Marine Biodiversity: An Economic Valuation

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Abstract

A goods and services approach has been applied to determine the economic value of marine biodiversity in the UK. This paper presents the goods and services resulting from marine biodiversity in UK waters, detailing the habitats and species which provide them, and the likely impact of a decrease in biodiversity. Where possible a monetary value was assigned to each of the goods and services. Valuing the environment in monetary terms is still controversial, and the problems with this approach are recognised and discussed with particular reference to marine biodiversity. The monetary figures provided here are the best value estimates currently available, but they should only be used as indicators of value, and the strength of this monetary data lies in its capacity to raise awareness of the importance of marine biodiversity.

A decline in UK marine biodiversity could result in a varying, and at present unpredictable, change in the provision of all these goods and services. This could result in severe impacts on society and the economy, including reduced resilience and resistance to change, declining marine environmental health and water quality, reduced fisheries potential, loss of recreational opportunities, decreased employment, and reduced carbon uptake.

Keywords: Marine; biodiversity; goods and services; valuation

Introduction

The valuation of environmental resources began to gain attention in the 1970's, with notable marine examples including Whitehead (1993), King (1995), and Costanza (1999). Research effort within this area has gradually increased during the last 30 years and valuation studies now form a staple of the economics literature (Ecological Economics 1995, 1998, 2002) and increasingly the wider natural science literature (Costanza *et al.* 1997, Daily *et al.* 2000). Despite their increasing popularity, valuation methodologies are still developing and there remains significant controversy regarding their use (Brito 2005). Several reviews have been published detailing the different valuation methods and the associated difficulties of their application (Ledoux and Turner 2002, Farber *et al*. 2002). It can be argued that valuing nature is implicit, by both individuals and society, whenever a decision is made about the environment. The use of monetary valuation only formalises this process. Without monetary valuation less apparent ecosystem services, such as nutrient cycling, can be overlooked or considered to be 'free' and therefore not considered within management strategies. This can lead to over-exploitation and degradation of the environment.

Biodiversity issues are playing an increasingly significant role in all areas of environmental policy (Sheppard 2006). The UK government has recently outlined its vision for 'clean, healthy, safe productive and biologically diverse oceans and seas' (Defra 2002a) and is currently considering a number of provisions to improve marine nature conservation, including biodiversity, as part of the proposed Marine Bill (Defra 2006a). In response to the UN Convention on Biological Diversity (1992) the UK government established a UK Biodiversity Action Plan. Policy makers are increasingly recognising the role of a wide variety of economic methodologies, including valuation, to guide, influence and support environmental policy. It is therefore not surprising that the current focus on biodiversity issues in policy has been mirrored with an increasing number of economic studies aspiring to value biodiversity. An aim of this paper was therefore to investigate the viability of valuing marine biodiversity.

Valuing biodiversity has proved both difficult and controversial (Christie *et al.* 2006). A significant amount of literature has been published on the valuation of biodiversity, (Barbier *et al*., 1994 Perrings *et al*., 1995 Swanson, 1995 Tacchoni, 2000, Nunes *et al.* 2003, Kettunen and Brink 2006, Defra 2006b, Patterson and Cole 1999, Mendonça *et al.* 2003), however, the majority of studies have not valued biodiversity *per se*, but individual species, habitats or ecosystem services. This misuse of the term biodiversity stems in part from a lack of a standardised quantitative descriptor of biodiversity amongst natural scientists (Sheppard 2006). The commonly accepted but all encompassing definition of biodiversity is that of the Convention of Biological Diversity '…the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.' Biodiversity is, however, a truly multidimensional concept (Purvis and Hector 2000), considered on many different levels from genetic variation between individuals and populations, to diversity of species, assemblages, habitats, landscapes and biogeographical provinces. 'Biodiversity' can encompass changes on a microscopic scale, to those spanning thousands of kilometres; many orders of magnitude in difference (Wilson 1992). Biodiversity will mean different things to different people (Harper and Hawksworth 1994). For ecologists, different elements of ecosystem goods and services will be dependent variously on the different elements and distribution of biodiversity such as the number and functional attributes of species, taxonomic relatedness of species and distribution of individuals amongst species. For example is a community with 40 species that is highly dominated in terms of abundance by just 2 species more diverse than a community of 15 species where individuals are distributed rather evenly among species? To overcome this problem it is essential that economists collaborate more closely with biologists to develop a better understanding of biodiversity and to improve valuation methods. Poor understanding of the natural science by economists can lead to flawed results and the dissemination of inaccurate information (Brito 2005).

