funiculina quadrangularis* (Hughes 1998).

Species diversification

The effect of megafaunal burrowing bioturbation on organisms within the sediment varies according to species and burrowing activity (Hughes 1998). Positive effects can include enabling macrofauna to inhabit otherwise uninhabitable sediment. In contrast, direct detrimental effects on other macrofaunal species may include predation (through being exposed) or burial, whilst indirect effects may arise from increased sediment compaction and/or increased turbidity (Hughes 1998). Overall, studies have indicated that megafaunal burrowers create a complex 'shifting-mosaic' of habitat patches with differing levels and types of disturbance and that the responses of macrofaunal species to this 'patchiness' will be a factor in influencing local species diversity (Hughes 1998).

Biogeochemical recycling and climate regulation

Where large numbers of megafaunal burrowers occur, they can have a profound influence on their environment (Hughes 1998). For example, field observations of the extensive burrowing habit of the mud shrimp *Callianassa subterranea* (Montagu) in the North Sea showed that the sediment expelled by *C. subterranea* formed unconsolidated volcano-like mounds which significantly modified the topography of the seabed surface (Rowden and others 1998). This species was estimated to turn over a total of 11kg (dry weight) of sediment per m^2 per year (Rowden and others 1998). As the burrow of each shrimp has multiple exhalent and inhalant openings, many kilograms of sediment per m^2 of bottom surface is expelled and reworked, resulting in large amounts of fresh organic carbon becoming buried (which can assist with climate regulation). The burrows also increase the surface area of seabed/water column interface and hence are important sites for nutrient exchange between the water column and the bottom.

Review of Beneficial Ecosystem Services

Fisheries

In general, the benthic invertebrates in sedimentary habitats, including mud, can be major dietary components of commercially targeted fish and shellfish species, including *Nephrops* fisheries which are of major economic importance (Hill 2008).

Nature watching

A link to nature watching is possible as the features are likely to be of interest and attract visitors to view them as a recreational activity (expert opinion).

33 Native oyster (*Ostrea edulis*) beds

Note: Native oyster (*Ostrea edulis*) beds can form ‘reef’ structures, referred to as biogenic reefs. The beneficial ecosystem processes and services provided by intertidal and subtidal biogenic reefs in general are considered in reviews 10 and 15.

Summary

Figure 31 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Services and Benefits (Figure 1) that have been identified for native oyster beds. **Beneficial ecosystem processes identified were food web dynamics, formation of species habitat, water purification (water quality), biogeochemical cycling, erosion control and climate regulation. Beneficial ecosystem services identified included fisheries, natural hazard protection, and environmental resilience.**

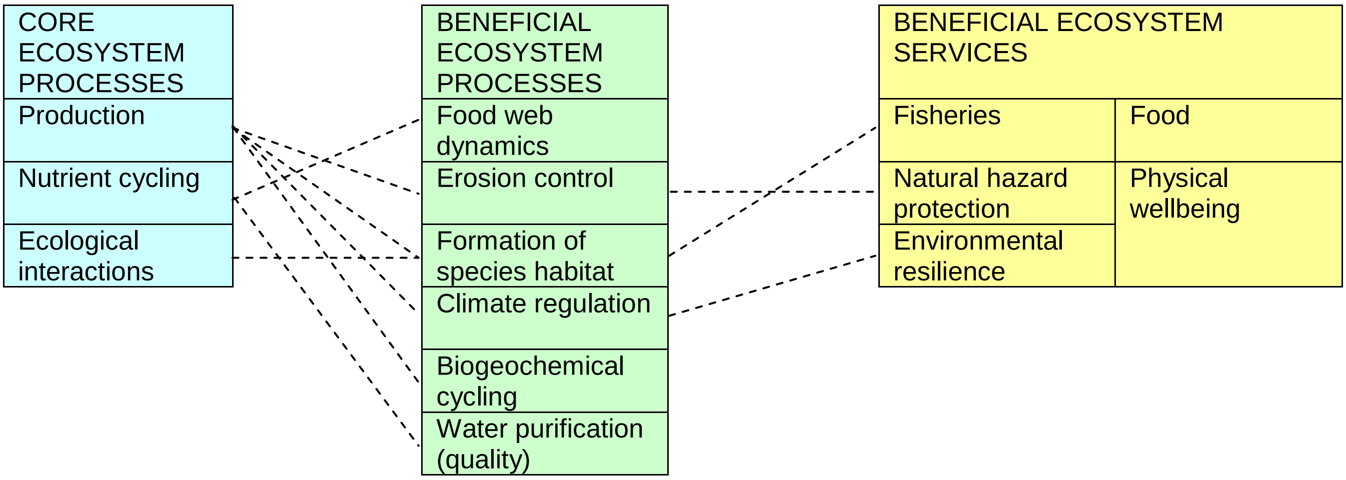

Figure 31 Marine ES Framework: Ostrea edulis (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Natural beds of the native oyster *Ostrea edulis* (defined as densities of five or more per m^2) are found in estuarine areas typically from 0-6m depth (although occasionally down to 30m) on sheltered but not muddy sediments, where clean and hard substrates are available for settlement (OSPAR 2008). Stock abundance was greatest in the 18^{th} and 19^{th} centuries when there were large offshore oyster grounds in the Southern North Sea and English Channel. However, abundance declined significantly during the 20th century mainly due to over-exploitation and the main UK stocks are now located in rivers/flats bordering the Thames Estuary, The Solent, River Fal, the west coast of Scotland and Lough Foyle (Anon 1999).

Review of Beneficial Ecosystem Processes

Food web dynamics

In Chesapeake Bay (United States), it has been noted that through the removal of organic particles in the water column, oysters divert energy to benthic food chains (Newell 1988 cited in Peterson and others 2003). This reduces nutrient levels in the water column, which may otherwise contribute to blooms of the jellyfish *Chrysaora quinquecirrha* (sea nettle) (Peterson and others 2003 and references therein).

Formation of species habitat

In general, oysters create new habitat for benthic invertebrates (Peterson and others 2003 and references therein) as well as fishes and mobile crustaceans (Peterson and others 2003 and references therein). This new biogenic habitat is a consequence of the structural complexity that the oyster shells create. Hicks and others (2004) and Cohen and others (1999) have noted that the native oyster (*Crassostrea virginica)* in Chesapeake Bay, USA is a keystone species that provides ecological services which benefit other species and overall ecosystem functioning. One of these functions is the improvement of water clarity, which enables other species, such as seagrass, to flourish and hence can lead to suitable habitat for many species of fish and birds.

Water Purification (Quality)

Hicks and others (2004) stated that one of the ecological benefits provided by the native oyster *C. virginica* (in Chesapeake Bay, USA) was the filtering of algae and sediment from the water column, resulting in increased water clarity. In a publication on the ecology of bivalves, Dame and others (1996 cited in Peterson and others 2003), stated that feeding oysters remove suspended inorganic matter, phytoplankton, and detrital particles, thereby reducing turbidity and improving water quality.

Biogeochemical cycling and Climate regulation

In general, oyster reefs sequester carbon in the form of calcium carbonate of the accumulating shell matrix (Hargis and Haven 1999) and thus contribute to global carbon budgets (Peterson and others 2003).

Erosion Control

In the United States it has been reported that the physical structure of a fringing oyster reef can protect salt marsh habitat by dissipating erosive wave energy (Meyer and others 1996 cited in Peterson and others 2003).

Review of Beneficial Ecosystem Services

Commercial and Recreational Fisheries

Peterson and others (2003) calculated the per-unit-area enhancement of production of fisheries and large mobile crustaceans expected to arise from the restoration of oyster reef habitat in the south east United States. Their calculations suggested that 10 m^2 of restored oyster reef in the southeast United States is expected to yield an additional 2.6 kg per year of production of fish and large mobile crustaceans for the functional lifetime of the reef, such that a reef lasting 20 to 30 years would be expected to augment fish and crustacean production by a cumulative amount of 38 to 50 kg per 10 m^2.

Management measures of *O. edulis* in Ireland have included the collection of spat to seed previously known beds and other suitable areas, which has elevated production of the fishery from 7 tonnes in the 1980s to the current level of 150 tonnes (OSPAR, 2008). The Solent holds the largest remaining naturally regenerating fishery for the European oyster (*Ostrea edulis)*. The fishery is of great local value, especially in the winter season when other fisheries are unavailable (Jensen 2000).

Other

It is assumed that erosion control processes will provide benefits for natural hazard protection and that climate regulation processes will improve environmental resilience (expert opinion).

34 Peat and clay exposures

Summary

Figure 32 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Processes and Services (Figure 1) that have been identified from peat and clay exposures. **The only beneficial ecosystem processes identified were species diversification and formation of species habitat. No evidence to support beneficial ecosystem services was identified for this feature.**

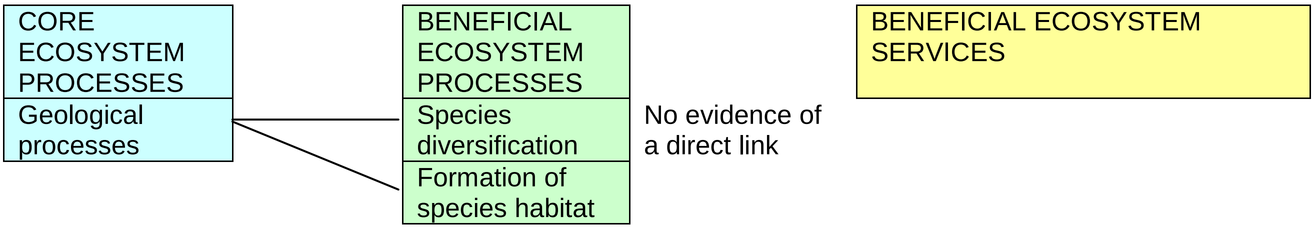

Figure 32 Marine ES Framework: Peat and clay exposures (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

There is relatively little known about the ecology of peat and clay exposures and the fauna characterising them (Hill and others 2010). Currently there is no accepted summary description. These unique and fragile habitats arise from former lake bed sediments and ancient forested peatland (or ‘submerged forests’). Depending on erosion at the site, both clay and peat can occur together or independently of each other (UK Biodiversity Partnership 2010). This habitat is distributed along the north and south coasts of Wales and the south and east coasts of England. Clay exposures with piddocks are also found in Cumbria. Despite this, in general, little is known about UK distribution of subtidal peat and clay exposures (UK Biodiversity Partnership 2008).

Review of Beneficial Ecosystem Processes

Species diversification

Peat and clay exposures support an array of mobile and attached fauna. Encrusting fauna are often dominated by suspension feeders including barnacles such as *Semibalanus balanoides*, hydroids (e.g. *Obelia longissima*) and the mussel *Mytilus edulis* (Hill and others 2010). The tube building polychaetes *Lanice conchilega* and *Sabella pavonina* may also be present as are anemones such as *Anemonia viridis* and the boring polychaete *Polydora ciliate* (Pinn and others 2008). In the littoral zone there may be a turf of algae including *Ceramium* spp. and *Enteromorpha* spp. (Murphy 1981). Piddocks, molluscs that excavate holes in the peat, increase the topographical complexity of soft substratum habitats, thereby increasing species diversity (Pinn and others 2008).

Formation of species habitat

Peat and clay exposures found in littoral and sublittoral habitats provide a soft substrate for fauna such as piddocks including the Common piddock (*Pholas dactylus)* and the American piddock (*Petricola pholadiformis*) to bore into, which would not be possible in harder clays and chalks (Duval 1963). The old bore holes of dead piddocks provide a habitat for a variety of crevice dwellers including small crabs such as *Carcinus maenas* and the snails *Littorina littorea* and *Gibbula cineraria.* Empty piddock shells protruding from the eroded surface of chalk or clay platforms an also provide an important settlement surface within this habitat (Hill 2008). The surface of fossilized peat substratum may be covered by a mat of red and green seaweeds (e.g. *Ceramium* and *Ulva* species) which provide habitat for small invertebrates (Budd 2008).

Review of Beneficial Ecosystem Services

No direct evidence of beneficial ecosystem services was found.

35 Sabellaria Reefs

Note: Where *Sabellaria* species form 'reef' structures, these are referred to as biogenic reefs. The beneficial ecosystem processes and services provided by intertidal and subtidal biogenic reefs in general are considered in sections 10 and 15.

Summary

Figure 33 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Services and Benefits (Figure 1) that have been identified for sabellaria reefs. **The beneficial ecosystem processes identified were the formation of species habitat, species diversification and food web dynamics. No direct evidence of beneficial ecosystem services was identified**.

