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Viewpoint

Identification, definition and quantification of goods and services provided by marine biodiversity: Implications for the ecosystem approach

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Abstract

This paper identifies and defines ecosystem goods and services provided by marine biodiversity. Case studies have been used to provide an insight into the practical issues associated with the assessment of marine ecosystem goods and services at specific locations. The aim of this research was to validate the definitions of goods and services, and to identify knowledge gaps and likely difficulties of quantifying the goods and services. A validated theoretical framework for the assessment of goods and services is detailed, and examples of the goods and services at a variety of case study areas are documented. These results will enable future assessments of marine ecosystem goods and services. It is concluded that the utilisation of this goods and services approach has the capacity to play a fundamental role in the Ecosystem Approach, by enabling the pressures and demands of society, the economy and the environment to be integrated into environmental management.

Keywords: Marine biodiversity; Goods and services; Ecosystem Approach; Environmental management

1. Introduction

To ensure environmental decision making is sustainable, efficient and equitable it is essential that all social, economic and environmental impacts of a development, both short and long term, are identified and measured (Daily et al., 2000). The need for this holistic approach is increasingly apparent in environmental policy and is implicit in the Ecosystem Approach. This approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. The term 'Ecosystem Approach' was first applied in a policy context at the Earth Summit in Rio in 1992, where it was adopted as an underpinning concept of the Convention on Biological Diversity. It

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now plays an integral part in environmental policy, for example it was endorsed by the World Summit on Sustainable development in Johannesburg in 2002, and is implicit in the European Water Framework Directive, the approach to halt the loss of biodiversity by 2010 as agreed in Gothenburg by the European Union Heads of Government, and the Ramsar Convention (Laffoley et al., 2004).

One method of ensuring the integration of social, economic and environmental demands and pressures, as required by the Ecosystem Approach, is to utilise the concept of ecosystem goods and services. Goods and services are defined as "the direct and indirect benefits people obtain from ecosystems". Assessing ecological processes and resources in terms of the goods and services they provide translates the complexity of the environment into a series of functions which can be more readily understood, for example by policy makers and non-scientists. Describing the environment in this way also enables a true understanding of exactly what is being gained and lost when exploitation and development takes place (Holmlund and Hammer, 1999; Borgese, 2000; Weslawski et al., 2006). Research on ecosystem goods and services began in the late 1960's and this area has developed rapidly in the last decade. However, despite many studies identifying, defining and classifying goods and services (Costanza et al., 1997; Pimentel et al., 1997; Ewel et al., 1998; Moberg and Folke, 1999; de Groot et al., 2002; Millenium Ecosystem Assessment, 2003), little research has been undertaken to assess if this approach is realistic or useful in management terms.

To address this issue this paper aimed firstly to identify and define the goods and services provided by marine biodiversity. Lewan and Söderqvist (2002) argue ecosystem services can be difficult to understand, and as such this paper aimed to present goods and services in a concise fashion with user friendly definitions. The focus is on marine biodiversity as the majority of the literature on goods and services has tended to be biased towards the terrestrial environment. In addition, biodiversity issues are playing an increasingly significant role in all areas of marine environmental policy (Sheppard, 2006; Defra, 2002, 2006). The term biodiversity has many different definitions (Sheppard, 2006), but as far as possible in this paper it is used to refer to richness and composition at species and functional type levels. However, goods and services accruing from living organisms are sometimes used as a proxy for those accruing from biodiversity, especially where information is not available. The provision of all the goods and services is linked to biodiversity, although the exact mechanism and quantification of this linkage is not discussed in this paper; further information on these linkages have been documented by Beaumont et al. (2006), Worm et al. (2006) and Balvanera et al. (2006).

Case studies have been used to provide an insight into the practical issues associated with the assessment of goods and services at specific locations. The aim of this research was to validate the list and definitions of goods and services, to investigate where goods and services are present, what form they take, the gaps in our knowledge and likely difficulties encountered when quantifying the goods and services. Quantification of the goods and services at the various case study sites was beyond the scope of this study. It was anticipated that providing a wide range of examples of the goods and services, at a variety of case study areas, would improve the overall understanding and definitions of the goods and services provided by biodiversity within the context of marine ecosystems.

2. Methodology

The study of goods and services crosses many disciplines, thus to facilitate this research a two day inter-disciplinary workshop, sponsored by the EU Network of Excellence: Marine Biodiversity and Ecosystem Function (MarBEF), was hosted by the Marine Biological Association, Plymouth, UK. At this workshop twenty one experts from a variety of disciplines adapted and refined previously defined approaches to goods and services (Holmlund and Hammer, 1999; Moberg and Folke, 1999; de Groot et al., 2002; Millenium Ecosystem Assessment, 2003), with the aim of identifying and defining the goods and services provided specifically by marine biodiversity. The results of this workshop are described in Section 3.1.

