SYSTEMIC INSIGHTS INTO THE MANAGEMENT OF ECOSYSTEM SERVICES IN THE MARINE ENVIRONMENT

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ABSTRACT

This paper centres on the application of The Ecosystem Approach in the management of the marine environment, involving the identification of multi-stakeholder needs and uses of ecosystem services. The Ecosystem Approach provides 'a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way', while ecosystem services are 'the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life'. Ever increasing and diverse use of the marine environment is leading to human-induced changes in marine-life, making necessary the development of a marine policy formation process that recognises and takes into consideration the full range of stakeholders and results in policy that addresses current, multiple, interacting uses (e.g. the EU's Maritime Policy and Marine Strategy Framework Directive). Taking a systemic approach, incorporating an understanding of marine ecosystem structure and functioning, we identify the diversity of stakeholders and their uses of the marine environment within the framework of ecosystem services (production, regulation, cultural and over-arching support services). Informed by the DPSIR (Drivers – Pressures - State Change – Impact - Response) approach - a framework for assessing the causes, consequences and responses to change – we assess the outcomes of competing human uses and emerging pressures on the marine environment, the complexity of decision making in this area, and provide a process for informing choices in conflict resolution involving a diversity of stakeholders. Case studies include the management of (i) marine aggregates extraction in UK waters and (ii) coastal biodiversity at Flamborough Head, UK.

INTRODUCTION

The increasing and diverse uses of the marine environment have produced human-induced changes in marine life, habitats and landscapes. We need to understand and evaluate these current multiple and interacting human uses to inform emerging over-arching marine policy which will guide the strategies, regulations and policies that will shape the future use of the marine environment. The Ecosystem Approach, the DPSIR (Drivers – Pressures - State Change – Impact - Response) modelling framework, and the emerging concept of ecosystem services provide an integrated methodology for developing such an understanding and a basis for an ecological and socio-economic evaluation. This exemplifies a systems approach given the multiple perspectives that it embraces.

The paper commences with an introduction to the concepts and / or frameworks of The Ecosystem Approach, DPSIR and ecosystem services, and develops an integrated methodology founded on these to allow case study analysis of multi-stakeholder perspectives. The novelty in the methodology, when compared to the existing literature, is a re-interpretation of the DPSIR modelling framework giving due attention to system boundaries. Application is made to two contrasting case studies: the first relates to the management of marine aggregates extraction in UK waters and, therefore, centres on a particular sector, while the second is non-sectoral in its focus on coastal biodiversity at Flamborough Head. Both case studies raise issues relating to the boundary of the system, and provide the opportunity to explore key elements of stakeholder perspectives in these specific contexts.

LITERATURE AND METHODOLOGY: THE ECOSYSTEM APPROACH, DPSIR AND ECOSYSTEM SERVICES

2.1 The Ecosystem Approach

At its most comprehensive, the concept of The Ecosystem Approach has been defined by The Convention for Biological Diversity (CBD, 2000) as:

‘a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. The application of the Ecosystem Approach will help to reach a balance of the three objectives of the Convention: conservation, sustainable use and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources’.

The Convention indicates that the implementation of The Ecosystems Approach should be based on 12 guiding principles for the achievement of sustainable management, as outlined in Box 1. It is notable that given the order proposed by the CBD, ecology is first mentioned at number 5.

Box 1: The twelve principles of the Ecosystem Approach (CBD, 2000).

1. The objectives of management of land, water and living resources are a matter of societal choices.
2. Management should be decentralised to the lowest appropriate level.
3. Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.
4. Recognising potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should: a) Reduce those market distortions that adversely affect biological diversity; b) Align incentives to promote biodiversity conservation and sustainable use; c) Internalise costs and benefits in the given ecosystem to the extent feasible.
5. Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.
6. Ecosystem must be managed within the limits of their functioning.
7. The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.
8. Recognising the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term.
9. Management must recognise that change is inevitable.
10. The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.
11. The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.
12. The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

With respect to this paper, the most important feature of the approach is the linking of natural aspects with the consideration and management of human activities. The Ecosystem Approach can be regarded as a philosophy for summarising the means by which the natural functioning and structure of an ecosystem can be protected and maintained while still allowing and delivering sustainable use and development by society (Elliott et al., 2006). Thus, the approach also requires an understanding of the way in which society manages the exploitation of nature and the adverse effects of its activities, including mitigation and / or compensation.

The term 'The Ecosystem Approach' now appears in many management and policy documents. For example, in the European context Article 1(3) of the European Commission's recent Marine Strategy Framework Directive (MSFD) states that:

'Marine strategies shall apply an ecosystem-based approach to the management of human activities, ensuring that the collective pressure of such activities is kept within levels compatible with the achievement of good environmental status and that the capacity of marine ecosystems to respond to human-induced changes is not compromised, while enabling the sustainable use of marine goods and services by present and future generations' (European Commission, 2008).

Further examples can be found in other EC Directives, OSPAR, and nature conservation reports (see: Pope & Symes, 2000a; 2000b; Laffoley et al., 2004; ICES, 2005).

2.2 The DPSIR Modelling Framework

The DPSIR approach, adopted by the European Environment Agency and others (EEA, 1999; Elliott, 2002; Gray & Elliott, 2009), describes a framework for assessing the causes, consequences and responses to change in a holistic way. In the context of the marine environment, the over-arching 'Drivers' of social and economic development change refers to the need for food, recreation, space for living, and other basic human needs (Gray & Elliott, 2009) which are delivered through fisheries, recreational sites, bioremediation of waste, and so forth. Each of these Drivers creates several or many particular 'Pressures' on the system, such as the exploitation of fisheries, removal of the seabed, demands for the conservation of coastal amenity and marine biodiversity, and the discharge of contaminated waters. As a result, the 'State' of the system (e.g. the benthos or the water column) is changed and undergoes 'Impacts' on society (e.g. degraded habitats, removal of species, loss of biodiversity, etc). Finally, there is need to identify the societal 'Response' to these changes in the marine system. The human responses have to meet 'the seven tenets for environmental management', these are that our actions have to be: environmentally/ecologically sustainable; technologically feasible; economically viable; socially desirable/tolerable; legally permissible; administratively achievable; and politically expedient (Gray & Elliott, 2009). Hence these aspects include aspects of governance (law, administration and politics), socio-economic demands and the ability to change and manage the system through mitigation and compensation technologies (McLusky & Elliott, 2004; Mee et al., 2008; Gray & Elliott, 2009). Figure 1 illustrates the DPSIR framework in this standard form, including feedback loops between 'Responses' and 'Drivers' and 'Pressures', and recognition that there are natural pressures (based on ecology, climate, and other dynamic conditions) on the ecosystem which can lead to 'State change'. Note that pressures on the system can be locally / regionally / internationally managed pressures (power generation, fisheries, etc.) or exogenic unmanaged pressures (climate change, volcanic eruptions, etc.). In the case of the latter and in contrast to the former, their complexity is such that we do not yet have sufficient knowledge of how and why change occurs in such systems and so our response is not management of the pressure but of the consequences of that pressure.

