MARINE BIODIVERSITY AND THE PROVISION OF GOODS AND SERVICES: IDENTIFYING THE RESEARCH PRIORITIES

Paper prepared for the UK Biodiversity Research Advisory Group

Prepared by: Austen, M.C., Burrows M., Frid, C., Haines-Young, R., Hiscock, K., Moran, D., Myers, J., Paterson, D.M, Rose, P.

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Executive Summary

Ecosystem goods and services are delivered through various combinations of ecosystem functions which are in turn delivered by different components of marine biodiversity. It is recognised that less is known of how marine biodiversity contributes to the delivery of goods and services relied upon by humanity given the difficulties in sampling and understanding the processes occurring in the marine environment.

On request from UK BRAG, a sub-group was established to explore current knowledge and research requirements on marine biodiversity and the provision of goods and services. The remit of discussions was limited to the UK policy and research area. It is however recognised that many of the results may have wider application.

It was recognised that some direct services such as food provision are relatively well understood and can be quantified whilst much less is known about indirect services such as gas and climate regulation and waste remediation and how to quantify them. A number of the research questions raised were considered to also have application to terrestrial ecosystems whilst others were not given the different spatio-temporal scales and physical aspects (e.g. fluidity) of the marine environment.

Two overarching strands of research with respect to marine biodiversity and the provision of goods and services were noted:

(1) Natural science: the need to understand how marine biodiversity contributes to delivery of goods and services. To understand what the ecological links between biodiversity, ecosystem function and provision of ecosystem goods and services are; and

(2) Social science: the need to value goods and services in a way that resonates to society. This concerns development of socio-cultural and economic valuation tools; valuation methodologies: both monetary and non-monetary, social choices and preferences.

In reality such research is cross-cutting and requires a multi-disciplinary approach.

Gaps in understanding of how marine biodiversity links to goods and service delivery were considered to be a combination of natural science and economic research questions:

1. ***Spatial and temporal ecology of marine systems*** – information is lacking on the scales at which the underlying ecosystem processes occur, how these relate to the scales at which goods and services are delivered and what the linkages are. In this context marine landscape ecology still needs considerable research effort compared to terrestrial ecosystems;
2. ***Role of marine biodiversity in the delivery of functional processes in the marine environment*** – the relationship between biodiversity and

ecosystem functions needs to be clarified. This includes gaining a greater understanding and use of the concept of functional diversity through increased understanding of the functional capacity of species;

3. ***Improved understanding of natural and non-coastal marine ecosystems*** - empirically derived theory concerning the nature of biodiversity-ecosystem functioning relationships needs to be tested under natural conditions and in a wide variety of marine habitats, particularly in sub-tidal areas;
4. ***Relationship between function (and/or biodiversity), process and provision of services*** - a diversity of available ecological processes underpin provision of each of the goods and services but the relationships between them need to be quantified and the key processes and elements of biodiversity need to be determined;
5. ***Development of modelling and predictive tools to link biodiversity to function and provision of service*** – to support policy and management there is a need to develop the capacity to anticipate the impacts of human activity on provision of ecosystem goods and services and hence manage such activities;
6. ***The role of biodiversity in providing resilience in the provision of ecosystem services*** – biodiversity supports and underpins the provision of ecosystem services even in times of natural and human impacts. With the onset of climate and global change (e.g. ocean acidification, fishing and pollution) there is a need to determine the extent to which marine biodiversity facilitates resistance to change in the delivery of ecosystem goods and services as well as the ability of marine biodiversity to recover and restore delivery of goods and services;
7. ***Limitations ('tipping points') of marine biodiversity*** – at some point changes in biodiversity will lead to a reduction in the capacity of marine ecosystems to provide goods and services. There may be a uniform relationship between biodiversity and provision of goods and services or there may be crucial non-linearities or tipping points at which delivery is no longer possible. These limits at which biodiversity can still provide a good or service need to be defined;
8. ***Defining the best mechanisms to afford the protection of goods and services*** – in order to prioritise management and policy strategies the species, habitats and functions that are critical to maintain and enhance delivery of goods and services need to be identified so that we can put in place mechanisms to protect and restore them. Knowledge to inform such management priorities is particularly limited in sub-tidal zones;
9. ***Development and application of technology to support research*** – some underwater technology is already available but has not been fully utilised to support research into linkages between marine biodiversity and goods and service delivery. For example, there are technologies to support underwater habitat mapping where data has been remotely collected. Underwater technology needs to be further developed to enable

large scale experimentation to scale up small laboratory experiments in the natural and to the subtidal environments (point 3 above);

10. ***Methodologies for building environmental accounts for the services associated with marine systems*** – an improved ability to convert ecological understanding into environmental and/or ecological economics is required to support policy and management. There is a need to clearly describe, quantify and value the assets and the processes that impact upon these goods and services and their value. Some methodology exists but the literature is rather fragmented and not framed around the full marine ecosystem services concept.

Four key research priority areas were identified from the above questions but it was recognised that when determining research priorities for marine biodiversity and the provision of goods and services, such priorities sit within the larger framework of fundamental marine research requirements.

It was considered that progress in the following four research areas will substantially enhance current understanding of the key processes and properties of marine ecosystems, why they are important, and how human activities impact upon them:

1. Biodiversity ecosystem function;
2. Critical properties;
3. Quantification of the goods and services; and
4. Implications of marine biodiversity change to the delivery of goods and services.

In addition to the priority research areas, there is a need to consider knowledge transfer as a key component of research activity, both within the research community and beyond. Such activities should not be seen as an 'addition' but an integral part of the process. Opportunities to engage scientists more positively should also be encouraged.

There is also a need to identify mechanisms to feed science findings into wider policy/funding agendas on understanding the role of biodiversity and the delivery of goods and services. Such socially relevant research is needed to derive the evidence base for policy makers to make well informed decisions on policy options. This document provides a useful basis to commence this engagement.

Identifying requirements for research and information on marine biodiversity and the provision of goods and services, assists researchers to develop topical, relevant research proposals, helps research funding mechanisms to shape strategies and research programmes, and provides a service to policy and decision makers not only by providing them with information and knowledge but also by clarifying the nature of the evidence they require.