Working groups of experts attempted to collate secondary data on the provision of the goods and services at seven case study sites. Comparatively well studied sites were selected to provide good spatial and ecological variability including deep water sites, off-shore islands, small coastal areas, and reduced salinity habitats and encompassed a spectrum from near pristine to heavily impacted sites. The locations of the seven case study sites are detailed in Fig. 1. Experts tried to identify readily available data that could be used to quantify the goods and services in the case study areas. Sources included the World Wide Web, peer reviewed and grey literature, published books, personal communications and expert opinion. The case study areas are briefly described below, and the results of their investigation are detailed in Section 3.2.

2.1. Atlantic frontier

The Atlantic Frontier comprises the waters at the edge of the continental shelf from the west of the Shetland Islands south to the Rockall Trough. It has a seafloor ranging from 200–2000 m water depth, opposing current streams of up to three knots, a strongly stratified water column varying in temperature by as much as 10 °C and strong down-slope variations in sediment type.

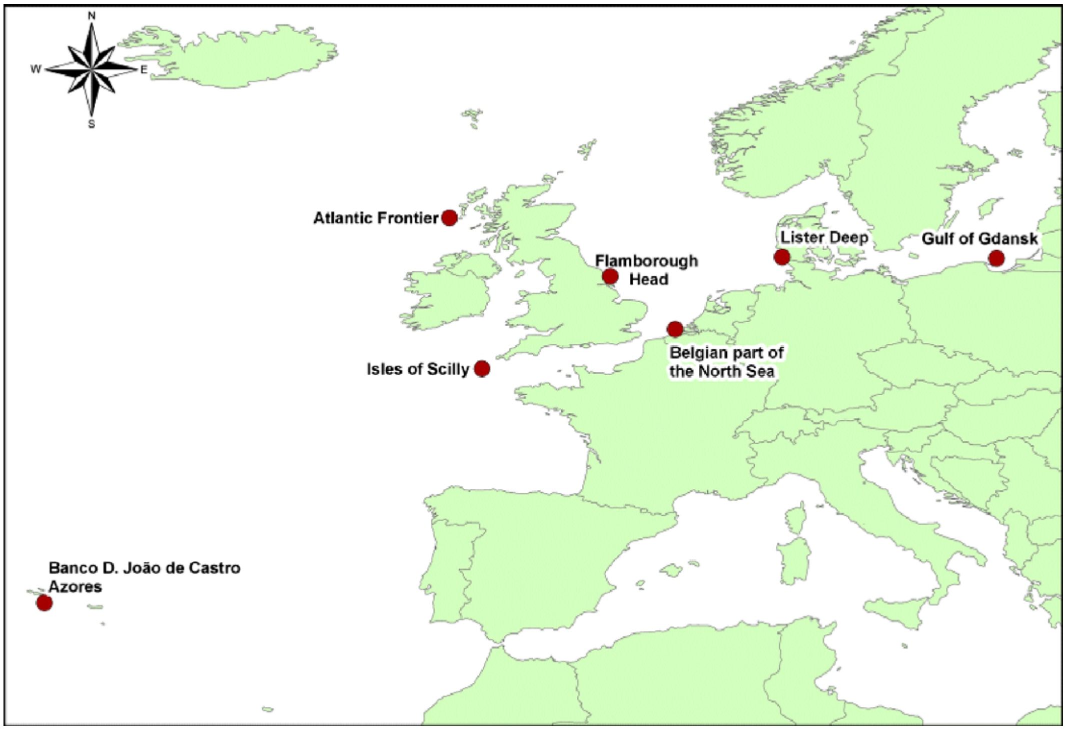

Fig. 1. Location of the seven case study sites.

2.2. Banco D. João de Castro, Azores

The sea mount Banco D. João de Castro is located in the Azores Archipelago between the islands of São Miguel and Terceira. The sea mount rises from an ocean bottom of 1000 m deep, its surface is at a depth of 13 m. From 13 to 45 m depth the ecosystem of Banco D. João de Castro is predominantly based on solar energy, but below that the ecosystem is based upon chemical energy as found at the sea mounts Menez Gwen and Lucky Strike also in the Azores waters.

2.3. Isles of Scilly

The Isles of Scilly is an archipelago of five inhabited islands and over 300 smaller islands, islets and rocks, 43 km WSW of the western extremity of the Cornish peninsula, mainland UK. The total area delimited by these islands is approximately 95 km^2 and much of this area is shallow sea. Marine habitats on the islands include intertidal rocky and sandy shores with a wide range of exposure, sublittoral sands, seagrass beds, kelp beds and rocks.

2.4. Belgian part of the North Sea

The studied area is part of the southern bight of the North Sea and is characterized by a complex system of sand banks which are virtually parallel with the coast, some of which emerge from the water at very low tides. The surface area of the Belgian part of the North Sea is 3600 km^2 (=0.5% of total surface area of North Sea), and the maximum water depth is 46 m.