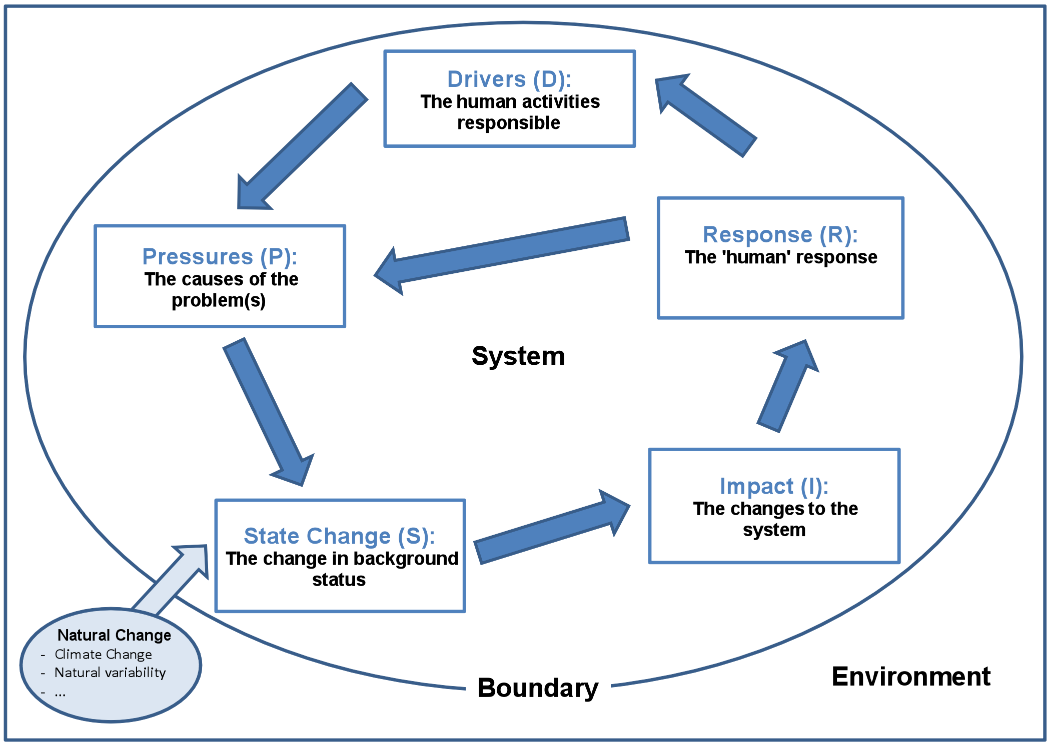

Figure 1: A system model for the management of ecosystem services in the marine environment

The focus of the DPSIR modelling framework is a complex adaptive system as defined by Buckley (1967), Holland (1992) and others. It is formed through the interconnection between natural systems (terrestrial, estuarine, coastal, oceans), designed systems (extractive industries, tourism, transportation, power generation, etc.) and social systems (fishing communities, etc). The modelling framework must take cognizance of the essential features of the systems and its complexity, and also seek to match its variety. While one might attempt to model, for example, management of a fishery using a single DPSIR narrowly or discretely bounded for that particular sector, to be consistent with The Ecosystems Approach such a 'marine fishery's DPSIR' is nested within a set of DPSIRs that encompass many sectors (i.e. marine aggregates, energy generation, aquaculture and so forth), with complex and non-linear linkages and feedback loops between parts of the whole. Most notably, the responses to one set of Drivers and

Pressures can affect others. For example, Responses to over fishing, by curtailing fisheries, will impact on aquaculture. Recognition of this complexity requires clarity and a critical perspective on how we are defining the boundary of the system being modelled as this has implications for what is being included.

In essence, individual elements of the DPSIR approach must be considered to have multiple interactions. In its most general form, each element of the DPSIR for the whole ecosystem can be represented as an order-five tensor; one dimension for each of Drivers, Pressures, State changes, Impacts and Responses, and with individual components within such a five-dimensional array being the outcome of a relationship and / or taking a value which might be positive, negative or zero. For example, while the Drivers may comprise a vector of basic human needs, from the viewpoint of modelling linkages and feedback loops inherent in this complex adaptive system, it should be depicted by an order-five tensor Dd,p,s,i,r where d denotes 1 ... u drivers; p denotes 1 ... v pressures; s denotes 1 ... w state changes; i denotes 1 ... y impacts; and r denotes 1 ... z responses. Allowance will also be needed for the influence of 'natural change' as identified above.

2.3 Ecosystem Services

Ecosystem services have been defined as the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life (Daily, 1997). As is evident in the earlier quotation (see Section 2.1) taken from the EU's MSFD on The Ecosystem Approach (European Commission, 2008), the importance of ecosystem services is now being recognised by policy makers. In the UK, the Government Department Defra (2007a) refer to ecosystem services as 'the wide range of valuable benefits that a healthy natural environment provides for people, either directly or indirectly' (p. 7), and suggests these services 'are not generally considered within policy appraisal at present and represent an area where a greater and more systematic focus would be very useful' (p. 3). The focus on privileging human interests above others, for example the ecological, may be regarded as problematic if a more holistic perspective is adopted. There is no single agreed way of describing ecosystem services, but the most widely recognised framework is that of the Millennium Ecosystem Assessment which identifies four categories of ecosystem services: provisioning services, regulating services, cultural services and supporting services (MEA, 2005). These ecosystem services in turn provide a range of benefits that support human health, wellbeing and prosperity.