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1. Introduction

Biodiversity plays an important role in supporting a wide range of functions which are essential for the maintenance of global cycles and the supply of materials which society relies upon. This includes the production and maintenance of energy through the fixation of carbon, the nutrients we require, the air that we breathe and the delivery of a range of goods including food provision and raw materials. Goods and services have been defined as "the direct and indirect benefits people obtain from ecosystems" (Beaumont *et al*., 2006).

The terminology of "ecosystem goods and services" is often used to recognise that the ecosystem can provide functional benefit but also can be exploited directly for products. The poorly controlled removal of goods from a system can lead to problems of over exploitation and uncontrolled use of services lead to ecosystem breakdown.

The ocean and its coastal margins represents the largest single habitat on the planet and acts as a major resource for goods and services exploited by humans. In addition, the ocean-atmospheric linkages determine climate and atmospheric conditions. The sustainable exploitation of marine resources and the impact of global change on the oceanic systems is critical to the future welfare of humanity. Many human activities can lead to biodiversity loss, which is of great concern as the existence of humans is dependant on species diversity to provide medicines, food, fibres, and other renewable resources. Human activity is changing the distribution and abundance of biota and predicting the consequences of this is an important issue.

Figure 1. Goods and services provided by marine biodiversity.
(Adapted from Beaumont et al.. (2006) and other sources. Drawings: Jack Sewell. Hiscock et al. 2006)

Any metabolic process, or any transport or transfer of material through an ecosystem can be described as an “ecosystem function”. Naeem *et al.* (2004) defines ecosystem function as: “the activities, processes or properties of ecosystems that are influenced by its biota”. Such processes may be referred to as “ecosystem services” where they are regarded as beneficial to humans. Assessing ecological processes and resources in terms of the goods and services they provide translates the complexity of the environment into a series of functions which can be more readily understood by the wider community (policy makers and non-scientists). Describing the environment in this way also enables a true understanding of exactly what is being gained and lost when exploitation and development takes place (Holmlund & Hammer, 1999; Borgese, 2000). In the marine environment, ecosystem services include disturbance prevention leading to protection against floods and storms through structures such as saltmarshes; gas and climate regulation through the sequestration and cycling of carbon and the production of climate active gases; food production; production of raw materials; the enhancement of recreation, leisure and cultural perceptions (Beaumont *et al.* 2007, 2008).

Numerous definitions for biodiversity exist, but in its simplest terms it refers to the range and variety of life found on earth, from the number of species occurring, their genetic differences, to larger units such as habitats and ecosystems. The number and type of species present in an ecosystem determine the functional traits present and therefore the capacity of the system to process material and produce goods and services. Functional traits describe the size, mobility, feeding methods etc. of a species, which are useful in determining the role it plays in delivery of ecosystem functions e.g. nutrient cycling. As such the level of biodiversity is thought to be linked to the ability of the system to continue to provide goods and services with which society relies upon.

1.1 Document purpose

The UK Biodiversity Research Advisory Group (UK BRAG) serves as the UK’s National Biodiversity Research Platform and exists to:

- Identify promote and facilitate biodiversity research to support UK and individual country biodiversity action plan commitments;
- Coordinate effective and efficient UK engagement with European biodiversity research issues, fulfilling the role of a national biodiversity research platform;
- Contribute to effective biodiversity research networking in the UK, leading to increased interdisciplinary capacity; and
- Support knowledge transfer activities in relation to biodiversity research.

UK BRAG does not act as a funding body for biodiversity research in the UK but explores major cross cutting themes in terms of current knowledge/understanding and to identify research requirements.

It is recognised that less is known on how marine biodiversity contributes to the delivery of goods and services relied upon by humanity given the difficulties in sampling and understanding the processes occurring in this environment. In the terrestrial environment, scientific studies are far easier to complete.

On request from UK BRAG a sub-group was established to explore current knowledge and research requirements on marine biodiversity and the provision of goods and services. The remit of discussions was limited to the UK policy and research scene. It is however recognised that many of the results may have wider application. Refer to Appendix A for the process by the sub-group to identify the research priorities outlined in this paper.

Identifying requirements for research and information on marine biodiversity and the provision of goods and services, assists researchers to develop topical, relevant research proposals, helps research funding mechanisms to shape strategies and research programmes, and provides a service to policy and decision makers not only by providing them with information and knowledge but also by clarifying the nature of the evidence they require.

This paper examines the current gaps in understanding of provision of ecosystem goods and services with a direct link to marine biodiversity. It was noted that some direct services such as food provision are relatively well understood and can be quantified. Much less is known about indirect services such as gas and climate regulation and waste remediation and how to quantify them. Many of the research questions raised here may also apply to terrestrial ecosystems and maybe being addressed there. However, the spatio-temporal scales and the physical aspects of the marine environment are very different from those of terrestrial ecosystems, and most marine habitats are much less accessible. Hence much of the related terrestrial research is not necessarily directly applicable in the marine environment.

2. Background

Ecosystem goods and services are delivered through various combinations of ecosystem functions which are in turn delivered by different components of marine biodiversity. Therefore there is likely to be a relationship between functional biodiversity and provision of ecosystem services (Beaumont *et al.,* 2008).

The functioning of marine ecosystems is affected by their properties, structures and processes. Marine ecosystems are different from terrestrial ecosystems in a number of ways including greater propagule and material exchange and more rapid biological processes due to the fluid nature of the aquatic environment (Giller *et al.*, 2004). Marine ecosystems are dynamic, often unpredictable and, ultimately, highly complex systems. As a result of this fluidity, the boundaries of marine ecosystems are often difficult to identify. Some propagules are readily dispersed and movements of planktonic and fish species are generally unimpeded by barriers. Thus many marine ecosystems are considered more open than terrestrial systems such as grasslands or freshwater ecosystems.