2.5. Flamborough Head

Flamborough Head is situated on the north-east coast of England and comprises of cliffs, platforms, gullies, chalk reefs, sea caves and ledges, which provide habitat for many marine species including algae, invertebrates, fish, and birds. The Flamborough Head European Marine Site (EMS) covers an area of 6470 ha, with subtidal depths reaching 40 m within the site.

2.6. Gulf of Gdańsk

The Gulf of Gdańsk is in the south-east of the Baltic Sea enclosed by a large curve of the shores of Gdańsk Pomerania in Poland, and Kaliningrad Oblast of Russia. The maximum depth is 118 m, and surface water salinity is 8.28 PSU. The total surface area of the Gulf of Gdańsk is 4296 km^2 and its volume is 236 km^3. Sandy bottom biotopes dominated by macrophyte vegetation mainly occur in the sheltered Puck Bay, There are also areas of stony (near the coastline) and muddy (deeper part) bottom covered with macrophytes and algae.

2.7. Lister Deep

Lister Deep is a tidal inlet with surrounding mud flats of the Wadden Sea located in the border area between

Denmark and Germany of the North Sea. Lister Deep covers about 400 km^2. Water exchange between the deep and the open North Sea takes place through a 2.8 km-wide tidal channel. 33% of the area belongs to the intertidal zone, 57% to the shallow subtidal (<5 m depth) and 10% to deeper tidal channels. The marine habitats include sandy and muddy tidal flats as well as sea grass and mussel beds.

3. Results

3.1. Goods and services provided by marine biodiversity

Many different methods of categorisation of goods and services have been defined (Costanza et al., 1997; Pimentel et al., 1997; Ewel et al., 1998; Moberg and Folke, 1999; Holmlund and Hammer, 1999; de Groot et al., 2002; Millenium Ecosystem Assessment, 2003, Hein et al., 2006). The over-arching classification applied here follows the Millenium Ecosystem Assessment (2003) and Hein et al. (2006) and divides goods and services into four categories:

- Production services are products obtained from the ecosystem.
- Regulating services are the benefits obtained from the regulation of ecosystem processes.
- Cultural services are the nonmaterial benefits people obtain from ecosystems.
- Supporting services are those that are necessary for the production of all other ecosystem services, but do not yield direct benefits to humans.

Within each category a range of goods and services has been identified (Table 1). Previous lists of goods and services have not included the less tangible benefits which are derived from the environment (Brito, 2005). As such, a small deviation from previous categorisations is the inclusion of the category "Option use value", with the accompanying service of future unknown and speculative benefits. This is the benefit associated with an individual's willingness to pay to safeguard the option to use a natural resource in the future, when such use is not currently planned. In other words, it is the value of being able to change one's mind, and of keeping one's options open. Hein et al. (2006) propose that option value is associated with all the categories, however, an option value for a specific service cannot be calculated, as this implies an expectation that this service *will* be used, and any *expected* future use is properly part of direct/indirect use, not option value. There is some debate associated with the definition and concept of option value, as detailed further by Hanemann (1989) and Walsh et al. (1984), but option value can only be properly calculated for the whole ecosystem, not for the individual goods and services.

Table 1
Goods and services provided by marine biodiversity

Category		Good or service
Production services	1	Food provision
	2	Raw materials
Regulation services	3	Gas and climate regulation
	4	Disturbance prevention (flood and storm protection)
	5	Bioremediation of waste
Cultural services	6	Cultural heritage and identity
	7	Cognitive benefits
	8	Leisure and recreation
	9	Feel good or warm glow (non-use benefits)
Option use value	10	Future unknown and speculative benefits
Over-arching support services	11	Resilience and resistance (life support)
	12	Biologically mediated habitat
	13	Nutrient cycling

3.1.1. Food provision

Definition: The extraction of marine organisms for human consumption.

Plants and animals derived directly from marine biodiversity provide a significant part of the human diet. Fisheries in particular, and the accompanying employment, provide a significant example of the importance of this function.

3.1.2. Raw materials

Definition: The extraction of marine organisms for all purposes, except human consumption.

A wide variety of raw materials are provided by marine biodiversity for a variety of different uses, for example, seaweed for industry and fertiliser, fishmeal for aquaculture and farming, pharmaceuticals and ornamental goods such as shells. The provision of raw materials results in significant employment opportunities. This category does not include dredge materials, oil or aggregates as these are not supported by living marine organisms.

3.1.3. Gas and climate regulation

Definition: The balance and maintenance of the chemical composition of the atmosphere and oceans by marine living organisms.

