**GOODS AND SERVICES RELATED
TO THE MARINE BENTHIC ENVIRONMENT**

by

Nicola J. Beaumont and Rob Tinch

CSERGE Working Paper ECM 03-14

**GOODS AND SERVICES RELATED
TO THE MARINE BENTHIC ENVIRONMENT**

by

Nicola J. Beaumont[1,2] and Robert Tinch [1]

**[1] The Centre for Social and Economic Research
on the Global Environment, School of Environmental Sciences, University
of East Anglia, Norwich, NR4 7TJ**

**[2] Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth,
DEVON, PL1 3DH**

**Contact details:
Nicola Beaumont: e-mail – nijb@pml.ac.uk
Tel: 0044(0)1752 633423, Fax: 0044 (0) 1752 633101**

**Robert Tinch: e-mail – r.tinch@macaulay.ac.uk
Tel: 0044 (0) 1224 498200, Fax: 0044 (0) 1224 498205**

Acknowledgments:

The support of the Economic and Social Research Council (ESRC) is gratefully acknow-ledged. This work was part of the interdisciplinary research programme of the ESRC Research Centre for Social and Economic Research on the Global Environment (CSERGE).

This research was also funded by the European Union Framework 5 programme.

ISSN 0967-8875

Abstract

Trawl fishing is now regularly used throughout the world as a method of catching bottom dwelling marine organisms. To ensure that trawl fishing continues in a sustainable manner it is essential to understand the potential impacts of this activity on all components of the environment, and hence on the provision of all other goods and services. Before this can be done the goods and services provided by the benthic environment must be identified.

This paper begins by detailing the type and extent of the impacts of trawl fishing. The goods and services provided by the benthic environment, which would be affected by trawl fishing, are then described, including: food provision and employment; gas and climate regulation; nutrient cycling; bioremediation of waste; biological control; recreation and eco-tourism; habitat; information service; option use; bequest and existence values. The benefits of having access to a complete list of all known potential goods and services in the management context are then discussed.

Key words: Goods and Services, Trawl Fishing, Benthic, Total Economic Value

1. Introduction

It has become apparent that it is generally not possible to exploit one function of the environment without influencing the availability of other functions; for example, exploiting forests for timber affects the biodiversity present, the climate regulation capacity of that environment, and so on. If our utilisation of environmental functions is to be sustainable, equitable, efficient, and as far as possible without detrimental side effects, we must first understand how the exploitation of one environmental function will impact on the provision of all other goods and services.

A considerable number of studies have been published assessing ecosystem functions and resultant goods and services. The overviews of goods and services (Groot *et al.* 2002, Costanza *et al.*1997, Pimental *et al.* 1997) provide valuable information, but it is the site-specific studies which are of direct use in the management context. To date the case study areas have been 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.

This paper investigates a less well known environment, hidden from human view, but nonetheless of great importance: the marine benthic environment. The term “marine benthic environment” is used throughout this paper in a very general sense, meaning the sea bed. It is appreciated that this is a complex environment, which can take many different forms, but for the purpose of this study it is discussed only in a general sense. It is a key area as it has suffered considerable anthropogenic impact, particularly over recent years, from the act of trawling for marine organisms. It is also currently impacted, but to a lesser extent, through localised recreational use in shallow waters, localised dredging to deepen shipping channels near harbour infrastructure, and localised siting of offshore drilling facilities. Trawling has been undertaken for hundreds of years, but the increasing extent of trawling, and developments in technologies employed, have resulted in increasing concerns that this activity is impacting other goods and services provided by this environment. These include fundamental services such as nutrient cycling and climate regulation, and indeed the capacity of this environment to provide a source of future fish stocks.

The paper begins with an overview of the trawling industry, and the known impacts associated with this activity. A new methodology for the classification of goods and services is then proposed, as it is considered that previous studies of goods and services have neglected several important components of value. The following section details all the known goods and services provided by the marine benthic environment, to provide a comprehensive picture of the potential impacts of trawl fishing. Finally the benefits of having access to a complete list of all known potential goods and services in the management context are discussed.

2. The Need for an Assessment of Benthic Environment Functions

Trawl fishing is now regularly used throughout the world as a method of catching bottom dwelling marine organisms. In 1999 demersal trawl, seine and nephrops trawls made up 43% of UK fleet and beam trawlers made up another 11% (P.C.M.E.A.E.F. 2000). Common target species include cod, plaice, shrimp and scallops. The industry is highly variable and complex, with vessels differing considerably in size, and the utilisation of several different types of gear (Watling and Norse 1998). The basic principle, however, is that large weighted nets are dropped to the sea bed and dragged along the bottom, stirring up the benthic environment, netting animals living above the bottom layer, and also flushing organisms out of the mud and into the nets. In recent years the trawling gear has become more efficient (Frid *et al.* 2000) and trawls are taking place in deeper and more remote areas. Traditionally estuaries, bays and the continental shelf would be fished using demersal trawling, but as fish stocks are diminished and fishing technology improves the harvested area has increased to depths of up to 1200m on the continental slope (Cryer *et al.* 2002).