Access to marine biodiversity by the general public is generally associated with coastal holidays rather than being under the water diving or snorkelling. As a result, public/policy awareness of what happens in the marine environment and the diversity of species and habitats present in UK waters is limited. There is a lack of data and information on the habitats, the species that live in them and their functioning and the impact of human activities upon them is likely to be less understood when compared to terrestrial systems. Human activities are therefore likely to be allowed rather than prevented due to the lack of information on the significance of impacts, and the limits or thresholds that the system can tolerate being unknown.

To overcome the lack of visibility of the marine ecosystem and its functioning, a policy driver for research on marine biodiversity is to find methods to value the goods and services provided in monetary terms. This common currency for ‘value’ is a term which resonates with the wider community, and provides a further evidence base when making policy and management decisions which may affect marine biodiversity and the provision of ecosystem goods and services. Consideration of non-monetary valuation/quantification methods may also be important for policy development where monetary valuation is not possible.

There have been several key changes in the last decade highlighting the fragile balance between technological progress, biodiversity and species loss. One such pressure is the threat of global warming and the impact this might have on the world’s biota. The potential influence of decreasing biodiversity cannot be overlooked as a consequence.

Reduction in species richness has been recorded in response to localised human disturbances such as oil pollution events and the release of contaminants into estuaries (e.g. TBT in the Crouch); and the homogenisation of habitats due to bottom fishing gear. There is a need to also understand the implications of these localised changes to biodiversity.

As the human population rises and the demand on natural resources and space increases, fragmentation along with destruction of habitats cause species loss, but the real impact of on ecosystem processes and society is not yet known. It is generally considered that species loss will adversely affect ecosystem function however the mechanisms underlying this principle are not clear and the way in which species are lost will be important in predicting changes to ecosystem functioning.

The consequences of mass species loss to humans are potentially huge and may include changes in the functioning of ecosystems that provide crucial services such as nutrient cycling and photosynthesis. Such changes could have a direct effect on the supply of resources (marketable) and non-market values such as the aesthetic beauty of biodiversity and habitat.

The research questions proposed by the UKBRAG sub-group are applicable at both global and local or regional scales. The relative importance of the different goods and services will vary according to the spatial scale considered. For example, gas and climate regulation at the global scale is likely to have a greater value than disturbance and flood prevention, whilst at the local scale flood defence is likely to be a more valuable service. The global ocean is the whole earth marine ecosystem, however within the different regions and habitats local events that impact upon marine biodiversity, and the provision of goods and services are linked and will ultimately impact at the scale and value of the global system.

2.1 Definitions - Goods and Service Terminology

The over-arching classification of marine ecosystem goods and services applied within this document follows the Millennium Ecosystem Assessment (MA) (2003) and Hein *et al.* (2006) which divides goods and services into four categories:

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

Within each category, a range of goods and services can be defined. Environmental economists have typically classified environmental goods and services in terms of their direct and indirect use and non use value to society. Direct uses, as the name suggests, tend to be more consumptive (e.g. fish), but also include materials extracted from marine environments (e.g. alginates for industrial processes) and other non consumptive goods such as recreational activities (e.g. scuba diving and competition sea-angling). Broadly speaking, the ecological services fall under the indirect use category. These services have a derived demand meaning humans only demand the attribute or service itself for the "socially valuable" endpoint that this service leads to (e.g. nutrient recycling and greenhouse gas mitigation). ‘Biologically mediated habitat’ and ‘resilience and resistance’ could be seen as properties of an ecosystem, essential for the provision of some goods and services, and not always as services in themselves. It is also important to note that the total value of these categories is likely to be greater than merely that contributed by biodiversity (e.g. microbial diversity is vital for nutrient cycling but physical ocean circulation is also of key importance). Refer to Table 1 for the range of goods and services within each MA category.

Table 1. Goods and services provided by marine biodiversity

MA Category	Good or Service	Description
Production services	Food provision	Plants and animals taken from the marine environment for human consumption
	Raw materials	The extraction of marine organisms and materials for all purposes, except human consumption
Regulation services	Gas and climate regulation	The balance and maintenance of the chemical composition of the atmosphere and oceans by marine living organisms
	Disturbance prevention (Flood and storm protection)	The dampening of environmental disturbances by biogenic structures
	Bioremediation of Waste	Removal of pollutants through storage, dilution, transformation and burial.
Cultural services	Cultural heritage and identity	The cultural value associated with the marine environment e.g. for religion, folk lore, painting, cultural and spiritual traditions
	Cognitive benefits	Cognitive development, including education and research, resulting from marine organisms
	Leisure and recreation	The refreshment and stimulation of the human body and mind through the perusal and engagement with living marine organisms in their natural environment.
	Feel good or warm glow (Non-use benefits)	Value which we derive from marine organisms without using them
Over-arching support services	Resilience and resistance (Life support)	The extent to which ecosystems can absorb recurrent natural and human perturbations and continue to regenerate without slowly degrading or unexpectedly flipping to alternate states (Hughes *et al..* 2005)
	Biologically mediated habitat	Habitat which is provided by living marine organisms
	Nutrient cycling	The storage, cycling and maintenance of availability of nutrients mediated by living marine organism
Option use value	Future unknown and speculative benefits	Currently unknown potential future uses of the marine environment

(source: Beaumont *et al.*, 2007)

3. Marine biodiversity goods & service delivery

3.1 Current research

Two overarching strands of research with respect to marine biodiversity and the provision of goods and services are noted:

(1) Natural science: the need to understand how marine biodiversity contributes to delivery of goods and services. To understand what the ecological links between biodiversity, ecosystem function and provision of ecosystem goods and services are; and

(2) Social science: the need to value goods and services in a way that resonates to society. This concerns development of socio-cultural and economic valuation tools; valuation methodologies: both monetary and non-monetary, social choices and preferences.

In reality such research is cross-cutting and requires a multi-disciplinary approach.

