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# Marine Biodiversity An economic valuation

## Building the evidence base for the Marine Bill

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# **Marine Biodiversity**

## **An economic valuation**

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# Executive Summary

The UK Government has recently outlined its vision for ‘clean, healthy, safe, productive and biologically diverse oceans and seas’ and is currently considering a number of provisions to improve marine nature conservation as part of the proposed Marine Bill.

In building the evidence base for the Marine Bill, Plymouth Marine Laboratory was commissioned by Defra to provide a valuation (based on best available information) of the goods and services resulting from marine biodiversity in UK waters, providing examples and monetary values where possible. The purpose of this work is to inform the need for further protection of marine biodiversity in UK waters.

Marine biodiversity plays a fundamental role in supporting a wide range of goods and services essential for the maintenance of the social and economic wellbeing of our society. Goods and services are defined within this report as indirect or direct benefits to humans arising from the natural environment. Biodiversity is defined as richness and composition at species and functional type levels, that is groups of species that carry out the same ecological functions.

The Total Economic Value (TEV) approach is used in this report. The application of this framework ensures all aspects of value associated with the goods and services of the environment are captured. This classification breaks the environment down into specific components but the inter-dependency of these components, and overall value of the environment should be remembered. Limitations to the application of monetary values to marine biodiversity are outlined and include existing shortfalls in data availability in the marine environment.

Chapter three of this report lists the goods and services provided by marine biodiversity, detailing the habitats and species which provide them, the likely impact of a decrease in biodiversity, and where possible a monetary value. An overview of the goods and services provided by the UK marine environment, and the available monetary values associated with these goods and services is presented in Table 1. Where the value placed on the good or service is classified as an ‘underestimate’, this is in consequence to existing data limitations allowing only one component of the good or service to be considered. For example, in the case of the service, gas and climate regulation, only carbon is considered. The absence of an economic value does not infer that this good or service is without value, only that the information is not available.

Valuing the environment in monetary terms is a well established but controversial approach and shortfalls are recognised. Despite the numerous and complex difficulties associated with monetary valuations the figures provided within this report are the best value estimates currently available. It should be stressed that the values presented are

indicative and should be treated as such. The strength of valuing marine biodiversity in monetary terms lies in its capacity to raise awareness of the importance of marine biodiversity.

Two case studies are outlined which investigate specific habitats and detail the goods and services which they provide, and how the provision of these goods and services is influenced by biodiversity. The first case study focuses on trawling in the North Sea to investigate how biodiversity declines following an anthropogenic impact, and the implications of this on the provision of goods and services. The second case study examines the benefits arising from a high biodiverse environment, Skomer Island.

The ability to provide an estimation of the total economic value of the UK's marine biodiversity is limited by a lack of relevant natural science, social and economic data. Quantification of how values change with declining or improving biodiversity could also not be undertaken due to insufficient information on the link between biodiversity and ecosystem function. A 'best estimate' of the strength of the linkage between biodiversity and the good or service is provided to indicate how sensitive the good or service is to changes in biodiversity (refer to Table 1).

The provision of all the goods and services presented within this report can be linked to marine biodiversity. From this analysis it was concluded that a decline in UK marine biodiversity will result in a varying, and at present unpredictable, change in the provision of goods and services. This change could result in severe impacts on society and the economy, including reduced resilience to change, declining marine health and water quality, reduced fisheries potential, loss of recreational opportunities, decreased employment, and reduced carbon uptake.

Further research on the valuation of goods and services is recommended, particularly in areas which currently could not be valued, including resilience and resistance, bioremediation of waste, biologically mediated habitat and option use. Improved information linking biodiversity to the provision of goods and services, or ecosystem function, is also required to quantify how values change with declining or improving biodiversity. There is a severe deficiency of UK case studies, and further UK site-specific research is strongly recommended in the future. The proposed Marine Protected Areas provide an ideal opportunity for case studies to potentially demonstrate the value of increasing biodiversity, and as such these areas should be monitored before and after designation.

Table 1. An overview of goods and services provided by UK marine biodiversity (see text for sources and further information)

Good/Service	Definition	Monetary value (per annum, UK £ 2004)	Method	Under / Over estimate	Link to biodiversity, low (1)–high (5)
<b>Food provision</b>	Plants and animals taken from the marine environment for human consumption	£513 million	Market	Under estimate	3
<b>Raw materials</b>	The extraction of marine organisms for all purposes, except human consumption	£81.5 million	Market	Under estimate	3
<b>Leisure and recreation</b>	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*	Market	Over estimate	3
<b>Resilience and resistance</b>	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 <i>et al.</i> 2005)	Valuation data not available	Valuation data not available	Valuation data not available	5
<b>Nutrient cycling</b>	The storage, cycling and maintenance of availability of nutrients mediated by living marine organism	£800 - £2320 billion**	Replacement	Use with caution	4
<b>Gas and climate regulation</b>	The balance and maintenance of the chemical composition of the atmosphere and oceans by marine living organisms	£0.4 - £8.47 billion	Avoidance	Under estimate	5
<b>Bioremediation of waste</b>	Removal of pollutants through storage, dilution, transformation and burial	Valuation data not available	Valuation data not available	Valuation data not available	5
<b>Biologically mediated habitat</b>	Habitat which is provided by living marine organisms	Valuation data not available	Valuation data not available	Valuation data not available	5
<b>Disturbance prevention and alleviation</b>	The dampening of environmental disturbances by biogenic structures	£0.3billion***	Avoidance	Under estimate	4
<b>Cultural heritage and identity</b>	The cultural value associated with the marine environment e.g. for religion, folk lore, painting, cultural and spiritual traditions	Valuation data not available	Valuation data not available	Valuation data not available	3
<b>Cognitive values</b>	Cognitive development, including education and research, resulting from marine organisms	£317 million*	Market	Over estimate	4
<b>Option use value</b>	Currently unknown potential future uses of the marine environment	Valuation data not available	Valuation data not available	Valuation data not available	5
<b>Non-Use values – bequest and existence</b>	Value which we derive from marine organisms without using them	£0.5 – 1.1 billion	Contingent valuation	Under estimate	5

\*Based on 2002 values.

\*\*Cost of treating UK waters once, not per annum.

\*\*\*In addition to £17-£32 billion capital costs.

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# Chapter 1 - Introduction

The UK Government has recently outlined its vision for 'clean, healthy, safe productive and biologically diverse oceans and seas' and is currently considering a number of provisions to improve marine nature conservation as part of the proposed Marine Bill.

In building the evidence base for the Marine Bill, Plymouth Marine Laboratory was commissioned by Defra to provide a valuation (based on best available information) of the goods and services resulting from marine biodiversity in UK waters, providing examples and monetary values where possible. The purpose of this work is to inform the need for further protection of marine biodiversity in UK waters.

## 1.1 Aims and objectives

The project aims and objectives are:

- To provide an estimation of the total economic value of marine biodiversity in UK waters including the goods and services and non-use values it provides;
- To provide examples of marine biodiversity value and the change in value if marine biodiversity improves or declines; and
- To provide an economic valuation using marine biodiversity change scenarios.

Marine biodiversity plays a fundamental role in supporting a wide range of goods and services essential for the maintenance of the social and economic wellbeing of our society. The term biodiversity has many different definitions (Sheppard 2006), but for the purposes of this report it is used to refer to richness and composition at species and functional type levels. Goods and services are defined as indirect or direct benefits to human society which arise from the natural environment. Current environmental management tends to focus on market linked goods and services, such as tourism and fisheries. It is this narrow approach which has contributed to the over exploitation and degradation of marine biodiversity. Only by understanding all the goods and services provided by marine biodiversity is it possible to appreciate the true value of this resource. This understanding is the key to developing sustainable management plans to maximise the benefits received from marine biodiversity.

## 1.2 Report structure

Chapter two of this report details the methods used and the limitations of this approach. Each good and service is provided by a variety of habitats and species, and likewise each habitat or species provides a variety of goods and services. A list of the goods and services, providing an indication of the habitats and species which provide them, the likely

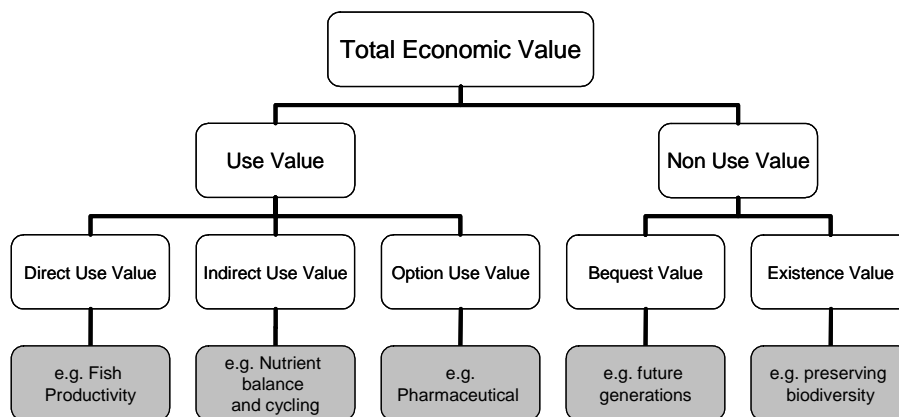
impact of a decrease in biodiversity, and where possible a monetary value is provided in Chapter 3. Chapter 4 presents two case studies (biodiversity decline and high biodiversity) to investigate specific habitats, detailing the goods and services which they provide, and how the provision of these goods and services is influenced by biodiversity. Chapter 5 presents the overall conclusions and recommendations from this report.

# Chapter 2 - Adopted approach

## 2.1 Methods

The Total Economic Value (TEV) approach is used in this report. Goods and services resulting from marine biodiversity in UK waters are outlined with monetary values provided where possible. All values are based on the best currently available information. The absence of an economic value does not infer that this good or service is without value, only that the information is not available. Given the focus of this research is on goods and services provided by marine biodiversity, any goods or services based on the physical attributes of the marine environment are not included. The geographical focus of this report is on UK open marine waters, although non-UK and coastal examples are used where no other information is available.