The chemical composition of the atmosphere and ocean is maintained through a series of biogeochemical processes. The maintenance of a healthy, habitable planet is dependent on processes such as the regulation of the volatile organic halides, ozone, oxygen and dimethyl sulphide, and the exchange and regulation of carbon, by marine living organisms. For example, organisms in the marine environment play a significant role in climate control through their regulation of carbon fluxes, by acting as a reserve or sink for CO_2 in living tissue and by facilitating burial of carbon in sea bed sediments. The capacity of the marine environment to act as a carbon sink will be affected by changes in marine biodiversity.

3.1.4. Disturbance prevention (flood and storm protection)

Definition: The dampening of environmental disturbances by biogenic structures.

Living marine flora and fauna can play a valuable role in the defence of coastal regions. The presence of organisms in the front line of sea defence can dampen and prevent the impact of tidal surges, storms and floods. This disturbance alleviation service is provided mainly by a diverse range of species which bind and stabilise sediments and create natural sea defences, for example salt marshes, mangrove forests and sea grass beds (Huxley, 1992; Davison and Hughes, 1998).

3.1.5. Bioremediation of waste

Definition: Removal of pollutants through storage, burial and recycling.

A significant amount of human waste is deposited in the marine environment. Waste material can be organic, such as oil and sewage, as well as inorganic, comprising a huge variety of chemicals. Through either direct or indirect activity, marine living organisms store, bury and transform many waste materials through assimilation and chemical de and re-composition. For example, the bioturbation activity (reworking and mixing of sediments) of mega- and macrofaunal organisms within the seabed can bury, sequester and process waste material through assimilation and/or chemical alteration. These detoxification and purification process are of critical importance to the health of the marine environment.

3.1.6. Cultural heritage and identity

Definition: Benefit of biodiversity that is of founding significance or bears witness to multiple cultural identities of a community.

There is benefit associated with marine biodiversity for example for religion, folk lore, painting, cultural and spiritual traditions. Human communities living by and off the sea often attach special importance to marine ecosystems that have played a founding or significant role in the economic or cultural definition of the community. This identification may be associated with a strong economic interest in the extraction of the site but as economic significance decreases the community may attach increased symbolic values to the preservation of the site. For example a mussel bed may long have lost its economic significance while the symbolic importance may be high. This valuation should be distinguished from the economic importance of revitalised and commercialised cultural heritage which is included below under the heading Leisure and recreation.

3.1.7. Cognitive benefits

Definition: Cognitive development, including education and research, resulting from marine organisms.

Marine living organisms provide stimulus for cognitive development, including education and research. Information 'held' in the natural environment can be adapted, harnessed or mimicked by humans, for technological and medicinal purposes. Current examples of the use of marine information include: the study of microbes in marine sediments to develop economical electricity in remote places (Chaudhuri and Lovley, 2003); the inhibition of cancerous tumour cells (Self, 2005); the use of *Aprodite* sp. spines to progress the field of photonic engineering, with potential implications for communication technologies and medical applications (Parker et al., 2001); the development of tougher, wear resistant ceramics for biomedical and structural engineering applications by studying the bivalve shell (Ross and Wyeth, 1997).

In addition, marine biodiversity can provide a long term environmental record of environmental resilience and stress. The fossil record can provide an insight into how the environment has changed in the past, enabling us to determine how it will change in the future. This is of particular relevance to current concerns about climate change. Bio-indicators, such as changes in biodiversity, community composition and ecosystem functioning, are also beneficial for assessing and monitoring changes in the marine environment caused by human impact. Ecophysiological responses of marine organisms to the changes in their environment, defined as biomarkers, can provide significant information for development of early warning systems for environmental degradation (Walker et al., 2001).

3.1.8. Leisure and recreation

Definition: The refreshment and stimulation of the human body and mind through the perusal and study of, and engagement with, living marine organisms in their natural environment.

Marine biodiversity provides the basis for a wide range of recreational activities including: (sea) bird watching, rock pooling, beachcombing, sport fishing, recreational diving, and whale-watching. The provision of this service results in significant employment opportunities.

3.1.9. Feel good or warm glow (non-use benefits)

Definition: Benefit which is derived from marine organisms without using them.

Bequest value: The current generation places value on ensuring the availability of biodiversity and ecosystem functioning to future generations. This is determined by a person's concern that future generations should have access to resources and opportunities. It indicates a perception of benefit from the knowledge that resources and opportunities are being passed to descendants.

Existence value: This is the benefit, often reflected as a sense of well being, of simply knowing marine biodiversity exists, even if it is never utilised or experienced, people simply derive benefit from the knowledge of its existence (Hageman, 1985; Loomis and White, 1996). The considerable importance which the wider public attach to maintaining diverse marine life is revealed through their interest in marine based media presentations, such as the "Blue Planet". In addition, articles on cold water corals frequently appear in the media (http://news.bbc.co.uk/1/hi/sci/tech/3719590.stm,2004), despite the fact the majority of the general public will never see a cold water coral, they are interested in them and benefit from their existence.