Assessment of economic value of marine ecosystem services was initiated by Costanza *et al*. (1997) with aspects of marine provisioning of services addressed in the Millennium Ecosystem Assessment. Economic assessment of ecosystem services has predominantly focused on consumptive use values with methodologies comparatively well developed for fisheries (e.g. Turpie *et al*., 2003). Case study research has taken place in conspicuous, well researched environments, which have been negatively impacted by human activity, for example mangroves (Ewel *et al.,* 1998), coral reefs (Moberg and Folke, 1999) and fisheries (Holmlund and Hammer, 1999). Less well publicised environments have been largely over looked e.g. muddy habitats. Studies are emerging on the value of marine protection (Togridou *et al*., 2006) and many more studies are being published relating marine biodiversity and ecosystem function. These are however based predominantly on comparatively small-scale empirical experiments and do not go on to relate ecosystem function to ecosystem services in either economic or ecological terms. Weslawski *et al.* (2004), Snelgrove *et al.* (2004) and Lavelle *et al.* (2004) provide initial reviews on the factors affecting delivery of marine ecosystem goods from the perspective of the marine benthos. Worm *et al*. (2006) recently investigated the impacts of biodiversity loss on ocean ecosystem services and analysed local experiments, long-term regional time series, and global fisheries data to test how biodiversity loss affects marine ecosystem services across temporal and spatial scales. Total economic valuation studies are increasingly being commissioned to support policy making (e.g. Williams *et al*., 2003, Beaumont *et al.,* 2008).

There is little published work on marine ecosystem goods and services. The EU project COST-IMPACT examined the impact of trawling on the value of marine ecosystem goods and services.

Following on from the COST-IMPACT study, within the EU Network of Excellence MarBEF Theme 3 – *The socio economic importance of marine biodiversity*[1]*,* researchers are developing and applying methodologies for social, economic and biological valuation or marine biodiversity and goods and services.

To support the delivery of the Impact Assessment which must accompany the draft Marine Bill, Defra funded research assessing the benefits that marine biodiversity may provide in economic terms with the implementation of a network of marine conservation zones (Moran *et al.*, 2007). This research represents the first of its type, and attempts to provide monetary estimates for particular goods and services delivered via particular marine landscape. The Natural Environment Research Council (NERC) has also funded relevant research within its Oceans 2025 programme[2] which includes the development of methodologies to quantify ecosystem goods and services. In addition the Department for International Development, NERC and the Economic and Social Research Council (ESRC) have recently made a joint call for proposals for a situation analysis of the challenges to the sustainable management of marine and coastal ecosystems to maximise poverty alleviation. In the US researchers are developing habitat maps that can be linked to provision of goods and services (McBreen *et al*., 2008; Friedlander *et al*., 2007; Fischer *et al*., 1996).

Marine Bill – Valuing the benefits of the marine nature conservation proposals

In order to support the development of the Impact Assessment which is required to support the Marine Bill, an assessment of the benefits (in monetary terms) to be accrued with the implementation of a network of marine conservation zones (MCZs) was undertaken.

The value generated by the implementation of different possible network scenarios was undertaken. Goods and services linked to marine biodiversity were identified and a total value estimated. These aggregated goods and services values were then apportioned across the selected network scenario to determine a likely value change with the greater level of protection in these areas.

The study identified a lack of relevant studies to allow the Benefits transfer approach to be applied in the marine environment. Values for several benefit categories could not be determined due to a lack of data/pertinent studies.

This study represents the first of its kind in terms of attempting to derive values for the totality of ecosystem goods and services arising from area designation and associated regulatory restrictions

Reference

Moran, D., Hussain, S., Fofana, A., Frid, C., Paramour, O., Leonie, R & Winrow-Giffin, A. (2007). *The Marine Bill – marine nature conservation proposals – valuing the benefits.* Defra Research CRO 380. Natural Environment Group Science Division, Bristol.

3.2 Headline gaps in understanding the links

Gaps in understanding how marine biodiversity links to goods and service delivery were considered to be a combination of natural science and economic

1 http://pml-preview.dev.tellonline.com/data/files/Cost%20Impact.pdf and http://www.ecoserve.ie/costimpact/

2 http:/www.marbef.org

2 http://www.oceans2025.org/

research questions. It is likely that most of these are truly marine questions, but a number could apply to terrestrial systems:

1. ***Spatial and temporal ecology of marine systems*** – information is lacking on the scales at which the underlying ecosystem processes occur, how these relate to the scales at which goods and services are delivered and what the linkages are. In this context marine landscape ecology still needs considerable research effort compared to terrestrial ecosystems;
2. ***Role of marine biodiversity in the delivery of functional processes in the marine environment*** – the relationship between biodiversity and ecosystem functions needs to be clarified. This includes gaining a greater understanding and use of the concept of functional diversity through increased understanding of the functional capacity of species;
3. ***Improved understanding of natural and non-coastal marine ecosystems*** - empirically derived theory concerning the nature of biodiversity-ecosystem functioning relationships needs to be tested under natural conditions and in a wide variety of marine habitats, particularly in sub-tidal areas;
4. ***Relationship between function (and/or biodiversity), process and provision of services*** - a diversity of available ecological processes underpin provision of each of the goods and services but the relationships between them need to be quantified and the key processes and elements of biodiversity need to be determined;
5. ***Development of modelling and predictive tools to link biodiversity to function and provision of service*** – to support policy and management there is a need to develop the capacity to anticipate the impacts of human activity on provision of ecosystem goods and services and hence manage such activities;
6. ***The role of biodiversity in providing resilience in the provision of ecosystem services*** – biodiversity supports and underpins the provision of ecosystem services even in times of natural and human impacts. With the onset of climate and global change (e.g. ocean acidification, fishing and pollution) there is a need to determine the extent to which marine biodiversity facilitates resistance to change in the delivery of ecosystem goods and services as well as the ability of marine biodiversity to recover and restore delivery of goods and services;
7. ***Limitations ('tipping points') of marine biodiversity*** – at some point changes in biodiversity will lead to a reduction in the capacity of marine ecosystems to provide goods and services. There may be a uniform relationship between biodiversity and provision of goods and services or there may be crucial non-linearities or tipping points at which delivery is no longer possible. These limits at which biodiversity can still provide a good or service need to be defined;
8. ***Defining the best mechanisms to afford the protection of goods and services*** – in order to prioritise management and policy strategies the species, habitats and functions that are critical to maintain and enhance

delivery of goods and services need to be identified so that we can put in place mechanisms to protect and restore them. Knowledge to inform such management priorities is particularly limited in sub-tidal zones;

9. ***Development and application of technology to support research*** – some underwater technology is already available but has not been fully utilised to support research into linkages between marine biodiversity and goods and service delivery. For example, there are technologies to support underwater habitat mapping where data has been remotely collected. Underwater technology needs to be further developed to enable large scale experimentation to scale up small laboratory experiments in the natural and to the subtidal environments (point 3 above);
10. ***Methodologies for building environmental accounts for the services associated with marine systems*** – to support policy and management an improved ability to convert ecological understanding into environmental and/or ecological economics is required. There is a need to clearly describe, quantify and value the assets and the processes that impact upon these goods and services and their value. Some methodology exists but the literature is rather fragmented and not framed around the full marine ecosystem services concept.