The sizes of the disturbed areas are striking. In the case of a beam trawler travelling at 6 knots, drawing two 12m beams, over a quarter of a million square metres of sea bed can be disturbed per hour. Beams can be up to 18m, hence disturbing areas 36m wide, and trawl speeds may exceed 6 knots, providing some indication of the large spatial scale of the disturbance (Jennings *et al.* 2001a). Watling and Norse (1998) calculate that an area equivalent to the world's continental shelf is swept by trawlers every two years. Of course there is substantial variability in the susceptibility of areas to trawling, with some areas never trawled (for example due to rocky bottoms) while others are very heavily impacted – each part of the Bay of St Brieuc, for example, may be trawled 7 times per year (Dayton *et al.*1995).

The trawl nets cause a significant physical disturbance to the sea bed, altering the spatial structure, species composition and biogeochemistry of the benthic environment (Jennings *et al.* 2001b, Thrush *et al.* 2002, Kaiser *et al.* 2000), and as a result altering the benthic community structure, biomass, total productivity and overall ecosystem functioning. Trawl fishing activity is thought to cause a decrease in invertebrate species richness, abundance, biomass and diversity (Cryer *et al.* 2002, Sparks-McConkey *et al.* 2001, Jennings *et al*. 2001b), and order of magnitude decreases in the biomass of macro fauna, such as bivalves and echinoderms, have been reported (Jennings *et al.* 2002). The impact of trawling on the benthic environment is considered to be comparable to forest clear cutting by some authors, completely changing the character of the environment (Watling and Norse 1998).

Benthic meio fauna, however, are reported to be less sensitive to trawling activity and it has been suggested that even chronic trawling has minimal effects on the size structure and production of these species (Jennings *et al.* 2002). This is partly because they avoid direct damage being re-suspended by the trawl gear and hence avoiding being crushed (Schratzberger *et al.* 2002). These smaller organisms also tend to be mobile and have fast life histories, with rapid recruitment and growth rates. The trawling activity could actually benefit them by removing competition and/or predation from larger organisms (Jennings *et al.* 2001b), and carnivorous nemertea benefit from the resultant increase in freshly dead and dying organisms (Sparks-McConkey *et al.* 2001).

The result of frequent trawling is thus thought to be a shift from communities of high biomass, sessile species to a dominance of low diversity communities of smaller, opportunistic, scavenging species (Kaiser *et al.* 2000). These new communities continue to play a critical role in energy cycling due to their ubiquitous distribution, rapid generation times, fast metabolic rates and high abundance (Schratzberger *et al.* 2002). It has been suggested that trawl activity actually 'farms' the sea bed, increasing productivity and improving feeding conditions for fish (CEFAS 2000). However, although the switch in community structure may lead to an increase in productivity per unit biomass, this is not enough to compensate for the overall loss of biomass and production (Jennings *et al.* 2001b). Jennings *et al.* (2002) conclude that beam trawling has little effect on the production of small infauna, and certainly does not increase the food supply of fish such as sole and plaice. Smaller infauna are also less significant as bioturbators, and as a result the sediment community function, carbon mineralization and biogeochemical fluxes will be significantly impacted by trawling (Jennings *et al.* 2002). Trawling can also radically alter the topographic complexity of seabeds (Kaiser *et al.* 2000), particularly when habitats are formed of living organisms, such as maerl beds and coral reefs (CEFAS 2000), thus changing their capacity to provide habitats and nursery grounds. Overall, trawling has the potential to significantly change benthic community structure, which in turn has the potential to cause significant changes in the benthic environment's ecosystem processes (Thrush *et al.* 2002).

The impact on the environment will depend on a number of factors including the spatial and temporal variability of the trawls. Many areas are repeatedly trawled, resulting in fundamental shifts in the community structure, for example in the Southern North Sea some areas may be trawled 10 or more times each year (Rijnsgorp *et al.* 1998). High frequency trawling of an area may change the environment indefinitely as it will not allow time for it to recover in between trawls. It was reported by Collie *et al.* (2000) that a permanently altered state is likely if an area is fished more than three times a year. Deeper environments may be less resilient to trawling activities, and will tend to have slower recovery

rates (Koslow *et al*. 2000) as they experience little natural disturbance, and are hence not pre-adapted to disturbance and are therefore more vulnerable (Brylinsky *et al.* 1994).

In addition to frequency, the spatial distribution of trawling is important. If large continuous areas are trawled the potential for re-establishment of communities through movement and migration will be reduced, whereas if only small areas are trawled, neighbouring undisturbed areas can act as a source of replenishment. It should also be stressed that there are still many unknowns associated with the impacts of trawling, as studies are not always realistic in their temporal and spatial scale. In particular, the acute disturbance of a scientific trawl will not equate to the chronic impact of the large scale, long term trawling activity of actual fisheries. prendi spunto per il dattero

Understanding the extent of this disturbance, in type and scale, is essential when determining future fisheries management plans. A key objective for fishing regimes is sustainability, meaning management in a way that will ensure the future capacity of the resource is not diminished. The European commitment to such an objective is set down in Council Regulation (EC) No 2371/2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy. Managers must balance the benefits of trawl fishing, for example food, income and employment, against the costs of fishing impacts and to do this a clear understanding of all the costs is essential.