Beaumont et al. (2007), informed by De Groot et al. (2002) and others, refers to ecosystem goods and services as 'the direct and indirect benefits people obtain from ecosystems' (p. 254). Ecosystem goods are distinguished from services in representing the 'materials produced' that are obtained from natural systems for human use. In the context of identifying, defining and quantifying goods and services provided by marine biodiversity alone, Beaumont et al. introduce a further category to those of the Millennium Ecosystem Assessment. Thus, the assessment framework comprises:

1. **Production services**, which involve products and services obtained from the ecosystem;
2. **Regulating services**, which are the benefits obtained from the regulation of ecosystem processes;
3. **Cultural services**, which are the non-material benefits people obtain from ecosystems;
4. **Option use values**, which are associated with safeguarding the option to use the ecosystem in an uncertain future; and
5. **Supporting services**, which are those that are necessary for the production of all other ecosystem services, but do not yield direct benefits to humans.

In the wider context relevant to the current paper, Table 1 places 17 different types of ecosystem services (or goods and services) derived from the marine environment into the five broad groups.

Table 1: Ecosystem services provided by the marine environment (adapted from Beaumont et al., 2007).

Category	**Ecosystem Services**
Production services	**Food provision** - extraction of estuarine/marine organisms for human consumption.
	Raw materials - extraction of minerals and organisms not for human consumption.
	Transport and navigation – use of waterways for shipping.
	Energy – non-consumptive use of the estuarine/marine environment for energy generation e.g. wave and tidal power.
	Residential and industrial water supply – abstraction of water for residential and industrial purposes.

Regulation services	**Gas and climate regulation** - balance and maintenance of the atmosphere.
	Disturbance prevention - flood and storm protection by biogenic structures.
	Bioremediation of waste - removal of pollutants by storage, burial and recycling.
Cultural services	**Cultural heritage and identity** - value associated with the estuarine/marine environment itself.
	Cognitive values - education and research resulting from the estuarine/marine environment.
	Leisure and recreation - refreshment and stimulation of the human body and mind through the perusal and study of, and engagement with, the estuarine/marine environment.
	Feel good or warm glow - value derived from the estuarine/marine environment without using it.
Option use values	**Future unknown or speculative benefits** - currently unknown future uses of the estuarine/marine environment.
Over-arching support services	**Resilience and resistance** - environmental life support by the estuarine/marine environment.
	Biologically mediated habitat - habitat provided by living estuarine/marine organisms.
	Physical habitat – habitat provided by the physical (non-living) environment
	Nutrient cycling – the storage, cycling and maintenance of nutrients by estuarine/marine environment.

In a further extension to the Millennium Ecosystem Assessment (MEA, 2005), drawing on Boyd and Banzhaf (2007) and others, Fisher et al. (2009) proposes that ecosystem services 'are the aspects of ecosystems utilised (actively or passively) to produce human wellbeing' (p. 645), hence consistent with the anthropocentric emphases. It is argued that, typically, the benefits that are secured from an ecosystem for human health, well-being and prosperity require the use of other forms of capital to combine with ecosystem services – for example, marine energy will require built capital (turbines) to harness the wind, tidal or wave power, while some forms of marine-based recreation (e.g. sailing) require physical and human capital to capture benefits. This suggests that ecosystem services are 'the link between ecosystems and things that humans benefit from, not the benefits themselves' (Luisetti et al., 2010, p. 5) and are ecological phenomena encompassing both ecosystem organisation or structure, which are the classes of the ecosystem (such as terrestrial, estuaries, coastal areas and the open sea), and ecosystem processes and functions, which are the time-dependent ways in which the ecosystem operates. According to Fisher et al., the distinction between ecosystem processes (a service that comes from other factors than the ecosystem itself) and ecosystem functions (the result of ecosystem process) leads to a generic classification based around intermediate services associated with indirect benefits, and final services associated with direct benefits. This approach avoids any potential for double counting of benefits, where there is competition and/or complementarities between ecosystem services, which is particularly important when it comes to (physical, monetary or other) evaluation. However, this distinction between processes and functions is inconsistent with ecosystem theory where the two are considered synonymous (e.g. Loreau et al., 2002).

Fisher et al.'s approach, adapted here for consistency with the ecosystem services identified in Table 1, is presented in Figure 2. For ease of presentation, only one ecosystem class (marine) is illustrated in this table, with its associated services and benefits defined; further ecosystem classes could be identified - such as coastal, estuarine and terrestrial – and each would imply a distinct although overlapping set of intermediate and final services and benefits. In addition, further disaggregation of the benefits is feasible – for example, food provision comprises fish, shellfish, algae, sea salt etc.