3.3 Recommended research priority areas

Four key priority research areas were identified from the list above. Progress in each of these will substantially enhance current understanding of the key processes and properties of marine ecosystems, why they are important, and how human activities impact upon them:

1. Biodiversity Ecosystem Function;
2. Critical properties;
3. Quantification of the goods and services; and
4. Implications of marine biodiversity change to the delivery of goods and services.

3.3.1 Biodiversity Ecosystem Function

An important aspect of the overall goods and services terminology is the role of biodiversity in maintaining the “health” of the global or local ecosystem. The scientific debate centres on how closely the overall biodiversity of different marine systems can be related to their functional importance. This is an expression of a wider Biodiversity-Ecosystem-Function (BEF) debate. The nature of this relationship is central to determining the importance of preserving organisms and habitats with regard to the pressures of marine exploitation and global change. This research is still fragmented and at an early stage where the questions have been framed as theories that may be tested. The empirical work and the development of modelling approaches requires a concerted effort before management tools and strategies will be properly supported by science.

There is a great deal to be learned from terrestrial studies but the scale and linkages that exist in marine system are quite different from those represented in terrestrial habitats. The ocean is essentially a single system where local pressures are buffered by connection to the greater whole. Transport between systems is driven by advective forces and the logistics of experimental work become more complex with depth. It is not surprising that the majority of empirical studies have been restricted to intertidal and shallow coastal regions. In addition, because of the inherent differences between the marine and terrestrial habitat it is entirely uncertain that theories developed for terrestrial systems will be fully, or even partially applicable to marine systems

Work still required for marine systems is in understanding the key functional features of particular habitats, and classifying them based on these functions. Maps that characterise the seabed by functional types (where there is sufficient survey information) could then be produced. It may be that such maps will differ from existing synoptic mapping of habitats in UK waters which are based on structural classifications. This information is required to provide greater depth of knowledge on which advances in the Biodiversity-Ecosystem functionality (BEF) debate for marine system may be firmly based and includes:

1. Understanding the space and time scales and the context in which biodiversity-ecosystem functioning relationships operate; and
2. Quantification of ecology (i.e. life traits) of species critical to delivery of goods and services (including recreational services).

Recent studies (Solan *et al.*, 2006) have begun to advance our knowledge of BEF relationships but the central tenets of the BEF debate are still being tested through various empirical and modelling approaches. Evidence is gathering on the linkages between goods and services and diversity but progress is slow given the complexity of the problem. There is still an imbalance, with more information on this topic for terrestrial systems when compared to marine systems.

The construction of synthetic assemblages in microcosm systems is open to criticism but allows empirical approaches to be tested. Such systems are not an accurate representation of natural systems but rather allow the development of theory that must be later be tested under more natural conditions as the theory and practice of BEF research develops (Loreau *2000*, Naeem & Wright 2003, Balvanera *et al.* 2006, Raffaelli 2006). There is now an urgent need to extend our understanding of functions and processes and to scale them up spatially and temporally beyond the intertidal and very shallow coastal waters. This will require significant financial investment. Development of underwater technology would support new experimental and survey approaches in the more inaccessible sub-tidal waters which have to date been relatively poorly researched.

Investigation of the effects of sequential (and predictable) species extinctions that arise from human impacts is required. Such experiments require realistic field scenarios. These are expensive and must be coupled with controlled *in vitro* experiments. Appropriately supported and integrated time series studies are required to give full environment and ecosystem perspectives.

There is a considerable knowledge gap in the understanding of the functioning of microbial communities within soft sediment marine benthic systems that cover most of the ocean sea-floor. The role of microbes in delivery of ecosystem services, how microbial communities are linked to higher trophic levels, and how this in turn influences ecosystem functions needs to be determined. Microbial studies in mesocosms coupled with field observations and manipulative experiments in the field would further our understanding of the relative roles of microbial communities and higher trophic levels.

Ecosystem functions can contribute to the delivery of several goods and services. For example the construction and irrigation of complex burrow systems by mud shrimps, known as bioturbation, facilitates cycling of nutrients, processing and burial (sequestration) of carbon, and stabilisation of sediment. Similarly, several components of an ecosystem contribute through various functions to the overall delivery of ecosystem goods and services. An example here is gas and climate regulation; maintenance of atmospheric CO_2 is facilitated by (among others): fixation of carbon by photoautotrophs that can include phytoplankton, subtidal seagrass, and coastal margin macroalgae; recycling of carbon in the water column by heterotrophic organisms from zooplankton to fish and whales; heterotrophic processing of carbon by benthic organisms (living at or in the seabed); and burial and sequestration (but also sometimes release) of particulate carbon within seabed sediments by bioturbating benthic organisms. This multi-functionality of marine systems combined with a lack of data on the rates of the underlying processes makes the comprehensive ecological quantification of the provision of goods and services highly complex.

3.3.2 Critical properties

The continued delivery of ecosystem goods and services in the face of environmental and human-induced threats depends on the underlying properties of the ecosystem. These consist of the physical habitat and its biological component. Variations in the delivery of ecosystem goods and services are generally governed by the species composition of the ecosystem, its biodiversity, with the number of each species and the ecological role they are fulfilling being critical. In marine systems many species can operate in a number of ecological roles, for example at different life stages/sizes or in response to food supply or the presence of competitor species. Some emerging concepts from research have direct relevance to management and understanding of the contribution of biodiversity to ecosystem functioning, but the main research challenge is to translate or operationalise these concepts to underpin an evidence approach to the management of marine systems.