Most obviously, trawling has a direct biological impact on the growth of any fish stock under exploitation, and associated impacts on other stocks through trophic or competitive links. Beyond that, there is the potential for disturbances to the marine benthic environment to reduce the capacity of this environment to support particular species, such as cod, plaice, shrimp and scallops. In addition the marine benthic environment provides additional goods and services which are both desirable and, in some cases essential, to human well being. It is critical that all of these impacts are taken into account to ensure that the current gain from the fishing activity is not at the expense of significant reductions in other environmental functions, now or in the future. Before decisions can be made it is important to know what the functions are and what can be expected to change, hence a list of associated goods and services will be a valuable tool in the derivation of future management plans.

3. Valuation of Ecosystem Functions

Describing natural environments in terms of the goods and services they provide is an increasingly common method of ensuring that we have a true understanding of exactly what we are gaining and losing when we exploit the environment (Holmlund and Hammer 1999, Borgese 2000). There are a number of methods used for classifying goods and services (Holmlund and Hammer 1999, Moberg and Folke 1999). Groot *et al.* (2002) recently proposed a framework for the description of goods and services, which includes a valuable list of environmental functions. This framework is applied in this study to ensure that the list of goods and services is comprehensive. The Groot *et al.* (2002) framework is coupled, however, with a different method of classifying the goods and services, that is by adapting the Total Economic Value (TEV) framework. This framework is used in environmental economics to divide an environment into different components of value (Pearce and Turner 1990). These 'valued' components can essentially be seen as equivalent to the 'goods and services' provided by the environment. Classifying the goods and services in this way provides an effective bridge between natural science, socio-economics and management.

The TEV of an environmental resource can be divided into its use value and non-use value, as depicted in Figure 1. A use value is a value which arises from humans actually using the environment, for example the coast for recreation, or a forest for timber. There are generally considered to be three types of use value:

Direct Use Values arise from the direct exploitation of the environment by humans. The environmental functions listed under direct use are generally demand driven goods, and would be listed as 'production functions' by Groot *at al.* (2002).

Indirect Use Values are benefits which are derived from the environment, without the intervention of humans, for example climate regulation and waste degradation.

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. In other words, it is the value of being able to change one's minds, the value of keeping one's options open. Any *expected* future use is properly part of direct/indirect use value, not option value. There is however some debate associated with the definition and concept of option value, as detailed further by Hanemann (1989) and Walsh *et al.* (1984).

Non use values are representative of the value which humans bestow upon an environmental resource, despite the fact they may never use or even see it. Non use values are generally divided into two categories:

Bequest Value is the value an individual places on ensuring the availability of a natural resource to future generations.

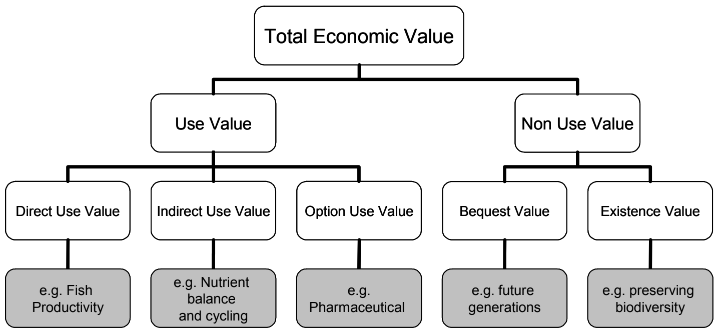
Existence Value is the value placed on simply knowing that a natural resource is there, even if it is never experienced. An example of this is the fact that many individuals would be willing to pay some amount to ensure the continued survival of some species, say polar bears, which they will never see, simply because that derive value from the knowledge of their existence.

The TEV framework ensures that all aspects of value associated with the goods and services of the environment are captured. Option, Bequest and Existence values may be difficult to define, quantify and isolate, but they can make up a significant part of an environment's value, so it is important to include them. These difficulties have resulting in these values being ignored by the majority of previous studies of goods and services, but they should be taken into account if management is to be is sustainable, equitable and efficient. A "strong" interpretation of sustainable development holds that future generations should have the same access to natural resources as the present generation; a weaker interpretation would allow reductions in natural resource values to be compensated for through increasing levels of man-made capital. Under either interpretation, and in particular if management is going to allow changes to ecosystem functions, goods and services, an understanding of the full value that ecosystems provide, both actually and in potential future scenarios, is a key input to the policy evaluation process.

The TEV framework is, however, not without problems in this regard. The sum of these components only tells us how much humans value the environment; values held by non-human entities, or intrinsic values, are not captured (Bateman and Langford 1997). This is not a particularly strong criticism of TEV, because clearly intrinsic values are, by definition, beyond human experience and so there is no adequate way that they could be taken into account in any human evaluation framework.

A more pertinent short coming (because it could in theory be addressed), is that the term "total economic value" notwithstanding, this sum of the values of individual functions is likely to be less than the (anthropogenic) value of the entire environment, owing to the primary life support function, the contribution of specific environmental assets to maintaining healthy and functional ecosystems. This is sometimes described as primary value, "glue" value, or infrastructure value (Pearce and Moran 1994, Gren *et al*, 1994). It arises because individual functions can 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. Thus, although this classification breaks the environment down into specific components, the inter-dependency of these components and overall value of the environment should be recognised, although at present this is unlikely to be quantified in monetary terms. Estimation of "glue" values is complicated by lack of scientific knowledge about the true interrelationships of ecosystem functions within and across ecosystems; this context of fundamental uncertainty takes analysis beyond the proper realm of environmental valuation, and into that of precaution and avoidance of irreversible calamities.