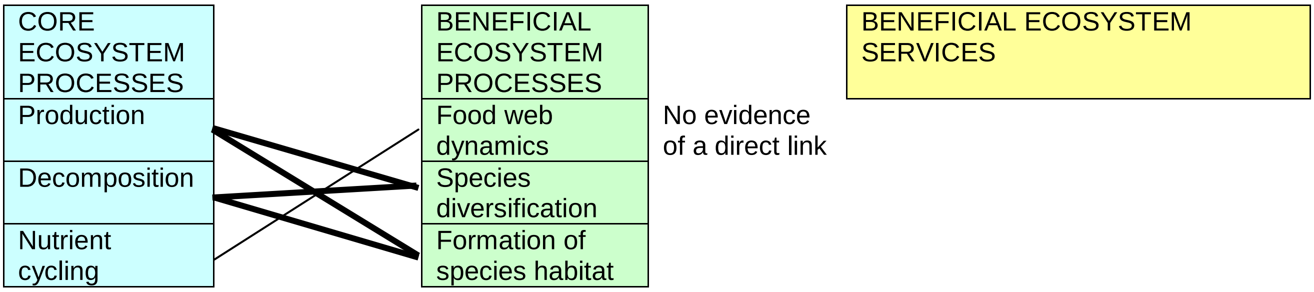

Figure 33 Marine ES Framework: Sabellaria alveolata and Sabellaria spinulosa reefs (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

The genus *Sabellaria* are polychaete worms that use sand to create reef structures. *Sabellaria alveolata* construct sand tubes in tightly packed masses (UK Biodiversity Partnership 2010). In general, *S. alveolata* builds structures of two major types: small sheet-like reefs adhering to rocks on the upper level of the intertidal zone and, less commonly, extensive formations located on sand flats lower down in the intertidal zone (Dubois and others 2003). Like *S. alveolata, Sabellaria spinulosa* polychaete worms can build reef structures out of sand, however, in contrast to *S. alveolata*, *S. spinulosa* reefs occur mostly in the subtidal area (Hill and others 2008). *S. spinulosa* attaches to hard surfaces (e.g. shell, rock or cobble) although they have also been observed to build reefs in stable sand environments in the Bristol Channel and The Wash (Hill and others 2010 and references therein; expert opinion). *S. spinulosa* is most frequently encountered as solitary individuals or in small clumps (Pearce 2009 cited in Hall and others 2010) and extensive reef structures are comparatively rare. Very extensive subtidal reefs occur in the Severn Estuary, and subtidal populations have also been reported in the Walney Channel (Morecambe Bay) and from Glassdrumman, Northern Ireland (Maddock 2008).

Review of Beneficial Ecosystem Processes

Formation of species habitat

In general, *Sabellaria* reefs increase the habitat complexity of the surrounding environment and one of the key ecological functions of the reefs is likely to be the provision of microhabitats for other organisms, in the form of crevices and cavities (Caline and others 1992 cited in Hill and others 2010). *S. alveolata* reefs in the UK also provide attachment for seaweed communities (e.g. Wilson 1976 cited in Hill and others 2010). Dubois and others (2006) described *S. alveolata* as an important ecosystem engineer whose reef structure adds topographic complexity and high levels of biodiversity to otherwise low-relief, low diversity, soft sediment environments in the Bay of Mont Saint-Michael, France. These authors also stated that these reefs play an important role in the ecosystem by filtering large volumes of water and altering the local flow regime.

Species diversification

Although *S. alveolata* reefs increase habitat complexity and hence provide habitats for a range of species, the overall influence of these structures on marine diversity is still debated (Holt and others 1998 cited in Hill and others 2010). Older reefs may have more diverse associated communities than younger ones (Holt and others 1998; Jackson 2008) and several studies have found that the highest levels of diversity are associated with degraded reef, where gaps and cavities in the reef provide shelter for a range of crevice dwellers and sediment retained within the reef structures provide a suitable substrate for interstitial animals (Hill and others 2010 and references therein). Sheets of *S. alveolata* appear to enhance algal diversity, apparently by providing barriers to limpet grazing (Cunningham and others 1984)

S. spinulosa reefs are home to crevice dwelling animals including the porcelain crab (*Pisidia longicornis)* and the polychaete worm species *Scoloplos armiger* and *Lumbrineris gracilis* (Hill and others 2010 and references therein). Larger gaps in the reef structure may be inhabited by large crabs and lobster as well as the queen scallop (*Aequipecten opercularis)* (Pearce 2009 cited in Hill and others 2010). On *S. spinulosa* reefs in the Bristol Channel, UK, George and Warwick (1985) reported an 80% increase in biodiversity associated with the reefs compared to the surrounding sand substratum, although it was noted in Hill and others (2010) that the surrounding sand environment was particularly species-poor and hence *S. spinulosa* reefs formed on different substratum (e.g. mixed gravel deposits) would be unlikely to show such dramatic effects on biodiversity.

S. spinulosa reefs in the proposed Haisborough, Hammond and Winterton SAC off Great Yarmouth, UK, have modified the sandy sea bed from being predominantly simply structured and soft to one that is predominantly hard and structurally complex (Natural England 2010b). The reefs therefore support a range of fauna untypical of a sand-dominated seabed, including hydroids, hornwrack, anemones, squat lobster, velvet swimming crab, brittlestars and pink shrimp (Natural England 2010b). The same site also provides spawning grounds for sand eel, lemon sole and sole and nursery grounds for cod, herring, mackerel, sole, lemon sole and plaice (Natural England 2010b). The site is an important feeding ground for little tern and there is a large breeding colony of 400 to 500 grey seals adjacent to the site (Natural England 2010b). Studying the same area, Cooper and others (2007) showed that some benthic macro-invertebrate communities supported higher species numbers and greater abundances of individuals compared to other areas, which may have been due, in part, to the presence of *S. spinulosa* reefs in those areas.

Food web dynamics

Dubois and others (2003) investigated the trophic role of *S. alveolata* reefs in Mont-Saint-Michel Bay in France and calculated that the *S. alveolata* reefs filtered about 396,500 m^3 of seawater during the 13 hours each day that the reefs are immersed. Dubois and others (2006) stated the *S. alveolata reefs* in this Bay play an important trophic role in the ecosystem (as a primary consumer of phytoplankton) by filtering large volumes of water.

Review of Ecosystem Services

No direct beneficial ecosystem services were identified from the reviewed literature.

36 Seagrass beds

Note: there is considerable overlap between this review and the review of subtidal macrophyte dominated sediment (14) and intertidal sediments dominated by aquatic angiosperms (9).

Summary

Figure 34 shows the relevant Core Ecosystem Processes, Beneficial Ecosystem Services and Benefits that have been identified for seagrass beds. **The beneficial ecosystem processes identified included primary production, food web dynamics, formation of species habitat, erosion control, species diversification, biogeochemical cycling, genetic diversification, formation of physical barriers, larval/gamete supply, biological control, and water purification (quality). The beneficial ecosystem services identified were fisheries, aquaculture, fertiliser, natural hazard protection, regulation of pollution, tourism and nature watching**.

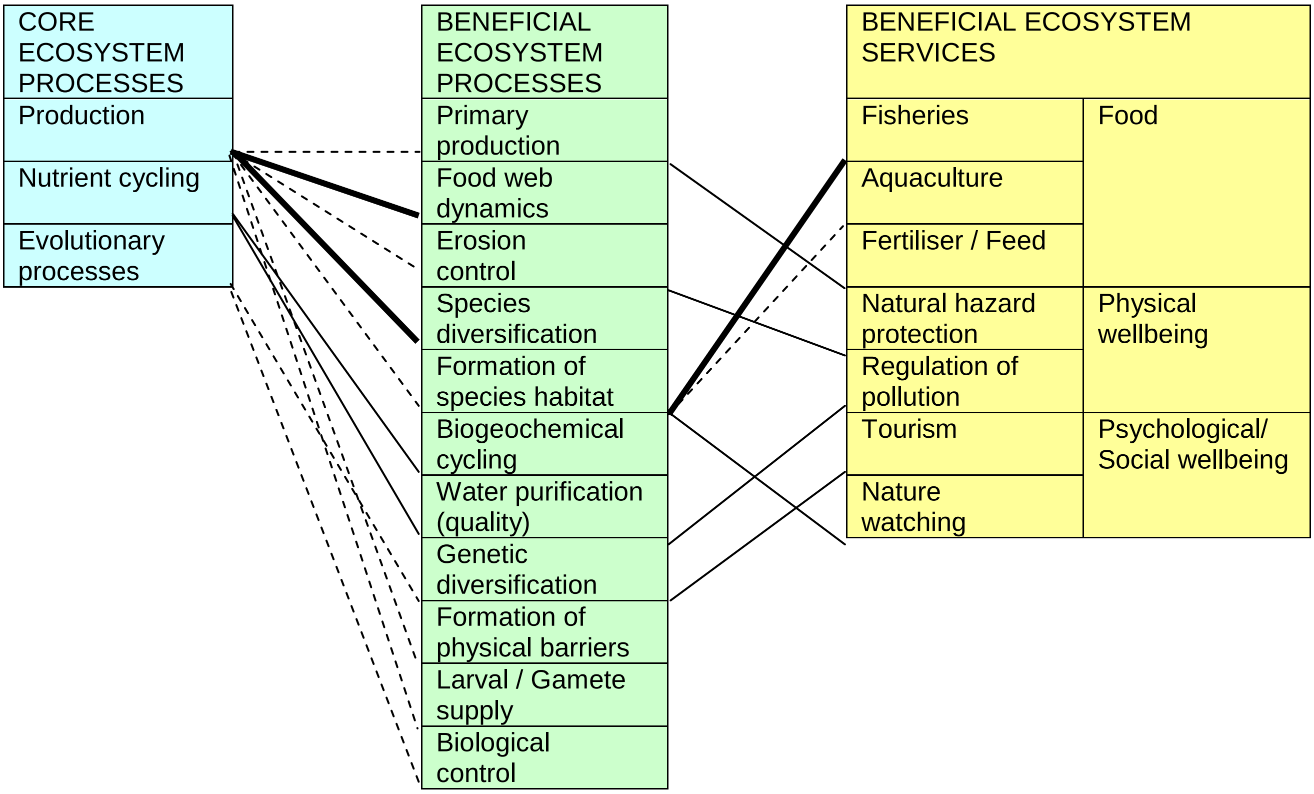

Figure 34 Marine ES Framework: Seagrass beds (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Seagrasses are unique in being the only truly marine flowering plants or angiosperms (Heminga and Duarte 2008). Typically seagrass is found on sheltered sandy or muddy substrata down to 4m but can occur to a maximum depth of about 10m around UK waters (Davison and Hughes 1998; Nielsen and others 2002). There are four confirmed species of seagrass found in UK waters: two species of tassel weed *Ruppia maritima* and the rarer *Ruppia spiralis* and two species of eelgrass, *Zostera noltii*, (dwarf eelgrass) and *Zostera marina* (common eelgrass). A third species of eelgrass that occurs in the UK, *Zostera angustifolia*, may actually be a variety of *Z. marina* rather than a distinct species. Seagrass beds are a Biodiversity Action Plan priority habitat (UK Biodiversity Partnership online), OSPAR threatened habitat (OSPAR 2008), and *Z. marina* is a BAP Species of National Conservation Concern. Although seagrass beds are not listed as an Annex I habitat under the European Community (EC) Habitats Directive they are a recognized component of several of these habitats, namely 'Lagoons', 'Estuaries', 'Large shallow inlets and bays', 'Intertidal mud and sand banks' and 'Sandbanks covered by sea water at all times'. It is also listed as a 'scarce' nationally important marine feature.

Review of Beneficial Ecosystem Processes

Biomass Production: Primary

No estimate of the rate of primary biomass production from seagrass beds in the UK has been sourced to date. However, in the Mediterranean Sea, the seagrass *Posidonia oceanic*a, together with microphytobenthos, was responsible for primary production values of 169-300g of Carbon per square metre per year (Danovaro and others 2002) whilst in Australia, the maximum productivity of the seagrass *Halophila ovalis* was reported to be up to 40 g dry weight per m^2 per day during the summer (Hillman and others 1995).

Food Web Dynamics

Eelgrass (*Zostera* spp.) provides food for grazing for overwintering wildfowl, particularly Brent geese and wigeon (Davison and Hughes 1998; Tubbs 1999). Grazing wildfowl can consume a high proportion of the available standing stock of *Zostera*. Portig and others (1994) found that in Strangford Lough, 65% of the estimated biomass (~1100 tonnes fresh weight) of *Zostera* was consumed by grazing wildfowl during the winter months but that up to 80% was disturbed by their feeding activity. Small crustaceans and crabs consume seagrass tissue whereas direct grazing by fish species is relatively uncommon among finfish (Hemminga and Duarte 2000).

Formation of species habitat and species diversification

Bouma and others (2009) describe seagrasses as ecosystem 'engineer' species which increase structural complexity and cause a large and/or distinct modification to the abiotic environment. For example, seagrass beds provide increased habitat complexity, increased substrate for other organisms to attach to and protection from predation, while reducing water velocity resulting in increased retention of particles and the accretion of sediment (described in further detail in the following sections). Several studies have shown that these physical changes tend to increase species richness and/or abundance in seagrass beds (Edgar and others 1994; Heck and others 1995; Bostrom and Bonsdorff 1997). Hily and Bouteille (1999) compared the faunal communities within a *Z. marina* meadow and adjacent non-vegetated sandy sediments in Brittany, France and showed that the number of species (both the total number of species and species per m^2), abundance (individuals per m^2) and biomass (g dry weight per m^2) were all significantly higher in the *Zostera* meadow than in the bare sediments. Similarly, Hirst and Attrill (2008) showed that even small patches of intertidal *Z. marina* in Torbay, Devon, supported higher levels of biodiversity than surrounding bare sand, indicating that just the presence of seagrass, irrespective of the size of the patch, influenced biodiversity. However, some studies, for example Bouma and others (1999), have not found increased species diversity in seagrass beds compared to surrounding sediment.