There is a good knowledge of the types of assemblages of species that occur around UK coasts and shelf seas. Species have been described, their identification is well supported by keys and guides. But, the UK does not have:

1. Knowledge of the types of assemblages of species for all coasts and shallow seas – there are significant gaps which, from the point of view of biodiversity, can only be filled by *in situ* survey;

2. Comparable data for species richness and abundance at and between different locations for most habitats;
3. Sufficient trained personnel with the species and biotope identification skills required to undertake *in situ* surveys or the monitoring studies necessary to document biodiversity change;
4. Knowledge of aspects of the biology of many species critical to understanding functioning (e.g. propagule dispersal, growth rates, longevity); and
5. Understanding of the character and reasons for decadal scale natural fluctuations in species abundance.

Existing biological traits information[3] has been collated but demonstrates that for many species there is no information on such features as longevity, growth rates and propagule dispersal which is required to assess recovery potential, and thus change in delivery of a service. Addressing specific detailed questions about particular species and biotopes would benefit from targeted research.

A key corner stone of (ecological) sustainability is the idea that once a perturbation caused by exploitation ceases the system has the ability to return to a ‘natural’ state. Several similar-sounding and similar-meaning concepts concern the nature of changes in ecosystems in response to environmental perturbations (McCann, 2000). ‘Stability’ reflects the ability of a system to return its equilibrium state after a small disturbance. Stable ecosystems have lower variability than unstable ones, and comprise species less likely to disappear from the system. ‘Resilience’ is a measure of how quickly a system returns to its equilibrium state. Resilient ecosystems return more rapidly to their equilibrium state. ‘Resistance’ is the ability of a system to resist change, A more resistant system will change less in the face of a particular perturbation than a less resistant one. Stability may be an aspect of what some describe as ecosystem ‘health’ and thus its ability to deliver key goods and services.

There are a number of theoretical models that suggest that stability, resistance and resilience correlate with various aspects of biodiversity. The available evidence from terrestrial systems does not universally support the results of such simple modelling while the situation for marine systems is uncertain (Ptacnik *et al.,* 2008; Chevassus-Au-Louis, 2008). For example, at small to medium scales, marine systems show more resilience than terrestrial ones due to the buffering effect provided by the long distance dispersal by planktonic propagules.

More complex food webs are generally thought to be either more or less stable than simple ones made up of a few species. When the trophic links among species are strong, such as when a predator species depends almost entirely on a single prey species, greater complexity begets greater instability. When food web links are weak, such as when predators eat a broad range of prey types, greater complexity (more links, more species) results in greater stability (e.g. Navarrete and Berlow 2006). Marine intermediate predators show very large diet breadths and considerable trophic plasticity, implying food webs that are stable

[3] www.marlin.ac.uk/biotic

and so able to continue to deliver production to the top consumers. This is not yet supported by field studies.

Many marine species have 'open' populations where recruitment is dependent on the stock of adult plants or animals over a wide area. These species tend to have widespread dispersal of larvae. In contrast, those with limited dispersal, laying eggs on the bottom or having very short-lived spores or larvae, have 'closed' populations. Dispersal scales in marine species are extremely wide-ranging – from millimetres distance from the adult producing larvae or spores to hundreds of kilometres. Kinlan & Gaines (2003) reviewed the topic of propagule dispersal in marine environments. Approximately half the taxa that they considered are unlikely to populate locations further than 10 km away. Excluding fish, this included the majority of species of marine invertebrates and algae.

Understanding impacts of change on these underpinning properties would significantly improve our knowledge of the sensitivity and vulnerability of goods and services from marine ecosystems. For example, in terrestrial habitats barriers to movement from increasing urbanisation and road-building have resulted in much reduced population connectivity and potentially greater instability of smaller, more isolated pockets of functionally relevant habitats. The very opposite problem may be faced in marine systems as greater marine transport moves species around and introduces invaders. In addition, sea defences are radically altering habitats around the coast, providing 'stepping-stones' for the movement of hitherto limited hard-bottom species.

There is thus a need to develop simple measures of ecosystem properties, i.e. stability, connectivity etc in order to develop the idea of ecosystem 'health' into a quantifiable concept. There is also a need to understand the links between these properties and continued provision of goods and services. Other areas where information is lacking include the effects of invasive species on food web complexity and stability; the tipping points which a community and its functions will switch to something different after successive loss of species and determining which species are of structural of functional importance.

3.3.3 Quantification of the goods and services

To quantify marine ecosystem goods and services in ecological terms, i.e. with ecological data we need to extend and improve our understanding not only of the BEF relationship, but also of how biodiversity and ecosystem functioning relates to delivery of goods and services.

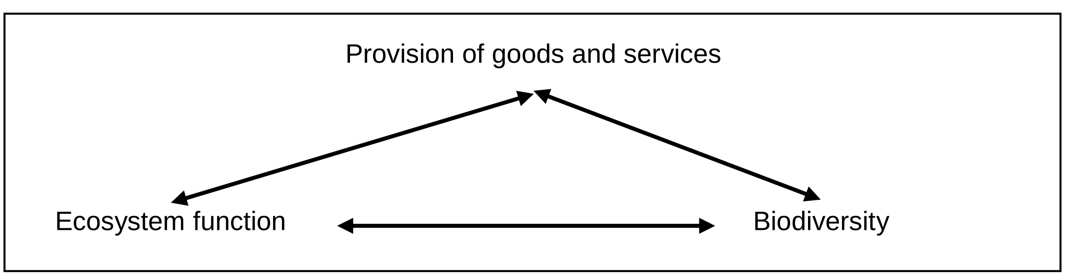

Figure 2. Simple Relationship between function, biodiversity and provision of the good or service.

There is need to understand how biological composition is linked to goods and service delivery and which are the key elements and functions of the community so that management actions can be prioritised. Understanding the nature of BEF and ecosystem goods and services relationship could be facilitated through large-scale comparative analysis of links between biodiversity (in its widest sense as defined in the Convention for Biodiversity as the '…*quantity, variety and distribution of genes, populations, habitats and communities*') and ecosystem structure, function and services. Projects working along time-series or spatial gradients of human impacts, such as fishing or climate variability, may provide macroecological insight and allow inference of causality of the linkages among these three domains.