The environment provides several different types of value to man, use and non-use, and these are defined by the TEV framework (Pearce and Turner 1990), and depicted in Figure 1. It has been argued that previous lists of goods and services have not included the less tangible benefits derived from the environment (Brito 2005). By applying the TEV framework all aspects of value associated with the goods and services of the environment are captured.



**Figure 1. The Total Economic Value (TEV) framework, in the context of the marine environment (adapted from Bateman and Langford 1997)**

Use values arise from humans actually using the environment and are presented in Table 2. Three 'use' values are generally considered, direct, indirect and option use. Non-use values are representative of the value which humans derive from an environmental resource, despite the fact they may never use or even see it, and are generally divided into two categories, bequest and existence. Values held by non-human entities, that is intrinsic values (Bateman and Langford 1997), or values

held by non-human organisms in their own right, are not considered within the context of this report.

**Table 2. Definition of Total Economic Value (adapted from Pearce and Turner 1990)**

<b>Value</b>	<b>Description</b>
<b>Use Values</b>	
<b>Direct Use</b>	arise from the direct exploitation of the environment, and are generally demand driven goods, e.g. fisheries. Chapter 3 (3.1 – 3.2)
<b>Indirect Use Values</b>	are benefits which are derived from the environment, without the intervention of man, e.g. climate regulation. Chapter 3 (3.3 – 3.11)
<b>Option Use Value</b>	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. Chapter 3 (3.12)
<b>Non-Use values</b>	
<b>Bequest Value</b>	is the value an individual places on ensuring the availability of a natural resource to future generations. Chapter 3 (3.13)
<b>Existence Value</b>	is the value placed on simply knowing that a natural resource is there, even if it is never experienced. Chapter 3 (3.13)

A comprehensive list of goods and services which are dependent on marine biodiversity (Table 3) was defined by adapting and refining previous research (Groot *et al.* 2002, Pearce and Turner 1990, Beaumont and Tinch 2003, Millennium Ecosystem Assessment 2006) at a workshop funded by the European Network of Excellence Marine Biodiversity and Ecosystem Function (MarBEF). 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.

Valuing the environment in monetary terms is still controversial, and problems with this approach are recognised (section 2.2). 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). However, it is argued that using these values to highlight the importance of marine biodiversity is a worthwhile exercise, provided it is set within context, that is by coupling the monetary valuations with detailed qualitative descriptions and outlined

limitations of the data. Calculation of changes to the value following changes in biodiversity cannot be made due to limitations on the natural science required to support the calculation of these values. Progress is however being made in this area, notably by MarBEF ([www.MarBEF.org](http://www.MarBEF.org)), a network of excellence funded by the European Union as a platform to integrate and disseminate knowledge and expertise on marine biodiversity. Monetary values are presented on an annual basis for the year 2004 where possible. These values will continue to be provided during the coming years, so the actual value (Net Present Value) of these goods and service is likely to be much greater than presented within this report.

The benefits we receive from the marine environment are entirely dependent on the state of the whole ecosystem, the sum of the parts of the system will be less than the value of the whole system, and the goods and services provided are intrinsically connected. Individual functions can also provide additional value when examined in the context of the other functions with which they coexist at wider scales (spatial or temporal) than the scale of investigation. In addition, the exploitation of goods and services may have negative, positive or neutral impacts on the other goods and services. Thus, although this classification breaks the environment down into specific components, the inter-dependency of these components, and overall value of the environment should not be underestimated.

Changes in biodiversity are understood to mean changes in richness and composition at species and functional type levels, that is groups of species that carry out the same ecological functions. As the provision of all the goods and services presented in this report are linked to marine biodiversity, a change in biodiversity will lead to a change in the provision of these goods and services with varying and at present unpredictable impacts on society and the economy.

## **2.2 Limitations and applications of values**

Valuing all environmental goods and services clarifies the importance of marine biodiversity and enables the costs and benefits of exploitative activity to be evaluated, facilitating the management process for the marine environment. Valuing non-market goods and services is, however, still controversial and can be problematic (see Annex 1 for an overview of the techniques applied in this review). The monetary values should be considered to play a complementary role within this report, to highlight the importance of marine biodiversity, with the accompanying text being of equal importance.

Despite the numerous and complex difficulties with the monetary data they are the best value estimates currently available. It is advised that they are used only as indicators of value, and should only be applied within the context of these limitations.

In using the findings of this report, the following limitations to the valuation data should be noted:

1. Estimates are likely to be conservative as only a component of the total good or service can be valued due to current limitations on data.
2. Values are standardised as far as possible, but a comprehensive benefit transfer of the values has not been undertaken. For example, some of the valuations use USA data which has been extrapolated to the UK. Extrapolation will generate inaccuracies (Woodward and Wui 2001), but in the absence of UK or European data, USA studies are believed to provide the best estimate available at the current time.
3. The monetary values cannot be aggregated to provide an overall figure for the value of UK marine biodiversity due to differing methods used to calculate values. As such values are not directly comparable. Even if the same method is applied, a small change in the method can lead to a significant change in the value. Aggregating the values is also misleading as there are significant gaps in the valuation literature, resulting in several of the goods and services not being quantified in monetary terms. Thus, any aggregated value will be a significant under estimate.
4. Some values provided are on a per area basis and then multiplied up to a UK area (for example gas and climate regulation and nutrient cycling). Problems with this approach include:
  - Environment types not being uniform, for example a wetland in Cornwall may be very different to a wetland in Renfrewshire;
  - 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 its value may increase, and vice versa;
  - multiplying the values up entails designating boundaries on the UK marine environment, and as many marine processes and organisms are mobile this is not realistic.
5. Values for nutrient cycling are very uncertain, as replacement values are applied. Replacement of this function is not possible. In addition, if all nutrient cycling stopped the marine system would break down. It could be therefore be argued that this renders the value meaningless. However, this value has been included here out of interest as a hypothetical value.

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). A single figure is not provided by this research for the reasons noted previously, but it is worth briefly considering the validity of this approach. In all these studies the open ocean was considered to offer six services (with a combined value of US\$252 per hectare):

- gas regulation;
- nutrient cycling;
- biological control;
- food production;
- raw materials; and
- cultural values.

All other goods and services were ignored. Despite a variety of methods being used to determine this estimate, the values were aggregated. The values for these services were also calculated by extrapolating from a wide variety of environments, increasing the error margins on this estimate. This value could easily be extrapolated to the U.K. but the resultant value would be a vast under-estimate of dubious quality.

A significant limitation of this report is a lack of relevant natural science, social and economic data. 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 marine environment is also extremely diverse and complex, resulting in significant limitations in current scientific knowledge of the effects of marine biodiversity on ecosystem functioning. 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).

## Chapter 3 - Description of goods and services and associated values

The goods and services which are provided by UK marine biodiversity are listed in Table 3. This chapter provides an indication of the habitats and species which provide these goods and services, and the likely impact of a decrease in biodiversity on their provision. Where possible the goods and services are valued in monetary terms.

**Table 3. Goods and Services provided by marine biodiversity**

Section number	Goods and Services
3.1	Food provision
3.2	Raw materials
3.3	Leisure and recreation
3.4	Resilience / Resistance
3.5	Nutrient cycling
3.6	Gas and Climate Regulation
3.7	Bioremediation of Waste
3.8	Biologically mediated habitat
3.9	Disturbance prevention (Flood and storm protection)
3.10	Cultural Heritage and identity
3.11	Cognitive Values
3.12	Future unknown and speculative benefits
3.13	Non-use values – Bequest and existence

### 3.1 Food provision

#### 3.1.1 Definition

*The extraction of marine organisms for human consumption.*

Plants and animals taken from the marine environment provide a significant part of the human diet and include fish, seaweed, and shellfish.

#### 3.1.2 UK example and valuation

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. A more detailed overview of UK marine food provision can be found in Annex 2.

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 full time fisherman.

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 include in the above figure as a result is considered to be an underestimate.

#### *Socio-economic impacts of declining biodiversity*

Reduced marine biodiversity would directly impact fisheries and any associated employment, through a reduction in the quantity and number of species available for commercial exploitation. Declining biodiversity would also indirectly impact UK fisheries through reduced primary productivity (Runge 1988), a declining ability to recover following disturbance (resilience) (section 3.4) and a reduction in refuge and breeding areas (section 3.8)

## **3.2 Raw materials**

### **3.2.1 Definition**

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

A wide variety of raw materials are provided by the marine environment 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.

### **3.2.2 UK example and valuation**

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. Further information on raw materials can be found in Annex 3.

*Socio-economic impacts of declining biodiversity*

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. However, the extent of the impact of reduced marine biodiversity will depend upon the specific species which are in decline and the prevalence of substitutes.

### **3.3 Leisure and recreation**

#### **3.3.1 Definition**

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

The marine environment provides the basis for a wide range of recreational activities including: (sea)bird watching, rock pooling, beachcombing, sport fishing, recreational diving, and whale-watching to name but a few. In addition, the provision of this good results in significant employment opportunities. Sports such as sailing are not included as this generally uses only the 'physical' marine environment, although it is recognised that in some cases biodiversity adds to the 'sailing experience' it is considered to play a minimal role.

#### **3.3.2 UK example and valuation**

The majority of leisure activities in the UK marine environment are based around the coastal areas, and include bird watching, rock pooling and diving. 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. It is useful to consider two more specific examples, 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% of this activity 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 in income for suppliers of angling services and materials (Shorney 2004).

#### *Socio-economic impacts of declining biodiversity*

A considerable component of leisure and recreation in the UK depends upon marine biodiversity, 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.

### **3.4 Resilience and resistance**

#### **3.4.1 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 than lower diversity systems (Hughes et al. 2005, Tilman et al. 2006). 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.

#### **3.4.2 UK example and valuation**

Small scale experimental studies of biodiversity and ecosystem function suggest that in marine ecosystems high species richness leads to greater resilience. In some cases this is exhibited as increased resistance, for example in seagrass (Hughes and Stachowicz 2004), or as enhanced recovery after a perturbation (Reusch et al. 2005).