3.1.10. Future unknown and speculative benefits

Definition: Currently unknown potential future uses of marine biodiversity.

Potential future uses of marine biodiversity have an option use value. This paper has explored current uses of marine biodiversity, option value reflects the importance of more uses being discovered in the future. The biodiversity may never actually be exploited, but there is benefit associated with retaining the option of exploitation. Any expected future use is not option value, but would belong under cognitive benefits.

3.1.11. Resilience and resistance (life support)

Definition: The extent to which ecosystems can absorb recurrent natural and human perturbations and continue to regenerate without slowly degrading or unexpectedly flipping to alternate states (Hughes et al., 2005).

Healthy ecosystems with high biodiversity can have greater resilience to natural or anthropogenic impacts (Hughes et al., 2005). However, high biodiversity alone does not necessarily lead to improved resilience. It is necessary to have a range of species that respond differently to various environmental perturbations to enhance resilience and/or resistance. For example, if all species within a functional group respond similarly to anthropogenic pressures, such as over fishing and pollution, increased biodiversity will not alleviate these pressures.

3.1.12. Biologically mediated habitat

Definition: Habitat which is provided by living marine organisms.

Many organisms provide structured space or living habitat through their normal growth, for example, reef forming invertebrates, meadow forming sea grass beds and marine algae forests. These 'natural' marine habitats can provide an essential breeding and nursery space for plants and animals, which can be particularly important for the continued recruitment of commercial and/or subsistence species. Such habitat can provide a refuge for plants and animals including surfaces for feeding and hiding places from predators. Living habitat plays a critical role in species interactions and regulation of population dynamics, and is a pre-requisite for the provision of many goods and services.

Table 2
Overview of provision of goods and services at case study areas

Good/Service	Case study areas						
	Atlantic Frontier	Banco D. João de Castro	Isles of Scilly	Belgian part of the North Sea	Flamborough Head	Gulf of Gdańsk	Lister Deep
Food provision	+	€	+	€	+	+	+
Raw materials	+	?	+	?	+	€	?
Gas and climate regulation	+	?	+	+	+	+	+
Disturbance prevention	0	0	0	0	0	+	?
Bioremediation of waste	+	?	+	+	+	+	+
Cultural heritage and identity	?	?	?	+	+	+	+
Cognitive benefits	+	+	+	+	+	+	+
Leisure and recreation	+	0	+	+	+	+	+
Feel good or warm glow	+	+	+	?	+	?	+
Future or speculative values	+	+	?	?	?	+	?
Resilience and resistance	?	+	+	?	?	?	?
Biologically mediated habitat	+	?	+	+	+	+	+
Nutrient cycling	+	+	+	+	+	+	+

Key: + present; 0 not present; ? unknown; € monetary value available.

3.1.13. Nutrient cycling

Definition: The storage, cycling and maintenance of nutrients by living marine organisms.

The storage, cycling and maintenance of a supply of essential nutrients, for example nitrogen, phosphorus, sulphur and metals, is crucial for life. Nutrient cycling encourages productivity, including fisheries productivity, by making the necessary nutrients available to all levels of the food chains and webs. Nutrient cycling is undertaken in many components of the marine environment, in particular within seabed sediments and salt marshes in shallow coastal waters and in the water column in deeper, offshore waters.

3.2. Assessing goods and services at seven case study sites

Data availability on goods and services at the case study sites was very varied in quality and quantity. Table 2 presents an overview of the results of the case studies. If the good or service is detailed as "present" this indicates that this good or service has been recorded at the case study area and that some information is available on the extent and method of provision, but it could not be quantified. Conversely, the term "not present" indicates that the data available suggests that the good or service is not present at the site. The term "unknown" is used when there is no information available on the good or service. Full details of the case study areas can be found in Annex 1. Quantitative information in the form of monetary value was generally available for food provision, but these figures tended to be underestimates of the benefits as the monetary values often did not include revenue and employment created through the fish processing industry, retail sales, exports, and unreported catches (e.g. illegal fishing and recreational fishing). Some quantitative data was available for raw materials and leisure and recreation, but this was minimal and also tended to represent only a small portion of the total service.

The remaining goods and services could not be quantified from the available information. Of the regulation services, gas and climate regulation and bio-remediation were perceived to be of considerable importance at most sites, but there was very little data available on these services. Disturbance prevention was only considered to be of importance in the Gulf of Gdańsk, and was not considered to be significant at any of the other sites, but this will probably not be the case at all coastal areas.

There was no information available on the service cultural heritage and identity at three of the sites: the Atlantic Frontier, the Isles of Scilly and the Banco D. João de Castro. This is due to a poor understanding of this service and very limited information availability. It may not be a true indication of the importance of this service. Leisure and recreation, cognitive benefits, and feel good or warm glow were all considered to be of importance at most sites. The specific information provided on all the cultural services was very varied, and this possibly stemmed from a difficulty in understanding the exact nature of these services.