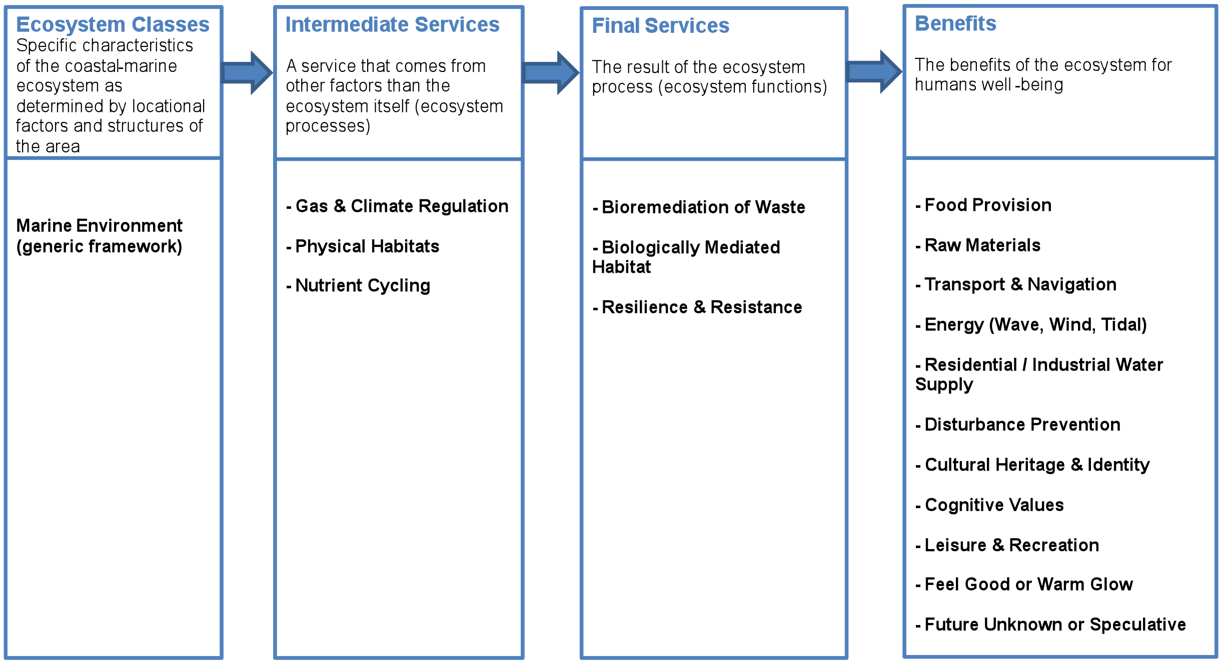

Figure 2: The separation of marine ecosystem processes and functions in intermediate and final services and the ecosystem service benefits (adapted from Fisher et al., 2009)

Ecosystem services evaluation has the potential to complement the DPSIR modelling, as discussed above, by providing a comprehensive basis for identifying and assessing the intermediate and final services and benefits provided by the ecosystem and the consequences of endogenic and exogenic pressures on the ecosystem. The breakdown of the ecosystem services in this comprehensive way clarifies the specific interests of agents with stakes in the ecosystem, provides a basis for exploring the legitimacy of these relationships and, in conjunction with monetary valuation, provides the basis for an assessment of their relative importance. The notion of stakeholders may refer to individuals, households, business organisations, government, and/or other societal/civil groups and communities. Additionally, stakeholders may be local, regional, national, or international/global depending on the specific characteristics of the ecosystem service in question. For example, the marine environment provides for bioremediation of waste which has direct implications for the waste management of water companies and other businesses who may derive benefits from such a regulation service at the local level while, at the same time, that same use may have implications for stakeholders with interests in recreation and tourism at the local and regional level, and in the conservation of marine biodiversity at the local through to the international level, depending on the particular site characteristics.

2.4 Evaluation of Ecosystem Services

Definition of Measures

Society attaches value to ecosystem services. Where the services are marketable, their market price may reflect their social worth. However, for many services it is evident that either market prices do not reflect society's true valuation or markets do not actually exist and the services are provided at a price of zero which, again, is not a reflection of their true social worth – both are instances of market failure. Given such circumstances, a range of methodologies is available to assess more accurately the values that society places on these benefits. These methodologies include: market analysis, productivity gains and losses, production function analysis, hedonic pricing, the travel cost method, contingent valuation, the choice experiment method, damage costs avoided, defensive expenditures, relocation costs, replacement/substitution costs, and restoration costs (see: Turner et al., 2001; Birol et al., 2006; Beaumont et al., 2008; Turner et al., 2010). These are explained further in Table 2 below with examples as they relate to the marine environment.

Table 2: Economic valuation methods and examples of their application in the marine environment

Economic Valuation Method	Description	Marine example
Market Analysis (MA)	Where market prices of outputs (and inputs) are available. Marginal productivity net of human effort/cost. Could approximate with market price of close substitute. May require shadow pricing where prices do not reflect social valuations.	Deriving the social and economic value of shellfish, such as oysters, from market prices.
Productivity Gains and Losses (PGL)	Change in net return from marketed goods: a form of (dose-response) market analysis.	Improvements in water quality leading to reduced purification requirements following shellfish harvesting which would be reflected in higher net returns.

Economic Valuation Method	Description	Marine example
Production Function Analysis (PFA)	An ecosystem good or service treated as one input into the production of other goods: based on ecological linkages and market analysis.	The use of wetlands as fish nursery areas for species which eventually become commercial catches.
Hedonic Pricing (HP)	Derive an implicit price for an environmental good from analysis of goods for which markets exist and which incorporate particular environmental characteristics.	House prices are determined by the characteristics of the houses, including environmental features such as their proximity to marine leisure facilities.
Travel Cost Method (TCM)	Cost incurred in reaching a recreation site as a proxy for the value of recreation. Expenses differ between sites (or for the same site over time) with different environmental attributes.	The costs borne by visitors to bird watching sites may be interpreted as the minimum value they attached to that site.
Contingent Valuation Method (CVM)	Construction of a hypothetical market by direct surveying of a sample of individuals and aggregation to encompass the relevant population. Problems of potential bias.	The public might be asked to value a hypothetical environmental improvement, such as increased biodiversity.
Cost-of-Illness (COI)	The benefits of pollution reduction are measured by estimating the possible savings in direct out-of-pocket expenses resulting from illness and opportunity costs.	Loss of earnings due to illness caused by poor water quality.
Choice Experiment Method (CEM)	Discrete choice model which assumes the respondent has perfect discrimination capability. Uses experiments to reveal factors that influence choice.	Can be used to investigate preference trade-offs involving security of water supply and biodiversity.

Economic Valuation Method	**Description**	**Marine example**
Damage Avoidance Costs (DAC)	The costs that would be incurred if the ecosystem good or service were not present.	A saltmarsh provides a natural form of flood prevention.
Defensive Expenditure Costs (DEC)	Costs incurred in mitigating the effects of reduced environmental quality. Represents a minimum value for the environmental function.	The cost of cooling water ponds to mitigate cooling water discharge effects.
Net Factor Income (NFI)	Estimates changes in producer surplus by subtracting the costs of other inputs in production from total revenue, and ascribes the remaining surplus as the value of the environmental input.	The economic benefits of improved water quality can be measured by the increased revenues from greater aquaculture productivity when water quality is improved.
Relocation Costs (RLC)	Expenditures involved in the relocation of affected agents or facilities: a particular form of defensive expenditure.	The costs of relocating activity following managed realignment or marine-based wind farms.
Replacement / Substitution costs (R/SC)	Potential expenditures incurred in replacing the function that is lost; for instance by the use of substitute facilities or 'shadow projects'.	The costs associated with the creation of intertidal habitat to compensate for habitat lost following industrial development.
Restoration costs (RC)	Costs of returning the degraded ecosystem to its original state. A total value approach; important ecological, temporal and cultural dimensions.	The costs of rehabilitating an affected/degraded wetland.