These small scale studies cannot necessarily be extrapolated to the entire marine environment but recent studies suggest the same phenomenon is observed at larger scales. High diversity kelp forest are considered to be more resilient than their lower diversity equivalents (Steneck et al. 2002, Steneck et al. 2004). The simplification of food

chains has also been found to have detrimental effects on the resilience of systems, for example the removal of predators, such as pelagic fish, can lead to an increased abundance of their prey, in this case plankton, resulting in plankton blooms (Hughes *et al.* 2005). Under similar environmental conditions increased species richness generally decreases susceptibility to invasion by exotic species. However several other factors may be more influential and mask the effects of species richness, such as disturbance regime and resource availability (Hooper *et al.* 2005).

There are no UK specific examples of this service, but based on this evidence it is reasonable to assume that high biodiversity in UK environments will lead to higher resilience. 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 change.

*Socio-economic impacts of a decrease in biodiversity:*

If biodiversity declines a loss of stability in the marine ecosystem may result. Systems may take longer to recover from disturbances, or not recover at all. This in 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).

### **3.5 Nutrient cycling**

#### **3.5.1 Definition**

*The storage, cycling and maintenance of availability of nutrients by living marine organisms.*

The storage, cycling and maintenance of availability of essential nutrients, for example nitrogen, phosphorus, sulphur, silicon and metals, is crucial for the existence of life (Hutchins and Bruland 1995). Nutrient cycling encourages productivity by making the necessary nutrients available to all levels of the food chains and webs. Marine biodiversity plays a critical role in regulating nutrient cycling (see Annex 4 for further details).

#### **3.5.2 UK example and valuation**

Many marine species which occur in the seabed (benthic organisms) in UK waters are known to be important bioturbators and thus play a significant role in nutrient cycling. Bioturbators is the term given to those organisms whose physical activity as they feed on, and move and/or burrow through the sediment has a physico-chemical effect on the sediment. Examples include burrowing urchins (Widdicombe and Austen

1998, Bird *et al.* 1999), polychaetes (Kristensen 1985, 1989, Hansen and Kristensen 1998) and mud shrimps (Howe *et al.* 2004). Trawl fishing has a significant impact on benthic communities, particularly the large bioturbators, which in turn has the potential to impact rates of nutrient cycling. The impact of trawl fishing is discussed in more detail in Chapter 4.

The marine system is currently nutrient limited and excessive inputs of nitrogen can result in eutrophication and Harmful Algal Blooms (HAB). These events may be alleviated by the presence of biodiversity, which removes biologically available nutrients through sediment denitrification (Seitzinger and Nixon 1985).

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<sup>3</sup>, (original source Richards *et al.* 1991). The UK territorial waters (out to 12 nautical miles from low-water mark) cover an area of 161,200 km<sup>2</sup> (<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<sup>12</sup> m<sup>3</sup>. This equates to a replacement cost for nutrient cycling of between £800 billion and £2320 billion (billion = 10<sup>9</sup>), to treat the entire UK waters once. To replace this service, this treatment process would need to be continually repeated, so the true value would be greater.

This estimate should be considered with significant caution as replacement of the entire UK marine 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 value is meaningless, however, it is included here out of interest as a hypothetical value.

*Socio-economic impacts of a decrease in biodiversity:*

The capacity of the environment to cycle nutrients is important for correcting detrimental anthropogenic effects, such as excessive nutrient loading resulting in HAB's and an increase in eutrophication. 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.

## **3.6 Gas and climate regulation**

### **3.6.1. 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. The marine environment plays a significant role in climate control through the regulation of carbon fluxes, in part due to its capacity to sequester carbon dioxide (CO<sub>2</sub>). It thus acts as a carbon sink but its capacity to do so will be affected by changes in the marine food webs. Changes in trophic dynamics will cause changes in the distribution of carbon throughout the marine environment. The gas and climate regulation is affected by the biodiversity of the pelagic and benthic marine systems (refer to Annex 5 for details).

### **3.6.2 UK example and valuation**

Carbon cycling is well researched, and is documented to have a significant impact on the environment. 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<sub>2</sub> (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<sup>-1</sup> (95% CI), which is slightly over 0.1% of global production (Smyth *et al.* 2005). Refer to Annex 5 for further information on this calculation

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). 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<sup>9</sup>) 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.

#### *Socio-economic impacts of a decrease in biodiversity*

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, see Annex 5), and thus it is reasonable to assume decreasing carbon sequestration. A decrease in biodiversity could have potential implications for climate change. In addition primary productivity has been linked to fisheries productivity (Runge *et al.* 1988), so a decrease in marine biodiversity may indirectly also reduce fisheries productivity.

### **3.7 Bioremediation of waste**

#### **3.7.1 Definition**

*Removal of pollutants through storage, dilution, transformation and burial.*

A significant proportion of anthropogenic waste finally settles in the marine environment. In addition to this continuous 'chronic' release, accidental 'acute' discharge of substances, every year a number of incidents such as shipwrecks or land-based industry releases occur. Waste types can be organic, such as oil and sewage, or inorganic, (metals and synthetic chemicals). Marine living organisms store, dilute, bury and transform many wastes through assimilation and chemical de and re-composition either directly or indirectly. This de-toxification and purification process is of critical importance to the health of marine environment.

The role of biodiversity in 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.

#### **3.7.2 UK example and valuation**

Bioturbation, will serve to bury, dilute, and recycle wastes through assimilation and chemical re-composition. As a result UK marine benthic diversity are an important factor in the environmental remediation of domestic, aquacultural and agricultural organic pollution. Benthic community succession is a known phenomenon associated with many types of organic pollution (Pearson and Rosenberg, 1978), and a large range of species are associated with the recovery and succession of marine benthic systems (Rosenberg 2001). See Annex 6 for further details.

Efforts to increase bivalve populations have been proposed as a method of improving water quality (Porter *et al.* 2004), as the loss of bivalve

species in the past (e.g. due to over-harvesting and reclamation of coastal areas for harbours and land-use) may have resulted in a decline in water quality (Dame *et al.* 2002). In addition, the bioremediation role of marine bacteria, algae and crab shells is highlighted by their application in heavy metal remediation (Iyer *et al.* 2005, Davis *et al.* 2003, Pascucci and Kowalak 1999, Vieira and Volesky 2000).

Salt marshes play an important role in the bioremediation of waste, for example they have been documented to have bioremediation capacities in response to oil release, with 95% degraded over the course of a year (Mills *et al.* 2003).

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.

An alternative method to quantify this service is to consider the levels of raw sewage discharged to the marine environment. In 2003/2004 an average of 36094.28 kg BOD<sub>5</sub>/day was discharged into the sea. To treat this sewage to a tertiary level would cost £2,931,000 per day, that is approximately £1 billion per year ([www.ofwat.gov.uk](http://www.ofwat.gov.uk), 2006). This cost is currently avoided by utilising the marine environment's capacity to accept waste. It could be argued however, that the capacity of the marine environment to accept this waste depends largely upon the physical dilution capacity, as opposed to biotic processes, and as a result this is not a true indication of the value of marine biodiversity. This value is therefore not included in the overview Table 4.

#### *Socio-economic impacts of a decrease in biodiversity*

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

## **3.8 Biologically mediated habitat**

### **3.8.1 Definition**

*Habitat which is provided by marine organisms.*

Marine systems contain organisms described as ecosystem engineers (*sensu* Jones *et al.* 1994, 1997), which have the ability to change the availability of resources for other organisms, and by doing so create and maintain habitats. Many marine species are responsible for the provision of living space which is both utilised and necessitated by many other species and is a pre-requisite for the provision of all goods and services. These biologically mediated habitats provide essential

breeding and nursery space for plants and animals (many of which have commercial value) and enable biodiversity to exist by providing a heterogeneous environment, this is essential for the continued recruitment of commercial and/or subsistence species. They also provide a refuge for plants and animals including surfaces for feeding and hiding places from predators.

### **3.8.2 UK example and valuation**

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.

The dead skeletons of coral, Maerl and shell fragments provide important habitat for a number of species. . Maerl is the collective term for the calcified product of coralline red algae (Kamenos *et al.* 2004a) and such grounds are patchily distributed around the UK but predominantly found on the west coasts. Maerl grounds 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).

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 also often reduce the harsh effects of temperature, wave action and light, providing more favourable conditions (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 and 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. Fishing has been identified as a threat to these habitats.

Further information on all these habitats can be found in Annex 7.

#### *Socio-economic impacts of a decrease in biodiversity*

A decrease in marine biodiversity could lead to a loss of these habitats through a decrease in the 'ecosystem engineers' which are necessary to provide them. This would result in loss of nursery and refuge areas for many other organisms, including commercially important species.

### **3.9 Disturbance alleviation and prevention**

#### **3.9.1 Definition**

*The dampening of environmental disturbances by biogenic structures.*

Living marine flora and fauna play a valuable role in the defence of coastal regions. The presence of biogenic structures in the front line of sea defence can dampen and prevent a number of environmental disturbances such as tidal, storm and flood damages. This disturbance alleviation is dominated by a diverse range of species which bind and stabilise sediments and create natural sea defences.

#### **3.9.2 UK example and valuation**

Biogenic structures which provide flood and storm prevention in the UK are only found around the coast. This is however a critical service, particularly as the risk of flooding has been accentuated in recent years by the onset of climate change (<http://www.incc.gov.uk/pdf/jncc334.pdf>).

Many types of flora can contribute to the reduction in wave energy in 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. Further information on disturbance prevention can be found in Annex 8.

King and Lester (1995) estimated that an 80m width of saltmarsh could result in cost savings, in sea defence terms, of £0.38 million to £0.71 million per hectare in terms of capital costs, and £7100 per hectare in terms of annual maintenance costs (adjusted to 2004 prices). Coupled with an area of 45,500 ha this equates to cost savings of between £17 billion and £32 billion for capital costs, and £0.3billion annual maintenance costs (billion 10<sup>9</sup>).

*Socio-economic impacts of a decrease in biodiversity*

Clear linkages between saltmarshes and flood prevention exist.