Future unknown and speculative benefits were considered to be important at four of the sites, and were classed as "unknown" at the remaining sites. This is indicative of the difficulty of defining, understanding and quantifying this service. The supporting services, biologically mediated habitat and nutrient cycling, were considered to be of importance at most sites. There was very little information on the service of resilience and resistance which was expected, as again this service is very difficult to define. Indeed, there was considerable confusion about precisely what this service was, thus quantifying it was likely to prove problematical.

4. Conclusions and discussion

This paper identifies and defines the goods and services provided by marine biodiversity, and presents an exploratory attempt to describe these goods and services at case study sites using only secondary data that was readily available. The case studies indicate that the list of goods and services is comprehensive, and that the majority of the definitions were workable and realistic. The definitions of the services cultural heritage and identity, resilience and resistance, and future or speculative values require further research as some confusion was noted about the precise meaning of these services.

The goods and services approach is a reductionist method, but the benefits arising from marine biodiversity are entirely dependent on the state of the whole ecosystem. The sum of the parts of the system is less than the value of the whole system, and the different goods and services provided are intrinsically connected. Individual services can also provide additional benefit when examined in the context of the other services with which they coexist at wider scales (spatial or temporal) rather than the scale of investigation (e.g. those of our individual case study sites). The exploitation of services can have negative, positive or neutral impacts on the other services. Thus, although this classification of services breaks the environment down into specific components, the inter-dependency of these components, and overall value of the environment should be remembered. In addition, it is sometimes easy to forget that species do not actively endeavour to provide any goods and services. The provision of goods and services is merely a consequence of living organisms natural functioning.

The case study sites are well studied and have more data available than most marine areas. Even so, using present knowledge quantifying all the goods and services at any given site, in a comparable way, would be impossible. This indicates the difficulties likely to arise in applying the Ecosystem Approach. If environmental, social and economic concerns are to be integrated into an Ecosystem Approach to environmental management, policy makers need to be able to quantify the provision of goods and services, on a before and after, site specific basis to get a true idea of the impact of a development or human activity. To choose between management options, the values of the associated goods and services must be quantifiable and comparable. Given the short time scales associated with most environmental policy and management decisions it is unlikely that this would be possible.

Limited knowledge should not, however, be used as an excuse to delay the implementation of the Ecosystem Approach (Laffoley et al., 2004). Despite the difficulties of quantifying all the goods and services it is still valuable to think about the importance of marine biodiversity in these terms since biodiversity generally, and marine biodiversity in particular, is a complex concept (Sheppard, 2006). Defining ecosystem processes and resources in terms of goods and services translates the complexity of marine biodiversity into a series of functions, which can be more readily understood, for example by policy makers and non-scientists.

As data is not available to quantify all of the goods and services, their assessment at a given site is likely to be biased towards those goods and services that are more data rich, such as food provision and recreation. There is a risk of assuming no data equates to no benefit. In the past this bias has contributed to the over exploitation, and resultant degradation, of the environment. The provision of goods are often given priority over services, as services cannot be seen or held, often do not yield immediate market value, and are generally more difficult to quantify. Services are, however, fundamental to providing humanity with a healthy and habitable planet, and are thus just as critical to human welfare as tangible goods. Utilising a goods and services framework reduces the likelihood that environmental managers will overlook certain goods and services when making a decision, and defining services alongside goods should raise their profile in environmental decision making. Adaptive management is required which utilises the available data within the context of the uncertainties, limitations and gaps in our knowledge.

The results of this study highlight knowledge gaps which should be addressed if an Ecosystem Approach to environmental management is to be successfully adopted. The disparity in data availability of goods versus services and the lack of availability of data to quantify services is less surprising if one considers that the ecosystem goods and services approach is adapted from a commonly used methodology of economists. Economists are accustomed to gathering data concerning benefits that accrue to man, primarily as valuation data. Natural scientists such as ecologists are only beginning to view ecosystem functioning in terms of its direct and indirect benefits to people. Whilst the benefits clearly exist, natural scientists are only just beginning to explore how to collect tangible data that can quantify them in a comparable way. Ecosystem services are a summary of complex interrelations of functions performed by a large variety of organisms at a range of spatial and temporal scales. The challenge is to model these functions in such a way that data can be made available to quantify the services, or alternatively to find proxies for or indicators of these interrelated functions. Services such as resilience and resistance play a fundamental role in the continued delivery of all other goods and services, but little is known about the contribution of biodiversity to this service. Time and resources should be devoted to the fundamental services rather than the already well understood goods and services. At a more holistic scale, there are still large gaps in our understanding of goods and services including, inter-dependences, inter-variability, and vulnerabilities.

