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A review of the ecosystem services provided by broad-scale marine habitats in England's MPA network

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ABSTRACT

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This paper presents an analysis of the marine ecosystem services delivered by the broad-scale habitats (EUNIS Level 3) that will be included in England's new Marine Protected Area (MPA) network developed under the Marine and Coastal Access Act (2009). The assessment of ecosystem services was undertaken through a systematic literature review to identify evidence for the existence of either beneficial ecosystem processes or beneficial ecosystem services provided by each broad-scale habitat. The review found that broad-scale marine habitats provide a wide range of ecosystem services, which in turn suggests that their protection genuinely provides both direct and indirect benefits to society. However, there was substantially more evidence of beneficial ecosystem processes than beneficial ecosystem services which potentially reflects the tendency to study how a habitat functions, rather than how it is (or could be) used. In particular, a clear research gap was found related to how marine features are used for sport and recreation, tourism, nature watching and other non-extractive activities. In addition, the role of such habitats in supporting overall environmental resilience was unclear. Despite the variability of the evidence base, this study is significant as it identified, for the first time, the extent of the evidence base for ecosystem services provided by broad-scale marine habitats within England's MPA network.

ADDITIONAL INDEX WORDS: *Marine governance, Marine habitats, Marine conservation, Coastal Management*

INTRODUCTION

This paper presents an analysis of the marine ecosystem services delivered by the broad-scale habitats (EUNIS level 3) that will be included in England's new Marine Protected Area (MPA) network (Table 1). The development of a network of MPAs in England is a requirement of the Marine and Coastal Access Act (2009) and is considered vital to achieving international and national commitments in the Marine and Coastal Access Act, the OSPAR Convention and the Convention of Biological Diversity. The MPA network will consist of existing MPAs, including European marine sites (Special Areas of Conservation, Special Protection Areas), Sites of Special Scientific Interest, and Ramsar sites, and newly designated Marine Conservation Zones (MCZs).

Coastal and marine ecosystems provide ecological functions that directly or indirectly translate to a variety of beneficial aesthetic and economic services of value to society. Examples include the production of food, climate regulation, flood protection, and recreation (Defra 2007; Remoundou 2009). Ecosystem services have been defined in many ways, including "the benefits human populations derive, directly or indirectly, from ecosystem functions" (Costanza *et al.,* 1997), "the benefits people obtain from ecosystems" (MEA 2003); the "services provided by the natural environment that benefit people" (Defra 2007), and "the direct and indirect contributions of ecosystems to human well-being" (TEEB 2009). Clearly, the various definitions of ecosystem services place emphasis upon the beneficial role played by ecosystems in enhancing or maintaining aspects of human well being and thereby human society.

The identification and monitoring of ecosystem services provided by an MPA and an MPA network offers potential benefits to MPA management and governance. For example, MPA management could be aligned with the socio-economic priorities of dependent human communities; socio-economic factors could be rigorously integrated into MPA policy choices; environmental change could be monitored through the altered availability of ecosystem services to society (which may have more resonance with the public); and in a more general sense, ecosystem services provide a mechanism to integrate socio-economic choices with ecological considerations.

There has been considerable debate over how ecosystem services should be classified. This reflects differing interpretations of how social benefits are linked with ecosystem functionality (Constanza 2008; Wallace 2007; Fisher *et al.,* 2008; Swedish Environmental Protection Agency 2008; Fisher *et al*., 2009; Granek *et al*., 2009). Several approaches to the classification of ecosystem services have been proposed which use similar, but distinctive, categories (e.g. Costanza e*t al*., 1997; de Groot *et al*., 2002; eftec, 2006; Frid, 2008). The diversity of classifications results in a lack of consistency and comparability between assessments. This has prompted Fisher *at al*. (2009) to suggest that a single ecosystem service classification will not be applicable in all circumstances and that a specific 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) in 2003. The MEA (2003) categorised ecosystem services as being either: provisioning, regulating, cultural, or supporting. This classification has been complimented as intuitive and highly useful as an educational and policy tool (TEEB, 2009). However, it has been widely criticised as not 'fit for purpose' as it exhibits logical inconsistencies within and between categories, and mixes processes (means) and benefits (ends) (Boyd and Banzhaf, 2007). The MEA classification is therefore particularly prone to the double-counting of benefits (Haines-Young and Potschin, 2007) and so is unable to produce an economically robust valuation of ecosystem services (Fisher *et al*., 2009).