Seagrass beds can also provide nursery areas for juvenile fauna. For example, Polte and others (2005) showed that there were significantly higher abundances and production (biomass) of juvenile shore crabs, brown shrimps and common gobies within intertidal areas of *Zostera noltii* compared to bare sand patches in the Wadden Sea during the ebb tide. The results also showed that there was a higher percentage of small individuals in seagrass beds compared to sand patches. The authors concluded that *Z. noltii* beds contribute to the function of tidal flats as extended juvenile habitat for some of the most important species in the Wadden Sea food web.

Genetic Diversification (and its influence on Biological Control)

In general, although seagrass meadows are often composed of only one or two dominant seagrass species, their genotypic (genetic) diversity can be very high. The ecological significance of this genetic diversity, with respect to ecosystem functioning of seagrass beds, has been investigated in a number studies. Hughes and Stachowicz (2004) found that in California, the plots of *Z. marina* with high genetic diversity exhibited greater resistance to grazing disturbance by Brent geese, although there was no effect of increased genetic diversity on the resilience (rate of shoot recovery following disturbance) of the eelgrass community. Hughes and Stachowicz (2004) concluded that genetic diversity may contribute to the resistance of communities to various disturbances and hence provide ‘biological insurance’ against environmental change. In the Baltic, Reusch and others (2005) showed that increasing the genotypic (genetic) diversity of *Z. marina* enhanced biomass production, shoot density and associated faunal (animal) abundance.

Formation of physical barriers (influencing erosion control and larval/gamete settlement)

In general, the three-dimensional structures of seagrass beds act as hydrodynamic barriers and erosion controls (Ronnback and others 2007). The canopies of submerged aquatic vegetation, including seagrasses, provide resistance that reduces current velocity and helps suspended material and larvae settle into the canopy (Eckman and others 1994; Gacia and others 1999; both cited in Abdelrhman 2003). Intermeshed plants can create dense barriers that deflect part of the water flow upwards and hence protect the sediment, larvae and plant roots from being scoured (Fonseca and others 1982).

Erosion Control

The dissipation of wave and tidal current energy by seagrasses in the intertidal and shallow subtidal zones is an important function in preventing coastal erosion (Terradoos and Borum 2004). Erosion control is further enhanced by sediment stability created by the binding effect of the roots / rhizomes (Terradoos and Borum 2004).

Biogeochemical (Nutrient) Recycling

Through photosynthetic activity seagrass beds produce oxygen and absorb carbon dioxide. By so doing, they contribute to the storage of carbon and thereby have an important role within the carbon cycle (Ronnback and others 2007). Seagrasses and associated algae are able to absorb inorganic nutrients through both roots and leaves. The acquisition of nutrients from the water column allows seagrasses to compete with phytoplankton for the inorganic nutrients that support the primary production of coastal ecosystems, having a beneficial effect on water quality. In a review of global studies assessing the impacts of seagrass loss on coastal ecosystems, Waycotta and others (2009) estimated the value of the nutrient cycling provided by seagrass meadows (presumably at a global level) at $US1.9 trillion per year.

Water Purification (Quality)

The ability of seagrass to take up inorganic nutrients benefits water quality by helping to reduce the risk of eutrophication (Terradoos and Borum 2004). It is also known that the root-rhizome system of *Zostera* may act as a metal ‘pump’ (Drifmeyer and others 1980; Lyngby and Brix 1984) and that some metals (chromium, nickel, lead, iron and copper) can be absorbed through the root system and translocated to the above-ground parts of the plant, and even released into the water column (Rigollet and others 1998 and references therein). However, the value of seagrass for water purification is variable as it is highly sensitive to nutrient levels.

Review of Beneficial Ecosystem Services

Fisheries and aquaculture

Sepia officionalis (cuttlefish) have a known association with seagrass habitat in the UK (Connor and others 2004). A cuttle fishery operates in the vicinity of the Cowes Outer Harbour Seagrass bed from April to August (ABPmer 2009). In the USA, shellfish harvesting for clam, and blue crab and scallop have all been associated with seagrass (Fonesca 1998). Cockle harvesting by both hand-picking and by suction dredging has been undertaken in the vicinity of *Zostera* beds in the UK. The damage caused by the introduction of mechanical cockle dredging replacing traditional hand picking in the Solway Firth between 1987 and 1992 resulted in the prohibition of mechanical harvesting from 1994 (Davison and Hughes 1998; Perkins 1988). Opportunistic pump scoop dredging of cockles in seagrass on Ryde Sands (Isle of Wight) resulted in the introduction of a Statutory Prohibition Order prohibiting this method of fishing throughout the Solent under the Habitats Directive. It is thought that cockle fishing is not economically viable in seagrass because the abundance of cockles is generally lower than on bare seabed and the *Zostera* root system inhibits effective use of pump scoop dredging (expert opinion).

In a review of the ecosystem goods and services provided by coastal habitats in Sweden, Ronnback and others (2007) stated that coastal habitats, including vegetated habitats such as seagrass, provide significant support to total marine finfish fisheries landings in Sweden as certain fish species utilise these habitats during at least some stage in their life cycle. Pihl and others (2006) compared fish assemblages between sites in Sweden where *Z. marina* still existed and sites where seagrass had vanished and found that the density of juvenile cod was reduced by 96% at the sites where *Z. marina* had been lost. Lugworm, *Arenicola marina*, and catworm, *Nephtys hombergi* are both associated with seagrass habitat and harvested commercially for bait; an activity that occurs on intertidal seagrass habitat in particular (South East of England Biodiversity Strategy 2008).

Fertiliser / feed

The nutrient content of seagrass has resulted in its use in agriculture, albeit rarely and predominantly overseas. Eelgrass is used as both animal feed for pigs, rabbits and hens and as a soil fertilizer (Terradoos and Borum 2004). Hemminga and Duarte (2000) note that it is extensively harvested in the Alveiro lagoon in Portugal for use as a soil fertilizer. Agricultural use in a number of countries has reduced over recent years because of bans on harvesting of seagrass.

Natural Hazard Protection

There are benefits provided from erosion control through the dissipation of wave and tidal current energy, improving sediment stability (Terradoos and Borum 2004).

Tourism/Nature watching

The association of *Zostera* beds with grazing wildfowl and waders makes them important for nature watching. Snorkelling and (to a lesser extent) diving in seagrass occurs at suitable sites, as at Bembridge on the Isle of Wight where the seagrass offers a rich and diverse seabed to explore in very shallow water.

Regulation of Pollution

Seagrass beds aid pollution prevention through their water purification role. They have a filtration role in coastal waters, trapping particles indirectly through the filter feeding activity of the organisms that they host and directly through capture of suspended particles to the mucus-covered leaf surfaces. In so doing they improve water transparency and quality (Terradoos and Borum 2004).

37 Sheltered muddy gravels

Note: information on Intertidal mixed sediments (section 6) and Subtidal mixed sediments (section 13), which have been reviewed separately in this review, may overlap with this habitat. Information on some specific sedimentary habitats (including this one) are scarce, hence this review may refer to beneficial ecosystem processes and services of ‘sedimentary habitats’ in general. In addition, some evidence in the literature did not provide information on which sediment habitat was studied; hence there is some unavoidable repetition of information between sections.

Summary

Figure 35 shows the relevant Core Ecosystem Processes and Beneficial Ecosystem Processes and Services that have been identified for sheltered muddy gravels. **Beneficial ecosystem processes identified were the formation of species habitat, species diversification, food web dynamics, biogeochemical cycling, waste assimilation, and climate regulation. Beneficial services identified were fisheries and other wild harvesting, environmental resilience and regulation of pollution.**

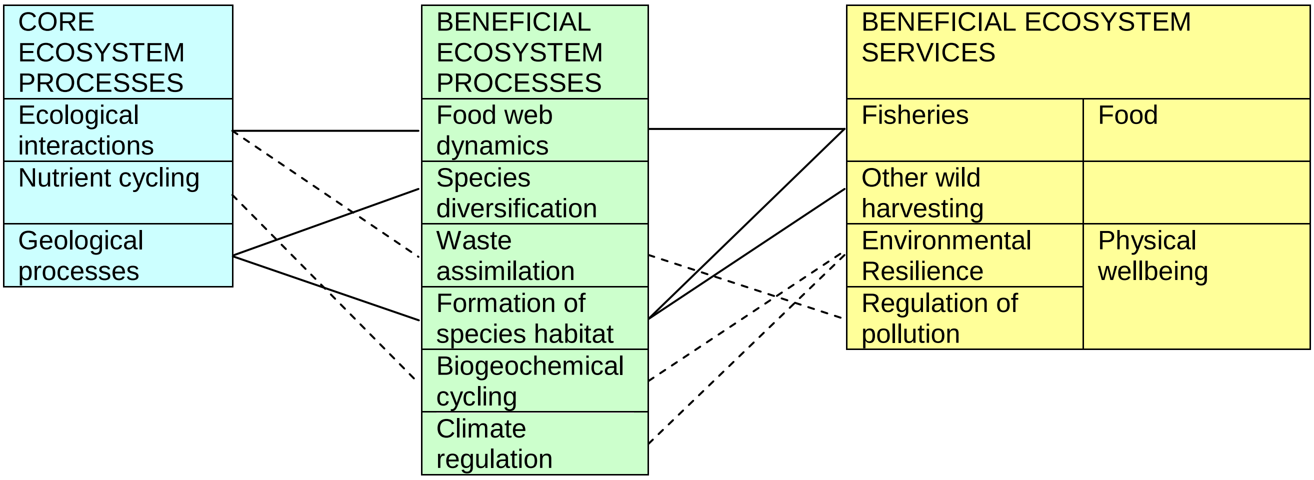

Figure 35 Marine ES Framework: Sheltered muddy gravels (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Sheltered muddy gravels are a marine habitat of mixed muds and gravel, comprising a variety of sediments ranging from fine silt and mud to pebbles and cobbles (Solent Forum 2010). Sheltered muddy gravel habitats occur principally in areas protected from wave action and strong tidal streams, including estuaries, rias (drowned river valleys) and sea lochs (UK Biodiversity Partnership 2010). Fully saline sheltered muddy gravel communities are scare in their British distribution, although it is found extensively in the Solent and Helford Rivers. Other locations include the Fal Estuary, Salcombe Harbour and Milford Haven, the Sound of Arisaig, Lough Foyle, the Dyfi Estuary and Llanbedrog on the Lleyn Peninsula (UK Biodiversity Partnership 2010).

Review of Beneficial Ecosystem Processes

Formation of species habitat and Species diversification

There is considerable variation in the composition of the communities in this habitat depending on the sediment composition and salinity regime. In fully marine conditions on the lower shore, this habitat can be extremely species-rich because of the complex nature of the substratum which provides habitat for a high diversity of organisms residing in and on the sediments. Polychaetes and bivalve molluscs are normally dominant and the most varied, but representatives of most marine phyla can be present (UK Biodiversity Partnership 2010). The presence of coarse gravel and stones at the sediment surface often provides substratum for the attachment of a variety of algae. Low salinity (mid to upper estuarine) muddy gravels have lower, but distinctive, species diversity including the cockle (C*erastoderma edule)* and the native oyster (*Ostrea edulis)* (UK Biodiversity Partnership 2010). The North East Scotland Estuarine and Intertidal Habitats Local Habitat Action Plan (North East Scotland Biodiversity 2009) states that the diverse sheltered muddy gravel habitat in the lower reaches of the Ythan estuary provides nursery areas for fish.

Food Web Dynamics

In general, the benthic invertebrates of sedimentary habitats can be major dietary components of commercially targeted fish and shellfish species which feed on these organisms either as juveniles or adults (Snelgrove 1999). Hence the benthic organisms of this habitat form an important part of the food chain and transfer organic carbon back into the pelagic (open water) realm (Snelgrove 1999). The North East Scotland Estuarine and Intertidal Habitats local Habitat Action Plan (North East Scotland Biodiversity, 2009) states that the diverse sheltered muddy gravel habitat in the lower reaches of the Ythan estuary provides food for estuarine wildfowl.

Biogeochemical cycling and climate regulation

The recycling of energy and nutrients in marine systems is performed mainly by microorganisms. In benthic habitats, the activities of microorganisms are enhanced by macroinvertebrates through their burrowing and burrow-irrigation activities. This process promotes the return of mineralised nutrients to the overlying seawater at a faster rate than diffusion alone (Paramour and Frid 2006). Sedimentary fauna influence global carbon dioxide dynamics, and hence climate, through their feeding and mixing activities (Snelgrove 1999).

Waste assimilation

In general, fauna residing in sediments can also influence the concentration and distribution of pollution. By pelletizing sediment as faeces or stabilising sediment through mucus excretion, animals within the sediment can increase or decrease the likelihood of sediment bound pollutants being resuspended and transported elsewhere (Snelgrove 1999). Vertical mixing of sediments by macrofauna (animals larger than 300µm) which move through, or move, sediment as they feed can influence the likelihood of pollutants being buried (Snelgrove 1999).

Review of Beneficial Ecosystem Services

Fisheries

In general, the food web dynamics of sedimentary habitats support commercially targeted fish and shellfish species (Snelgrove 1999). Specifically in sheltered muddy gravel habitat, intertidal mollusc beds, including *Venerupis senegalensis* and *Mercenaria mercenaria,* may be harvested for export and local consumption (UK Biodiversity Partnership 2010).

Other wild harvesting

Bait digging for the king rag worm (*Alitta* (*Neanthes) virens)* occurs where this species is common (especially in slightly reduced salinity conditions) (UK Biodiversity Partnership 2010).