Figure 1: The Total Economic Value Framework, in the context of benthic biodiversity (adapted from Bateman and Langford 1997)



Having defined a list of goods and services, and the component values making up the TEV to which they give rise, each component should, if possible, be valued in monetary terms. This enables the costs and benefits of exploitative activity to be evaluated, facilitating the management process. There are several excellent reviews of the valuation techniques which may be applied (see for example Ledoux and Turner 2002) and there is no need here to repeat these. However it is important to note that the marine benthic setting implies an environment with which people have little familiarity, and this tends to rule out direct application of stated preference techniques, which rely on individuals making direct assessments of the value to them of specific changes in particular environmental goods and services. Rather, it is necessary to use scientific concepts to break down the goods and services provided by the benthic environment into components which:

- can be valued directly through market-based methods (for example, fish harvests), or
- can be explained to individuals in comprehensible terms (for example, reductions in marine mammal populations), or
- can be linked scientifically to other effects which can themselves be valued (for example, impacts on nutrient cycling linked to primary benthic productivity linked to pelagic fish productivity and harvests), or
- can be evaluated in terms of opportunity cost in relation to contributions to pre-determined targets (for example, changes in the contribution of the benthos to CO_2 regulation might be evaluated in terms of the implication for the extent and cost of action required elsewhere in order to meet emissions / atmospheric concentration targets)

The last of these is not a true "valuation" but rather an approximation based on cost-effectiveness of achieving pre-determined targets. It begs the question of what the target should be, but is pragmatic in accepting overarching targets at a scale well beyond the particular system in question, in cases where true valuation of the costs and benefits is extremely difficult

The goods and services are defined here in an overview format, in qualitative terms, with a description of the benefit to humans, and an evaluation of the potential for this function to be impacted by trawling activity. It is however, beyond the scope of this study to provide details of the significance, vulnerability, or recovery rates of the goods and services. The environmental interactions are clearly very complex, and a complete list of goods and services affected by trawl fishing could be very lengthy, so only the goods and services directly associated with the marine benthic environment are included here. The potential for wider secondary effects to cascade through many environments should not be forgotten and further research in this field will be required.

3.1 Direct use

Food provision and employment

Plants and animals which are neither cultivated or farmed, but taken directly from the wild, make up a significant part of the human diet. In the case of the marine benthic environment the major organisms which are extracted for use as food are fish, shrimps and bivalves. In 1999 the UK trawl fisheries employed 8700 fisherman, and assuming that for every one job at sea there are three on land trawl fisheries are estimated to provide approximately 35,000 jobs. The value of the UK trawl landings was in the region of £320million (P.C.M.E.A.E.F. 2000).

There is also a market for marine benthic algae, for example as food additives and in pharmaceuticals. In Japan marine algae are cultivated for use as both food and industrial materials. At least 50 different species are eaten, and supply an important source of vitamins and minerals (Murata and Nakazoe 2001). Marine algae is a popular food in Japan in part owing to its medicinal properties (van Netten *et al.* 2000). It should be noted, however, that algae will not grow below the photic zone, which is approximately 35m in the U.K.

The capacity of this environment to provide a food source, and the accompanying employment, is clearly a significant function of the benthic environment. Alongside, and intrinsically linked to, the provision of food and employment, is the support of cultural and spiritual traditions associated with fishing communities.

There is some dispute in the literature about the effects which trawling has on the future productivity of areas for commercial fisheries, as detailed in the previous section. Particularly in the case of algae, there can be little doubt, however, that the trawling activity has the potential to impact the capacity of this environment to provide food, through the physical impact on the benthic habitat, including refugia and nursery grounds, impacts on target species, wider impacts on community structure, and impacts on nutrient cycling. These effects could also spill over into changes in the pelagic fisheries. Some studies into this area are reported in Section 2; further research is required to determine the nature and scale of this impact.

3.2 Indirect use

Nutrient cycling:
The cycling and maintenance of availability of essential nutrients, for example N, P, S, and metals, is crucial for life. In the case of the benthic environment nutrient cycling is an important factor in maintaining productivity (Friedrich *et al.* 2002). Another result of nutrient cycling is the breakdown of nutrients and compounds, thus resulting in waste degradation and the maintenance of clean seawater.

The replacement value for this function was estimated by Costanza *et al.* (1997) as $62.1 - $174 per ha per year. Replacement cost, however, is not a satisfactory measure of value as the cost of replacing a function is not the same concept as the value that the function provides, and could be more or less than that value. To give a simple example, if a window in your house is broken, you will certainly replace it: the cost or price of the replacement is much less than the value of the functions the window serves. This example also makes clear a major shortcoming resulting from the confusion of cost and value: using replacement cost in lieu of value is singularly uninformative from the perspective of deciding whether or not to undertake replacement expenditure. If the value of the service is estimated as the cost of replacing it, then a simple

cost-benefit analysis would yield a benefit: cost ratio identically equal to 1, and the implication would be that it didn't matter whether or not the function was replaced. Clearly, that would be unhelpful and misleading. Replacement costs are only useful if it can be determined by other means whether or not replacement would have to be carried out. For example, if it is agreed that the functions in question are "essential", then it is useful to know how much it would cost to replace the functions, because expenditure up to that level on protecting the functions would be warranted. In this case the correct concept of cost to use is opportunity cost, taking into account the best alternative uses of the resources used to replace the lost function, and this is not necessarily the same as the financial expenditure required.