Christie *et al.* (2006) and Turpie (2003) attempted to value biodiversity through the application of stated preference techniques which capture both use and non-use values of non-market goods and services, such as biodiversity. However, the accuracy of the results is heavily dependent upon the respondents understanding of the environmental good being investigated (Christie *et al.* 2006) The general public has a poor understanding of the term 'biodiversity' (Turpie 2003, Spash and Hanley 1995) and Defra (2002b) observed that 26% of survey respondents had not heard of biodiversity. This does not indicate that the public do not care about biodiversity, to the contrary, Christie *et al.* (2006) found that the public does have positive values for biodiversity. This low level of understanding is, however, a cause of considerable concern when using a stated preference technique. In addition, Christie *et al.* (2006) found that the public has stronger preferences for ecosystem functions which directly affected human welfare. Whilst this is expected the result is that ecologically important services, such as nutrient cycling, may be under valued due to a lack of public understanding.

Valuing marine biodiversity suffers the added complication that the marine environment is extremely diverse. Of the plant and animal kingdoms, thirty-two of the thirty-three phyla are found in the marine environment; and fifteen of these are endemic (Ray and Grassle 1991). In addition the marine environment is difficult to sample and monitor (Ray and Grassle 1991). This complexity results in significant limitations in current scientific knowledge of the effects of marine biodiversity on ecosystem functioning. As a result valuation studies have tended to focus on the terrestrial environment. A brief review of marine valuation studies is provided by Ledoux and Turner (2002). Patterson and Cole (1999) attempted to place a value on New Zealand's biodiversity, but omitted a value for the open ocean from their final valuation as marine biodiversity was considered too difficult to value. Pimental *et al.* (1997) undertook a study of the economic benefits of biodiversity in the United States, and included no marine examples except fisheries. The research we report here is currently unique in its aim to value marine biodiversity, defined as richness and composition at species and functional type levels.

A wide range of goods and services that are essential for the maintenance of the social and economic wellbeing of our society are supported by marine biodiversity. In a goods and services approach an ecosystem is valued by developing an understanding of the services which it provides (Ewel *et al.* 1998, Moberg & Folke 1999, Groot et al. 2002, Millenium Ecosystem Assessment 2003), and valuing these services in turn (Costanza et al.1997, Pimental et al. 1997). Pimental *et al.* (1997) and Patterson and

Cole (1999) took this approach to valuing biodiversity, in the U.S. and New Zealand respectively. However, both studies include only a selection of services and the examples were predominantly terrestrial.

We adopted the goods and services approach to valuing marine biodiversity. The over-arching classification that we applied follows the Millenium Ecosystem Assessment (2003) and Hein *et al.* (2006), and divides goods and services into four categories:

- Production services are products obtained by 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.

Previous lists of goods and services have not included the less tangible benefits which are derived from the environment (Brito 2005). We therefore included the category "Option Use Value". This is the value 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, or the value of keeping one's options open (Pearce and Turner 1990). Hein *et al.* (2006) proposed that option value should be associated with all the categories, however, an option value cannot be calculated for a specific service, as this implies an expectation that this service will be used, and any *expected* future use is properly part of direct/indirect use value, 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, and as such was included as a separate category. Values held by, or benefits to, non-human entities, that is intrinsic values (Bateman & Langford 1997), were not included. This is justified as intrinsic values are, by definition, beyond human experience and so there is no adequate way that they could be taken into account in any human evaluation framework.

Goods and services provided by marine biodiversity have been defined by Beaumont *et al.* (submitted). In this paper we have detailed each good and service in the context of UK marine biodiversity. The role of marine biodiversity in the provision of ecosystem goods and services remains the subject of considerable debate (Wall 2004, Worm *et al*. submitted,) We have examined evidence for linkages framed around an assumption of declining biodiversity as previous studies have implied that marine biodiversity is more likely to decline in the future (Worm *et al.* submitted). Each of the services was valued, where possible, in monetary terms. The aim of this valuation process was not to determine a single value for UK marine biodiversity, but to detail current knowledge and to provide a better understanding of the research required to value biodiversity in the future.

Methods

A comprehensive list of the individual goods and services which are dependent on marine biodiversity (Table 1) was defined at a workshop organised by the European

Network of Excellence Marine Biodiversity and Ecosystem Function (MarBEF) (Beaumont *et al.* submitted).