Other

Although no additional direct evidence for beneficial ecosystem services was identified for sheltered muddy gravels, it is assumed that this habitat supports both the regulation of pollution, through influencing pollutant concentrations and distribution (Snelgrove 1999), and environmental resilience, as sedimentary fauna influence the global carbon dioxide dynamics and hence global warming through their feeding and mixing activities (Snelgrove 1999).

38 Subtidal chalk

Summary

Figure 36 shows the relevant Core Ecosystem Processes and Beneficial Ecosystem Processes and Services that have been identified for subtidal chalk. **The beneficial ecosystem processes identified were species diversification and formation of species habitat. No direct evidence of beneficial ecosystem services provided by subtidal chalk was identified.**

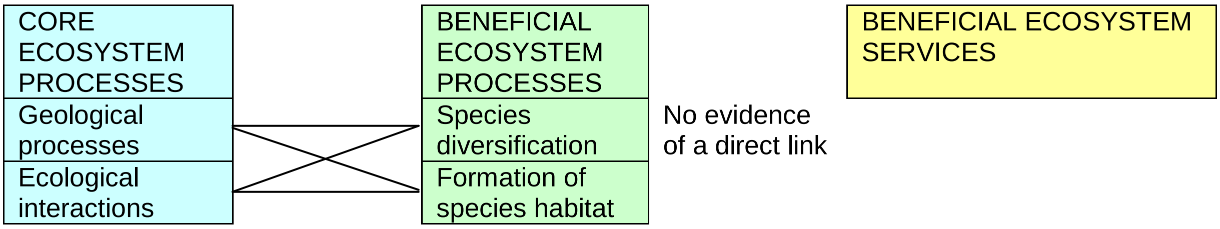

Figure 36 Marine ES Framework: Subtidal Chalk (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

A characteristic of chalk coasts, in contrast to many harder rocky coasts of western and northern Britain, is the geomorphological structure in which, because of subaerial erosion (erosion that occurs when land is exposed to the atmosphere) and marine erosion, a vertical cliff face abuts an extensive wave eroded foreshore platform often extending several hundreds of metres seawards. This is of significance in the formation of subtidal chalk sea cave and reef habitats and the occurrence of the associated communities / biotopes (Tittley and others 1998 cited in UK Biodiversity Partnership 2010). The most extensive areas of subtidal chalk in Britain occur in Kent and Sussex.

Review of Ecosystem Processes

Formation of species habitat and Species diversification

The diversity of subtidal chalk habitats varies between different regions of the UK. For example, in southeast England, shallow subtidal (up to 5m) communities are limited or absent due to the easily eroded nature of chalk and the harsh environmental conditions (high levels of turbidity, siltation and scouring) (UK Biodiversity Partnership 2008). However, shallow subtidal chalk habitats in Flamborough, the Isle of Wight and Studland (Dorset) are more diverse and extend into deeper waters (UK Biodiversity Partnership 2010).

Rathlin, an island off the coast of County Antrim (Northern Ireland) has extensive subtidal exposures of chalk and sublittoral caves which support rich populations of rare species (UK Biodiversity Partnership 2008). It is reported that sublittoral chalk and limestone areas of the island have a greater biodiversity than any other rock types (UK Biodiversity Partnership 2010).

Subtidal chalk is often bored by bivalve molluscs, such as the common piddock (*Pholas dactylus)* and the empty bore holes provide habitat for a range of crevice dwelling animals (Hill and others 2010). For example, much of the shallow subtidal along the Thanet coast (which has the longest continuous stretch of coastal chalk in the UK) is characterised by kelp growing on chalk reef. This has been bored into by piddocks and the habitat is particularly species rich as other invertebrates, such as anemones, crabs and worms, can occupy the empty piddock burrows (English Nature 2000).

Review of Beneficial Ecosystem Services

No direct beneficial ecosystem services were identified from the reviewed literature.

39 Subtidal sands and gravels

Note: Subtidal sand and subtidal coarse sediments may be considered to be components of this habitat and have been reviewed in section 13 of this document. Information on some specific sedimentary habitats are scarce, hence this review may refer to beneficial ecosystem processes and services of 'sedimentary habitats' in general. In addition, some evidence in the literature did not provide information on which sediment habitat was studied; hence there is some unavoidable repetition in information between sections.

Summary

Figure 37 shows the relevant Core Ecosystem Processes and Beneficial Ecosystem Processes and Services that have been identified for subtidal sands and gravels. **Beneficial ecosystem processes were identified as formation of species habitat, species diversification, food web dynamics, biogeochemical cycling, and waste assimilation. The beneficial ecosystem services identified were fisheries, aquaculture, environmental resilience and regulation of pollution.**

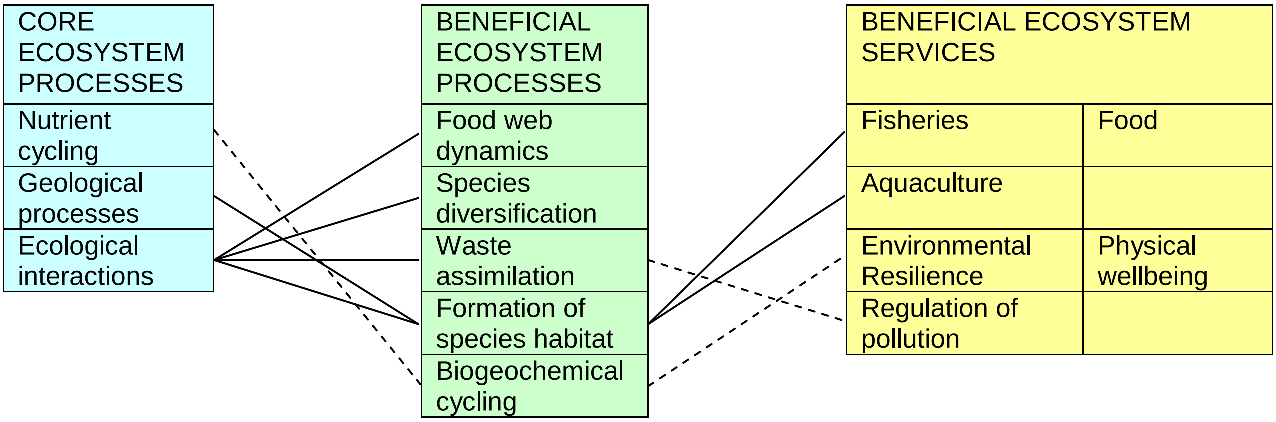

Figure 37 Marine ES Framework: Subtidal sands and gravels (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Subtidal sand and gravel habitats occur in a wide variety of environments, from sheltered sites (such as sea lochs, enclosed bays and estuaries) to highly exposed conditions (typically the open coast). The particular structure of these habitats ranges from mainly sand, through various combinations of sand and gravel, to mainly gravel. While very large areas of seabed are covered by sand and gravel in various mixes, much of this area is covered by only very thin deposits over bedrock, glacial drift or mud. The strength of tidal currents and exposure to wave action are important determinants of the topography and stability of sand and gravel habitats (UK Biodiversity Partnership 2010).

Review of Ecosystem Processes

Formation of species habitat and species diversification

In general, the presence of benthic invertebrates in sedimentary habitats increases habitat complexity through the creation of tubes and burrows (Paramour and Frid 2006 and references therein). Offshore circalittoral mixed sediment habitats support a relatively diverse and abundant benthic fauna, with high densities of infaunal polychaete (worm) and bivalve species (Paramour and Frid 2006 and references therein). In contrast, offshore circalittoral sand habitats are characterised by a diverse range of polchaetes (worms), amphipods (small crustaceans), bivalves and echinoderms (e.g. brittle stars and sea urchins) (Paramour and Frid 2006 and references therein). In offshore circalittoral sand habitats, the high densities of one tube-building polchaete, *Owenia fusiformis*, has been shown to increase the number and abundance of other polychaetes, as their tube structures provide refuge from predators and improve sediment stability (a factor influencing biodiversity) (Paramour and Frid 2006 and references therein). Fine sand sediment can also provide refuge for juvenile flatfish, which are able to bury themselves in the sand to avoid predators (Paramour and Frid 2006 and references therein). Offshore circalittoral coarse sediment habitats tend to have benthic communities that are lower in diversity and abundance compared to more 'stable' sand or gravel habitats (Paramour and Frid 2006 and references therein).

Many commercially targeted fish species, such as Atlantic cod and sand eels, utilize coarse (sand and gravel) sedimentary habitats. For example, gravel habitats provide spawning substrate for the eggs of some demersal fish species and act as nursery grounds for other fish species (e.g. juvenile cod and haddock in Georges Bank, northwest Atlantic (Collie and others 2005). Gregory and others (1997) showed that juvenile cod in Placenta Bay (Newfoundland) were associated with specific habitats; 80% of 2-4 year old cod associated with areas of coarse substrate and high bathymetric relief (i.e. submarine cliffs) while 59% of age 1 cod were found primarily in areas of gravel substrate with low relief.

Biogeochemical cycling

The recycling of nutrients and initial transfer of energy in marine systems is performed mainly by microorganisms. In benthic habitats, the activities of microorganisms are enhanced by macroinvertebrates through their burrowing and burrow-irrigation activities. Burrowing promotes the return of mineralised nutrients to the overlying seawater at a faster rate than diffusion alone (Paramour and Frid 2006). Permeable sands are efficient particulate organic matter filters and accelerate the mineralization of organic carbon and recycling nutrients. For example, in the North Sea (southern German Bight) Ehrenhauss and others (2004) demonstrated that biogenic silica and organic matter are rapidly degraded in permeable coastal sands revealing that these sediments are very active sites of nutrient recycling. Sedimentary fauna influence global carbon dioxide dynamics, and hence climate, through their feeding and mixing activities (Snelgrove 1999).

Food Web Dynamics

In general, the benthic invertebrates of sediment habitats can be major dietary components of commercially targeted fish and shellfish species which feed on these organisms either as juveniles or adults (Snelgrove 1999). Amphipods, decapods, polchaetes and echinoderms dominated the diet of Atlantic cod, haddock, dab, plaice and sole (Paramour and Frid, 2006 and references therein). Hence the benthic (bottom dwelling) organisms of sedimentary habitats form an important part of the food chain and transfer organic carbon back into the pelagic realm (Snelgrove 1999). Sandeels, which are found in subtidal sand habitats, are an important food resource for birds and fish (Paramour and Frid 2006).

Waste assimilation

In general, fauna residing in sediments can influence the concentration and distribution of pollution by pelletizing sediment as faeces or stabilising sediment through mucus excretion (Snelgrove 1999). Animals within the sediment can therefore affect the likelihood of sediment bound pollutants being resuspended and transported elsewhere (Snelgrove 1999). Vertical mixing of sediments by macrofauna (animals larger than 300µm) which move through, or move, sediment as they feed can influence the likelihood of pollutants being buried (Snelgrove 1999). Microbes inside the burrows of the brittlestar (*Amphiura filiformis)* were observed to degrade polyaromatic hydrocarbons at a rate double to that on the sediment surface in offshore circalittoral sand habitats (Granberg and others 2005 cited in Paramour and Frid 2006).

Review of Beneficial Ecosystem Services

Fisheries and aquaculture

In general, the food web dynamics of sedimentary habitats support commercially targeted fish and shellfish species (Snelgrove 1999) and many commercially important fish species utilise coarse sedimentary habitats (subtidal sand and gravel) as spawning and nursery grounds. The benthic communities found within 'offshore circalittoral mixed sediment' habitats are recognised as an important food source for valuable fish species while sandeels, which are found in subtidal sand habitats, are harvested for the production of feed pellets for aquaculture (Paramour and Frid 2006).

Other

Although no additional direct evidence for beneficial ecosystem services was identified for sheltered muddy gravels, it is assumed that this habitat supports both the regulation of pollution, through influencing pollutant concentrations and distribution (Snelgrove 1999) and environmental resilience, as sedimentary fauna influence the global carbon dioxide dynamics and hence global warming through their feeding and mixing activities (Snelgrove 1999).

40 Tide Swept Channels

Summary

Figure 38 shows the relevant Core Ecosystem Processes and Beneficial Ecosystem Processes and Services that have been identified for tide swept channels. **The beneficial ecosystem processes identified were secondary production and species diversification. No direct evidence of beneficial ecosystem services was found during this review.**

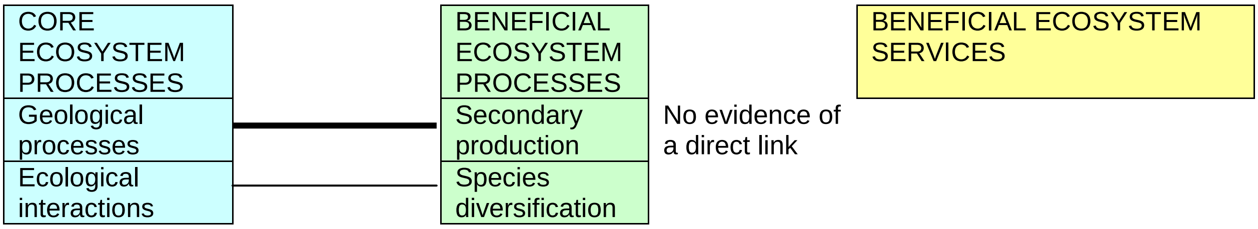

Figure 38 Marine ES Framework: Tide swept channels (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

The conditions which define tide swept channels are broad and encompass a range of habitats (Hill and others 2010 and references therein). In the UK BAP Priority Habitat Descriptions (UK Biodiversity Partnership 2010), tide-swept areas are covered by the term 'tidal rapids', which is used to aggregate a broad range of high energy environments including deep tidal streams and tide-swept habitats. The JNCC`s Marine Nature Conservation Review defined rapids as “strong tidal streams resulting from a constriction in the coastline at the entrance to, or within the length of, an enclosed body of water such as a sea loch”. Depth is usually shallower than 5m. In deeper situations (more than 5m), for example the entrances to fjordic sea lochs, between islands, or between islands and the mainland, particularly where tidal flow is funnelled by the shape of the coastline, tidal streams may generate favourable conditions for diverse marine habitats (UK Biodiversity Partnership 2010). An important range of tidal rapid habitats are found in Scottish and Irish fjordic and fjardic sea lochs, for example, Strangford Lough in Northern Ireland has a long rapids system with very strong tidal streams up to 8 knots (UK Biodiversity Partnership 2010). The Menai Strait, North Wales and the Scilly Isles are also examples of tide-swept communities considered to be of national importance.