From a management perspective it is important to understand how delivery of goods and services will change under different scenarios and to monitor the impacts of human activities and of global change. It may not be possible to comprehensively quantify many of the goods and services, particularly regulating and support services. There is likely to be a high degree of uncertainty and imprecision in the due to lack of suitable data and adequate methodology. Instead it may be feasible to develop indicators of the different services. Measures of biodiversity could be a good surrogate for provision of individual goods and service and aid rapid assessment, in which case we need to understand which components of biodiversity are relevant and for which goods and services. Statistical analysis and conceptual modelling should be applied to available data to integrate biodiversity measures and the variety of underpinning ecosystem functions to quantify goods and services and to guide development and application of methodology. Such approaches should be developed into spatially-explicit and dynamic modelling and process studies at sea-basin scales that can then be developed into modelling and scenario analysis of place-based case studies to support spatio-temporal management.

Direct uses of the marine ecosystem services tend to be consumptive (e.g. fish), but also include use of materials extracted from marine environments and non-consumptive goods such as recreational activities. Marine biodiversity arguably has use value, but is typically not valued for itself. Economists have fairly well defined approaches for measuring Use Values as these tend to be linked to markets and can be valued with undistorted market price information. Economists need more assistance in understanding and developing the *production functions* that define the relationship between changes in management regimes of human activity (e.g. area restrictions on activities, changes in gear or technology types) and the productivity of direct use goods. This is important as most relevant policy questions are trying to value marginal (as opposed to total) changes in resource use; for example: How does fish productivity change in response to designating additional km^2 of protected area in a certain biogeographical zone?

Economic analysis is forced to consider how total values can be arbitrarily pro rated over smaller spatial scales. The science that validates these estimates is extremely weak. Most of the literature that exists on production function methods is limited to tropical mangrove and coral reef systems (e.g. Barbier & Strand, 1998) which cannot be transferred to temperate marine systems.

Again, for the ecosystem services mediated by marine biodiversity that fall under the indirect use category, economists can use value endpoints (e.g. the social cost of carbon) but there is a scientific gap in understanding the production functions that allow us to quantify how marginal changes in management affect the endpoint.

While the research on production functions is a common focus for conducting ecological-economic research, current economic appraisals are relying on the best use of existing values that can be transferred from elsewhere. Benefits transfer is still more of an art than a science and relies on relevant scientific studies to undertake the transfer. There is currently a lack of relevant studies for temperate marine waters, which was highlighted by the recent Defra Valuation study (Moran *et al*., 2007).

There is a need to improve our ability to quantify the contribution of natural capital and ecosystem services to the national economy and human well-being. At the same time improved methods to determine and demonstrate the socio-cultural value of marine ecosystems and their biodiversity is required. Lack of public understanding of biodiversity and marine ecosystems is a fundamental problem when trying to apply some of the mainstream valuation methods (e.g. stated preference methods).

As well as generic pro-rata characterisations and assessments of marine services there is a need to develop methodology and collect data to enable application to specific locations and to couple this with the relevant social systems.

Some of the goods (stocks) and services (flows) are already included in conventional national income accounts and some double counting is possible. Environmental accounting models should be developed that are applicable to marine services and take into account specifically marine issues concerning sustainability of stocks by controlling flows. Such bioeconomic approaches have been developed for the ecosystem approach to managing fisheries but have clearly not yet been successful or successfully implemented. Management of activities in the marine environment has largely not taken into account impacts on the full spectrum of goods and services provided by marine biodiversity and marine ecosystems.

From a management perspective agreed objectives related to biodiversity and goods and services are required. The next step is to then develop a clearer understanding of which management actions maintain biodiversity, goods and services and to what level.

3.3.4 Implications of marine biodiversity change to the delivery of goods and services

Marine ecosystems are subjected to global change pressures such as climate change, ocean acidification and overfishing, as well as local pressures arising from pollution, fishing, land reclamation, harbour development and flood defence. There is a need to understand how these impact upon the BEF - provision of goods and services interrelationships to make it possible to implement restrictions or reductions through management actions and hence mitigate against them.

There is a need to understand the role of ecosystem resilience and develop ways of quantifying its importance. Research is required:

1. To enable the drivers of change in marine ecosystems to be differentiated;
2. To identify whether changes are long or short term; and
3. To distinguish natural variation from other changes.

Building on existing understanding of the impacts of single stressors in the marine environment will improve understanding of the combined multi-sectoral impacts on the pattern of biodiversity and delivery of goods and services over long and short term pressures and at a range of spatial scales.

Some of the changes to provision of goods and services will be positive and these should be identified. There is a need to be able to distinguish the impacts on the different goods and services and hence to identify the 'winners and losers' so that trade-offs can be made between provision of different services. Such knowledge will facilitate development of management approaches that mitigate the social distribution of the impacts of change and allow decisions to be made that are fair and equitable.

Research suggests that biodiversity may aid recovery of damaged systems, for example in Liverpool Docks restoration projects (Russel *et al.,*1983). The mechanisms for this need to understood and methodologies to use and restore biodiversity to mitigate further change developed.

Will climate change affect the role of marine biodiversity in supplying goods and services?