The action of bio-turbation by benthic organisms, mainly through the construction of burrows, plays a significant role in nutrient cycling. This movement transports materials from the deep sediment layers to the surface, and vice versa. Burrowing transports oxygen to what would otherwise be anoxic sediments, and the presence of the burrows increases the area of sediment-water interface. These two effects alter the sedimentary micro-environment, which in turn influences the types and rates of chemical reactions, including the recycling of nutrients. Mega fauna play a significant role in bio-turbation, and as detailed earlier it is these organisms which are most vulnerable to trawling activity. Nutrient cycling is also more generally affected by storage, internal cycling, processing and acquisition by marine benthic organisms, for example fish mineralize N and P via excretion. Changes in the marine benthic community, in particular the mega fauna, will clearly impact the environments' capacity for nutrient cycling. Nutrient cycling is thus likely to be significantly affected by trawling activity.

Gas and Climate Regulation:
Series of biogeochemical processes maintain the chemical composition of the atmosphere and ocean. In particular processes such as the regulation of the CO_2/O_2 balance, ozone, and SO_x, are essential for the maintenance of a healthy habitable planet, and breathable air. These gas regulation processes also play a critical role in climate regulation. The marine benthic environment plays a significant role in the regulation of carbon fluxes, in part due to its capacity to sequester CO_2 and act as a carbon sink. Costanza *et al.* (1997) suggest that the value of CO_2 absorbed was US$20 per tonne, based on a damage avoidance function. Estimating the damage of climate change is very complex and highly sensitive to assumptions, in particular about discount rates, so estimates are highly uncertain. As noted above, an alternative is to use abatement cost estimates related to the marginal cost of achieving certain targets; this could justify values of Euro 50 per tonne of Carbon or more (COHERENCE 2000).

Biochemical processes will be affected by trawling activity in a similar way to nutrient cycling, for example, changes in bio-turbation will impact carbon sequestration rates due to an increased movement of carbon and oxygen, and also through the change in sediment-water interface area. The capacity of the marine benthic environment to act as a carbon sink will also be affected by changes in the marine food webs, as changes in trophic dynamics will cause changes in the distribution of carbon throughout the marine environment. Organic matter is removed by fishing gear, resulting in the re-suspension and oxidation of carbon, and hence increasing the supply of carbon to the water column, and in turn the atmosphere. This re-suspension will also increase the oxygen demand in the water column, which could affect plankton and nekton species. (Watling and Norse 1998)

Trawling activity has the potential to significantly affect the gas regulation and climate control capacity of the marine benthic environment, potentially reducing the capacity of this environment to act as a carbon sink. Although the extent of this impact is not yet known, with the current concerns regarding climate change, it is an area which should be investigated in further detail in the immediate future.

Bioremediation of Waste:

The sea floor is where a significant amount of human waste (organic and inorganic waste) finally settles. It is washed off land, through rivers and estuaries, and then eventually sinking to the marine benthic environment where it is stored, diluted and recycled through assimilation and chemical re-composition. This de-toxification and purification process is of critical importance to the health of marine environment. The benthic organisms play a significant role in this process, through uptake of toxic metals, for example, the marine deposit feeding polychaete, *Nereis succinea*, uptakes heavy metals (Wang *et al.* 1999), and bioturbation affects the redistribution of contaminants, for example toxic metals, pesticides and radio-nuclides.

Trawling affects the marine community as previously discussed in both the nutrient cycling and gas regulation sections, and as a result these changes impact the processing of wastes on the sea floor, directly through organism uptake and also through the changes they cause in the sediment biogeochemistry and structure. Trawling also causes significant re-suspension of sediments which in turn could mean the re-suspension of toxics.

It is difficult to generalise the impact of trawling on waste treatment, as the types of waste in the benthic environment will vary tremendously. Trawling may result in some pollutants becoming more stable as the high suspended sediment loads may encourage complexation, resulting in a reduction of their

bioavailability and bio-toxicity. Trawling may also reduce bio-turbation, allowing the contaminants to become permanently buried. Equally trawling may reduce the rate of chemical reactions through reduced bioturbation, causing the compounds to remain in a toxic state for longer, and also the physical activity of trawling may re-suspend previously buried toxics into the water column.

Biological control:

Ecosystems have innate interactions and feedback mechanisms, leading to varying levels of stability within the community. Even small changes in the food web can significantly affect the resistance and resilience of an ecosystem to perturbations. Changes in marine food webs can influence the capacity to provide food resources, the distribution and sequestration of Carbon, the cycling of nutrients, and waste storage and degradation. Marine benthic organisms provide mobile and passive links between systems, transporting energy and nutrients. The benthic-pelagic coupling plays an essential role in the movement of particulate organic matter (Wassman 1998). Thus, as chronic trawling is anticipated to permanently change the community structure, and remove several species types from the food webs, this function of biological control is expected to also be dramatically altered, but whether this will have positive or negative implications is uncertain.