Review of Beneficial Ecosystem Processes

Biomass Production: Secondary

Productivity in tide swept channels can be significant as the tide replenishes food regularly, encouraging the growth of suspension feeders (Hill and others 2010 and references therein). For example, measurements of flow and chlorophyll concentrations in the Menai Strait revealed that the strong flow (about 500 m^3 per second) transported phytoplankton from the open sea into the channel where much of it was consumed by suspension feeders, mainly in commercial beds of *Mytilus edulis* (blue mussels) (Simpson and others 1979).

Species diversification

Tide swept channels are characterised by diverse assemblages of attached and encrusting fauna, including a wide range of filter and suspension feeding organisms such as sponges, ascidians (sea squirts), tube building polychaete worms and bryozoans (sea mats), soft corals, hydroids (sea firs), sea anemones and mussels, which receive a large supply of water borne particles as food supply (Hill and others 2010). Hydroid species may form turf on tide and wave swept rock. In shallower areas where light conditions are suitable algae and kelp may be present (Hill and others 2010).

Review of Beneficial Ecosystem Services

No direct beneficial ecosystem services were identified.

41 Starlet sea anemone (*Nematostella vectensis*)

Summary

Figure 39 shows the Core Ecosystem Processes, Beneficial Ecosystem Processes and Beneficial Ecosystem Services that have been identified for the Starlet sea anemone (*Nematostella vectensis*). **The only beneficial ecosystem process identified was food web dynamics. No beneficial ecosystem services were identified.**

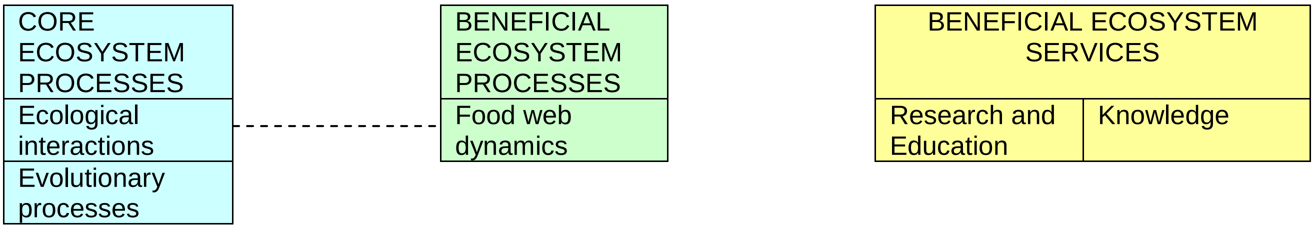

Figure 39 Marine ES Framework: Starlet sea anemone (Nematosella vectensis) (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

The starlet sea anemone, *Nematostella vectensis*, is found in sheltered brackish habitats on the Atlantic and Pacific coasts of North America and within saline lagoons on the south and east coasts of England. In the UK, the species is limited to relatively few sites (Sheader and others 1997). The species is listed as *Vulnerable* by IUCN/WCMC and *Rare* on the GB Red List and is protected under Schedule 5 of the Wildlife and Countryside Act 1981 (UK Biodiversity Partnership 2010). UK populations are currently considered to be a female clone, indicating the possibility of a non-native introduction (Pearson and others 2002).

Review of Ecosystem Processes

Food Web Dynamics

The species is a predator of other lagoonal invertebrates at various stages in the life cycle (Sheader and others 1997).

Review of Ecosystem Services

Research

The remarkable amenability of this species to laboratory manipulation has made it a productive species for exploring cnidarian development. A proliferation of molecular and genomic tools, including the currently ongoing *Nematostella* genome project, further enhances the usefulness of this species. In addition, the ease with which *Nematostella* populations can be investigated within their natural ecological context suggests that research into this species may be expanded to address important questions in molecular and evolutionary ecology (Darling and others 2005; Sullivan and others 2006).

42 Sunset Cup Coral (*Leptopsammia pruvoti*)

Summary

Figure 40 shows the Core Ecosystem Processes, Beneficial Ecosystem Processes and Beneficial Ecosystem Services that have been identified for the Sunset Cup Coral *Leptopsammia pruvoti*. **The only beneficial ecosystem process identified was formation of species habitat. The beneficial ecosystem services identified were recreation/sport, nature watching and research and education.**

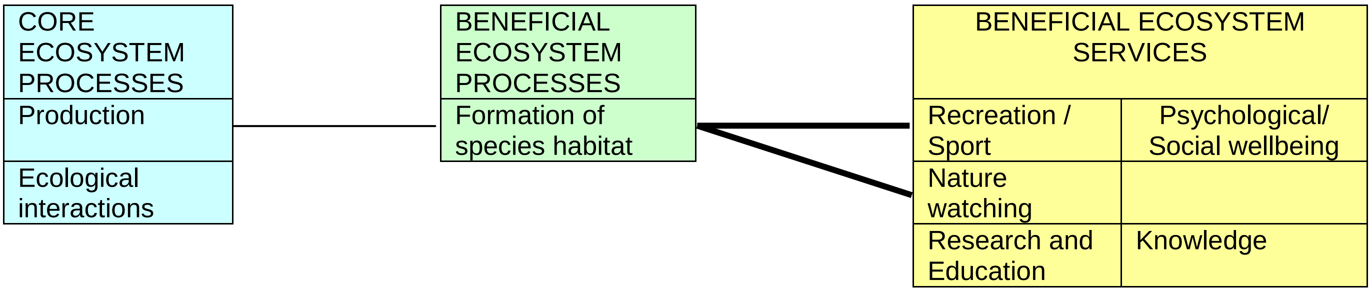

Figure 40 Marine ES Framework: Sunset Cup Coral (Leptopsammia pruvoti) (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Leptopsammia pruvoti, the sunset cup coral, is a slow growing, long lived (40-100 years) coral that often lives in small groups of 10 to over 200 or as solitary individuals (Hill and others 2010). It attaches to rock in caves, gullies and overhangs where there are light currents in the shallow sublittoral to a depth of 40m (Hill and others 2010). This species is a UK BAP priority marine species and is considered nationally rare. This species has only been recorded in Portland Bill, Lyme Bay, off Plymouth Sound, the Isles of Scilly and Lundy in Britain (Jackson 2008).

Review of Beneficial Ecosystem Processes

Formation of species habitat

L. pruvoti provides substratum (and hence habitat) for the barnacle *Bosica anglica* and is also bored into by the horseshoe worm (*Phoronis hippocrepia)*, the fan worm (*Potamilla reniformis),* and the bivalve (*Hiatella arctica)* which further enlarges these boreholes (Irving 2004 and references therein; Jackson 2008).

Review of Beneficial Ecosystem Services

Recreation / Nature Watching

Species such as *L. pruvoti* attract divers to areas where they are found, such as Lyme Bay and Lundy (Rees and others 2010).

Research and education

Corals and sponges are the most studied groups of benthic invertebrates in marine chemical ecology according to Marti and others (2005).

43 Gooseneck Barnacle (*Mitella pollicipes*)

Summary

Figure 41 shows the Core Ecosystem Processes, Beneficial Ecosystem Processes and Services that have been identified for the Gooseneck Barnacle *Mitella pollicipes*. **The beneficial ecosystem processes identified were secondary production, food web dynamics and the formation of species habitat. The only beneficial ecosystem service identified was fisheries.**

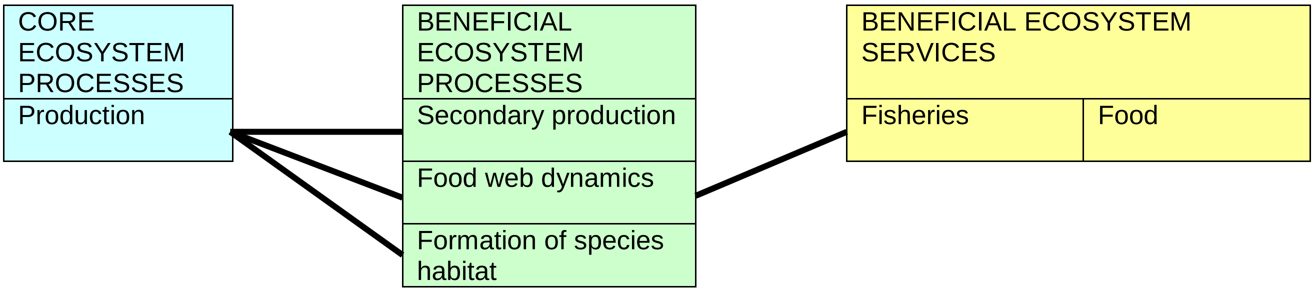

Figure 41 Marine ES Framework: Gooseneck barnacle (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Mitella pollicipes, the gooseneck barnacle (also known under the synonym *Pollicipes pollicipes*), is a stalked barnacle that grows up to 30 cm on the lower rocky shore and subtidally, where there is a suitable hard substratum, deep crevices, or overhangs. The coasts of south-west England and south-west Ireland mark the northern most boundary of the gooseneck barnacle's range, as it is mostly found in warmer waters off France, Spain and Portugal (Southward 2008). They are a UKBAP Priority Species and species of principal importance for the purpose of conservation of biodiversity under the Natural Environment and Rural Communities Act 2006 (Natural England 2010).

Review of Beneficial Ecosystem Processes

Biomass Production: Secondary

The biomass production of *M. pollicipes* is thought to support commercial fisheries (Borja and others 2006). Borja and others (2006) determined that the average biomass of this species in the Gaztelugatxe Marine Reserve, northern Spain, was 3.3-4.3kg per m^2, with a maximum production of 10.6kg per m^2. Very few individuals, however, are currently found in the UK (Southward 2008).

Food Web Dynamics

M. pollicipes is predated on by various species, for example seabirds, dog whelks and some crab and starfish species (Hill and others 2010).

Formation of species habitat

Adults of *M. pollicipes* are often seen with algae, bryozoans (sea mats) and lamellibranchs (bivalve molluscs) attached to them. They may also be host to juvenile *M. pollicipes* and adults of other barnacles which may settle on the stalk or main body (Barnes 2009).

Review of Beneficial Ecosystem Services

Fisheries

In some regions of Europe, *M. pollicipes* is targeted commercially and mainly harvested for the Spanish and Portuguese domestic markets (Cardoso and Yule 1995; Molares and Freire 2003). Borja and others (2006) cited the harvest of *M. pollicipes* in Brittany, France to be between 100-300 tonnes per year and the harvest in Galicia, Spain to be approximately 100 tonnes per year with plans for a future harvest of 600 tonnes per year (Borja and others 2006 and references therein). UK populations are less frequent and are not commercially exploited.

44 Spiny lobster (*Palinurus elephas*)

Summary

Figure 42 shows the Core Ecosystem Processes, Beneficial Ecosystem Processes and Services identified at for Spiny lobster. **The only beneficial ecosystem process identified was secondary production. The only beneficial ecosystem service identified was fisheries.**

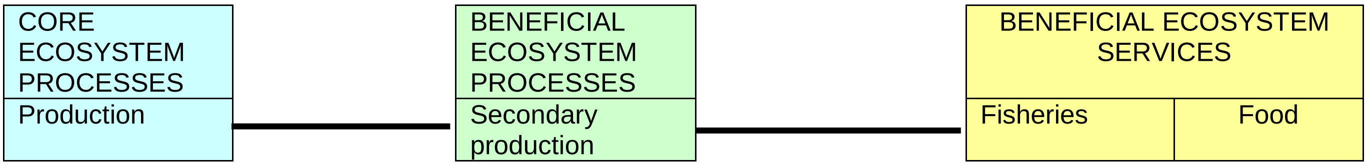

Figure 42 Marine ES Framework: Spiny Lobster (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Palinurus elephas (European spiny lobster, also sometimes referred to as Crayfish or Crawfish) is a large spiny lobster, growing up to 60 cm in total length. This species lives subtidally on rocky, exposed coasts at depths typically 5-70m, but has also been recorded as deep as 170m. The main populations are confined to rocky bottoms on the west coast of Scotland, the extreme south-west coasts of England and Wales, and the west coast of Ireland. Only occasional occurrences have been noted elsewhere (Jackson and others 2009).

Review of Beneficial Ecosystem Processes

A review of peer-reviewed and grey literature did not provide any evidence of beneficial ecosystem processes for this specific species; however, it is assumed that secondary production does occur.