This research provides a validated theoretical framework for the quantification of ecosystem goods and services, including a wide range of examples from a variety of case study areas. It is intended that these results will enable and encourage future assessments of goods and services. The utilisation of this goods and services approach has the capacity to play a fundamental role in the Ecosystem Approach, by enabling the three pillars of society, the economy and the environment to be integrated into environmental management. However, the continued development of this approach must be undertaken in a cohesive manner. Established frameworks of goods and services should be applied to enable comparison between studies. Ideally a database of marine case studies and values should be collated, to again enable comparison between studies, and also allow benefit transfer of values which will reduce the time and resources required to undertake a study.

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Annex 1. Provision of goods and services at case study areas

Good/Service	Atlantic Frontier	Banco D. João de Castro	Isles of Scilly	Belgian part of the North Sea	Flamborough Head	Gulf of Gdańsk	Lister Deep
Food provision	Deep water fisheries have developed in last decade and include: black scabbardfish, blue ling, leafscale gulper shark, greenland halibut, orange roughy, roundnose grenadier	The value of registered fisheries is 1.5 Million € per year	There are 30 registered shellfish boats, potting or using large mesh (12.5 in.) fixed nets for crabs and lobsters, employing about 50 persons. There is only one small (8 m) trawler	Belgian sea fishing industry (both catches inside and outside) in 2002: landings: 25,810 tonnes (23,445 tonnes demersal fish/106 tonnes pelagic fish/2259 tonnes shellfish) profit: 91,911,000 €	Four main fishing methods: trawling, netting, potting and lines, to catch white fish, salmon and sea trout, and shellfish. There is also a developing sea bass fishery using pair trawling techniques	Total landings of commercial fishes (cod, herring, flat fishes, roach and others) in the Gulf of Gdańsk were 19067 tonnes in 2001. Seasonal freshwater fishery e.g. eel, pike perch and perch	Professional licensed fishery for mussels and cockle at a low level. Low scrimp trawling activity in the German part of the deep
Raw materials	The Portuguese dogfish and the leafscale gulper shark are valued for their liver oils, particularly squalene which are used in lubricants, as cosmetic bases and in the pharmaceutical industry	Unknown	Dried marine organisms are used in arts and crafts which are sold locally, and in arts and crafts lessons. Kelp is occasionally used locally as fertiliser	Unknown	Bait digging occurs on the shores from Sewerby to Flamborough Head. Fossil collection takes place at Sewerby and the South cliffs	The value of the Polish amber market is estimated to be in the region of 20 million €. Empty mussels are collected by people walking on the beach	Unknown
Gas and climate regulation	Sink for global carbon	Unknown	Bioturbators in the sediment will affect sediment-water fluxes of carbon and degradation and storage of carbon	Low density of phytoplankton and no macroalgae present so low impact on gas and climate regulation	Kelp forests act as a source and/or a sink for CO_2	Oxygen production and carbon sink by marine plants. DMS production by microplankton. Benthic organisms influence carbon circulation	High productivity of the ecosystem will affect carbon circulation
Disturbance prevention	Not present	Not present	Not present	Not present	Not present	Along coastline, macrophytes and macroalgae influence coastal erosion. Rhizomes and roots stabilize the sediment and leaves can reduce wave energy (unpublished data)	Marine biodiversity have an influence on sedimentation though the extent is unknown
Bioremediation of waste	Since 1982 no waste is dumped at sea, but contaminants will be washed off the land. Bioturbator activity will bury dilute and recycle contaminants	Unknown	Marine organisms bio-remediate waste that derives from sewage and agricultural run off. There is no industrial pollution on the Islands	This is a high energy area with great turbidity and sediment bedload transport, the organisms are capable of withstanding waste compounds, including organic matter from rivers, and redistributing them	Marine biodiversity is believed to be affected by, and play a role in processing a variety of wastes, including outputs from the distilling, brewing and food industries and sewage treatment works	Filtration by micro- and macro-organisms reduces the numbers of suspended particles, increasing water transparency. Bioturbation, is provided by macrofauna including polychaete worms, priapulids and bivalves	High productivity, deposition and filtering capacity. Although Eutrophication and pollution negatively impact marine species
Cultural heritage and identity	Unknown	Unknown	Unknown	Traditional shrimp fisheries take place which attracts some tourists	The site is a designated stretch of Heritage Coast and is internationally important for wildlife. This creates a special interaction between people and the environment	Local society (Cassubia) is strongly connected with the sea through culture, folklore, legends, and fisheries festivals. Local old traditionally run companies (maszoperie)	Local identity is connected to the sea. Historical evidence of the co-existence of humans and marine animal populations is present in landscape and society

(*continued on next page*)

Annex 1 (*continued*)