Saltmarshes comprise of a diverse range of species which are necessary to enable the flood defence function of this habitat. A decline in saltmarsh area, and thus biodiversity, 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).

### **3.10 Cultural Heritage and Identity**

#### **3.10.1 Definition**

*The value associated with the marine environment e.g. for religion, folk lore, painting, cultural and spiritual traditions.*

Much of the research on marine cultural heritage is focussed upon archaeology, ancient monuments (Marine and Coastal Environment Group, 2004) and shipwrecks (Oxley 2001). As documented by the Millennium Ecosystem Assessment (2006), marine biodiversity is also a critical part of our cultural heritage and identity. The diversity of ecosystems affects the diversity of cultures, and many religions attach spiritual and religious values to marine life. The development and sustenance of many societies depends heavily upon marine ecosystems, in particular fishing communities. In addition, considerable value is placed upon the maintenance of culturally significant species. Finally, varied marine life provides inspiration for arts, local customs, traditions, crafts and skills, language and dialect.

#### **3.10.2 UK example and valuation**

Our national cultural identity is shaped by the rich and diverse heritage which stems from the UK marine biodiversity. 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.

*Socio-economic impacts of declining 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](http://www.planarch.org)).

### **3.11 Cognitive values**

#### **3.11.1 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. In addition, the marine environment can provide provides a long term environmental record which can be provide insight into environmental resilience and stress. This record can provide an insight into how the environment has changed in the past, enabling us to determine how it may change in the future. This may be of particular relevance when studying climate change. Bio-indicators are also of value for assessing and monitoring changes in the marine environment

#### **3.11.2 UK example and valuation**

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 by natural substances from marine organisms (Self 2005);
- the use of spines of the polychaete worm *Aphrodite sp.* to progress the field of photonic engineering, with potential implications for communication technologies and medical applications (Parker *et al.* 2001); and
- the development of tougher, wear resistant ceramics for biomedical and structural engineering applications by studying the bivalve shell (Ross and Wyeth 1997).

As detailed in the bioremediation section, heavy metal remediation through common physio-chemical techniques is expensive and environmental unfriendly (Iyer *et al.* 2005), whereas marine bacteria, algae and crab shells (Davis *et al.* 2003, Pascucci and Kowalak 1999, Vieira and Volesky 2000) can all remove these substances naturally.

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 (Pugh and Skinner 2002). These estimates include all marine areas and are considered an over-estimate.

*Socio-economic impacts of declining biodiversity*

Cognitive values are intrinsically 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.

## **3.12 Option Use Value**

### **3.12.1 Definition**

*Currently unknown potential future uses of the marine environment.*

Option use Value 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. This review has explored many uses of the marine environment, but this service is the value we attach to uses which have not yet been discovered. We may never exploit the environment for these resources, but there is value associated with retaining the option of exploitation. Any *expected* future use is not option value but is properly part of direct/indirect use value and would belong under cognitive values.

For every species we lose, we may lose a potential cure for disease, and as such even though we may not use every species in the future, there is value in maintaining them, so that we have the option to use them. This value is expected to be significant, considering the benefits arising from marine biodiversity to date (see all other goods and services).

### **3.12.2 UK example and valuation**

The genetic resources available from the UK marine environment are not currently being utilised commercially. It is expected that they 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. 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).

*Socio-economic impacts of declining biodiversity*

Option use value is intrinsically linked with biodiversity, if biodiversity declines our future options will also decrease, resulting in a reduced value to society and the economy.

### **3.13 Non-Use Values – bequest and existence**

#### **3.13.1 Definition**

*Value which we derive from marine organisms without using them.*

Non-use values are generally divided into two categories: bequest and existence value. Bequest Value is the value the current generation places on ensuring the availability of biodiversity and ecosystem functioning to future generations. This is determined by our concern that future generations should have access to resources and opportunities, that is, we gain benefit from the knowledge that resources and opportunities are being passed to our descendants.

Existence Value is the value placed on simply knowing marine biodiversity is there, even if it is never utilised or experienced, people simply derive value from the knowledge of its existence (Hageman 1985, Loomis and White 1996). People derive a substantial sense of well being purely from the knowledge that diverse marine life exists. Existence values are not associated with any human use or option of human use, but simply reflect utility experienced from the knowledge that an environment exists in a certain state.

#### **3.13.2 UK example and valuation**

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”. 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.

Existence and bequest values are difficult to determine accurately, and despite the considerable literature published in this area there is no comprehensive study of marine non-use values. When values are determined it is difficult to separate the existence value from the bequest value.

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 the UK marine environment, as only a small component of

non-use value is considered, but they do provide an insight to some potential values.

*Socio-economic impacts of declining biodiversity*

The UK general public attaches considerable value to the diversity of UK marine life, exhibited through their interest in a wide variety of species they may never directly experience. A decline in biodiversity would negatively affect the general public perception of the UK marine life, and as a result considerable value would be lost if biodiversity declined.

Table 4. An overview of goods and services provided by UK marine biodiversity (see text for sources and further information)

Good/Service	Definition	Monetary value (per annum, UK £ 2004)	Method	Under / Over estimate	Link to biodiversity, low (1)–high (5)
<b>Food provision</b>	Plants and animals taken from the marine environment for human consumption	£513 million	Market	Under estimate	3
<b>Raw materials</b>	The extraction of marine organisms for all purposes, except human consumption.	£81.5 million	Market	Under estimate	3
<b>Leisure and recreation</b>	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*	Market	Over estimate	3
<b>Resilience and resistance</b>	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 <i>et al.</i> 2005)	Valuation data not available	Valuation data not available	Valuation data not available	5
<b>Nutrient cycling</b>	The storage, cycling and maintenance of availability of nutrients mediated by living marine organism	£800 - £2320 billion**	Replacement	Use with caution	4
<b>Gas and climate regulation</b>	The balance and maintenance of the chemical composition of the atmosphere and oceans by marine living organisms	£0.4 - £8.47 billion	Avoidance	Under estimate	5
<b>Bioremediation of waste</b>	Removal of pollutants through storage, dilution, transformation and burial.	Valuation data not available	Valuation data not available	Valuation data not available	5
<b>Biologically mediated habitat</b>	Habitat which is provided by living marine organisms	Valuation data not available	Valuation data not available	Valuation data not available	5
<b>Disturbance prevention and alleviation</b>	The dampening of environmental disturbances by biogenic structures	£0.3billion***	Avoidance	Under estimate	4
<b>Cultural heritage and identity</b>	The cultural value associated with the marine environment e.g. for religion, folk lore, painting, cultural and spiritual traditions	Valuation data not available	Valuation data not available	Valuation data not available	3
<b>Cognitive values</b>	Cognitive development, including education and research, resulting from marine organisms	£317 million*	Market	Over estimate	4
<b>Option use value</b>	Currently unknown potential future uses of the marine environment	Valuation data not available	Valuation data not available	Valuation data not available	5
<b>Non-Use values – bequest and existence</b>	Value which we derive from marine organisms without using them	£0.5 – 1.1 billion	Contingent valuation	Under estimate	5

\*Based on 2002 values.

\*\*Cost of treating UK waters once, not per annum.

\*\*\*In addition to £17-£32 billion capital costs

## Chapter 4 - Case Studies

Case studies presented in this report aim to document how specific habitats and species provide goods and services, and how biodiversity influences this provision. The first case study examines how biodiversity declines following an anthropogenic impact, and the implications of this on the provision of goods and services. The second case study investigates the benefits arising from a high biodiverse environment. Ideally these case studies would document an environment which had changed from low biodiversity to high biodiversity, but there are no suitable UK examples of these circumstances at the time of writing this report. Kettunen and ten Brink (2006) have documented several further case studies linking biodiversity loss to loss of goods and services.

### 4.1 Case study 1: The impact of trawl fishing on benthic biodiversity

Mobile bottom-fishing gear is used to catch species that live within, on or in close contact with the seabed such as scallops, shrimp and flatfishes. This gear causes varying levels of disturbance that alters seabed complexity, removes, damages or kills biota, and reduces benthic production, leading to substantial changes in benthic community structure and habitat.

The EU project COST-IMPACT investigated the impacts of trawl fishing on benthic biodiversity, and in turn, the provision of goods and services. Publicly available data on the impact of fishing on marine benthos was analysed, using meta-analysis, to predict the outcome of using different fishing techniques in different habitats. This meta-analysis provided input to the model used by the project. A synthesis of the European Regional Seas Ecosystem Model (ERSEM) (Baretta *et al.*, 1995, as modified by Blackford *et al.*, 2004), and the General Ocean Turbulence Model (GOTM) (Burchard *et al.*, 1999) was used to investigate changes in benthic community structure caused by demersal trawl fishing and how these changes further affect benthic nutrient recycling and pelagic production.

The ecosystem modelling suggested that the biogeochemical impact of demersal trawling is most significant in regions where the gear type, trawl frequency and sea-bed type cause high levels of filter feeder mortality. This results in a substantial increase in the oxygen content of the benthic system and significant changes in the biogeochemistry of the system. However the impacts of these changes on the overlying pelagic ecosystem are buffered by the physical environment and the ability of phytoplankton to vary their internal cell nutrient contents. Yet there may be more subtle implications on pelagic community structure including a shift towards the microbial loop and a potential increase in the probability of harmful algal bloom events.

The predictions derived from the meta-analysis and ecological models have been used as the baseline data for the effects of fishing on the economic value of the marine ecosystem goods and services. Scenarios were run over 5 years and included two different types of fishing gear (otter and beam trawls), in a variety of sediment types (gravel, sand and mud), in stratified and un-stratified water columns in the central North Sea which are typical of the North West European shelf. Nine goods and services were identified as being impacted by the trawling and resultant change in biodiversity: food provision, employment, nutrient cycling, gas and climate regulation, waste remediation, information (cognitive), option, bequest and existence. An example of the how the provision of these goods and services changes under the varying scenarios is shown in Table 5. The scenarios are described in the left hand column, with the services detailed across the top row. The figures in the table describe the predicted extent of provision of the service under the different scenarios. For example, if only beam trawling in stratified gravelled areas (BT, G, Stratified) is permitted the resultant food provision would be valued at 201 million € per year, and a 9.25% increase in nutrient cycling would be observed. It was not possible to attribute a value to waste remediation, and the bequest and existence value were scored only a 1 to 5 scale based on expert knowledge.