Table 1: Goods and services provided by marine biodiversity

Category	**Good or Service**
Production services	Food provision *The extraction of marine organisms for human consumption*
	Raw materials *The extraction of marine organisms for all purposes, except human consumption*
Regulation services	Gas and Climate Regulation *The balance and maintenance of the chemical composition of the atmosphere and oceans by marine living organisms*
	Disturbance prevention (Flood and storm protection) *The dampening of environmental disturbances by biogenic structures*
	Bioremediation of Waste *Removal of pollutants through storage, dilution, transformation and burial*
Cultural services	Cultural Heritage and identity *The value associated with marine biodiversity e.g. for religion, folk lore, painting, cultural and spiritual traditions.*
	Cognitive Values *Cognitive development, including education and research, resulting from marine organisms*
	Leisure and recreation *The refreshment and stimulation of the human body and mind through the perusal of, and engagement with, living marine organisms in their natural environment*
	Non-use values *Value which we derive from marine organisms without using them*
Option use value	Future unknown and speculative benefits *Currently unknown potential future uses of marine biodiversity*
Supporting services	Nutrient cycling *The storage, cycling and maintenance of availability of nutrients by living marine organisms*
	Resilience / Resistance *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)*
	Biologically mediated habitat *Habitat which is provided by marine organisms*

The extent to which these goods and services are dependent on biodiversity in UK shelf and coastal waters was determined through literature and internet searches, as well as the authors own personal knowledge. Only currently available data was used to value the goods and services. No primary studies were undertaken. Relevant information was gathered through reviews of studies that had used standard valuation methods including direct and indirect monetary valuation, replacement costs and contingent valuation. Data were derived from, among other sources, peer reviewed journals, Defra sea fisheries statistics 2004, European Parliament Report 2004 and Hebridean Whale and Dolphin Trust.

Results

Food provision

The UK fishing fleet comprises a variety of vessels, utilising a mixture of gears and techniques, including beam trawlers, pelagic gears and line and net, to catch a broad variety of fish, such as mackerel, cod, scallops, dogfish and sprats. In the year 2004, the UK fleet landed 654 thousand tonnes of sea fish with a total value of £513 million, at first point of sale. Although not all of this will have been caught in the UK's territorial waters, 70% of all landings by the UK fleet were caught in three areas: West coast of Scotland, Northern North Sea, and Central North Sea. This fleet comprised of 11,559 fishermen, with 84% of these being employed full time as fishermen.

Reduced marine biodiversity would result in a reduction of the number of species available for commercial exploitation. In addition, species rich ecosystems have been observed to have a lower rate of fishery collapse than species poor equivalents, and post-collapse recovery rates were also positively correlated with fish diversity (Worm *et al.* submitted). Declining biodiversity has also been linked to reduced primary productivity (Runge 1988), potentially negatively impacting fisheries productivity.

Market based values are not always representative of the true value of a resource and the figure of £513 million does not include the added value of fish processing. Further revenue and employment were created through the fish processing industry, retail sales, and exports, with fish processing employing approximately 18,180 people, and 1,300 fishmongers (Defra sea fisheries statistics 2004). Unreported catches (e.g. illegal fishing and recreational fishing), which may be considerable, are also not included in the above figure. As a result the figure of £513 million is considered to be an underestimate.

Raw materials

A wide variety of raw materials are provided by UK marine biodiversity for example, seaweed for industry and fertiliser, fishmeal for aquaculture and farming, pharmaceuticals and ornamental goods such as shells. Reduced marine biodiversity will impact the provision of raw materials, and associated employment, through a reduction in the number and quantity of species available for extraction

Two significant raw materials extracted from the UK marine environment are fishmeal and fish oil, and seaweed. Fishmeal and fish oil are key constituents of pelleted diets for the intensive production of carnivorous fish species. In 2004, 192 000 tonnes of fishmeal were consumed in the UK of which 50 000 were produced locally with the remainder imported. The total value of the fish meal UK market in 2004 was £81 million (European Parliament Report 2004). Almost all commercial seaweed harvesting is concentrated on the Phaeophytes (brown seaweeds) including, *Laminaria, Ascophyllum* and *Fucus* spp.. These are used in various applications which include as components of cosmetics, as food, in agriculture where raw seaweeds and by-products are used as solid state fertiliser, and in industrial applications such as textiles, food and medicine. Estimated total gross income from seaweed in 1994 was between £270,000 and £450,000, (£349,819 to £583,032, 2004UK£) although the true figure probably lies towards the lower end of this range. Market values could not be found for all of the marine raw materials exploited in the UK, and as a result the total value of this good is considered to be an underestimate.

Gas and climate regulation

The chemical composition of the atmosphere and ocean is maintained through a series of biogeochemical processes regulated by marine living organisms. Changes in biodiversity will influence the biogeochemical cycling of carbon and nutrients, and ultimately have a strong feedback on the atmosphere and the climate (Legendre and Rivkin 2005). Decreasing biodiversity has been linked to decreasing productivity (Tilman *et al.* 2006), and thus it is reasonable to assume decreasing carbon sequestration. A decrease in biodiversity could have potential implications for climate change.