Table 3, which is adapted from Birol et al. (2006), identifies the different valuation procedures available to assess the monetary value of ecosystem services to society. While these different methodologies may imply the collection of primary economic evidence, such evidence can be costly to collect both in terms of time and resources. The transfer of values obtained in different studies conducted in other locations may offer some advantage in this respect; although it has problems if not used correctly e.g. if sites are not similar in character.

Table 3: Economic valuation methods for marine ecosystem benefits.

Category	Ecosystem services	Economic valuation methods*
Intermediate services	Gas and climate regulation	PFA, RC, DAC, PGL, DEC
	Physical habitat	CVM, CEM
	Nutrient cycling	RC, COI
Final services	Bioremediation of waste	RC, COI, DAC
	Biologically mediated habitat	CVM, CEM
	Resilience and resistance	PFA, RC, DAC, PGL
Benefits	Food provision	MA
	Raw materials	MA
	Transport and navigation	MA
	Energy	MA
	Residential and industrial water supply	PFA, NFI, RC, MA, PGL
	Disturbance prevention	PFA, RC, MA, DAC, PGL, DEC
	Cultural heritage and identity	CVM, CEM
	Cognitive values	CVM, CEM
	Leisure and recreation	TCM, HP, CVM, CEM
	Feel good or warm glow	CVM, CEM
	Future unknown or speculative benefits	CVM, CEM

*Acronyms refer to: Production Function Analysis (PFA), Net Factor Income (NFI), Replacement/Substitution Cost (R/SC), Market Analysis (MA), Cost-of-Illness (COI), Travel Cost Method (TCM), Hedonic Pricing (HP), Contingent Valuation Method (CVM), Choice Experiment Method (CEM), Damage Avoidance Costs (DAC), Productivity Gains and Losses (PGL), Defensive Expenditure Costs (DEC).

The Evaluation Process

On the basis of this integrated methodology, an evaluation of ecosystem services comprises a number of steps and can be demanding in terms of its data requirements. Following Defra (2007a), Figure 3 contains a generic five stage procedure for policy evaluation together with its data requirements. After an initial assessment of the biological and physical environment, a list of ecosystem services provided by the environment in question can be established (Step 1). The potential impact on these ecosystem services can be assessed qualitatively (Step 2), and then quantitatively for those services considered to be of greatest importance (Step 3). This assessment of ecosystem services can be undertaken for a range of policy options, at different spatial and temporal scales. The effects on human welfare can then be assessed as a result of changes in ecosystem services and the benefits that we derive from these services (Step 4). Finally, any observed changes in ecosystem services can be valued using a range of economic valuation techniques (Step 5).

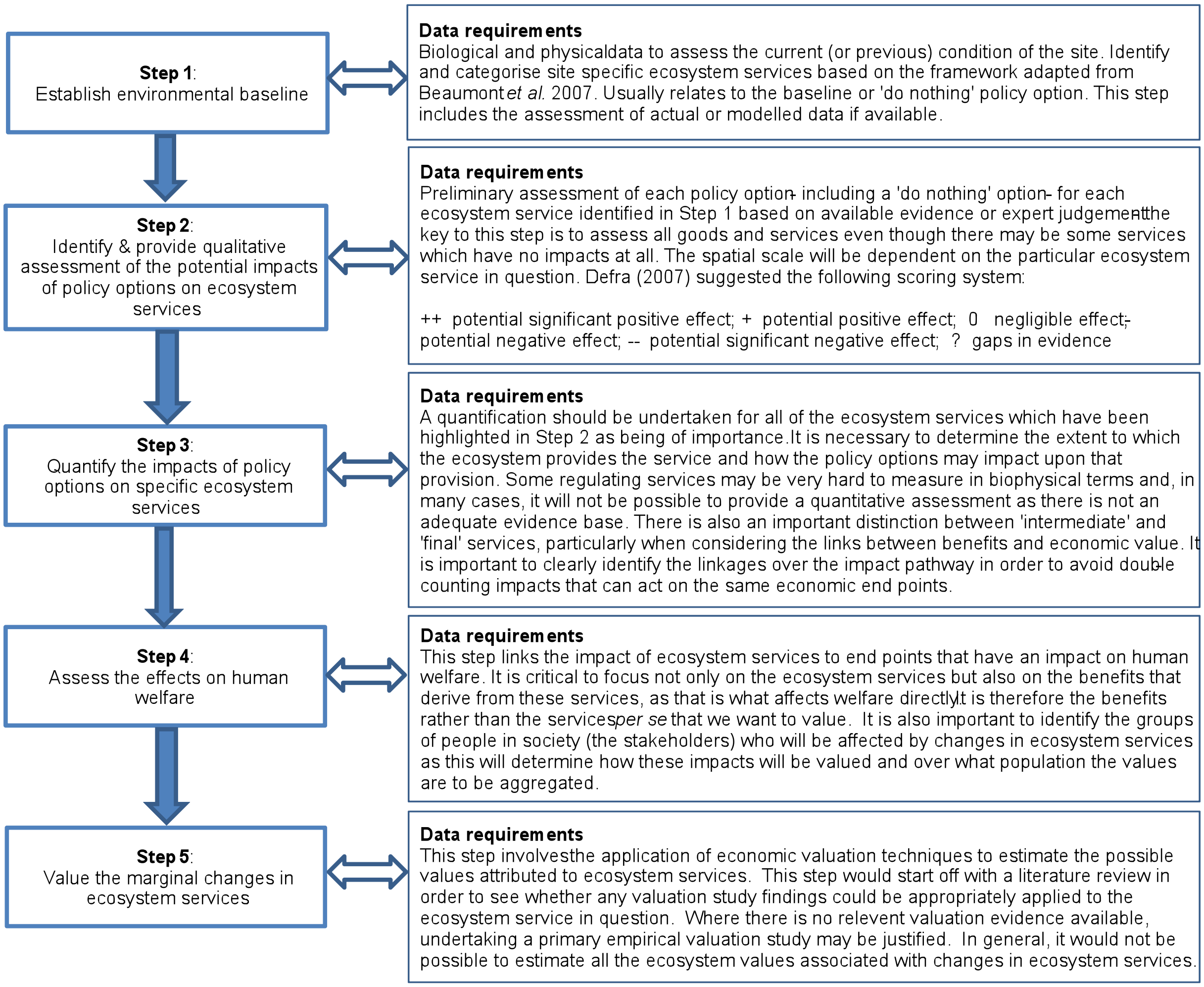

Figure 3: Evaluation of policy options using an ecosystem services approach (adapted from Defra, 2007a)