**Table 5. Data matrix for trawl fishing in the North Sea scenarios**

Scenario	Food Provision (million Euro, 2003)	Employment (people, 2003)	Nutrient Cycling (% change)	Gas and Climate (% change)	Info (% change in abundance)	Option (%change in abundance)	Existence	Bequest
BT, G, Stratified	201	12760	+9.25	+1.016	51	51	--	--
BT, S, Stratified	201	12760	+7.15	+2.578	51	51	--	--
OT, S, Stratified	98	10828	+5.23	+0.952	46	46	-	-
OT, M, Stratified	98	10828	+4.00	+1.67	46	46	-	-
BT, G, Well Mixed	201	12760	+27.58	+6.86	51	51	----	----
BT, S, Well Mixed	201	12760	+27.83	+14.88	51	51	-----	-----
OT, S, Well Mixed	98	10828	+14.27	+6.26	46	46	---	---
OT, M, Well Mixed	98	10828	+18.29	+8.42	46	46	---	---

**Key:** BT: Beam Trawling; OT: Otter Trawling; G: Gravel; S: Sand; M: Mud

Following a trawling event, and the resultant change in biodiversity, the rate of nutrient cycling and gas and climate regulation (proxy productivity) increased. Food provision and employment also increased with increasing trawling activity, but were not affected directly by changes in biodiversity. The change in biodiversity did, however, result in a decrease in the provision of the information service, and the option, bequest and existence values also declined. This analysis indicates that trawling activity impacts UK marine biodiversity, which in turn has a

mixed impact on the provision of goods and services. A more detailed description of this study can be found in Annex 9.

## **4.2 Case Study 2: Skomer Marine Nature Reserve. An example of high biodiversity and high associated economic value**

Skomer is a small island situated off the Pembrokeshire coast, Wales. It is an area of high biodiversity with a number of important and high profile species, including grey seals, basking sharks, and porpoises (www.bbc.co.uk 2006). It is the largest single seabird colony in Southern Britain supporting a number of gull species (Perrins and Smith 2000), guillemots, razorbills, kittewakes, puffins and 40% of the Global population of Manx shearwaters (Poole 1995, www.unep-wcmc.org 2006). Although residing on the island, seabirds are an integral part of the marine ecosystem, influencing energy flow and food web dynamics. The waters around Skomer harbour a vast number of species of conservation importance, such as the pink sea fan.

Skomer was declared a National Nature reserve (NNR) in 1959 and was designated a Marine Nature Reserve (MNR) in 1990. Skomer is now managed by the Wildlife Trust of South West Wales under lease from the Countryside Council for Wales. It is also classified as Special Protection Area (under the 1979 EC Bird's Directive). Despite these designations certain types of fishing are still allowed in the waters. There is little data on how the biodiversity has changed before and after the designation as a marine reserve, although it appears from survey data that the designation as an NMR has resulted in increased king scallop populations (CCW/WW/04/2) and increased abundance and diversity of sponge populations (CCW/WW/04/4).

The majority of visitors to Skomer are to see marine wildlife. The number of visitors has increased gradually during the last 40 years with up to 14,000 visitors recorded in 2005. During the next few years the maximum boat revenue is estimated at £160,000 and the administration fee to the Wildlife Trust could be up to £120,000 per annum.

Diving has been popular at Skomer for many years and there has been a noticeable shift towards using local diver charters (Kate Lock *pers. comm.*), resulting in considerable benefits for the local economy. As the area is heavily protected commercial fishing effort is relatively low and is primarily with pots which target both lobster and crab. Recreational angling is however very popular with an annual average of 360 visitors between 1992 and 2004 (excluding 1996 because of the Sea Empress oil spill). Boating attracted an annual average of 998 visitors, also between 1992 and 2004 (excluding 1996 because of the Sea Empress oil spill), and although this may not be directly associated with the

biodiversity it is probable that the extensive marine life plays a role in attracting these visitors.

Since the introduction on the MNR, there has been an increase in the number of visitors, recreational anglers and boating activity. A decrease in the number of divers has however been noted and may be explained by external factors, such improved facilities in other locations. The link between increased visitors and increased biodiversity is only correlative, but it appears very likely that the success of Skomer as a tourist destination is due to the biodiversity which is present. The social and economic benefits associated with, and dependent upon, this high bio-diverse environment are substantial, particularly to the local economy.

### **4.3 General conclusions from the case studies**

The impact of trawling on benthic biodiversity (Case study 1) suggests that a decline in biodiversity will result in a decline in the provision of some, but not all, goods and services. Indeed, the provision of some of the goods and services will increase with the change in biodiversity. Case study 2 on Skomer Nature Reserve implies that increased biodiversity results in increased goods and services, with tangible economic and social benefits.

It is difficult to extrapolate general conclusions about UK marine biodiversity from these two case studies. It is realistic to expect that a decline in biodiversity will result in a decline in the provision of goods and services, although the results of case study 1 suggest this will not always be the case. There is a real need for more UK case studies researching the quantitative linkages and dynamic relationships between biodiversity and the provision of goods and services.

## Chapter 5 – Concluding remarks

A wide range of goods and services are provided by UK marine biodiversity, resulting in significant social and economic benefits. Table 4 provides a summary of these goods and services. Despite the numerous and complex difficulties with the monetary data they are the best value estimates currently available. It is advised, however, that the monetary figures are used only as indicators of value, and should only be applied within the context of these limitations, and alongside the qualitative information provided within the report.

Monetary values are estimated for eight of the thirteen goods and services. The absence of an economic value does not infer a lower value, only that the information is not available. Where the value is classified as an 'underestimate' only one component of the good or service has been valued, so a considerable portion of the function has not been considered in the valuation. There are significant limitations associated with this monetary data, and most of the figures presented are under-estimates. In particular the values for nutrient cycling are very uncertain, as replacement values cannot in truth be applied. The strength in the use of these indicative monetary values lies in their capacity to highlight the importance of marine biodiversity.

The descriptive text for each of the goods and services should be considered as important as the monetary data, and clarifies the linkages between biodiversity and the provision of these functions. Due to a lack of data it is currently impossible to establish quantitative links between biodiversity and goods and services. However, a best estimate of the strength of the linkages between biodiversity and the good or service is provided to indicate how sensitive the good or service is to changes in biodiversity (refer to Table 4).

Monetary values presented in this report cannot be aggregated to provide an overall value of the marine environment. This is because different methods have been used to calculate the values, and hence the values are not directly comparable. Even if the same method is applied, a small change in the method can lead to a significant change in the value. Aggregating the values is also misleading as there are significant gaps in the valuation literature, resulting in several of the goods and services not being quantified in monetary terms. Providing a single monetary value for UK marine biodiversity would incorrectly infer a comprehensive understanding.

It has not been possible to quantify how values change with declining or improving biodiversity due to data limitations and the current uncertainty in links between biodiversity and ecosystem function. Progress is however being made in this area.

The classification applied divides marine biodiversity into specific components, but the inter-dependency of these components is apparent. It is therefore important to recognise that the benefits received from the marine environment are entirely dependent on the state of the whole ecosystem, and the exploitation of one function is likely to impact the provision of another.

The goods and services approach used in this report is a valuable tool for the implementation of marine spatial planning and conservation planning as detailed in the Marine Bill. This methodology enables the ecosystem approach by ensuring the trade offs between different activities, and the goods and services they impact, are both transparent and comparable.

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 to change, declining marine health and water quality, fisheries, loss of recreation, decreased employment and reduced carbon uptake.

## **5.1 Recommendations**

The three original aims and objectives have been achieved to varying degrees. The extent to which the aims and objectives have been met provides a valuable indication of future research requirements and recommendations.

- Aim: To provide an estimation of the total economic value of marine biodiversity in UK waters including the goods and services and non-use values it provides.

The total economic value of UK marine biodiversity has been estimated, and the goods and services it provides have been detailed. The monetary data have not been aggregated to provide a single figure as the resultant value would be a vast under-estimate of dubious quality, as discussed in Section 2.2. It is of particular interest that the goods and services which biodiversity are judged to have the highest impact on, are often the areas where valuation data does not exist. Further research focusing on the valuation of goods and services is recommended, particularly in areas which currently could not be valued, including resilience and resistance, bioremediation of waste, biologically mediated habitat and option use.

- Aim: To provide examples of marine biodiversity value and the change in value if marine biodiversity improves or declines.

A significant limitation of this report was a lack of relevant natural science, social and economic data. Quantification of how values change with declining or improving biodiversity could not be undertaken due to insufficient information on the link between biodiversity and ecosystem function. The marine environment is extremely diverse and complex, and 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). 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.

- Aim: To provide an economic valuation using marine biodiversity change scenarios.

At the outset of this project it was agreed that this final aim would not be achievable as suitable data from UK waters is not currently available to undertake detailed and comprehensive scenario analysis. There is a severe deficiency of UK case studies, particularly in the social sciences. Although values were standardised wherever possible, extrapolation will incur inaccuracies. Further UK site-specific research is strongly recommended in the future. The proposed Marine Protected Areas provide an ideal opportunity for case studies to potentially demonstrate the value of increasing biodiversity, and as such these areas should be monitored before and after designation.

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## Annex 1: Valuation techniques

Several reviews of valuation techniques exist (see for example Ledoux and Turner 2002), and as such only a brief overview of the techniques applied is provided.