Carbon cycling is well researched, and although much of the research effort for carbon cycling is on open ocean systems, shelf systems can also play an appreciable role in the carbon budget (Frankignoulle *et al*. 1996). Marine productivity in UK ocean, shelf and coastal waters has been examined to determine the amount of carbon sequestered by phytoplankton. Phytoplankton sequester CO_2 (to incorporate into organic tissue) and cause an inward flux into the oceans, thus the standing stock of phytoplankton at any point in time locks up a significant amount of carbon.

Large scale marine primary production can best be determined by remote sensing methods to quantify the concentration of photosynthetic pigments (Joint and Groom 2000). Production can then be calculated using the photosynthesis model of Smyth *et al.* (2005). Application of this model was applied to the UK territorial waters area to calculate primary productivity. The average annual primary production (carbon sequestered by phytoplankton) was calculated to be 0.07 +/- 0.004 Gt carbon yr^{-1} (95% CI), which is slightly over 0.1% of global production (Smyth *et al.* 2005).

Savings from damage avoidance can be used to calculate the "social value" per metric tonne of sequestered Carbon. Clarkson and Deyes (2002) advise a range of £6 - £121 /tC (adjusted to UK£ 2004), and also note the limitations associated with these values. Based on carbon storage, and coupling these estimates with the previously discussed primary productivity estimates, this service could be valued at between £420 million and £8.47 billion (billion 10^9) but is considered an underestimate given only primary production is considered. Many other processes which act to balance and maintain the chemical composition of the atmosphere and oceans also exist and should be included for a true value to be estimated.

Disturbance alleviation and prevention (flood and storm protection)

Biogenic structures prevent and alleviate the damage caused by flooding and storm events in coastal zones the UK. This is a critical service, particularly as the risk of flooding, both in terms of severity and frequency, has been accentuated in recent years by the onset of climate change (http://www.jncc.gov.uk/pdf/jncc334.pdf). Many types of flora can contribute to the reduction in wave energy in UK coastal zones. Seagrasses (Fonseca and Cahalan 1992) and halophytic (salt tolerant) reeds (Coops *et al*. 1996) play a minor role in the UK due to their small spatial scale. In the UK the major contribution to disturbance prevention is from saltmarshes (Paramor and

Hughes 2004). Saltmarshes are areas of vegetation that colonize intertidal sediments and are inundated by the tide at least once every lunar month (Hughes and Paramor 2004). The total extent of UK saltmarsh is approximately 45,500 ha, concentrated in eastern England (http://www.ukbap.org.uk/UKPlans.aspx?ID=33#1). Saltmarshes attenuate and dissipate wave and tidal energy and thereby substantially reduce the cost of flood defence measures (Morris *et al*. 2004, Brampton 1992, Möller 1996). Coupled with this, salt marshes act like giant sponges absorbing vast amounts of water when inundated and then slowly releasing it afterwards, preventing flooding. Clear linkages between saltmarshes and flood prevention exist. A decline in saltmarshes, and the diverse range of species which comprise them, would have deleterious consequences for coastal flood defence (Hughes and Paramor 2004). This problem will be exacerbated by increased frequency of storms and higher sea levels resulting from climate change and lead to increased damage caused by disturbance events and increased costs to prevent and alleviate (Blackwell *et al*. 2004).

King and Lester (1995) estimated that saltmarshes could result in cost savings on both capital and maintenance costs in sea defence terms of £0.38 million to £0.71 million per hectare, adjusted to 2004 prices. Coupled with an area of 45,500 ha this equates to cost savings of between £17 billion and £32 billion (billion 10^9). This valuation is considered to be an under-estimate as only saltmarshes are considered, and many other processes act to prevent and alleviate disturbance. In addition, this estimate should be treated with some caution, as the monetary values are originally calculated on a per area basis and multiplying these values up to a UK scale can generate inaccuracies. These inaccuracies stem in part from:

1. environment types not being uniform, for example a wetland in Cornwall may be very different to a wetland in Renfrewshire;
2. the values do not take into account variations in per unit value as the environment is exploited, for example as an environment or resource is diminished it's value may increase, and vice versa.

Bioremediation of waste

The role of biodiversity in UK bioremediation is complex. Organisms in the marine environment contribute to a huge number of processes that can affect anthropogenic waste, ranging from burial, dilution and detoxification to re-suspension and transformation to more toxic compounds, as well as bio-magnification to make toxic compounds available within the human food chain. Added to this complexity is the huge number of potential and actual contaminants in the marine environment.

A decline in biodiversity would probably reduce the environments capacity to process waste, with a decline in marine health and water quality.