Instead, this study draws from an ecosystem service classification developed through 'The Economics of Ecosystems and Biodiversity' (TEEB) project. The TEEB (2009) ecosystem service classification is based on a distinction between ecological processes and the benefits experienced by humans. It therefore avoids the risk of double counting by separating such benefits from underlying ecosystem processes. The TEEB (2009) classification has three components:

- **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.

Core ecosystem functions are the underlying processes of an ecosystem, such as production, decomposition and nutrient cycling. These support beneficial ecosystem processes, such as primary and secondary production, that directly underpin beneficial ecosystem services. The beneficial ecosystem services, such as fisheries, medicine and recreation, are the benefits directly obtained by society through the functioning of the ecosystem. For every beneficial ecosystem service, there is a combination of beneficial and core ecosystem processes supporting its' provision. Tables 2-4 present the three-tier category definitions used in this study, adapted version of the TEEB (2009) classification. Adaptations were necessary in order to tailor the classification to the marine environment, as in general terms, the TEEB (2009) classification is more suited to terrestrial environments. Such adaptation of ecosystem service classifications to suit a specific application is advocated by Fisher *et al*. (2009).

Table 1. Broad-scale marine habitats included in this study.

Broad-scale marine habitat
Intertidal rock (high, moderate and low energy)
Intertidal coarse sediment
Intertidal sand, muddy sand and mixed sediments
Intertidal mud
Coastal saltmarshes and saline reedbeds
Intertidal sediments (aquatic angiosperms)
Intertidal biogenic reefs
Infralittoral rock (high, moderate and low energy)
Circalittoral rock (high, moderate and low energy)
Subtidal sediment (coarse, sand, mud, mixed)
Subtidal macrophyte-dominated sediment
Subtidal biogenic reefs
Deep-sea bed

METHODS

In order to identify the ecosystem services associated with the broad-scale habitats included in England's MPA network, a systematic review of evidence was undertaken. Once a source was identified, it was evaluated for its relevance to this study. Once accepted into the study, the source was read and the evidence contained therein noted. Evidence directly related to England the UK was prioritised in the searches, but where this was not available or was limited in scope, research from comparable temperate environments was sought. A three-tier approach to finding evidence was used, as follows:

Table 2. Classification of core ecosystem processes (adapted from TEEB, 2009).

Category	Definition
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.
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.
Ecological interactions	Inter- and intraspecific interactions between organisms.
Evolutionary processes	Genetically-based processes by which life forms change and develop over generations.

Table 3. Classification of beneficial ecosystem processes (adapted from TEEB, 2009).

Category	Definition
Primary production	Production of plant biomass.
Secondary production	Production of animal biomass.
Larval/Gamete supply	Transport of larvae and gametes.
Biological control	Interactions resulting in reduced abundance of species that are pests, diseases or invasives.
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.
Erosion control	Control of the processes leading to erosion.
Formation of physical barriers	Formation of structures that attenuate (or block) the energy of water or wind flow.
Formation of pleasant	Formation of seascapes that are

Category	Definition
scenery	attractive to people.
Climate regulation	Modulation of regional/local climate.
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.
Water purification (quality):	Removal of contaminants from water in an ecosystem.

Table 4. Classification of beneficial ecosystem services (adapted from TEEB, 2009).

Category	Definition
Food	From capture fisheries, wild sources, and for fertilizer and feed .
Raw materials	Salt and ornamental materials.
Energy	Biofuels.
Physical wellbeing	From: medicines, natural hazard protection, regulation of pollution, and environmental resilience.
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.