- Market-based methods are used to determine the value of food provision, raw materials, leisure and recreation, and cognitive benefits arising from UK marine biodiversity. Market based values are, however, not always representative of the true value of a resource. For example, in the case of food provision, the estimated value 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. Unreported catches (e.g. illegal fishing and recreational fishing), which may be considerable, are also not included in the estimated value.
- Cost-based techniques are applied to estimate the value of nutrient cycling, gas and climate regulation, and disturbance prevention and alleviation. These techniques determine the costs to man in providing a proxy for the environmental function, such as, replacement costs, damage costs, and avoidance expenditure. This is not an ideal measure of value as, for example, the cost of replacing a function is not the same concept as the value that the function provides. In addition, in the case of nutrient cycling the replacement of this function is not possible, this it could be argued that this renders the value meaningless.
- Stated preference techniques are used to estimate the non-use value of UK marine biodiversity. This is the only method available for determining non-use values and generally involves the use of questionnaires to determine individuals preferences for environmental goods and services, for example by asking their willingness to pay, or willingness to accept, a specific change in the environment. Limitations of stated preference techniques include protest bids, information bias, the fact respondents may not consider their income as a realistic constraint, free riding and non-response bias.

In the case of the cost-based and stated preference techniques values are provided on a per area, or per person, basis and then multiplied up to a UK scale. Problems with this approach include:

- Environment types not being uniform, for example a wetland in Cornwall may be very different to a wetland in Renfrewshire;
- 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;

- multiplying the values up entails designating boundaries on the UK marine environment, and as many marine processes and organisms are mobile this is not realistic.

Despite the limitations of these techniques, at present we have no other way of determining values for things which don't have an explicit market (monetary) value, for example biodiversity. The monetary figures presented in this report are all the best estimates currently available, and it is argued that it is better to have an estimated monetary value than to present no value.

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## Annex 2: Food provision

### UK Fleet structure

The structure of the UK's fishing fleet is based on the recorded activity of fishing vessels, with each vessel attributed to a category on the basis of the fishing activity it carries out most often. Table 6 shows the number of vessels, tonnage and engine power in 2004.

**Table 6. Main activity of the UK fishing fleet by segment (Defra sea fisheries statistics 2004)**

Fleet	Number	Registered tonnes	GT	Power
Under 10m	5395	19292	18870	274327
DSN	852	78778	80151	241401
Shellfish: Fixed	253	5671	6129	36141
Shellfish: Mobile	166	9181	9595	41161
Line and Nets	123	12258	12377	32830
Bean trawl	102	22360	22522	79842
Notknown	85	15922	15530	47741
Pelagic gears	31	42408	42408	83684
Mussel Dredgers	13	1275	1281	3860
Distant water	10	14154	14154	22474
Total	7030	221299	223017	863461

### Number of fishermen

Surveys carried out by the Sea Fisheries Inspectorates in England, Wales and Northern Ireland, and by the Sea Fisheries Protection Agency in Scotland showed that in 2004 the total number of fishermen in the UK was 11,559 with 84% of them being regular fishermen (Table 7).

**Table 7. Summary of the number of fishermen for each region of the UK (Defra sea fisheries statistics 2004)**

Region	Regular	Part-time	Total
England and Wales	4995	670	5665
Scotland	4124	1151	5275
Northern Ireland	535	84	619
Total	9654	1905	11559

### Quantity and value of landings

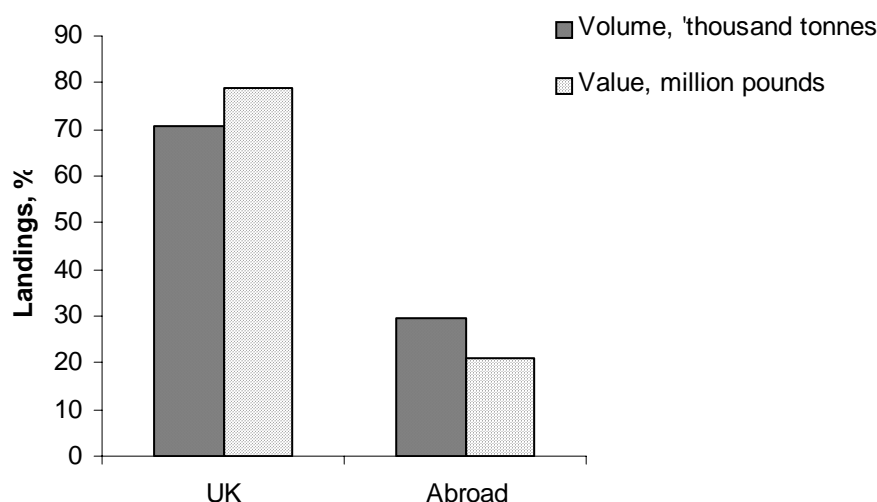
In 2004, the UK fleet including the Channel Islands and Isle of Man vessels landed in the UK and abroad 654,000 tonnes of sea fish (including shellfish) with a value of £513 million (Table 8). Demersal species represented 35% of

total landings in terms of quantity and 44% in terms of value whereas pelagic species accounted for 45% of landings by quantity and 21% by value.

**Table 8. Quantity ('000 tonnes) and value (£ million) of fish landings (including shellfish) by UK vessels into the UK and abroad in 2004 (Defra sea fisheries statistics 2004)**

Landings	Volume	Value
Demersal	231	224
Pelagic	291	106
Shellfish	132	184
Total	654	513

Around 71% of fish caught by the UK fleet were landed in the UK the remainder were landed at ports abroad. In terms of value, 79% of UK fleet landings were made in the UK (Figure 2).



**Figure 2. Comparison of the percentage volume and value of landed by the UK fleet in the UK ports and abroad (Defra sea fisheries statistics 2004)**

Main species caught

Haddock, cod and blue whiting were the main demersal species landed while mackerel and herring were the two main pelagic species landed. Two main species (by weight) of shellfish landed are crabs and nephrops. In 2004, 30,500 tonnes of nephrops and 22,000 of crabs were landed by the UK fleet into UK ports and abroad (Table 9).

**Table 9. Breakdown of the quantity and value for each of the 20 most common fish species in UK landings (Defra sea fisheries statistics 2004)**

Species	Quantity	Value	Price per tonne of live weight
Mackerel	128.5	64	495
Herring	61.6	8.5	136
Haddock	53.7	38.8	721
Cod	52.1	62.4	1496
Whiting, Blue	44.9	2.6	54
Nephrops	30.5	70.5	2313
Scallops	22.4	34	1509
Crabs	22	23.9	1084
Saithe	17.5	7.9	416
Cockles	12.9	10.1	781
Monks or anglers	12.6	26.6	2104
Mussels	12.1	2	167
Whiting	7.7	5.3	676
Dogfih	6.5	5.9	962
Skates and Rays	5.7	6	1029
Queens	5.2	1.9	368
Ling	5.1	5.2	1019
Plaice	4.3	5.2	1223
Sprats	3.9	0.7	189
Megrims	3.6	8.2	2289

All data from the Defra sea fisheries statistics (2004).

## Annex 3: Raw materials

### Fishmeal and fish oil

Fishmeal and fish oil are key constituents of pelleted diets for the intensive production of carnivorous fish species. A small proportion of the catch landed in the UK is used to make fish oils and animal feeds. In 2004, 192 000 tonnes of fishmeal were consumed in the UK of which 50 000 were produced locally and the remainder imported. The total value of the UK market in 2004 was £81 m. Average price per tonne of fishmeal was £422.50. 84% of the fishmeal produced in the UK comes from trimmings. The revenue generated from one tonne of trimmings is given in Table 10. Fish oil production by the UK in 2004 was 11,600 tonnes while consumption was 69 800 tonnes (European Parliament Report 2004).

**Table 10. Revenue generated from 1 tonne of trimmings**

	Euros per tonne
Fishmeal	84-115
Silage	14-58
Freezing for mink/pet food	50-58
Land fill	-116 costs
Incineration	-181 costs

There are three dedicated meal plants in the United Kingdom, one in Aberdeen, one in Shetland and one in Grimsby. These are owned (or part owned in the case of Shetland) by one company, UFI. The Shetland plant is owned jointly with stakeholders in Shetland including the pelagic processing plant, the Harbour Trust and local fishermen. The plants collectively process around 240,000 tonnes of meal per year, most of which is derived from offal (including a significant quantity of pelagic offal). The Shetland plant processes the bulk of the feed fish product. The Aberdeen plant processes around 60% of the total UK meal product. UFI employ 105 workers: 55 in Aberdeen, 20 in Shetland and 30 in Grimsby.

Currently demersal fish processing waste can generate income of up to £40 per tonne but £10-£30 per tonne is more common. Pelagic fish may generate an income of up to £70 per tonne with about £30 per tonne being common.

### Seaweed

Almost all commercial seaweed harvesting are concentrated on the Phaenophytes (brown seaweeds) including, *Laminaria*, *Ascophyllum* and *Fucus* spp. Harvesting is done by hand with serrated sickles or scythes from the rocks at low tide. Seaweed has various uses including: cosmetics, food, agriculture where raw seaweeds and by-products are used as solid state fertiliser, and in industrial applications such as textiles, food and medicine.

At present around 3000-4000 t (wet)/year of *Ascophyllum* are harvested in the Uists and sold to Kelco via a local haulier who transports the wet weed to the

Girvan plant. The numbers of people currently employed in supplying seaweed from the Western Isles to outside buyers are 20-26 regular and 35 occasional. The value of wet *Ascophyllum* and air-dried tangle from the Western Isles delivered to Kelco's alginate production plants on mainland Scotland is believed to be of the order of £200,000-£250,000 per annum, with income for harvesters/collectors representing some £80,000-£90,000 (32-45%) of this figure. Revenues for the Keose operations are less certain; a speculative estimate would put these somewhere between £70,000 and £200,000. In very broad terms then, total gross income from seaweed in 1994 would appear to lie somewhere between £270,000-£450,000, with a probability that the true figure lies towards the lower end of this range.

In the UK the market leader in the production of seaweed based fertilisers is Maxicrop International Ltd who market a natural extract and also use this as a base for a range of seaweed based fertilisers suited to different crops, plants and soil conditions. Maxicrop export to a variety of countries. Like many of their competitors they use dried seaweed meal produced from *Ascophyllum* as their raw material.

Seaweed is used both as an ingredient in animal feedstuffs and as a fodder supplement, although this market is now in decline. While *Ascophyllum* has traditionally been used in this area, there is no evidence to suggest it is more effective than other algae, and it is not likely to be profitable to pursue diversification into the market for animal feedstuffs.