- **There will be a shift in the distribution and abundance of species as a result of seawater and air warming as well as a small number of changes of the biotope present at a location (Hiscock *et al.* 2004).**
- **The species of fish that are caught for consumption have already shifted and will in the future shift further towards warmer water species (e.g Red mullet, John Dory and Sea bream are being caught in larger numbers than ever before in UK waters).**
- **Much valued cold water fish species such as cod may become less abundant in UK waters, but still available further north (if fisheries conservation measures are effective).**
- **If warm water species are introduced for aquaculture, they may adversely affect, directly or indirectly, native species and habitats (for instance, introducing ormers which, when they become established in the wild, will result in boulder turning and mortality of native species).**
- **There may be new or more frequent occurrences of damaging warm water species such as the string jelly *Apolomia uvaria* which causes death of farmed fin fish.**
- **There may be more frequent blooms of harmful algae such as the non-native dinoflagellate *Gymnodinium aureolum* (now *Karenia mikimotoi*) and consequent death of communities important for services such as nutrient recycling as well as commercial fish species and the food of fish.**
- **Southern species are often colourful and attractive. Although a large scale influx of southern benthic species is unlikely (because of geographical barriers such as the English Channel), the UK seabed may become more attractive for recreation.**

Reference:

Hiscock, K., Southward, A., Tittley, I., & Hawkins, S. 2004. Effects of changing temperature on benthic marine life in

3.4 Potential barriers to research

Research needs described within this document are at the boundaries of blue sky and applied research, are multi-disciplinary, and are at physical boundaries (the interface between sea and land tends to be ignored or forgotten). The cost difference between executing research in the marine environment when compared to its terrestrial counterpart is also considerable. Such cost implications have created a coastal bias in marine research that needs to be redressed in order to understand and quantify the global importance marine biodiversity and the provision of goods and services.

To date funding opportunities have been limited as such research does not fall wholly into any one category or into any one single funding body's remit. The multi and transdisciplinary research that is required is eligible for some funding by many but supported by few and as such there is a need for targeted funding. Research is also limited by the availability and application of appropriate technology. For example, in comparison with terrestrial environments marine scientists have only very limited maps of subtidal marine habitats and species.

Communication amongst researchers on research being undertaken within and between disciplines could be enhanced. Transdisciplinary research findings are often considered outside the scope of high impact journals with a particular focus area.

Part of the transdisciplinary communications issues arise from a mismatch in confidence between ecologists and economists. Economists take the perspective that the failure to value a resource service (flow or stock) is tantamount to undervaluation, which in the extreme equates to a zero value, and over-exploitation. Much valuation literature is not predicated on any notional "true" resource value, instead most economists accept that environmental (shadow) values are likely to be approximations. This perspective runs counter to precision sought in the natural sciences. Economists require underlying science that allows quantification in ways that are policy relevant. As a consequence it is often difficult to engage natural scientists in transdisciplinary research as they have concerns about the potential for inappropriate use of data/information from science/research projects that could be subsequently fed into policy/models. Such concerns arise from use of data that was often not originally collected for use in policy advice and a lack of control once the information is released.

4. Conclusions & Recommendations

Identifying requirements for research and information on marine biodiversity and the provision of goods and services, assists researchers to develop topical, relevant research proposals, helps research funding mechanisms to shape strategies and research programmes, and provides a service to policy and decision makers not only by providing them with information and knowledge but also by clarifying the nature of the evidence they require.

Within this context it is recognised that marine survey and monitoring are critical requirements to assist in answering research questions and to augment research results in the production of evidence to support policy and decision making. Such data will need to be spatially resolved and long-term in nature to allow trends to be identified.

Two overarching strands of research with respect to marine biodiversity and the provision of goods and services were noted:

(1) Natural science: the need to understand how marine biodiversity contributes to delivery of goods and services. To understand what the ecological links between biodiversity, ecosystem function and provision of ecosystem goods and services are; and

(2) Social science: the need to value goods and services in a way that resonates to society. This concerns development of socio-cultural and economic valuation tools; valuation methodologies: both monetary and non-monetary, social choices and preferences.

In reality such research is cross-cutting and requires a multi-disciplinary approach.

Four key research priority areas were identified by the UK BRAG subgroup. It should be remembered that determining research priorities for marine biodiversity and the provision of goods and services, also sits firmly within the larger framework of fundamental marine research requirements. Such research is also socially relevant science needed to derive the evidence base for policy makers to make well informed decisions on policy options.

Progress in these four research areas will substantially enhance current understanding of the key processes and properties of marine ecosystems, why they are important, and how human activities impact upon them:

1. Biodiversity Ecosystem Function;
2. Critical properties;
3. Quantification of the goods and services; and
4. Implications of marine biodiversity change to the delivery of goods and services.

In addition to the priority research areas, there is a need to consider knowledge transfer as a key component of research activity, both within the research community and beyond. Such activities should not be seen as an ‘addition’ but an integral part of the research process. Opportunities to engage scientists more positively, perhaps through models similar to IPPC e.g. UK Millenium Ecosystem Assessment, the ESRC-NERC interdisciplinary collaborations and MarBEF should also be encouraged.

There is also a need to identify mechanisms to feed science findings into wider policy/funding agendas on understanding the role of biodiversity and the delivery of goods and services. This document will provide a useful basis to commence this engagement.

Continual update of the knowledge on the marine environment including biodiversity (e.g. species; biotopes) as new technologies are developed will improve understanding of how the system operates and allow more informed decisions to be made.

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Appendix A: UK BRAG Subgroup – adopted process

Identify key experts from a range of backgrounds and institutes to form the working subgroup (Identify 'core' members and those that could be corresponding members). Include a small number of experts from outside of the ecosystem category being considered e.g. terrestrial if marine or freshwater is being considered. Invitation should be made to academic experts; government bodies and scientific organisations/laboratories in order to encourage the widest viewpoints on the subject matter. An expert group no larger than 12-15 is advised.

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Develop terms of reference for the group; a clear timescale for input, the expected milestones and outputs should be completed and circulate with an invitation email to the identified experts. This should include details on purpose of the work and its value and any key dates (i.e. timeframe for returning the questionnaire; the likely date for the workshop etc).

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Develop a questionnaire for consultation with the identified experts. Responses from the questionnaire will then be compiled into a backing paper which will form the basis of a 1 day workshop.

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Execute a one-day workshop. The outcome from the day should be a draft report outline and lead authors identified for each section and agreement on key messages, conclusions and recommendations.

Lead authors to provide section text within 4 weeks of the workshop date. All sections are then to be compiled by the workshop chairperson and a final report is circulated to the group for comment (4 week window provided).

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A revised report is re-circulated to the working group and also provided to the UK BRAG committee (4 week window provided for comments to be returned).

Comments are taken into consideration and a Final Report released