Stage 1: Peer-reviewed literature search. The first stage of the review was a peer-reviewed literature search. Peer-reviewed evidence was considered to be the most reliable form of evidence. Boolean search strings were used to search four academic databases (CAB Abstracts, Scopus, Science Direct, and Web of Knowledge) in order to ensure that all relevant papers were identified. A habitat-specific search was undertaken in each database. Where the search of peer-reviewed sources identified insufficient evidence from which to draw any meaningful conclusions about the beneficial ecosystem processes and services provided by a broad-scale habitat, 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 habitat, a grey literature search was also undertaken. This resulted in a grey literature search being conducted for all broad-scale habitats.

Stage 2: 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, such as Google Scholar. In addition, specific organisational websites were searched which were likely to host relevant evidence sources. Where insufficient evidence of ecosystem services was available from the grey literature, it was concluded that a research gap existed and expert opinion was sought.

Stage 3: 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.

Once all of the evidence was collated (over 400 sources were utilized), it was possible to summarise the beneficial ecosystem processes and beneficial ecosystem services provided by each broad-scale marine habitat. In the following presentation of results, it is important to recognise that the absence of evidence does not necessarily reflect an absence of beneficial ecosystem processes or services. A lack of evidence may simply reflect that a particular aspect of the habitat has not been studied.

RESULTS AND DISCUSSION

Marine habitats were found to provide a wide range of ecosystem services, which suggests that the protection of marine habitats through MPAs and MPA networks provides both direct and indirect benefits to society. Tables 5 and 6 summarise, for each broad-scale marine habitat, the presence and quality of the evidence found for the provision of beneficial ecosystem processes or services as categorised according to the adapted TEEB classification. Where evidence was found, the quality of the evidence is indicated in the tables using a simple 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. Hatching denotes cases in which beneficial ecosystem services have been assumed to exist, regardless of the presence or absence of an evidence base.

The results illustrate that the evidence base for beneficial ecosystem services provided by broad-scale marine habitats is highly variable, with some habitats offering the potential for relatively strong assessments, whereas others have little or no evidence, making ecosystem service assessments somewhat tentative. In contrast, although gaps were identified, the evidence base for the provision of beneficial ecosystem processes by marine habitats was stronger. Specifically, evidence was found to verify the existence of 95 beneficial ecosystem processes and 50 beneficial ecosystem services. Of these totals, peer-reviewed evidence validated 53 beneficial ecosystem processes and 24 beneficial ecosystem services whilst the grey literature validated the existence of 26 beneficial ecosystem processes and 7 beneficial ecosystem services. Expert opinion identified comparable numbers of beneficial ecosystem processes and services (16 and 19 respectively) which reflected the specific nature of the questions posed to the experts rather than the extent of the pre-existing evidence base. Within the evidence base for beneficial ecosystem processes, most evidence was available to support secondary production, larval/gamete supply, food web dynamics, formation of species habitat, and species diversification**.**

Variation in the available evidence base was also found to exist between broad-scale marine habitats**.** Coastal saltmarshes were found to have the most evidence available related to beneficial ecosystem processes and services, with more peer-reviewed evidence available than any other habitat. Additional habitats with relatively strong evidence bases were intertidal biogenic reefs, intertidal sediments dominated by angiosperms, and macrophyte

Table 5: Evidence for beneficial ecosystem processes and beneficial ecosystem services for broad-scale marine habitats protected by England's MPA network.

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													
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													
Water quality regulation													
Biogeochemical cycling													
Water cycling													
Water purification (quality)													
Beneficial Ecosystem Services													
Fisheries													
Other wild harvesting													
Aquaculture													
Fertiliser / Feed													
Salt													
Ornamental materials (shells)													
Biofuels													
Medicines													
Natural hazard protection													
Environmental Resilience													
Regulation of pollution													
Tourism													
Recreation / Sport													
Spiritual/cultural wellbeing													
Aesthetic benefits													
Nature watching													
Aquaria													
Research and Education													

dominated subtidal sediment. Infralittoral rock, circalittoral rock and the deep sea bed exhibited the least extensive evidence bases, with a total of 8 beneficial ecosystem processes and services each. For each of these habitats, the evidence base for beneficial ecosystem processes was considerably stronger than for beneficial ecosystem services. In the case of infralittoral rock and circalittoral rock, the evidence base was primarily derived from the grey literature. In contrast, for deep sea bed habitats, the evidence base was primarily derived from the peer-reviewed literature.