Review of Beneficial Ecosystem Services

Fisheries

P. elephas is of commercial value in the Atlantic and Mediterranean (Galhardo and others 2005 cited in Hill and others 2010) and is the most commercially important spiny lobster species in the Mediterranean and the North East Atlantic (Jackson and others 2009). Goni and Latrouite (2005) reviewed national fisheries for this species and described the fisheries in the UK which targeted *P. elephas* as being restricted to Cornwall and Western Wales with occasional catches from the Scottish Western Isles, with tangle and trammel netting being the principal means of capture rather than the traditional method of using pots. The Irish fishery comprises a small fleet of 20-25 vessels which targeted *P. elephas* from May to September with trammel nets, although by catch in static net fisheries and to a lesser extent trawls also occurs (Goni and Latrouite 2005 and references therein).

45 Fan mussel (*Atrina pectinata*)

Summary

Figure 43 shows the Core Ecosystem Processes, Beneficial Ecosystem Processes and Services that have been identified for Fan mussel. **The beneficial ecosystem process identified were species diversification and formation of species habitat. Beneficial ecosystem services identified were fisheries and ornamental materials.**

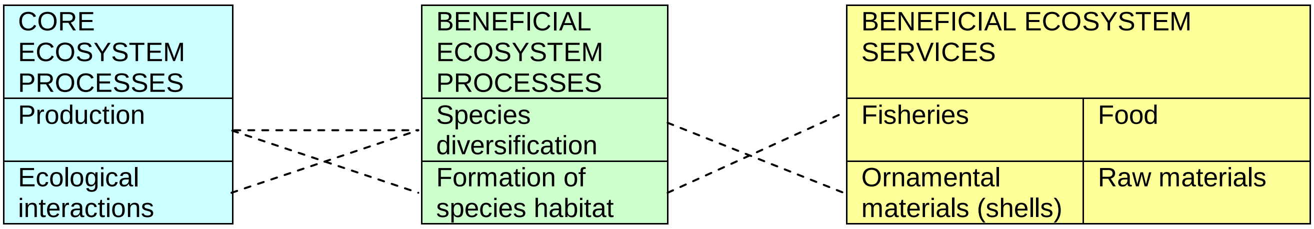

Figure 43 Marine ES Framework: Fan mussel (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Atrina pectinata, the fan mussel is found buried, either individually or in groups, within mud, sandy mud or silty sediments or attached to shell and stones by its byssus threads (Hill and others, 2010). The recorded distribution of *A. pectinata* is predominantly the southern and western shores of the UK from North Scotland to the Iberian Peninsula, including the Channel Islands, although the present distribution and abundance is likely to be greatly reduced compared with the historical abundance (Tyler-Walters and Wilding 2009). *A. pectinata* is a nationally scarce marine species, a UK BAP species and is protected under the Wildlife and Countryside Act 1981. The species was formerly known as *Atrina fragilis*.

Review of Ecosystem Processes

Formation of species habitat

This species may provide substratum for other organisms (Tyler-Walters and Wilding 2009). Studies in the Gulf of Venice found that encrusting organisms may settle on *A. pectinata* and that the mussel may help recruitment of other bivalves, such as scallops, to an area (Hall-Spencer 1999).

Species diversification

The ecology of *A. pectinata* has not been studied in the UK, but research conducted in New Zealand on a closely related species *Atrina zelandica* (the New Zealand Fan Shell) has indicated that dense populations of *A. zelandica* modify the physical structure and biogeochemical cycling of the habitat by adding complexity to sediment habitats, altering near-bed hydrodynamics and through the production of organically rich biodeposits (i.e. production of large quantities of faeces and pseudofaeces) with subsequent major effects on local biodiversity and ecosystem functioning (Hughes and Nickell 2009 and references therein). For example, seafloor sediments within 10cm of *A. zelandica* were shown to be enriched in carbon and nitrogen, compared to sediments over 30cm away, and to have more diverse and abundant macrofaunal assemblages (Norkko and others 2001).

In an assessment of the ecological importance of *A. pectinata* in Scottish waters, Hughes and Nickells (2009) state that it is unlikely that any *Atrina pectinata* populations exist in Scottish waters at densities able to exert such significant ecosystem effects. Tyler-Walters and Wilding (2009) note that any such effects of *A. pectinata* on benthic community structure are likely to be reduced in comparison to *A. zelandica*, due to the far lower densities of *A. pectinata* in the UK.

Review of Ecosystem Services

Fisheries

Due to its ability to form habitat for other species it is thought that *A. pectinata* may indirectly support commercial scallop fisheries.

Ornamental materials (shells)

Populations of *A. pectinata* exist in deep mud in the Bay of Concarneau (France) where they are dredged to sell as curio shells (expert opinion).

46 Ocean quahog (*Arctica islandica*)

Summary

Figure 44 shows the Core Ecosystem Processes, Beneficial Ecosystem Processes and Services that have been identified for the Ocean Quahog (*Arctica islandica*). **The beneficial ecosystem processes identified were secondary production and food web dynamics. The beneficial ecosystem services identified were fisheries and research.**

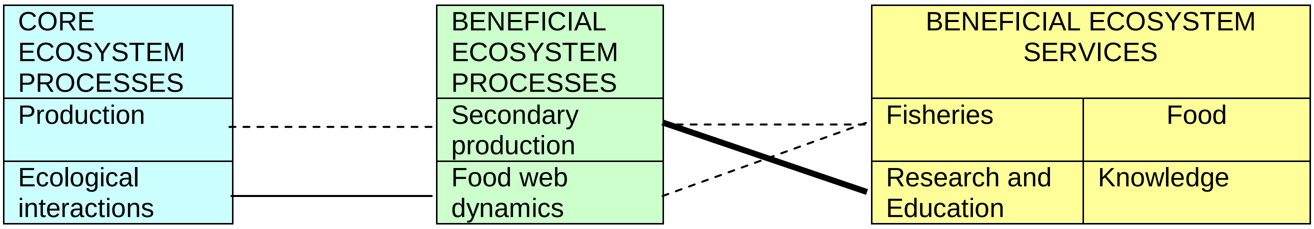

Figure 44 Marine ES Framework: Ocean Quahog (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Arctica islandica (Ocean Quahog) is an infaunal filter feeding bivalve mollusc found buried in sediment on sandy and muddy sand from the low intertidal down to 400m (OSPAR 2008). It is a long-lived species with a very slow growth rate. The species occurs on both sides of the North Atlantic and in the Baltic Sea. Within the North East Atlantic it has a distribution that extends from Iceland and the Faroes, to the Bay of Biscay, and includes the Irish Sea and North Sea (OSPAR 2008).

Review of Beneficial Ecosystem Processes

Biomass Production secondary:

Brey and others (1990) investigated the growth of *Arctica islandica* in Kiel Bay, Western Baltic. The annual production in Kiel Bay was estimated to be 15g ash free dry weight per m^2 and accounted for about 40% of the estimated annual benthic community production (Rees and Dare 1993).

Food web dynamics

Arctica islandica has a range of predators including haddock, ocean pout and various crustaceans (Hill and others 2010). It is an important food source for cod (*Gadus morhua*) in the Baltic (Sabatini and Pizzolla 2008). For example, it was estimated that 40% of the annual production of cod in Kiel Bay (Western Baltic) was dependent on *A. islandica* in the period 1970-1985 (Brey and others 1990 cited in Sabatini and Pizzolla 2008). *Arctica islandica* has also been found in the stomach of North Sea cod (Rees and Dare 1993 and references therein).

Review of Beneficial Ecosystem Services

Fisheries

A. islandica is commercially fished in the United States and Iceland (Sabatini and Pizzolla 2008).

Research

A. islandica has been recognised as a particularly important long term monitor of ocean conditions on the continental shelf owing to its longevity (200+ years), abundance and wide geographical distribution throughout the northern North Atlantic Ocean. For example, Weidman and others (1994) showed that analysis of the annual banding pattern of *Arctica islandica* shells could be used to reconstruct within and between year records of the continental shelf bottom temperature. Similarly, Stott and others (2009) have described a potential method for reconstructing past marine environmental and climatic variability in Scottish coastal waters through investigating the annual growth of *A. islandica* shells. Liehr and others (2005) investigated the use of *Arctica islandica* as a bioindicator for contaminated sediments at two sites in the western Baltic Sea and concluded that the shells of this species can be used as an indicator for heavy metal accumulation in pollutant biomonitoring research. The results indicated that the shells were more suitable for reflecting historical contamination events than the soft body tissue.

47 Couch's goby (*Gobius couchi*)

Summary

Figure 45 shows the Core Ecosystem Processes, Beneficial Ecosystem Processes and Services that have been identified for Couch's goby. **The only beneficial ecosystem process identified was food web dynamics. The only beneficial ecosystem service identified was nature watching.**

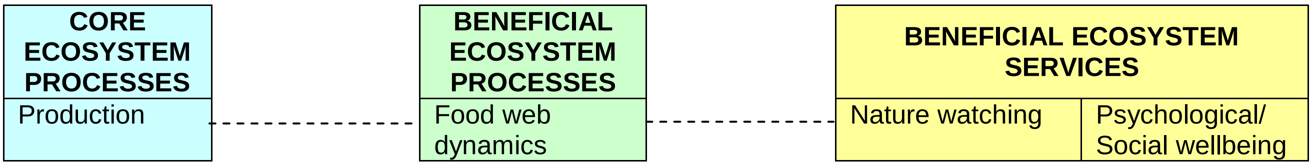

Figure 45 Marine ES Framework for Couch's goby (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Gobius couchi is found in the lower intertidal and inshore waters, under stones or algae on sheltered muddy sand. *G. couchi* is a typically shaped goby, reaching a maximum of 9cm in length. It is fawn-brown to grey in colour with dark markings on its back. This species has only been recorded from four locations in the British Isles: Helford in south Cornwall; Portland Bill, Dorset; Lough Hyne, County Cork, Ireland; and Mulroy Bay, County Donegal, Ireland.

Review of Beneficial Ecosystem Processes

Food Web Dynamics

Due to their small size (<8 cm), the diet of *G. couchi* is limited to polychaetes, algae, crustaceans and bivalves (Miller 1986; Costello 1992).

Review of Beneficial Ecosystem Services

Nature Watching

In Southern Europe *G. couchi* is frequently encountered in rock pools (Miller 1986).

48 European eel (*Anguilla anguilla*)

Summary

Figure 46 shows the Core Ecosystem Processes, Beneficial Ecosystem Processes and Services that have been identified for European eel. **The beneficial ecosystem processes identified were secondary production, larval/gamete supply, and food web dynamics. The beneficial ecosystem services identified were fisheries, aquaculture, and recreation/sport.**

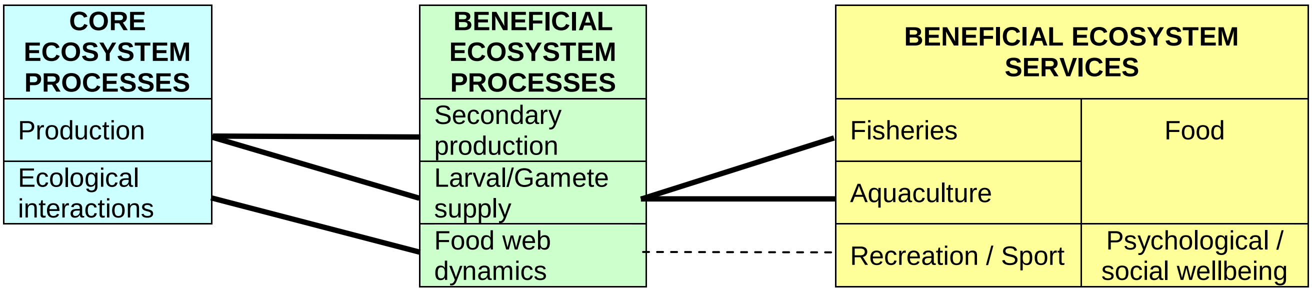

Figure 46 Marine ES Framework for European eel (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

European eels are fished commercially, but over-harvesting has contributed to the decline in eel numbers, as has pollution, hydropower dams and parasites. The quantity of juvenile eels has been reduced to no more than 5% of the numbers recorded in the 1970s. The number of adults is thought to have declined by 80% in the past 60 years. Once in decline, their numbers take a long time to recover, as is the case with other long-lived, slow growing animals (Natural England 2010).

Review of Beneficial Ecosystem Processes

Biomass Production: Secondary

There is no published estimate of the overall eel biomass production in the UK however, it has been reported that some populations of European eel have declined 75-95% since the 1980s (Aprahamian and Walker 2008). Eel biomass is estimated during their freshwater phase and is reported on catchment basis (Aprahamian and Walker 2008). In other European rivers, eel biomass is reported to vary greatly between catchments with mean populations ranging from 3-39 eels per $100/m^2$ (Acou and others 2009). Yellow and silver eel indices suggest that the current estimate of stocks derived from these data are 20% of those of the late 1980s and mid 1990s (Aprahamian and Walker 2008).

Larval/Gamete supply

In the UK, estimates of annual catches of glass eels/elvers over the last three decades range from 4-100 tonnes per year (Aprahamian and Walker 2008).

Food Web Dynamics

Eels prey on benthic invertebrates with a diet dominated by larval Ephemeroptera and Trichoptera. Typically eel diet will be divided into 1% zooplankton, 12% fish and 87% zoobenthos. During their freshwater phase, eels will be predated by top predators such as pike or otters, which select eels preferentially (Miranda and others 2008).