The only known valuation work undertaken on bioremediation of waste in marine environments is focussed on wetlands (Gren 1995, Bystrom 2000, Breaux *et al.* 1995). Breaux *et al.* (1995) estimate the value of the bioremediation function of wetlands in terms of potential savings over using more conventional waste water treatment. They determine the present value of wetlands, calculated over 30 years using a discount rate of 9%, to be £1096.81 - £1236.54 per acre in terms of savings. As these studies are not specific to salt marshes, they cannot be readily extrapolated to the UK.

Cultural heritage and identity

The UK national cultural identity is shaped by the rich and diverse heritage which stems from UK marine biodiversity. Declining biodiversity is likely to adversely affect the value our cultural heritage and identity. This cultural heritage and identity is non-renewable, as once evidence of the past has been destroyed it can never be replaced (www.planarch.org). Little information is currently available on the cultural benefits of marine biodiversity, although this is believed to be indicative of a lack of documented research, as opposed to a lack of value.

Cognitive values

Cognitive values are fundamentally linked to marine biodiversity, if biodiversity declines so will the cognitive value. A decline would result in reduced technological and medicinal applications, with economic and social implications. There is significant value in education, training and university involvement in marine science. Pugh and Skinner (2002) compiled data on marine research funding, including research in higher education, the public sector and the industrial sector, and calculated value added research and development in the marine sector to be £292 million. In addition education and training was valued at £24.8 million. These estimates include all marine research and application areas, not just biodiversity, and are therefore considered an over-estimate of the current cognitive value of biodiversity.

Leisure and recreation

A significant component of leisure and recreation in the UK depends upon coastal marine biodiversity (e.g. bird watching, rock pooling and diving) which in turn supports employment and small businesses. The very rapid growth of sea angling based on sustainable practices is recognized as significant opportunity for UK economy. If UK marine biodiversity declines the value of this sector will decrease, with a potential loss of revenue through a shift of activity to alternative non-UK destinations, and a decline in the number foreign visitors.

The total net value of marine leisure and recreation in the UK in the year 2002 was estimated as £11.77 billion by Pugh and Skinner (2002) and included holiday tourism, cruising and leisure craft services. This value will not be entirely dependent upon marine biodiversity, and is considered an overestimate.

Activities which are based in the open marine waters and are dependent upon marine biodiversity include, sea angling, diving, and whale watching. Two specific examples are marine mammal watching and sea angling. Whales and dolphins are highlighted as Scotland's number one wildlife attraction. A quarter of million tourists are involved with whale-tourism activities annually in West Scotland, with the total income generated by whale-tourism being estimated at £7.8 million in 1994 (Source: The Hebridean Whale and Dolphin Trust (HWDT) website). In addition, a baseline study of seal watching commissioned by the International Fund for Animal Welfare (IFAW), estimated that seal watching provided at least £36 million to the UK economy in 1996. Wildlife watching also has important implications for the small rural communities in terms of employment and raising the awareness of local marine wildlife, inspiring the public and teaching a healthy respect for their natural environment. The total expenditure by sea fish anglers resident in England and Wales was estimated as £538 million per year from 12.7 million angler days of activity in 2004. 52% was by own boat anglers, 37% by shore anglers and the remaining by charter boats. In terms of first round impacts, the spending translates to 18,889 jobs and 71 million pounds in suppliers' income (Shorney 2004).

Non-use values

Non use values are generally divided into two categories, bequest and existence value, and are difficult to determine accurately. When values are calculated, it is often problematic to separate the existence value from the bequest value, and a result a combined value is usually presented. Despite the considerable literature published in this area there is no comprehensive study of marine non-use values.

The wider public are considered to attach importance to maintaining diverse marine life. This is revealed through their interest in marine based media presentations, such as the "Blue Planet" and UK focused "Coast". 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 put value on their existence. A decline in biodiversity is likely to negatively affect the general public perception of the UK marine waters. The UK general public clearly attach high values to UK marine biodiversity and this considerable value would be lost if biodiversity declined.

Hageman (1985) and Loomis and White (1996) estimated that the average household's willingness to pay to ensure the continued survival of various sea mammals varied between £19 and £46 annually, depending on the sea mammal. These values are willingness to pay per species of sea mammal. However, respondents of contingent valuation studies can tend towards multiple allocation of resources, that is they have 'x' amount of money which they will allocate repeatedly. It is therefore assumed that the willingness to pay to maintain one sea mammal species is equivalent to the willingness to pay to maintain all sea mammal species. The National Statistics office estimates that there are 24.7 million households in the UK in 2004. It is therefore estimated that the non-use value of marine mammals varies between £469 million and £1,136 million. These values are an under-estimate of the total non-use value of UK marine biodiversity, as only a small component of non-use value is considered, but they do provide an insight to some potential values.