Recreation and eco-tourism:

The benthic environment is not currently a significant provider as a recreational resource. However, it does support sport/line fishing and to a small extent diving activity.

Habitat:

The presence of healthy habitat is a pre-requisite for the provision of all goods and services, without this fundamental base the ecosystem would cease to function. The ‘natural’ benthic habitat structure provides a refuge for plants and animals including surfaces for feeding and hiding places from predators. It also provides an essential breeding and nursery space for plants and animals, this is essential for the continued recruitment of commercial and/or subsistence species. For example, in the benthic environment cod is very dependent on nursery areas. The habitat thus plays a critical role in species interactions and regulation of population dynamics (Watling and Norse 1988).

Trawling dramatically changes the benthic environment, both through direct impact of the trawl gear, and also by altering the community structure. The mega-fauna play the most significant role in the development of complex habitat structure and, as discussed earlier, are most significantly affected by trawling activity. Trawling is thus expected to decrease the spatial complexity of the benthic environment, reducing its capacity to provide refuge, nursery grounds, and areas for breeding.

Information service:
The benthic environment can provide an insight into environmental resilience and stress, and provides a long term environmental record, which may provide an insight into how the environment has changed in the past, enabling us to determine how it may change in the future. The benthic environment also can provide information for the development of science. Through investigating natural technologies we will be able to improve our own. For example:

i. Through the study of the bivalve shell formation process there is potential to provide an insight into new tougher, wear resistant ceramics for biomedical and structural engineering applications (Ross and Wyeth 1997)
ii. Recent research on the sea mouse, *Aphrodite sp*., has discovered that its spines have a remarkable capacity for reflecting light. This capacity may provide important information for use in the field of photonic engineering, and potentially in the development of new communication technologies (Parker *et al*.2001).

Trawling reduces the biodiversity and complexity of the environment, and thus reduces its capacity to act as a source of information of this type.

3.3 Option use
The majority of previous studies on goods and services have only considered current uses of the environment. It is critical however that we also consider potential uses of the environment. We may never exploit the environment for these resources, but there is value associated with having the option of exploitation.

Current uses of the benthic environment for food and raw materials may be further developed in the future, for example:

- Food provision and employment –
  It is possible that as trends for homeopathic treatments continue to grow in popularity that the demand for marine algae will increases, and spread throughout the world. There is also potential for other marine benthic organisms to provide a food source in the future as tastes and demands change.

Other potential uses of the benthic environment include:

- Pharmaceutical and medicine: Tropical rainforests have been valued at \$0.01 - \$21 per ha based on their genetic diversity, and their resultant potential to yield successful pharmaceutical products. In the same way it is possible that the diversity held in the benthic communities may provide valuable information for future medicines (Simpson *et al.* 1996)
- Genetic Resources: The genetic diversity held within the benthic communities may be of significant importance in the future, for uses such as cross breeding or genetic engineering to improve existing commercial species for fish farming.
- Information service: As the study of this environment is relatively new there is a vast amount of information to be discovered. This information will provide an insight into the system's stress and resilience by providing a long term environmental record. As detailed earlier natural technologies used in this environment may provide information for the development of man-made technologies.
- Recreation and Eco-Tourism (e.g. diving or submarine safaris)
- Underwater space for living
- Marine Archaeology
- Museum exhibits and collections
- Provision of raw materials

3.4 Bequest and Existence Values
There is value associated with the marine benthic environment which does not concern our use of this environment, but is determined by our concern that future generations should have access to resources and opportunities. While the value to future generations of their own use of resources should be reflected through the use value categories (given a suitably lengthy time horizon and subject to the constraints of discounting), over and above this there may be utility to current generations from knowing that resources and opportunities are being passed to their descendants. This is bequest value. Beyond this, there may be existence values which 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. Estimation of these values is difficult, with techniques limited to stated preference, but nevertheless if the values are real (if people genuinely do gain benefit from these bequest and existence motives) then they ought not to be overlooked in any assessment which is based on consumer sovereignty and aggregation of individual preferences. These values are, however, not quantified here.

4. Use of Goods and Services in a Management Context

Exploitation of an environment for one purpose can alter that environment's capacity to provide other goods and services. It is essential to know all the potential consequences of our actions if we are to exploit the environment in a sustainable fashion, and maximise the benefit derived from that environment. By deriving a list of goods and services, all potential impacts of exploitation are highlighted, and awareness of these enables their inclusion in management decisions. The definition of ecosystem processes in terms of goods and services is also a valuable method of translating the complexity of an environment into a series of functions, which can be readily understood by a wide audience, including environmental managers and policy makers. This definition makes the potential consequences of exploitation very apparent, and the trade-offs very clear.

Most of the functions arising from the benthic environment are services. Other than fish production there are not many direct uses for benthic biodiversity, and thus it is rarely used as a good. It is the action, or service, of keeping the rest of the system functional that it is particularly valuable. The provision of services tends to overlooked in comparison to provision of goods, particularly in the management context. Services cannot be seen or held, and often do not yield immediate market value, and as a result are often taken for granted, however, these functions are fundamental to providing humanity with a healthy and habitable planet, and are thus just as critical to our well being as tangible goods. It is critical that the services provided by the benthic environment are well documented and included in management decisions, and not overlooked as they may have been in the past.