Review of Beneficial Ecosystem Services

Fisheries

In the UK, the estimated annual catches of glass eels/elvers over the past three decades have been fairly variable but have been below 1-2 tonnes per year since 2001 (Aprahamian and Walker 2008). This can be compared with catches of glass eel around to 10-70 tonnes per year in the 1970s and 1980s. Around 1100 glass eel licenses were sold annually in England and Wales from 1980 to 1994, increasing to around 2500 in 1998, but has declined to about 800 since 2001 (Aprahamian and Walker 2008).

Aquaculture

European eels are not farmed as such but larvae (glass eels/elvers) are collected from wild populations and grown in aquaculture facilities. Across Europe, eels support a fairly large aquaculture production.

Recreation / Sport

Across Europe eels are a popular angling species.

49 Giant goby (*Gobius cobitis*)

Summary

Figure 47 shows the Core Ecosystem Processes, Beneficial Ecosystem Processes and Services that have been identified for Giant goby. **The only beneficial ecosystem process identified was food web dynamics while the beneficial ecosystem services identified were environmental resilience and recreation/sport.**

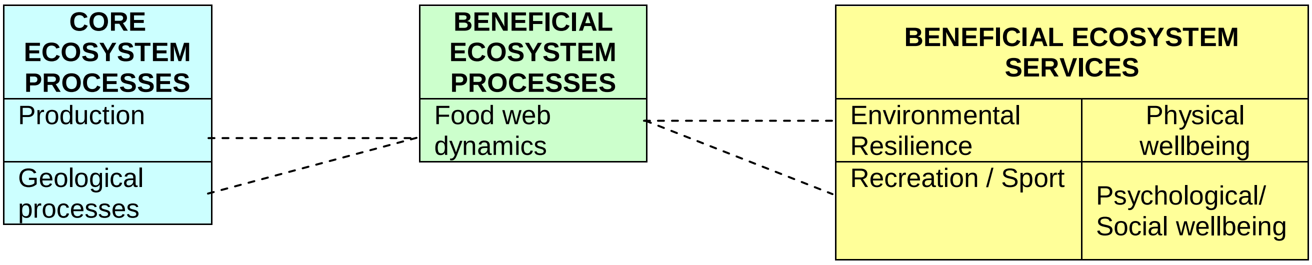

Figure 47 Marine ES Framework for Giant goby (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Gobius cobitus occurs primarily in intertidal zones, among rocks, weeds and pools where the water is usually brackish. Their diet is based upon green algae (*Enteromorpha*), crustaceans (amphipods, crabs), polychaetes, and insects (Miller 1986, 1990; Maugé 1986). Larger fish have been reported as predating on other fishes (Faria and Almada 2009).

Review of Beneficial Ecosystem Processes

Food Web Dynamics

Studies in Portugal suggest that *G. cobitus* provide a food source for marine feeding otters, although the otters tend to predate mainly on other species (Beja 1995).

Review of Beneficial Ecosystem Services

Nature Watching

As *G. cobitus* is frequently encountered in rock pools (Faria and Almada 1999; Perez-Ruzafa and others 2006), they are a fish typically captured by children using a small hand net.

Environmental resilience

Populations are relatively resilient to change in both their physical environment (Perez-Rufaza and others 2006) and changes in population number (Faria and Almada 1999). For example, following their physical removal from rock pools, the numbers of fish in the rock pools returned to their former levels in a ‘few’ weeks (Faria and Almada 1999).

50 Seahorses (Hippocampus hippocampus and Hippocampus guttulatus)

Summary

Figure 48 shows the core ecosystem processes, beneficial ecosystem processes and services that have been identified for seahorses (*Hippocampus hippocampus* and *Hippocampus guttulatus)*. **The beneficial ecosystem process identified were larval/gamete supply and food web dynamics. The only beneficial ecosystem services identified was nature watching.**

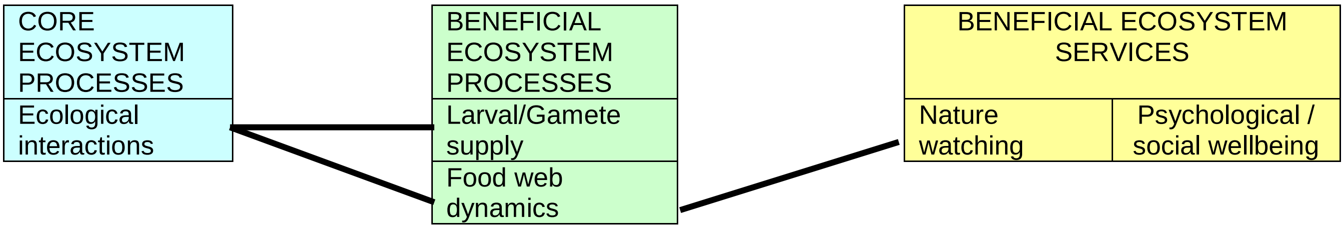

Figure 48 Marine ES Framework for Seahorses (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

There are two species of seahorses in the UK, the short-snouted seahorse (*Hippocampus hippocampus)* and the spiny seahorse (*Hippocampus guttulatus). H. hippocampus* is distributed from the Shetland Islands to the south coast of England and from the North Sea to Southwest England, Channel Islands and Ireland (Garrick-Maidment 1988). They are found in shallow muddy waters, in estuaries or inshore amongst seaweed and seagrasses (Garrick-Maidment 1988; 2007). *H. hippocampus* can also be found in rocky areas. *H. guttulatus* is found around the south and south west coasts of Britain and Ireland, and on the western coasts of Orkney and Shetland, where they favour shallow waters (Neish 2007). *H. guttulatus* is predominantly associated with seagrass (*zostera* spp.) whereas *H. Hippocampus* has a broader range of habitats (Garrick-Maidment and others 2010).

Review of Beneficial Ecosystem Processes

Larval/Gamete supply

Seahorses spawn from April to October. Males carry the eggs in a brood pouch which is found under the tail. *H. guttulatus* in Studland Bay, Dorset, UK, is reported as having five broods per year (Garrick-Maidment and others 2010).

Food Web Dynamics

The diet of seahorses is known to largely consist of crustacean, including amphipoda, decapoda and mysidacea (Kitsos and others 2008) with these three prey categories accounting for 80% of the diet of *H. hippocampus*.

Review of Beneficial Ecosystem Services

Nature watching

It is thought that seahorses may encourage snorkelling and diving to view this species, although there is no formally recorded evidence to support this assertion.

51 Smelt (Osmerus eperlanus)

Summary

Figure 49 shows the core ecosystem processes, beneficial ecosystem processes and services that have been identified for smelt. **The only beneficial ecosystem process identified was food web dynamics. The beneficial ecosystem services identified were fisheries and recreation / sport.**

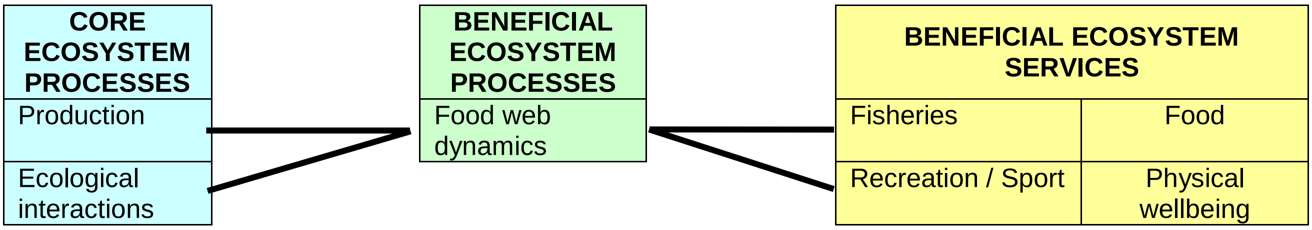

Figure 49 Marine ES Framework for Smelt (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Smelt (*Osmerus eperlanus)* are shoaling fish, distantly related to the salmon. They are found in estuaries and around the mouths of rivers. During May to August the smelt come upriver to spawn in fresh water before returning to the sea. Smelt are silvery-green in colour and usually around 20cm long, although they can grow to twice that length. Most of the recorded populations in Scotland are now extinct, as are a third of those from estuaries in England and Wales. Populations can recover in areas where several estuaries interconnect, as one can restock another. However, once smelt have become locally extinct from isolated estuaries, they will not return (Natural England 2010).

Review of Beneficial Ecosystem Processes

Food Web Dynamics

The food web dynamics of *O. eperlanus* is dependent on the body size of individuals. Smaller smelt tend to feed on shrimps and small crustaceans whilst larger smelt predate on smaller fishes (Ivanova 1978; Billard 1997; Rochard and Elie 1994). Where *O. eperlanus* populations are located in brackish waters, such as in transitional waters, their feeding on micro-crustacea may impinge on other fish species and cause dietary shifts through competition (Lammens and others 1985). They can contribute a high proportion to the diet of fish eating birds, although this can result in declines in their population abundance (Van Eerden and others 1993).

Review of Beneficial Ecosystem Services

Fisheries

Osmerus eperlanus is a fish commonly found in coastal areas of the UK, including transitional waters. Consequently, artisanal fisheries that operate in these areas may regularly exploit smelt (Maitland 2003). During late spring, spawning migrations into the lower reaches of rivers occur which may result in high exploitation. Catch statistics on *O. eperlanus* in the UK are scarce and lack detail. Maitland (2003) reports that in some rivers in Norfolk and Suffolk, established fishermen are capable of catching, on a sustainable basis, between 3 and 6 tonnes per annum, but newer fishermen using practises that are not sustainable are jeopardising this. Consequently, it is apparent that local populations may be vulnerable to high fishing pressure. The captured fish are used for eating and for baits used in recreational angling.

Recreation / Sport

Although *O. eperlanus* is not itself exploited for recreational angling, it is a very popular bait fish for the freshwater northern pike (*Esox lucius*) and is used in large quantities in the UK for this purpose (Maitland 2003).

52 Undulate ray (*Raja undulata*)

Summary

Figure 50 shows the core ecosystem processes, beneficial ecosystem processes and services that have been identified for Undulate ray. **The only beneficial ecosystem process identified was food web dynamics. The only beneficial ecosystem service identified was fisheries.**

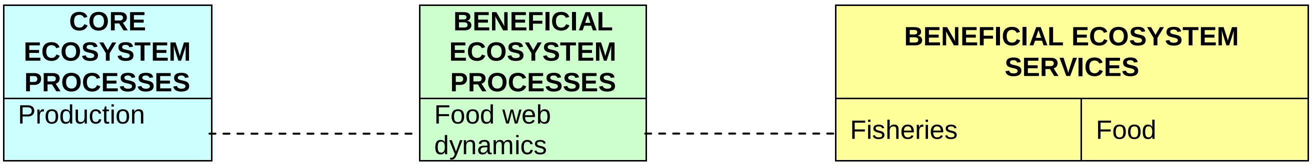

Figure 50 Marine ES Framework for Undulate ray (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

Undulate rays have a vivid pattern of swirling brown stripes and yellow and white spots on their skin, which camouflages them against the sandy seabeds on which they live. Their rounded, flattened bodies grow up to 1m in length, and they have a thin, whip-like tail that is almost the same length again. Their backs and tails are spiny for protection from predators (they are harmless to people), and they also have prickly skin on their underside. Undulate rays are found in comparatively deep water (50-200m depth), and they eat a variety of bottom-dwelling prey including crabs. Undulate rays produce oblong eggs with pointed horns at the corners, and lay them into the sand, mud or gravel seabed. Because they lay only a few eggs they are vulnerable to fishing, as it takes a long time for the population to recover when numbers begin to decline (Natural England 2010).

Review of Beneficial Ecosystem Processes

Food Web Dynamics

The diet of *Raja undulata* changes according to their body size, with rays of less than 550 mm tending to feed on small, semi-pelagic prey and those greater than 550 mm tending to feed on large, benthic prey (Moura and others 2008).

Review of Beneficial Ecosystem Services

Fisheries

It is known that *Raja undulata* has been captured in the trammel net fishery of Southern Portugal, in which *Raja undulata* is the most common species captured. This species is also an important component of by-catch in other fisheries in Southern Europe, some of which are discarded (Baeta and others 2010). However, as it is a species that matures relatively late in life and produces only small numbers of progeny, their vulnerability to exploitation is relatively high (Gibson and others 2006). As a consequence of this, the species received full protection from the European Council under ICES, so now captured fish cannot be retained or landed. No specific information related to *Raja undulata* was identified in the review.