CASE STUDIES

3.1 The management of marine aggregates extraction in UK waters

The first case study demonstrates the application of the DPSIR modelling framework and the importance of identifying ecosystem services in the management of the marine aggregate (sands and gravels) extraction industry in the UK. The multi-user needs and uses of the ecosystem services of the UK marine environment provides the context for the application of the DPSIR modelling framework, as outlined above, which can be used to highlight the main system components relevant to the aggregate extraction activity and an assessment of management options. Given that in some places, dredging companies operate in close proximity to those undertaking other activities, such as commercial shipping and leisure sailing, port operations, fishing, and offshore energy, and may preclude future developments such as seabed pipelines, this can result in the potential for spatial conflict between activities (BMAPA, 2010). These competing activities all imply the potential for the development of alternative DPSIR models and the need to be critical in the definition of what is included within and what is assigned to the environment by the system boundary. The DPSIR framework will be applied to identify the main system components which may be affected by aggregate extraction and an assessment will be made of potential changes in ecosystem services before and after dredging operations have taken place. Finally, this case study will investigate the potential changes in ecosystem services as a result of multiple seabed restoration options, following the approach outlined in Figure 3.

Following Figure 4, Drivers and Pressures are mainly associated with obtaining aggregate to supplement land-based sources for the construction industry, in addition to being used for beach nourishment projects and coastal defence works (Cooper et al., 2008). In the UK, marine aggregate extraction has taken place since the early 1960s, with extraction levels peaking in the late 1980s, and extraction levels being relatively stable since that period (Austen et al., 2009). Within UK waters, there are nine main aggregate extraction areas, 79 production licences, with a total production of just under 21 million tonnes of aggregate in 2009 (The Crown Estate, 2010).

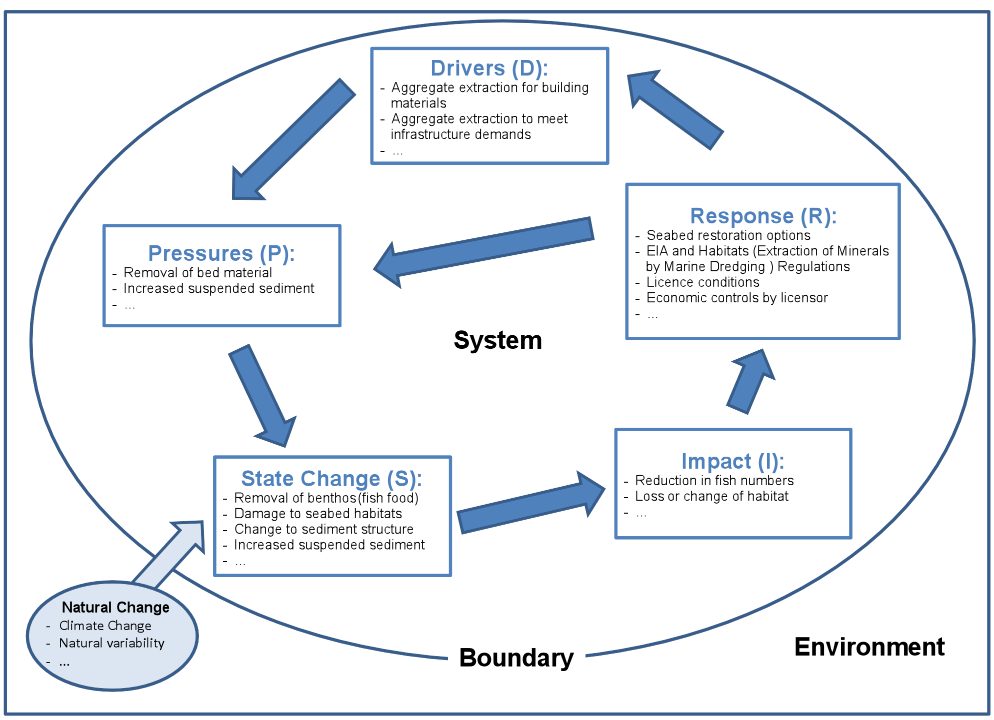

Figure 4: The DPSIR approach for the management of aggregate extraction in UK waters.

There is a growing literature assessing the State Changes associated with marine aggregate extraction. This literature has examined, for example, the benthos (Boyd et al., 2003; Boyd et al., 2005; Cooper et al., 2008; Ware et al., 2009), fish populations (Stelzenmüller et al., 2010) and habitats (Erftemeijer & Lewis, 2006). In general, environmental State Changes involve both the physical systems (e.g. the changes to particle size on the seabed, increased water column turbidity, etc) and the biological systems (e.g. removal of benthos and the subsequent impact on availability of food for fish populations, etc). While marine life is inevitably affected by dredging, evidence suggests that the principal effects are confined to the actual dredging area, are generally short-lived and represent no long-term influence on biodiversity (BMAPA, 2010). By their nature, aggregate areas are mobile, high energy sites with moderately sparse biota which is adapted to sediment disturbance.

There is very little literature evaluating ecosystem services with respect to the marine aggregate industry, and this is at the site-specific level. An example is Austen et al. (2009) where the focus is on aggregate extraction sites located within the Eastern English Channel Marine Natural Area (ECMNA), UK. This study identifies and then quantifies the impacts of the marine aggregate extraction industry on the economic value of ecosystem services following Beaumont et al. (2007) and notes systemic issues. This area is identified as one of the principle sources of aggregate supply in the UK, landing 6.7 million tonnes (29% of the UK supply) in 2007. However, the study reports for example, that crab landings in the ECMNA were valued at £1.9 million in 2003 but observed a decline in crab populations within the aggregate extraction areas, when compared with adjacent ports. Austen et al. note that crabs are known to lay eggs in ecosystems comprising sands and gravels and therefore this raises issues for the management of the marine aggregates sector. Other ecosystem service contributions within the ECMNA that are valued include leisure and recreation such as sea angling and seaside day trips (£1,096 million), food provision including both fish and shellfish landings (£10.5 million) and regulation of gases and climate (£1.4 million - £6.6 million).