It is important to have a quantitative understanding of how changes in the benthic biodiversity affect these goods and services. There is a gap in our understanding of the type and extent of impacts caused by trawling, and the next step should be to investigate the goods and services in more detail, including their inter-dependences, inter-variability, vulnerabilities, recovery rates, and system resilience. It is also useful to value marine biodiversity, in both monetary and non-monetary terms. Converting the values of the different goods and services to the same units, for example €, enables the ready comparison of the costs and benefits of different management regimes. This process also increases the likelihood of all goods and services being taken into account in the decision making process, as opposed to just those with a market value.

It is useful for research and management purposes to break down the global environment into manageable sub-sections, but the inter-linkages both within and between the environments must be remembered. Although environmental

functions are categorised separately they are inter-dependant, and in reality the use of one function will influence the availability of the others. Changes in the benthic environment will also influence surrounding environments and the impacts of trawl fishing can cascade indefinitely: if the benthic environment is significantly and irreversibly damaged, it could cause irreversible damage to life supporting services, and the ramifications may be observed throughout the marine, atmospheric, freshwater and terrestrial environments. Also, as discussed earlier, dividing any environment into components can be misleading as the sum of the parts is invariably less than the whole.

Environmental degradation does not increase linearly, for example, as increasing areas are utilised structural integrity may be lost. The spatial and temporal variability of the marine benthic environment should also be recognised, as the goods and services will vary within and between benthic environments, hence no one estimate of goods and services could be considered as comprehensive for all marine benthic environments. As in terrestrial environments, further research will be required to examine the extent of transferability of estimates from one benthic environment to another.

5. Discussion

This paper has argued that the marine benthic environment has the potential to provide many functions which are of great value to humans. Trawling activity for marine benthic organisms has a significant impact on the marine benthic environment, both by immediately altering the physical environment and by causing changes in the marine biodiversity. These impacts will alter this environments capacity to supply a number of valuable functions, and as such it is critical that we develop a clearer understanding of true costs and benefits of trawling activity. Determining a list of goods and services for the marine benthic environment provides very valuable management information in its own right. It distils complex environmental information into a format which can be readily understood by environmental managers, and ensures that they recognise that trawling is having a significant impact, not only on fish populations, but on many more environmental functions.

Since previous reviews have tended to be largely terrestrial in focus, the review and methodology presented here is of particular value as it applies these methods of classifying these goods and services to a marine environment, hopefully paving the way for future marine studies. In contrast with many terrestrial environments, application of environmental valuation techniques to marine environments, and in particular benthic and deep ocean environments, is undeveloped. Recognition of the range and importance of the services provided by these environments is the first step towards a fruitful programme of valuation research providing important information for the better management of these systems.

References

Bateman I.J. and Langford I.H. (1997) Non-users Willingness to Pay for a National Park: An application and critique of the contingent valuation method. *Regional Studies* 31.6: 571-582

Borgese E.M. (2000) The economics of the common heritage. *Ocean and Coastal Management* 43: 763-779

Brylinsky M., Gibson J., Gordon D.C. (1994) Impacts of flounder trawls on the intertidal habitat and community of the Minas Basin, Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Sciences* 51 (3): 650-661

CEFAS: Centre for Environment, Fisheries and Aquaculture Science (2000) Does Trawling Damage the Ecosystem. *CEFAS Handout*, 2000

COHERENCE (2000) "Economic evaluation of quantitative objectives for climate change" (Report to European Commission, see http://europa.eu.int/comm/environment/enveco/climate_change/ecoeva.pdf

Collie J.S., Hall S.J., Kaiser M.J., Poiner I.R. (2000) A quantitative analysis of fishing impacts on shelf-sea benthos. Journal of Animal Ecology 69 (5): 785-798

Costanza R., d'Arge R., de Groot RS., Farber S., Grasso M., Hannon B., Limburg K., Naeem S., O'Neill R., Paruelo J., Raskin R., Sutton P., van den Belt M. (1997) The value of the world's ecosystem services and natural capital. Nature 387: 253-260

Cryer M., Hartill B, O'Shea S. (2002) Modification of marine benthos by trawling: Toward a generalization for the deep ocean? Ecological Applications 12 (6): 1824-1839

Dayton, P., Thrush, S.F., Agardy, M.T. and Hofman, R.J. (1995). "Environmental effects of marine fishing." Aquatic Conservation: Marine and Freshwater Ecosystems 5: 205-232

Ewel K.C., Twilley R.R., Ong J.E. (1998) Different kinds of mangrove forest provide different goods and services. Global Ecology and Biogeography Letters 7: 83-94

Frid C.L.J., Harwood K.G., Hall S.J., Hall J.A. (2000) Long-term changes in the benthic communities on North Sea fishing grounds Ices Journal of Marine Science 57 (5): 1303-1309

Friedrich J., Dinkel C., Friedl G., Pimenov N., Wijsman J., Gomoiu M.T., Cociasu A., Popa L., Wehrli B. (2002) Benthic nutrient cycling and diagenetic pathways in the north-western Black Sea. Estuarine Coastal and Shelf Science 54 (3): 369-383