Good/Service	Atlantic Frontier	Banco D. João de Castro	Isles of Scilly	Belgian part of the North Sea	Flamborough Head	Gulf of Gdańsk	Lister Deep
Cognitive benefits	Research on impact of deep water trawls on the seabed and coral banks. Long-term environmental datasets exist (e.g. PAP and Rockall Trough) which are valuable, as they show evidence of large-scale change in diversity over time	The annual investment on research at this site by the Department of Ocean Sciences of Azores University is between 3000 and 10000 Euros	This is a pristine location for research and education e.g. by Plymouth Marine Laboratory, EU projects, and universities. Local schools use the shoreline for educational purposes. Regular diving expeditions to record subtidal marine life. This is a monitoring location for English Nature and the Joint Nature Conservation Committee	Few field trips at sea by universities and secondary schools, mostly education on the beach and dunes. The area has been explored by scientists (e.g. biologists, geologists, hydrologists), and there is good knowledge of various ecosystem components. Scientific data from the area is frequently used by international scientists	The habitats are a resource, used by schools and universities for education and research. Statutory monitoring is undertaken by authorities in relation to public health issues, specific surveys and national programmes	Importance in educational events, including use by schools, universities, technical universities, and local educational initiatives	The habitats and biodiversity of the Wadden Sea area is important for schools, universities and all kinds of educational activities. The area is intensively researched through more than 100 years
Leisure and recreation	Whale watching	Due to its distant position the demand for recreation is minimal	Tourism accounts for 85% of the Isles of Scilly economy, including sea angling, seal watching, scuba diving and bird watching	Diving, angling, Beach fisheries with bottom set gill nets, bird watching	Bathing, walking, bird watching, angling, rock-pooling, boating/canoeing, diving, day-trip cruises, rock pools and the Royal Society for the Protection of Birds reserve at Bempton Cliffs	Sea-bird watching, sea angling, recreational diving (35% of fishermen with fishing boats organize boat trips for recreational fishing). Limited by poor bathing water quality	Tourism is a major part of the economy on Rømø and Sylt. Activities include bird watching, recreational fishing, hunting, seal watching and beachcombing
Feel good or warm glow	Articles on the Darwin mounds and cold water corals frequently appear in the media, despite the fact the majority of the general public will never see a cold water coral	There is a major interest in the videos and reports produced about this site	There is a local branch of the UK based Wildlife Trust charity within the Islands	There is no knowledge available of the public's point of view on this subject. Few people know what biodiversity exists at this site	Feel good values are considered likely to be positive because of its outstanding natural features	Not many people realize that there is marine biodiversity present in the site	Major interest in the conservation and restoration of ecosystem on local, national and international levels
Future unknown or speculative values	Poor knowledge of environment, thus it is likely that there are unknown habitats and species ($\geqslant$50% species in any deep sea samples are new)	Possibilities for scuba diving	Unknown	Unknown	Unknown	The cold brackish waters may have produced unique genetic forms, so potentially considerable future value	Unknown
Resilience and resistance	Research provides an insight into environmental resilience and stress in the deep sea, but role of biodiversity unknown	High concentration of biodiversity that sustains, with other sea mounts and islands, the resilience of the surrounding ocean	In their pristine state they provide a reservoir for European biodiversity	Unknown	Unknown	Unknown	Unknown

Biologically mediated habitat	The coldwater coral and mass occurrence of large demosponges provide nursery and refugia for many deeper water species	Unknown	Extensive seagrass and sublittoral kelp beds. Encrusting epifauna on many of the rocky surfaces. Habitat modifying bioturbators are present in the sand	Epibiota associated with wrecks provide refugia for other organisms. *Lanice conchilega* reefs (protruding tubes) also provide refugium	Significant kelp forests (*Laminaria hyperborea*) near shore, and forests of *Laminaria saccharina* with red algal undergrowth in near shore	Seagrasses beds especially within the Puck Bay are used as refuge, nursery as well as feeding grounds by fish including commercial and protected species and sea-birds	Important refugia for birds and nursery for fish
Nutrient cycling	Physical upwelling and biological cycling by phyto and zoo plankton	The remoteness from emissions sources of nitrogen, phosphorus and sulphur leads to a negligible role of the biodiversity in nutrient cycling	Bioturbators that facilitate nutrient cycling are abundant in the sediments	High recycling due to high productivity, owing to anthropogenic inputs from the river Scheldt. High inputs of nitrogen from rivers and atmosphere result in *Phaeocystis* algal blooms	Flamborough Front is the boundary of the northern and southern North Sea and communities differ noticeably during the summer creating a very productive, nutrient-rich environment	Twenty three percent of nitrogen load, and 34% of phosphorous load are retained in system All of the retained phosphorus and a small part of the nitrogen is buried in the bottom sediments. The majority of the nitrogen was denitrified and removed from the system	High productivity results in high recycling. Import of nutrient from the North Sea due to tidal water exchange and from rivers

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