Turning to Response, in the UK the seabed is owned by the Crown Estate, which has responsibility for managing dredging activities, and adopts a licence scheme for this purpose. The seabed is also subject to both national and EU regulation; Environmental Impact Assessments (EIAs) and Habitats (Extraction of Minerals by Marine Dredging) Regulations form part of the regulatory regime, and mitigating strategies are proposed to counteract any potential impact from the activities. Conditions on each licence are site-specific and can cover issues such as boundaries of extraction areas, extraction rates, how the seabed must be left at the cessation of dredging and the precise environmental attributes that must be monitored before, during and after dredging (Defra, 2002; 2007b). Each individual licence also requires an indication of the social need and economic costs and benefits of marine aggregate use. For post-dredging sites Bellew and Drabble (2004) suggest five potential policy options: 1) non-intervention, allowing natural recovery, 2) exclusion of other users to increase the rate of recovery, 3) conservation of the altered habitat, 4) restoration, in order to return the area to its pre-dredge condition, and 5) habitat creation/enhancement. For each of these restoration options it is important to identify and quantify the ecosystem services in the marine environment before the dredging took place, to understand how the dredging affects these and to assess the potential for restoration options to restore the services back to their original state.

3.2 The management of coastal biodiversity at Flamborough Head, UK

The second case study examines the application of the methodology to the management of biodiversity at Flamborough Head, UK. This coastal site has multi-user characteristics and is also distinctive for being designated as a European Marine Site for its diverse habitats (designated as an SAC under the EU Habitats Directive (92/43/EEC)) and abundant seabird colonies (designated an SPA under the EU Wild Birds Directive (79/409/EEC)) (for further details see Burdon & Atkins, 2007). As with the last case study, defining system boundaries is central to the application of the modelling framework and it contrasts with the last case study as its EU designations restrict permitted activities and influences other management interventions. An assessment of the ecosystem services provided by the marine environment surrounding Flamborough Head will provide insight into the key stakeholders and will highlight potential conflicts between their activities and the integrity of the site.

As a European Marine Site, the UK Habitats Regulations 1994 make provision (under Regulation 34) for Relevant Authorities to establish a management scheme. In 2000, the first management scheme was produced by the Flamborough Head Management Group for the Flamborough Head EMS (Evans, 2000) and highlighted the requirement for integrated management for the site. As part of the Management Scheme, the Flamborough Head Maritime Forum was also established and provides a focus for stakeholder involvement in the management of the Flamborough Head EMS and is open to all stakeholders not present on the Management Group. The Management Scheme was reviewed in 2007, and is now referred to as the Flamborough Head Management Plan (Stockdale, 2007) with the aim to 'ensure that human activities at Flamborough Head are managed in a way that is compatible with the natural assets of Flamborough, and to seek opportunities to improve these assets and the human activities that depend upon them'. Thus the Management Plan plays a central role in determining types and level of activity and other interventions within the Flamborough Head EMS.

The complexity of the management of this protected site is demonstrated conceptually in Figure 5. It recognises the multiple activities undertaken at Flamborough Head through the DPSIR modelling framework of multiple users within the boundary of this system. Importantly, Responses in the DPSIR model are guided by the Management Plan, hence this is depicted centrally within the figure. A number of sectoral activities can be identified at Flamborough Head. These are depicted in Figure 5 by DPSIR models (I, II, III, IV...N) and can be associated with activities such as commercial mixed fisheries, recreational fisheries, leisure activities associated with cultural heritage, bioremediation of waste associated with industrial activity and waste water treatment plants and so forth. The boundary of this system is placed so that these activities are within, while it is recognised that the system will be subject to exogenic natural change. The complexity of this system is reflected by the linkages and feedback loops drawn between the sectors.