Option use value

It is expected that the genetic resources available from the UK marine biodiversity may be of significant importance in future for food provision, for example in cross breeding or genetic engineering to improve existing commercial species for fish farming. Option use value is intrinsically linked with biodiversity and if biodiversity declines our future options will also decrease, resulting in a reduced value to society and the economy. Tropical rainforests have been valued at £0.01- £ 19.38 per ha based on their genetic diversity, and their resultant potential to yield successful pharmaceutical products. In the same way it is probable that the genetic diversity held in the marine communities may provide valuable information for future medicines (Simpson *et al.* 1996).

Nutrient cycling

The capacity of the environment to cycle nutrients is an important function and can alleviate anthropogenic effects, such as excessive nutrient loading, which can result in

Harmful Algal Blooms (HAB), eutrophication and other detrimental effects. A decrease in biodiversity could lead to changes in the extent of nutrient cycling, although the direction and degree of these changes is currently unknown. As nutrient cycling is closely linked to productivity, changes in nutrient cycling, as a result of decreasing biodiversity could indirectly alter productivity rates with social and economic ramifications.

Costanza *et al*. (1997) proposed a replacement cost method for the valuation of the environment in its nutrient cycling capacity. The values which they propose, adjusted to 2004 prices, are £0.10 to £0.29 per m^3, (original source Richards *et al.* 1991) The UK territorial waters cover an area of 161,200 km^2 (*http://www.jncc.gov.uk/page-1478*); with the majority of this area on the continental shelf. With an estimated average depth of 50m (best estimate), the approximate volume of UK waters is 8 x 10^{12} m^3 which equates to a replacement cost of nutrient cycling between £800 billion and £2320 billion (billion = 10^9). This estimate should be considered with significant caution as replacement of the nutrient cycling function is impossible, and if all nutrient cycling did stop the marine system would break down. Thus it could be argued that this monetary value is meaningless, however, it is included as a hypothetical value.

Resilience and resistance

There are no UK specific examples of this service, but based on limited natural science evidence (e.g. Steneck *et al.* 2002, Steneck *et al.* 2004, Hughes and Stachowicz 2004, Reusch *et al.* 2005, Hughes *et al.* 2005, Tilman *et al.* 2006) it is reasonable to assume that high biodiversity in UK environments will lead to higher resilience. As biodiversity declines the resilience and resistance of marine ecosystem may decline. Systems may take longer to recover from disturbances, or not recover at all. This is turn will have a significant impact on the provision of all other goods and services. Maintaining a diversity of organisms with different functional roles and response types will help to ensure a variety of management options are available (Hooper *et al.* 2005).

Estimation of resilience and resistance values is complicated by a lack of scientific knowledge about the relationships between biodiversity and resilience. This context of fundamental uncertainty makes this service impossible to value at the current time and as a result it can tend to be overlooked. This is despite the fact that a systems resilience and resistance to disturbance is critical to the provision of all other goods and services, especially in the current climate of increased environmental perturbation.

Biologically mediated habitat

UK examples of biologically medicated habitat include maerl grounds, seagrass and kelp beds, mussel patches and cold-water coral reefs. Maerl is the collective term for the calcified product of coralline red algae (Kamenos *et al*. 2004a). Maerl grounds are patchily distributed around the UK but are predominantly on the west coasts. They are highly diverse habitats supporting a large number of species (Jackson *et al*. 2004). This includes the provision of refuge and food for juvenile life stages of commercially important shellfish such as the queen scallop, (Kamenos *et al*. 2004b), and juvenile gadoid fish Atlantic cod, saithe and pollack (Hall-Spencer *et al*. 2003, Kamenos *et al*. 2004c). The dead skeletons of coral, maerl and shell fragment are included here as although the majority of the habitat they provide is from the skeletons of dead organisms as opposed to the living element per se, it is biogenic in origin.

Seagrass has only a patchy distribution in the UK, but has been found to provide both refuge and nursery habitat for a number of commercial fish species (Murphy *et al*. 2000) including Atlantic cod, halibut, flounder and plaice (Gotceitas *et al*. 1997, Thayer *et al*.1975) and also commercial shell fish (Davidson and Hughes 1998, Stevens and Armstrong 1984). In addition, seagrasses can be important food sources for wildfowl (Thayer *et al*.1975). Kelp and many other species of marine macrophytes are widely distributed in UK waters (Birkett *et al*. 1998) and support a diverse range of species, (Orth *et al*. 1984), for example invertebrate abundance is particularly high in the holdfast of kelp (Norderhaug *et al*. 2002), whilst kelp forest provide refuge for fish species such as juvenile Atlantic cod (Cote *et al*. 2002).