Ground or powdered seaweed, as well as phycocolloids, are used in the manufacture of cosmetic products including soaps, shampoos, powders, creams and sprays. Very often the algal content of such products will be small, even where the use of seaweed is highlighted in the marketing of a product. A variety of seaweeds are used in cosmetics. Among the brown algae *Laminaria spp* are among the most common, although the bladder wracks such as *Fucus vesiculosus* and *Ascophyllum nodosum* are also utilised. *Chondrus crispus*, *Mastocarpus stellatus* and *Porphyra spp* are some of the red algae which may be employed as cosmetic ingredients. Overall, though, the quantities of seaweed used in this sector are minimal. Wholesalers/suppliers in this sector are thought to pay ca £1/kg for seaweed meal made from fucoids. Laminarians can be more valuable, as can seaweed which is further processed beyond a basic meal. Generally UK suppliers only stock small quantities of seaweed. It is possible to sell direct to some manufacturers of cosmetic products.

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## Annex 4: Nutrient cycling

Nutrient cycling encourages productivity, including fisheries productivity, by making the necessary nutrients available to all levels of the food chains and webs. A large amount of nutrient cycling occurs within the pelagic systems and is highly efficient as these systems are nutrient limited. For example, in stratified waters particulate organic carbon generated during primary production will often be remineralised above the pycnocline. In shelf and coastal waters, benthic systems are a major source of nutrients for the overlying water (Hopkinson *et al.* 2001) and are estimated to supply up to 100% (Sündback 2003) of the total nutrients used in water column productivity. This 'benthic-pelagic coupling' plays a major role in determining the production and biological structure of pelagic systems (Valiela 1995). Regenerated nutrients stimulate pelagic bacterial and phytoplankton production, which stimulates zooplankton production and this perpetuates up the food chain (Wainright 1987) and ultimately influence fisheries and other goods and services.

Marine biodiversity plays an important role in regulating nutrient cycling, and variations in biodiversity can change the rate of nutrient cycling, although the direction and degree of these changes will depend upon the species affected. Although nutrient cycling is microbially driven many larger marine organisms stimulate the rate at which it occurs and hence are a vital element of the nutrient cycling process. Marine benthic species play an important role regulating the flow of nutrients through marine ecosystems (Sündback 2003, Rhoads 1973). The rate and extent of the degradation, preservation and burial of organic matter in the sediment depends on bioturbation, which is the physical activity of organisms as they feed on, and move and/or burrow through the sediment that has physico-chemical effects on the sediment. Denitrification has also been shown to increase due to the bioturbatory activity of many organisms (De Roach *et al.* 2002, Webb and Eyre 2004, Sayama and Kurihara 1983). By constructing burrows and tubes, bioturbating fauna significantly increase the surface area of the sediment-water interface and also continuously translocate material between reaction zones (oxic and anoxic) (Kristensen 1984). In addition the ventilation activity of bioturbating fauna affects solute transport and water movement in which inorganic nutrients are dissolved, Kristensen (1984). The overall result of this activity is that the rate of nutrient exchange is increased.

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## Annex 5: Gas and climate regulation

The marine exchange of carbon dioxide (CO<sub>2</sub>) is primarily determined by the difference in partial pressure across the air-sea interface (Kaltin and Anderson 2005). However, biotic influences can reduce the pressure of CO<sub>2</sub> in the water, increasing its rate of uptake (Álvarez et al. 1999). The reduction in partial pressure occurs during primary production where carbon fixation results in the conversion of CO<sub>2</sub> into organic compounds. This production and the diffusion of atmospheric CO<sub>2</sub> into the surface waters are known collectively as the 'Biological Carbon Pump' (Volk and Hoffert 1985). By uptaking CO<sub>2</sub>, marine systems have the ability to sequester carbon and act as a sink a proportion of which will be stored in sediments. The significance of marine systems in climate control through the regulation of carbon fluxes is of great importance. Globally the oceans play a large role in the cycling of carbon, storing an estimated forty-thousand gigatons (Grace 2004).

Marine flora and fauna are of fundamental importance in carbon cycling (Hoppema 1991, Kaltin and Anderson 2005). The pelagic food web plays a vital role, not only in regulating the exchange of CO<sub>2</sub> between the atmosphere and the ocean, but also in the downward transport of organic carbon and the transfer of organic carbon between species (Legendre and Rivkin 2002, Legendre and Rivkin 2005). The extent of phytoplankton production determines the upper limit of carbon which can be transferred or exported (Levinsen and Nielsen 2002). The size structure, nutritional status and taxonomic composition of the primary producers also determines how carbon is transferred into the rest of the food web and what proportion is lost from the system (Legendre and Rivkin 2002, 2005).

The export of carbon from pelagic ecosystems is largely determined by the size structure of primary producer organisms and how this component of the food chain then interacts with grazing organisms (Legendre and Rassoulzadegan 1996). Herbivory in the surface water layers controls the quantity of suspended biomass and often results in decreased carbon supply to the bottom waters and sediment. Carnivores have been shown to reverse this, giving rise to increased carbon export (Wassman 1993).

Some carbon from the pelagic surface layers will be exported to the sediment surface through sinking (Suess 1980). A proportion of this deposited organic matter that survives bacterial degradation is accumulated and eventually stored in marine sediments. The quantity of carbon storage (the percentage of organic matter) in the sediment is highly related to the rate of sedimentation (Ingall and van Capellen 1990) with high sedimentation leading to higher storage (Betts and Holland 1991).

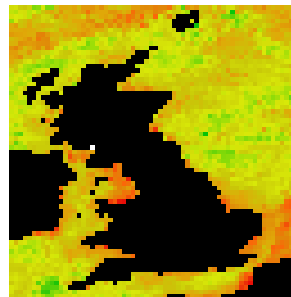
Benthic biodiversity can affect the amount of carbon which remains stored in the sediment. The activity of benthic species such as the polychaete worm *Nereis virens* can increase the rate at which particulate organic carbon is decomposed in the sediment (Kristensen and Blackburn 1987). This in turn, increases the flux of carbon dioxide back into the water column.

Total or annual marine production benefits from the increased diversity of phytoplankton. Different attributes of species relate to their success at different times during the seasonal cycle. In coastal regions diatoms will often dominate during early succession when nutrients are available whereas flagellates will become prevalent when waters become stratified (Mann 1993). Diversity is an important component of temporal phytoplankton dynamics and production.

“DOC and POC from the surface waters will either be respired or reach either large metazoans or deep waters. Thus the transfer of OC to large metazoans and to depth is of significance to fisheries and carbon sequestration, respectively.” (Legendre and Rivkin 2002)

*UK example:*

This example examines marine productivity in UK ocean, shelf and coastal waters. Remote sensing methods are by far the most useful ways for determining production on a large scale (Joint and Groom 2000). These techniques quantify the concentration of photosynthetic pigments which can be extrapolated using algorithms to calculate production. The photosynthesis model described in Smyth et al. (2005) was applied to an area incorporating UK territorial waters (shown in figure 3) to calculate primary productivity. Monthly data ( $\text{Gt C month}^{-1}$ ) was summated for each year between 1998 and 2003 to calculate annual productivity. Annual productivity between 1998 and 2003 was compared to find the inter-annual variability in production. For the area in Figure 3, the average annual primary production was  $0.07 \pm 0.004 \text{ Gt carbon yr}^{-1}$  (95% CI). Smyth et al. (2005) found global production to be  $55 \text{ Gt C yr}^{-1}$  so UK waters are estimated to contribute slightly over 0.1% of this.



**Figure 3. A map of the area for which primary productivity was calculated. The latitudinal range was from 49.75N to 61N and the longitudinal range was from 8w to 3E.**

A number of caveats exist in the remote sensing methods used to examine marine productivity in UK ocean, shelf and coastal waters. The chlorophyll algorithm used to calculate production is not entirely satisfactory close to the coast as there are problems with suspended particulate matter (SPM) and colour dissolved organic matter (CDOM). See Smyth et al. (2005) for further information.

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## Annex 6: Bioremediation of waste

Marine benthic diversity is an important component associated with the remediation of domestic, aquacultural and agricultural organic pollution. Benthic community succession is a known phenomenon associated with many types of organic pollution (Pearson and Rosenberg, 1978). After a pollution event the fauna will be dominated by a high number of few 'enrichment opportunists' such as *Capitella capitata* and *Scolelepis fuliginosa*. These species, under normal conditions are only a small fraction of the background community. As organic matter is processed by these pioneering benthic fauna system recovery occurs as the high organic load is incorporated into biomass and processed (see nutrient cycling). Organic pollution sites are often characterised by stimulated benthic metabolism and elevated cycling of some nutrients (Berelson et al. 2002, Kelly et al. 1985, see also nutrient cycling review). The opportunistic community is replaced by transitory communities which are also succeeded by 'normal' communities (Pearson and Rosenberg 1976). Thus a vast range of species are associated with the recovery and succession of marine benthic systems (Rosenberg 2001). Temperate benthic estuarine systems have been shown to recover quickly from sewage pollution when exposure has discontinued (Oviatt et al. 1984) and benthic species are associated with this recovery process.

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## Annex 7: Biologically mediated habitat

### *Maerl Habitat*

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. In England and Wales maerl is rare (Birkett et al. 1998) with the bed in the Fal Estuary (150 ha) considered to be of national importance, and a small area is present on the Pembrokeshire coastline. In Scotland it is more common and is found across the west coast and also by Orkney and Shetland.

Maerl grounds are highly diverse habitats, supporting a larger number of species (Jackson et al. 2004) some of which are rare, unusual or poorly known (Birkett et al. 1998). Maerl grounds provide refuge for juvenile life stages of commercially important shellfish species such as the queen scallop, *Aequipecten opercularis* (Kamenos et al. 2004b). Maerl has also been found to be important for the juvenile gadoid fish: Atlantic Cod (*Gadus morhua*), Saithe (*Pollachius virens*) and Pollack (*Pollachius pollachius*). These species have all been found to use maerl grounds during their juvenile life stages due to the availability of food and refuge from predators (Hall-Spencer et al. 2003, Kamenos et al. 2004c).