Gren, I.M., C. Folke, K. Turner, and I. Bateman (1994) Primary and Secondary Values of Wetland Ecosystems, Environmental and Resource Economics 4(1):55-74 de Groot R.S., Wilson M.A. and Boumans R.M.J. (2002) A typology for the classification, description and valuation of ecosystem functions, goods and systems. Ecological Economics 41 (3): 393-408

Hanemann W.M. (1989) Information and the concept of option value. Journal of Environmental Economics and Management 16: 23-37

Holmlund C.M. and Hammer M. (1999) Ecosystem services generated by fish populations. Ecological Economics 29: 253-268

Kaiser M.J., Ramsay K., Richardson C.A., Spence F.E., Brand A.R. (2000) Chronic fishing disturbance has changed shelf sea benthic community structure. Journal Of Animal Ecology 69 (3): 494-503

Koslow J.A., Boehlert G.W., Gordon J.D.M., Haedrich R.L., Lorance P., Parin N. (2000) Continental slope and deep-sea fisheries: implications for a fragile ecosystem. Ices Journal Of Marine Science 57 (3): 548-557

Jennings S., Pinnegar J.K., Polunin N.V.C., Warr K.J. (2001a) Impacts of trawling disturbance on the trophic structure of benthic invertebrate communities. Marine Ecology Progress Series 213: 127-142

Jennings S., Dinmore T.A., Duplisea D.E., Warr K.J., Lancaster J.E. (2001b) Trawling disturbance can modify benthic production processes. Journal of Animal Ecology 70 (3): 459-475

Jennings, S., Nicholson, M.D., Dinmore, T.A. and Lancaster, J.E. (2002) "Effects of chronic trawling disturbance on the production of infaunal communities." *Marine Ecology Progress Series* 243:251-260

Ledoux, L., and Turner, R.K. (2002) "Valuing ocean and coastal resources: a review of practical examples and issues for further action." Ocean and Coastal Management 45:583-616.

Moberg F. and Folke C. (1999) Ecological goods and services of coral reef ecosystems. Ecological Economics 29: 215-233

Murata M., Nakazoe J. (2001) Production and use of marine algae in Japan. Jarq-Japan Agricultural Research Quarterly 35 (4): 281-290

van Netten C., Cann S.A.H., Morley D.R., van Netten J.P (2000). Elemental and radioactive analysis of commercially available seaweed. Science of the Total Environment 255 (1-3): 169-175

Parker, A. R., R. C. McPhedran, D. R. McKenzie, L. C. Botten and N. A. Nicorovici (2001) Photonic engineering: Aphrodite's iridescence. Nature 409: 36-37

P.C.M.E.A.E.F. (2000) Promotion of Common Methods for Economic Assessment of EU Fisheries. Economic performance of selected European fishing fleets. Annual report. ISBN 90-5242-624-4

Pearce D. and Moran D. (1994) The economic value of biodiversity. Earthscan Publications Ltd.

Pearce D.W. and Turner R.K. (1990) Economics of natural resources and the environment. Harvester Wheatsheaf

Pimentel D., Wilson C., McCullum C., Huang R., Dwen P., Flack J., Tran Q., Saltman T., Cliff B. (1997) Economic and environmental benefits of biodiversity. Bioscience 47 (11): 747-757

Rijnsdorp A.D., Buys A.M., Storbeck F., Visser E.G. (1998) Micro-scale distribution of beam trawl effort in the southern North Sea between 1993 and 1996 in relation to the trawling frequency of the sea bed and the impact on benthic organisms. Ices Journal Of Marine Science 55 (3): 403-419

Ross I.M. and Wyeth P. 1997 Sharp concepts, or just another boring bivalve? http://www.rdg.ac.uk/biomim/97ross.htm Centre for Biomimetics, The University of Reading

Schratzberger M., Dinmore T.A., Jennings S. (2002) Impacts of trawling on the diversity, biomass and structure of meiofauna assemblages. Marine Biology 140: 83-93

Simpson, R.D., Sedjo R.A., Reid J.W. (1996) Valuing biodiversity for use in pharmaceutical research. Journal of Political Economy 104 (1): 163-185

Sparks-McConkey P.J. and Watling L. (2001) Effects on the ecological integrity of a soft-bottom habitat from a trawling disturbance. Hydrobiologia 456: 73-85

Thrush S.F. and Dayton P.K. (2002) Disturbance to marine benthic habitats by trawling and dredging: Implications for marine biodiversity. Annual Review of Ecology and Systematics 33: 449-473

Walsh RG, Loomis JB, Gillman RA (1984) Valuing option, existence, and bequest demands for wilderness. Land Economics 60 (1): 14-29

Wang W.X., Stupakoff I., Fisher N.S. (1999) Bioavailability of dissolved and sediment-bound metals to a marine deposit-feeding polychaete. Marine Ecology-Progress Series 178: 281-293

Wassmann P. (1998) Retention versus export food chains: processes controlling sinking loss from marine pelagic systems. Hydrobiologia 363: 29-57

Watling L. and Norse E.A. (1998) Disturbance of the seabed by mobile fishing gear: A comparison to forest clear cutting. Conservation Biology 12 (6): 1180-1197