Mussel patches reduce the harsh effects of temperature, wave action and light, providing favourable conditions for other species (Seed and Suchanek 1992), and as a result create habitat for a wide range of associated fauna (Suchanek 1980, Lintas and Seed 1994). Both living and dead shells can be used as substratum available for colonisation by other species and/or provide refuge from predation (Gutiérrez *et al*. 2003).

Cold water corals, such as *Lophelia pertusa*, are found in waters of the UK coast from north of the Shetlands into the North-East Atlantic, with the Darwin Mounds and around the Rockall Bank the main known areas (Wilson 1979). This species and several others can form colonies which aggregate over time into reef structures. Cold water reefs, like their tropical counterparts, have been found to provide habitat for various species of invertebrates (Bett 2001, Gage 2001). Fish in cold water coral reefs have been found to be present in significantly higher densities than the background environment (Bett & Jacobs 2000). Deep sea corals are slow growing and consequently take a long time to recover from damage caused by bottom impacting fishing gears which are particularly destructive.

A decline in marine biodiversity, for example through human activities such as dredging, is inherently linked to a decline in biogenic structures. The loss of these habitats will result in further decline of biodiversity due to a loss of nursery and refuge areas. There is currently no information on the valuation of marine biologically mediated habitats, although it is clear from their variety, abundance and function as nursery habitat and refuge that this service of marine biodiversity will be of considerable value.

Table Two: An overview of goods and services provided by UK marine biodiversity (see text for further information)

Good/Service	**Definition**	**Monetary value (per annum, UK £2004)**	**Method**	**Under / Over estimate**
Food provision	Plants and animals taken from the marine environment for human consumption	£513 million	Market	Under estimate
Raw materials	The extraction of marine organisms for all purposes, except human consumption.	£81.5 million	Market	Under estimate
Gas and climate regulation	The balance and maintenance of the chemical composition of the atmosphere and oceans by marine living organisms	£420million - £8.47 billion	Avoidance	Under estimate
Disturbance prevention and alleviation	The dampening of environmental disturbances by biogenic structures	£17 – 32 billion	Avoidance	Under estimate
Bioremediation of waste	Removal of pollutants through storage, dilution, transformation and burial.	Valuation data not available	Valuation data not available	Valuation data not available
Cultural heritage and identity	The cultural value associated with marine biodiversity e.g. for religion, folk lore, painting, cultural and spiritual traditions	Valuation data not available	Valuation data not available	Valuation data not available
Cognitive values	Cognitive development, including education and research, resulting from marine organisms	£317 million (2002)	Market	Over estimate
Leisure and recreation	The refreshment and stimulation of the human body and mind through the perusal and engagement with, living marine organisms in their natural environment.	£11.77 billion (2002)	Market	Over estimate
Non Use values – Bequest and Existence	Value which we derive from marine organisms without using them	£0.5 – 1.1 billion	Contingent valuation	Under estimate
Option use value	Currently unknown potential future uses of marine biodiversity	Valuation data not available	Valuation data not available	Valuation data not available
Nutrient cycling	The storage, cycling and maintenance of availability of nutrients mediated by living marine organism	£800 - £2320 billion	Replacement	Use with caution
Resilience and resistance	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)	Valuation data not available	Valuation data not available	Valuation data not available
Biologically mediated habitat	Habitat which is provided by living marine organisms	Valuation data not available	Valuation data not available	Valuation data not available

Discussion

A viable method of valuing biodiversity?

The results of this study suggest that the goods and services approach is a viable and comprehensive methodology to value biodiversity. This approach ensures all components of biodiversity are considered, including the regulatory and supporting functions which may be overlooked when using a stated preference technique (Christie *et al*. 2006), and the less tangible benefits such as non-use and option values which have not been taken into account by previous economic valuations (Brito 2005).

Eight of the thirteen goods and services were valued in monetary terms, with varying degrees of confidence. The production services were straightforward to value in monetary terms as market data was readily available. It was possible to assign monetary values to the majority of the regulatory services using avoidance cost techniques. However, the bioremediation service could not be valued as the waste types and associated processes were considered too varied and complex. A value for this service could have been derived from U.S. wetland studies, but this was not considered to be representative of UK marine biodiversity. Most of the cultural services were valued using contingent valuation methods and market data. A monetary value was not assigned to cultural heritage and identity due a fundamental lack of information. None of the supporting services were valued with confidence. This is due in part to the generic nature of these services. The monetary values are considered to be 'best estimates' only, and further research is required to improve the accuracy of these valuations.