### *Seagrass and Kelp Habitats*

Seagrass is the common name for a large group of higher flowering plant species. Five species of seagrass are found around the British Isles: two species of Tassel weed and three species of eel grass (*Zostera* spp.) (Davidson and Hughes 1998). Eelgrasses have 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, eelgrasses can be important food sources for wildfowl, such as ducks, brant and geese (Thayer et al. 1975). Seagrasses in general are important areas for juvenile fish, including flatfish and shellfish.

The existing data and previous records indicate that the UK *Zostera* beds have made a poor or slow recovery from the impact of wasting disease in the 1920s-30s (Davidson and Hughes, 1998). Sea grass is now considered to be nationally scarce with a patchy distribution, only 20 of Britain's 155 estuaries have eelgrass meadows more than 1ha in extent, and the known areas of sea grass total only 21.9km<sup>2</sup>, although there are locations of seagrass which have not been recorded in area format so this estimate is a severe minimum (Davidson and Hughes 1998)

Kelp and many other species of marine macrophytes support a diverse range of species, both as a foods source and a living resource (Orth et al. 1984). 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, *Gadus morhua*, (Cote et al. 2002). Kelp is widely distributed in

UK waters, and can be found in most places with suitable water quality and substratum (Birkett et al. 1998).

### *Mollusc Communities*

The commercially important mussel species can have distinct effects on biodiversity. Mussel patches are structurally and functionally complex and consequently create habitat for a wide range of associated fauna (Suchanek 1980, Lintas and Seed 1994). Mussel patches also often reduce the harsh effects of temperature, wave action and light, providing more favourable conditions (Seed and Suchanek 1992). Applicable to many molluscan species, 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). Processes which change the availability of shell resources and other biogenic structures can have consequential effects for many other organisms and secondary production. This may in turn affect commercially important species.

### *Reef*

Cold water corals, such as *Lophelia pertusa*, are found in waters of the British coast from north of the Shetlands into the North-East Atlantic. 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 and 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. Also improvements in equipment mean that areas which were previously protected through gear limitation are now accessible (Frame and Gillelan 2005).

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## Annex 8: Disturbance prevention

Many types of flora can contribute to the reduction in wave energy in coastal zones. Seagrasses (Fonseca and Cahalan 1992) and halophytic reeds (Coops et al. 1996) play only 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 a very cost effective way of attenuating average energy and there by substantially reducing the cost of flood defence measures (Morris et al. 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 fauna and flora are often highly diverse communities (Cooper 2005) that contain nationally rare species (Doody 2001). The most recent saltmarsh surveys of the UK estimate the total extent of saltmarsh (including transitional communities) to be approximately 45,500 ha. This resource is concentrated in the major estuaries of low-lying land in eastern England (<http://www.ukbap.org.uk/UKPlans.aspx?ID=33#1>)

Much research into saltmarshes has been conducted in the south-east of England where these are a prevalent coastal landscape feature. In this region much of the land is low lying and is currently protected from flooding by seawalls (Dixon and Weight 1996) but the seawalls themselves are protected by saltmarshes. Saltmarshes attenuate and dissipate wave and tidal energy which has been shown in a number of UK studies (Brampton 1992, Möller 1996, 1999). Recent studies found saltmarshes to reduce wave energy by 82.5% (Möller 1999) and another by 79%, 96% and 99% at three separate sites in The Wash, Norfolk (Cooper 2005). The reduction in wave energy associated with saltmarshes diminishes the potential for erosion. Coupled with this, salt marshes act like giant sponges absorbing vast amounts of water when inundated and then slowly releasing it afterwards, preventing flooding.

Brouwer *et al.* (1997) document a meta-analysis of contingent valuation studies on wetlands from around the world. This meta-analysis finds the largest mean willingness to pay by wetland function to be for flood control. This estimates the value of wetlands, in their function as storm and flood protection, to be £105.09 per household per year. UK specific studies include that undertaken by King and Lester (1995) who calculated that the loss of saltmarshes from Essex would cost 600 million for the increased maintenance of the seawalls.

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## Annex 9: Case Study 1: The impact of trawl fishing on benthic biodiversity

Mobile bottom-fishing gear (used to catch species that live within, on or in close contact with the seabed such as scallops, shrimp and flatfishes) causes varying levels of disturbance that alters seabed complexity, removes, damages or kills biota, and reduces benthic production, and thereby can lead to substantial changes in benthic community structure and habitat. As nets and dredges pass over the seabed, they unavoidably damage *in situ* and remove a large biomass of the resident biota. Sea-bed disturbance by fishing gear will, in the short term, directly affect seabed chemistry and nutrient cycling. The EU project COST-IMPACT was concerned with the longer lasting effects on benthic biodiversity and whether and how these effects permeate through to the whole marine ecosystem affecting marine goods and services (COST-IMPACT final report).

Within COST-IMPACT publicly available data on the impact of fishing on marine benthos was collated into a unified meta-database. Meta-analysis was then applied to these data to predict the outcome of using different fishing techniques in different habitats, in terms of the relative initial impact upon the fauna and the time taken for recovery to be achieved after the alleviation of fishing disturbance.

COST-IMPACT then used a synthesis of the European Regional Seas Ecosystem Model (ERSEM) (Baretta *et al.*, 1995) as modified by Blackford *et al.* (2004) and the General Ocean Turbulence Model (GOTM) (Burchard *et al.*, 1999) to investigate changes in benthic community structure caused by demersal trawl fishing and how these changes further affect benthic nutrient recycling and pelagic production. A number of perturbation experiments simulated trawling events with different types of fishing gears in different seabed habitats and the effects of different intensities of fishing. These simulations used estimations of the mortality of benthic fauna derived from the meta-analysis and model outputs provided predictions about changes in the whole marine ecosystem. The predictions derived from the meta-analysis and ecological models have been used as the baseline data for the effects of fishing on the economic value of the marine ecosystem goods and services. The simulated scenarios extracted for this case study are the effects of 5 years of fishing on a sandy seabed with two different types of fishing gear (otter and beam trawls) and two different intensities of fishing (low – twice per year, and high – 5 times per year). The simulations were of generic stratified and unstratified water columns in the central North Sea which are typical of the North West European shelf.

The ecosystem modelling suggested that the biogeochemical impact of demersal trawling is most significant in regions where the gear type, trawl frequency and sea-bed type cause high levels of filter feeder mortality. This results in a substantial increase in the oxygen content of the benthic system

and significant changes in the biogeochemistry of the system. However the impacts of these changes on the overlying pelagic ecosystem are buffered by the physical environment and the ability of phytoplankton to vary their internal cell nutrient contents. Yet there may be more subtle implications on pelagic community structure including a shift towards the microbial loop and a potential increase in the probability of harmful algal bloom events.

For indicators of biodiversity change we have used total macrofauna change (=suspension feeders + deposit feeders). The meta-analysis indicates that the model results for macrofauna abundances are broadly accurate. Similar data is not available for meiofauna which has been excluded from the indicator of biodiversity due to uncertainty about the response in the model. However it should be noted that there is probably a relationship between meiofauna, macrofauna and fishing.

For gas and climate change we have used use net primary production

For nutrient flux we have used use the first principal component (PC1) from a principle components analysis (PCA) of three nutrient variables (explains 89% of variability; the second principal component (PC2) explains 10% and better reflects the intensity of fishing effects but fishing gear habitat combinations have a greater effect than intensity in the PCA therefore PC1 is probably a better measure.)

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**Table 11. Change (and standard deviation) in biomass of benthic fauna, benthic nutrient efflux and net primary production after 5 years of trawling as a percentage of the untrawled state, at unstratified and stratified sites**

Site Type	Unstratified				Stratified			
Trawl type	Beam		Otter		Beam		Otter	
	trawling		trawling		Trawling		trawling	
Trawl freq yr <sup>-1</sup>	2	5	2	5	2	5	2	5
	low	high	low	high	low	high	low	high
<b>Suspension feeders</b>	-99.0	-99.9	-7.8	-9.1	-88.3	-99.9	-2.4	+5.47
	10.8	1.1	8.6	13.3	13.2	0.2	5.7	11.6
<b>Deposit feeders</b>	+13.1	-18.3	-25.3	-72.4	-67.3	-96.8	-68.3	-97.4
	26.1	24.8	22.8	30.0	13.7	4.4	15.6	3.7
<b>Total macrofaunal change</b>	<b>-85.9</b>	<b>-118.2</b>	<b>-33.1</b>	<b>-81.5</b>	<b>-155.6</b>	<b>-196.7</b>	<b>-70.7</b>	<b>-91.93</b>
<b>Meiofauna</b>	-56.7	-58.5	+8.0	+79.3	+14.7	+3.9	+41.6	+62.9
	1.2	15.8	8.7	24.2	5.8	18.3	12.12	3.3
<b>Phosphate efflux</b>	-23.7	-24.5	-0.9	-3.6	-10.9	-15.6	-1.4	-1.5
	10.1	4.6	5.8	8.1	2.6	2.2	0.0	1.8
<b>Nitrate efflux</b>	+30.4	+17.4	-12.7	-14.6	-2.8	-14.5	-7.2	-13.7
	8.3	7.8	10.3	12.4	3.1	6.3	3.7	4.2
<b>Ammonium efflux</b>	-38.7	-38.6	+1.4	-6.6	-18.0	-17.3	+2.1	+5.7
	9.0	5.2	7.3	10.3	1.2	3.8	2.6	2.8
<b>'Nutrient flux' PC1</b>	<b>-41.5</b>	<b>-33.8</b>	<b>14.4</b>	<b>15.9</b>	<b>-2.0</b>	<b>3.9</b>	<b>18.3</b>	<b>24.7</b>
<b>Net primary production</b>	-2.2	-3.0	-0.1	-1.0	-2.6	+1.5	-0.8	-1.8
	0.3	0.5	0.08	0.3	0.8	1.1	0.3	0.3