In terms of ecosystem services alone, again, coastal saltmarshes exhibited the greatest range of evidence for ecosystem services, the majority of which was peer-reviewed. However, coastal saltmarshes were the exception as most other broad-scale habitats had weak peer-reviewed evidence for the existence of beneficial ecosystem services with relatively little additional grey or expert evidence. Commercial fisheries were the beneficial ecosystem service with the strongest evidence base, perhaps reflecting its tradition of record-keeping and academic study .

Table 6: The number of adapted TEEB categories for which there was evidence of beneficial ecosystem processes and services for each broad-scale habitat.

	Peer-reviewed		Grey		Expert opinion		
	Processes	Services	Processes	Services	Processes	Services	**Total**
Intertidal rock	4	2	3	0	0	2	**11**
Intertidal coarse sediment	3	0	0	0	2	2	**7**
Intertidal sand and mixed sediments	6	0	0	0	0	4	**10**
Intertidal mud	7	2	1	0	0	1	**11**
Coastal saltmarshes	8	7	2	0	0	0	**17**
Intertidal sediments (angiosperms)	3	4	0	0	4	2	**13**
Intertidal biogenic reefs	1	0	4	4	4	1	**14**
Infralittoral rock	1	1	4	0	1	1	**8**
Circalittoral rock	0	0	5	0	1	2	**8**
Subtidal sediment	7	2	1	1	0	0	**11**
Subtidal sediment (macrophyte)	3	2	4	1	1	2	**13**
Subtidal biogenic reefs	4	3	2	1	2	2	**14**
Deep-sea bed	6	1	0	0	1	0	**8**
Total	**53**	**24**	**26**	**7**	**16**	**19**	**145**

CONCLUSION

Quantifying socio-economic benefits available from marine conservation through the identification of beneficial ecosystem processes and services is potentially useful provided the evidence base is adequate. As this study shows, the evidence base for the existence of ecosystem services from broad-scale marine habitats in England is at present, highly variable. Certain habitats, such as coastal saltmarshes have a reasonably strong peer-reviewed evidence base for the provision of ecosystem services, while other habitats, such as deep seabed, have a relatively weak evidence base primarily grounded in the grey literature. The peer-reviewed evidence base for the provision of beneficial ecosystem processes from broad-scale marine habitats was stronger, yet was also variable in its extent.

The variability of the evidence base can be attributed to differential research effort both in terms of habitat and focus. In many cases, habitat-specific studies focused upon physical and ecological processes (and relationships between them), without considering the potential benefits to society that would arise from those processes. This is perhaps not surprising given the relatively recent emergence of ecosystem services theory and practice. Given that the absence of evidence should not be considered to equate to the absence of beneficial ecosystem processes or services, the variable evidence base presents challenges for marine conservation. With respect to England's MPA network, this study has highlighted that there are uncertainties about the full range of ecosystem services available from an individual MPA and therefore the benefits that an MPA network might provide. In particular, there is a research gap related to how marine features provide benefits to society related to environmental resilience, sport and recreation, tourism, nature watching and other non-extractive activities. More broadly, the variability of the evidence base creates challenges for the use of ecosystem services in marine conservation and MPA governance.

However, where the evidence base for beneficial ecosystem processes and services is strong or a precautionary approach to the existence of beneficial ecosystem services is adopted, it is clear that there is potential to use ecosystem services as a powerful tool in marine conservation and in the governance of an MPA network. Despite the limitations of the evidence base, this study is significant as it has identified, for the first time, the extent of the evidence base for the ecosystem services provided by broad-scale marine habitats in England's emergent MPA network.

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