The benefits arising from marine biodiversity are entirely dependent on the state of the whole ecosystem, and the sum of the parts of the system is less than the value of the whole system. The goods and services provided are intrinsically connected. Individual services can provide additional value when examined in the context of the other services with which they coexist at wider scales (spatial or temporal) than the scale of investigation. In addition, the exploitation of services may have negative, positive or neutral impacts on the other services. Thus, although this approach divides biodiversity into specific components, the inter-dependency of these components, and overall value of biodiversity should be remembered. Considering biodiversity in terms of goods and services can imply that species actively endeavour to provide any goods and services. This is obviously not the case and such provision is merely a consequence of living organisms natural functioning.

A single value for biodiversity?

Previous studies have provided a single figure for the value of the marine environment or biodiversity (Costanza *et al.* 1997, Williams *et al.* 2003, Patterson and Cole 1999, Pimental *et al.* 1997). Costanza *et al.* (1997) considered the open ocean to provide six services: gas regulation, nutrient cycling, biological control, food production, raw materials, and cultural values, with a combined value of US$252 per hectare, which was then multiplied up to a global scale. This method has been criticised, notably due to inaccuracies relating to benefit transfer, aggregation and extrapolation to a global scale (Balmford *et al.* 2002). However, the benefit of providing a single figure is in simplifying the data and raising awareness of the economic and societal importance of the environment.

A single value for biodiversity was not provided by this study for two primary reasons. Firstly only eight of the thirteen services were assigned a monetary value, thus any single value would be a significant underestimate. Aggregating the data would erroneously imply a comprehensive understanding and disguises gaps in current knowledge. It is considered that attention should be drawn to the missing values, as this information is critical to focus future research. Secondly, the error associated with aggregating the data was considered too significant. The monetary values cannot be aggregated to provide an overall value of the marine biodiversity as different methods have been used to calculate the values, and hence they are not directly comparable. Even if the same method is applied, small variations within the approach can lead to a significant change in the value. For example, in the case of stated preference techniques, values will vary depending on the survey type, payment options, the interviewer characteristics, the current political climate.

Limitations and benefits of the approach

A significant limitation of this study was a lack of relevant natural science, social and economic data, particularly with reference to the UK. There are significant limitations in our scientific knowledge of the effects of marine biodiversity on ecosystem functioning, and for most services the importance of biodiversity can only be quantified in a limited number of habitats or for a limited number of species or functional types (Hooper *et al.*2005). More information linking biodiversity to the provision of goods and services, or ecosystem function, is essential if we are to fully understand the implications of declining biodiversity on the society and economy.

The majority of the monetary values are under estimates as only a component of the total good or service has been valued due to an absence of data. There are also a number of limitations associated with the monetary data. The monetary figures calculated using avoidance, replacement and contingent valuation techniques are all constrained by the well-known limitations of valuation methods (Chee 2004, Ludwig 2000, Ledoux and Turner 2002). Market values are also not always representative of the true value of a resource, not least because they tend to omit added value. Extrapolation of monetary values using benefit transfer, as applied in the nutrient cycling calculation, can also generate inaccuracies (Woodward and Wui 2001). Finally, multiplying up monetary values that have been provided on a per area basis, as in the case of the disturbance alleviation and nutrient cycling calculations, can also produce erroneous results.

Despite these limitations, the monetary figures provided here are the best value estimates currently available. The aim of this valuation process was not to determine a single value for UK marine biodiversity, but to detail current knowledge, identify knowledge gaps, and to provide a better understanding of the research which will be required to value biodiversity in the future. This goods and services approach provides a comprehensive and transferable framework for site specific assessment, enabling the costs and benefits of exploitative activity to be evaluated, facilitating the management process for marine biodiversity. Finally, this study clarifies the social and economic importance of marine biodiversity, and as such will be beneficial to support and influence future marine environmental policies.

Conclusions

A wide range of goods and services are provided by UK marine biodiversity, resulting in significant social and economic benefits. The strength of this valuation data lies in its capacity to raise awareness of the importance of marine biodiversity, but it should only be used alongside the qualitative information and with a clear understanding of the associated limitations. The descriptive text for each of the goods and services is as important as the monetary data, and clarifies the linkages between biodiversity and the provision of these functions in UK coastal and shelf waters. This paper has provided an indication of what can currently be valued in a meaningful sense and highlights the knowledge gaps which should focus future research.

Changes in biodiversity are understood to mean changes in richness and composition at species and functional type levels, which is groups of species that carry out the same ecological functions. The provision of all the goods and services presented are linked to marine biodiversity. A decline in UK marine biodiversity will result in a varying, and at present unpredictable, change in the provision of all these goods and services. This could result in severe impacts on society and the economy, including reduced resilience and resistance to change, declining marine environmental health and water quality, reduced fisheries potential, loss of recreational opportunities, decreased employment and reduced carbon uptake.

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