53 Peacock's tail (*Padina pavonica*)

Summary

Figure 51 shows the core ecosystem processes, beneficial ecosystem processes and services that have been identified for Peacock's tail. **The only beneficial ecosystem process identified was climate regulation. The beneficial ecosystem services identified were fisheries, fertiliser/food, medicines, and research and education.**

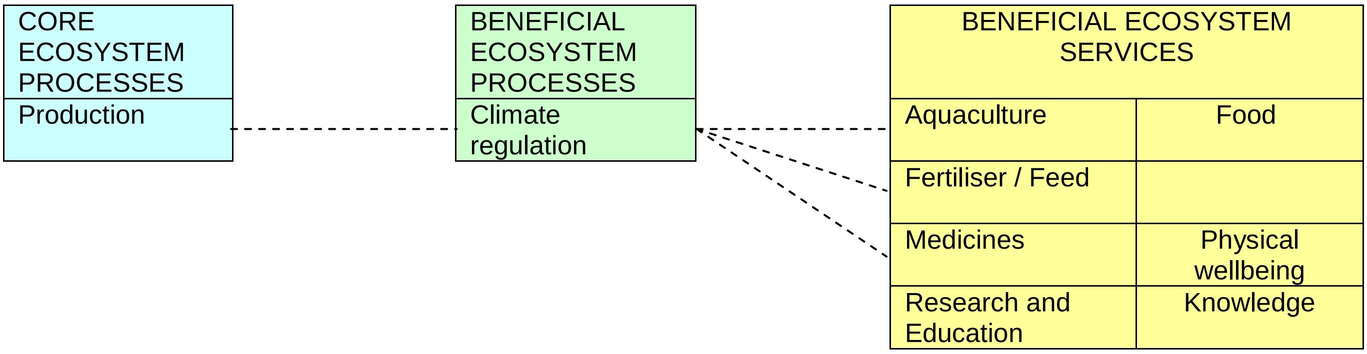

Figure 51 Marine ES Framework: Peacock's tail (solid line indicates evidence is UK related, feature specific and peer reviewed; thin line indicates UK related but grey literature, dashed line indicates overseas papers or expert evidence)

Introduction

The species has a widespread global distribution, particularly in sub-tropical and tropical seas, yet reaches a northerly limit in UK waters, where it is found in rock pools from the High Water Neap tide mark to Low Water Springs, and currently restricted to Devon, Dorset and the Isle of Wight (Price and others 1979; Herbert and others *in Press*). Unsurprisingly, the majority of knowledge and information on the species is from nearer the centre of its geographical range in southern Europe and the Mediterranean. Listed as 'scarce' it is a UKBAP Priority Species due to a long historical record, restricted distribution and potential vulnerability to coastal management interventions (Price and others 1979; Fletcher 1987; Herbert and others *in press*).

Review of Beneficial Ecosystem Processes

Climate regulation

The genus *Padina* has extracellular aragonite crystals and is the only genus of the brown algae that has calcification in its fronds (Littler 1976; Okazaki and others 1986). As with other calcareous algae, this species will have a role as a carbon sink through the uptake of carbon dioxide through photosynthesis and its deposition as calcium carbonate (Nelson 2009). The extent and importance of this process in the context of climate regulation for this species is unknown.

Review of Beneficial Ecosystem Services

Aquaculture

P. pavonica is harvested for the pharmaceutical industry and fertilizer feed products in the Mediterranean, especially around Malta. It is encouraged to settle on specially created limestone slabs deployed sublittorally off the coast. The alga is harvested by divers, who prune the fronds to increase productivity (expert opinion).

Fertilizer / Feed

An extract of the alga obtained through cultivation in the Mediterranean is used as chicken feed to enhance egg shell growth and as feed in shrimp aquaculture (expert opinion).

Medicines

Algal extract obtained through cultivation in the Mediterranean is used in the pharmaceutical industry (Ktari and Guyot 1999). There have been encouraging clinical trials incorporating the alga into medicine to improve bone mass density in older women (Ktari and Guyot 1999). *P. pavonica* is also valuable for the screening of anti-cancer agents (Ktari and Guyot 1999; Award and others 2008).

Research and education

There continues to be research into the pharmaceutical and agricultural potential of *P. pavonica* algal extracts, particularly its antifungal properties and applications as a fertiliser (Ommezine and others 2009). The dichloromethane extract of the brown alga *P. pavonica* was found to be cytotoxic towards certain tumour cells, which is valuable for screening anti-cancer agents (Ktari & Guyot, 1999; Award and others 2008). The use of this species as a bio-indicator of climate change in temperate seas has been suggested in the UK and in Portugal (Lima and others 2007) where shifts in the geographic distribution of this species in response to changing sea temperatures have been, and continue to be, investigated. In the Mediterranean and other sub-tropical regions, there is interest in the use of the alga as a bio-indicator of metal contamination and as a biosorbant for the potential removal of metals, especially cadmium, chromium and lead (Campanella and others 2001; Raize and others 2003).

54 Information gaps

No information was found on the beneficial ecosystem processes or beneficial ecosystem services provided by the following species:

Timid Burrowing Anemone (*Edwardsia timida*)

Bearded red seaweed (*Anotrichium barbatum*)

Stalked jellyfish (Haliclystus auricular)

Stalked jellyfish (Lucernariopsis campanulata)

Stalked jellyfish (Lucernariopsis cruxmelitensis)

Tentacled Lagoon Worm (*Alkmaria romijni*)

Lagoon sandworm (*Armandia cirrhosa*)

Lagoon sea slug (*Tenellia adspersa*)

Defolin’s Lagoon snail (*Caecum amoricum*)

Lagoon sand shrimp (*Gammarus insensibilis*)

Amphipod shrimp (Gitanopsis bispinosa)

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Appendix 1: Marine Features included in the Study

Broad-scale habitats to be protected within MPAs of the MCZ Project area
High energy intertidal rock
Moderate energy intertidal rock
Low energy intertidal rock
Intertidal coarse sediment
Intertidal sand and muddy sand
Intertidal mud
Intertidal mixed sediments
Coastal saltmarshes and saline reedbeds
Intertidal sediments dominated by aquatic angiosperms
Intertidal biogenic reefs
High energy infralittoral rock
Moderate energy infralittoral rock
Low energy infralittoral rock
High energy circalittoral rock
Moderate energy circalittoral rock
Low energy circalittoral rock
Subtidal coarse sediment
Subtidal sand
Subtidal mud
Subtidal mixed sediments
Subtidal macrophyte-dominated sediment
Subtidal biogenic reefs
Deep-sea bed

Marine habitats listed in Annex I the EC Habitats Directive not listed elsewhere
Saline lagoons
Submarine Structures made by leaking gases
Submerged or partially submerged sea caves

Habitats of conservation importance to be protected within MPAs of the MCZ Project area
Blue mussel beds
Cold-water coral reefs
Coral Gardens
Deep-sea sponge aggregations
Estuarine rocky habitats
File shell beds
Fragile sponge and anthozoan communities on subtidal rocky habitats
Intertidal underboulder communities
Littoral chalk communities
Maerl beds
Modiolus modiolus beds
Mud habitats in deep water
Sea-pen and burrowing megafauna communities
Ostrea edulis beds
Peat and clay exposures
Sabellaria alveolata reefs
Sabellaria spinulosa reefs
Seagrass beds

Sheltered muddy gravels
Subtidal chalk
Subtidal sands and gravels
Tide-swept channels

Low or limited mobility species of conservation importance to be protected within the MCZ Project area

Anotrichium barbatum	Bearded Red Seaweed
Cruoria cruoriaeformis	Red seaweed
Dermocorynus montagnei	Red seaweed
Lithothamnion corallioides	Coral Maërl
Padina pavonica	Peacock's tail
Phymatolithon calcareum	Common Maërl
Alkmaria romijni	Tentacled Lagoon-Worm
Armandia cirrhosa	Lagoon Sandworm
Gobius cobitis	Giant Goby
Gobius couchi	Couch's goby
Hippocampus guttulatus	Long snouted seahorse
Hippocampus hippocampus	Short snouted seahorse
Osmerus eperlanus	Smelt
Anguilla anguilla	European eel
Victorella pavida	Trembling sea mat
Amphianthus dohrnii	Sea-fan Anemone
Edwardsia timida	Timid Burrowing Anemone
Eunicella verrucosa	Pink Sea-fan
Funiculina quadrangularis	Tall sea pen
Haliclystus auricular	Stalked jellyfish
Leptopsammia pruvoti	Sunset Cup Coral
Lucernariopsis campanulata	Stalked jellyfish
Lucernariopsis cruxmelitensis	Stalked jellyfish
Nematostella vectensis	Starlet sea anemone
Gammarus insensibilis	Lagoon sand shrimp
Gitanopsis bispinosa	Amphipod Shrimp
Mitella pollicipes	Gooseneck Barnacle
Palinurus elephas	Spiny lobster
Arctica islandica	Ocean quahog
Atrina fragilis	Fan Mussel
Caecum armoricum	Defolin's Lagoon Snail
Ostrea edulis	Native Oyster
Paludinella littorina	Sea snail
Tenellia adspersa	Lagoon sea slug
Raja undulata	Undulate ray

Appendix 2: Keywords used as search terms

When searching using keywords, where appropriate, wild cards were used. These are shortened versions of words that allow for a variety of word endings to be searched. For example, the wildcard 'aquari*' would allow both 'aquaria' and 'aquarium' to be found from the same search.

Aesthetic
Air pollution
Alien species
Angling
Aquaria
Aquculture
Bquaculture
Beach combing
Bequest
Bioalgae
Biodiversity
Biofuels
Biogeochemical
Bioturbation
Birdwatching
Carbon cycling
Carbon sequestration
Climate regulation
Coastal defence
Coastal protection
Connectivity
Convergence zones
Culture
Ecosystem Resiliance
Ecotourism
Environmental education
Environmental education culture
Fertiliser
Fisheries
Fishery
Flooding
Fossil collecting
Gamete supply
Genetic diversity
Geological
Grazing
Green Tourism
Habitat creation
Harvest
Hazard
Hydrodynamic barriers
Hydrological
Invasive species
Legacy
Leisure
Longshore movement
Larval
Managed realignment
Mariculture
Marine Curios
Medicine
Metalloids
Metals
Nature watching
Navigation
Networks
Nuclear
Nuclear Energy
Nutrient cycling
Ornamental
Ownership
Oxygen cycling
Phosphorus
Pollution
Primary
Recreation
Resilience
Secondary
Sediment retention
Sediment sinks
Sediment sources
Sediment transport
Shellfish medicine
Shelter
Sinks
Spillover
Spiritual
Sport
Stability
Storms
Sulphur
Tourism
Trophic
Waste assimilation
Water cycle
Watersports
Wave power
Windpower

Appendix 3: List of experts

The sources of expert opinion used in this report were:

- Justine Saunders, ABPmer
- Caroline Roberts, ABPmer
- Natalie Frost, ABPmer
- Ray Drabble, ABPmer
- Rob Britton, Bournemouth University
- Rudy Gozlan, Bournemouth University
- Roger Herbert, Bournemouth University
- Richard Stillman, Bournemouth University
- Anthony Jensen, National Oceanography Centre, Southampton
- Ian Reach, Natural England
- Charles Saliba, ICP Malta

In addition, expert opinion was provided by Natural England specialists during the interim review of this document.

Appendix 4: Glossary

Benthic	Lives on the seabed
Biofilm	Thin layer of microscopic algae, bacteria and fungi
Biogenic	Something produced by living organisms e.g. a reef
Biogeochemical reactivity	The ability of biological systems to change or utilise chemicals
Biomass	The dry weight of the organisms per unit area
Biota	Living things
Cetaceans	Dolphins and whales
Chitons	Small limpet-like molluscs with a segmented shell
Copepods	Small plankton crustaceans
Desiccation	Drying out
Detritic	Made of dead organic material
Diatoms	Microscopic plant plankton
Emersion	Period of exposure to the air
Epibenthic	Lives on the surface of the seabed
Epibiotic	Lives on the surface of another organism
Epifauna	Animals living on the surface of the sea bed or on other organisms
Eukaryotic	Organisms with complex cells that include animals, plants and algae
Eutrophication	An excess of nutrients
Fauna	Animals
Foliose	Leaf-like structure
Fucoids	Brown algae belonging to the ‘wrack’ family
Gadoids	Family of bony fish that include cod and hake
Gorgonians	Soft coral colonies that are tree or fan-like
Halophytic	Salt tolerant plant
Holdfasts	The base of a seaweed that is used for attachment
Hydrolysis	A chemical reaction with water
Infauna	Animals that live in sediments
Invertebrate	Animal without a backbone
Littoral	The region between high and low tide
Lysis	The destruction of cells
Macroalgae	Large easily visible seaweeds
Macrofauna	Larger sized animals, normally greater than 0.5mm (500µm)
Macroflora	Algae large enough to be visible to the naked eye
Macroinfauna	Larger animals greater than 0.5mm (500µm) that live in sediments
Macroinvertebrates	Larger animals greater than 0.5mm (500µm) without backbones
Meiofauna	Animals between 50-500µm in size
Microalgae	Microscopic algae
Microhabitats	A small, specialised habitat
Microphytobenthic	Film of algae on the surface of seabed
Microphytobenthos	Thin film of algae that live on the surface of seabed
Neritic	The region of the sea between the coastal zone to a depth of 200m
Pelagic	Lives in the water column
Photosynthetic	An organism capable of converting sunlight energy into sugars and oxygen
Physiological stress	Stress on the body
Prokaryotic	Simple organisms that include bacteria
Propagules	Larvae, spores or seeds that can be transported by water or wind
Salinty	Salt content per unit volume of water
Scleractinians	Stony corals
Sessile	Attached or fixed on the seabed or other organism, unable to move
Strandline	Where the last high tide has left seaweed and rubbish
Stylasterids	Lace corals or hydrocorals
Substrate	Any surface where an animal or plant might grow
Taxa	Any group or rank in the classification of organisms

Thalli	The main frond or body of a seaweed
Trophic levels	Feeding groups e.g. herbivores and carnivores
Ungulates	Hoofed animals