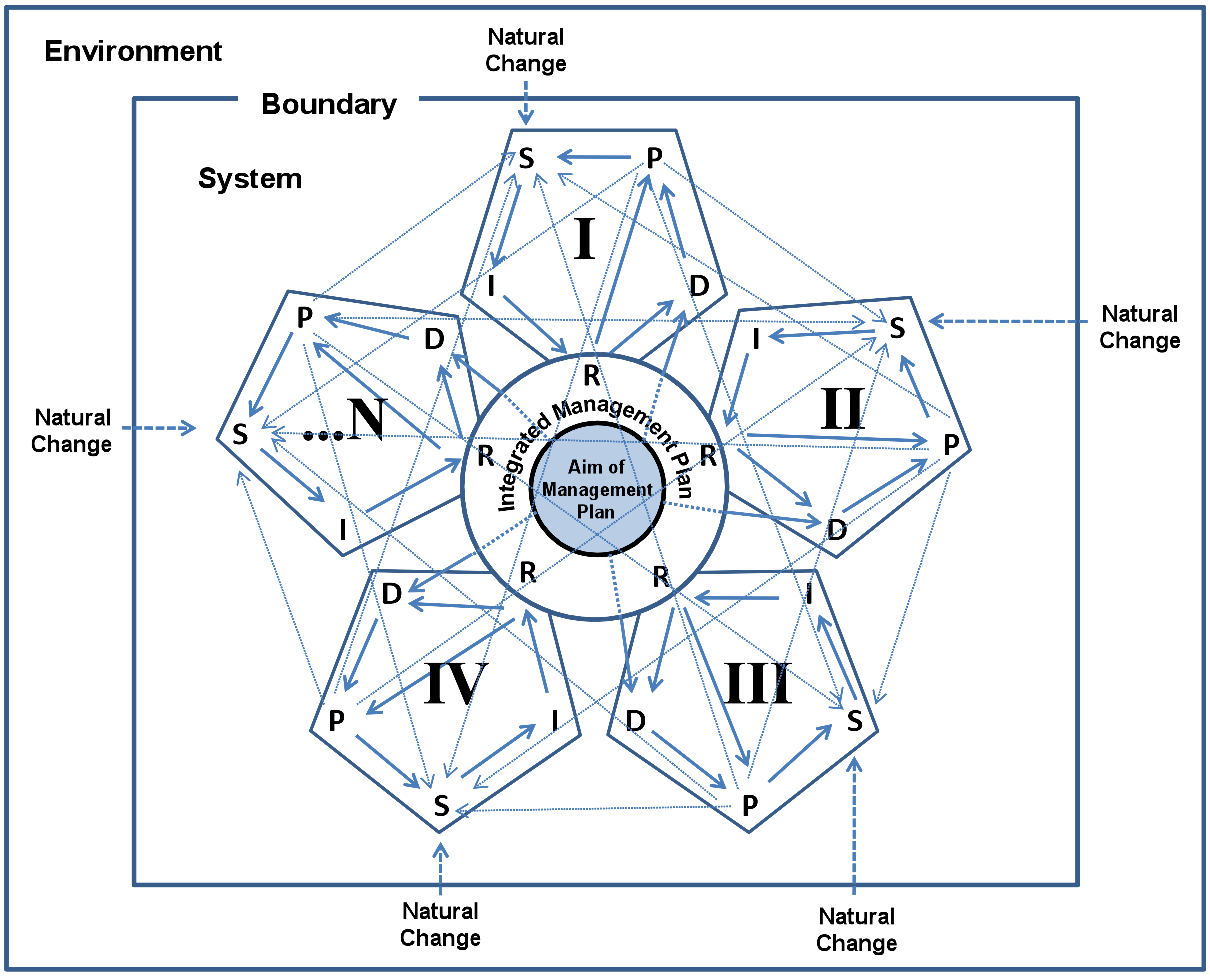

Figure 5: A conceptual model of the management of the marine environment at Flamborough Head, UK.

In the case of Flamborough Head the activities undertaken in response to the Drivers may include for example, fishing, industrial development and the requirement for recreational amenity provided by the site. The coastal waters in and adjacent to the Flamborough EMS support a high level of commercial and recreational fishing activity (Stockdale, 2007) exploiting a mixed fishery through various methods of potting, trawling, netting and lines. Yorkshire Water is responsible for a number of sewage treatment works which are located within the vicinity of the Flamborough Head EMS. In addition, distilling, brewing and food malts for domestic and export markets are produced at Flamborough Maltings, Muntons plc. All of these activities must be managed within the integrated framework of the Flamborough Head Management Plan.

A number of Pressures, resulting from these activities, can be placed upon the system, including the exploitation of fisheries, industrial discharges and the demand for conservation of biodiversity. For example, there are currently 9 inshore vessels (<10m) registered at Flamborough, all with shellfish licences, who exploit populations of European lobster, edible crab, velvet crab and whelks from around Flamborough Head. Yorkshire Water sewage treatment works (STWs) discharge from Flamborough, North Landing, Bempton and Bridlington with Scarborough STW also to the north of the EMS. Yorkshire Water has also installed a long sea outfall at Bridlington. The industrial trade effluent from Flamborough Maltings discharges a maximum of 2,500m^3/day consented for 100 mg/l of suspended solids, 300mg/l of BOD and 10mg/l of ammonia (Cefas discharge consent database, 2000). The outstanding natural features associated with Flamborough Head, in addition to its proximity to the tourist resorts of Flamborough, Bridlington, Scarborough and Filey make it a popular tourist / recreational attraction, with over 56,000 visitors per year (East Riding News, September 2006).

The above mentioned Pressures, in turn can lead to there being State Changes in the environment, for example if not managed correctly commercial fisheries may remove unsustainable levels of fish / shellfish species from the area, trawling activities may damage some of the subtidal habitats, and the industrial effluents may increase the level of pollutants in the water / sediments. State Change can be monitored, for example the Defra landings from the inshore vessels around Flamborough Head for the years 2007-2009 are presented in Table 4.

Table 4: Defra landings returns from ICES sub-rectangle 37E99 (data taken from Thomson et al., 2010).

Landings	2007	2008	2009
European Lobster (Kg)	17,832	23,853	47,853
Edible Crab (Kg)	44,635	34,398	64,527
Velvet Crab (Kg)	4,064	2,901	492
Whelk (Kg)	144	0	0

It must be remembered that although State Changes can be detected, it is more difficult to provide direct evidence of cause and effect relationships given the complexity of competing uses in the marine environment and that there is also natural change in the system which must be taken into account. For example, there is anecdotal evidence of Enteromorpha spp. growth on the intertidal area fronting the organic discharge from Muntons plc however there is no direct evidence of a significant effect.

State Changes in the environment can then lead to Impacts which affect society, for example, a loss of biodiversity and / or habitat may have an impact on the local fish populations which use these services for as a source of food and shelter; a loss in fish populations (e.g. sand eels) may also have a potential impact upon bird numbers at the RSPB Reserve at Bempton Cliffs resulting in fewer wildlife watchers visiting the site; and a reduction in bathing water quality, as a effect of industrial discharges, may result in fewer tourists visiting the beaches around Flamborough Head.

Given the aim of the Flamborough Head Management Plan and its legal status, it provides an integrative basis for managing Pressures and determining Responses associated with the various activities. For example, with respect to commercial fisheries at Flamborough Head, activities are monitored by the North Eastern Sea Fisheries Committee (NESFC) which aims to 'manage, regulate and develop and protect the fisheries...with a view to ensuring the sustainability of the marine environment both now and into the future'. Two projects within the NESFC district are of relevance here as they represent human Responses to Pressures on the system:

- At present there are three Prohibited Trawl Zones (PTZ) designated within the NESFC jurisdiction, located to the North of Whitby, in Filey Bay (off Filey Brigg) and along the Holderness coast (between Hornsea and Spurn Point) (Allen, 2008).

Whilst the primary objectives of the creation of these areas was to protect static gear fisheries and to prevent conflict between mobile and static gear interests they potentially also have wider benefits for marine diversity by contributing to resource management, conservation and habitat enhancement (Thomson et al., 2010).

- In April 2008, it was agreed that an area within the Flamborough Head SAC was to be chosen as an experimental No Take Zone (NTZ) which is to be enforced by the implementation of a Byelaw (currently awaiting approval) (Thomson et al., 2010). The designation of a NTZ adopts the Ecosystem Approach by protecting both the commercial species and their habitat thereby serving as a conservation measure as well as a fisheries management tool. The regulation will therefore protect the interest features of the Flamborough Head SAC and ensure that the NESFC is meeting its statutory duties in accordance with the Conservation (Natural Habitats, &c.) Regulations 1994. The draft objectives for the site include monitoring of species to help inform site management, to allow part of the SAC to return to a more natural state, to use the site as a tool for education and research, to monitor and assess the potential benefits for commercial and recreational fisheries and tourism and to enagae with stakeholders in the devlopment and management of protected areas (Thomson et al., 2010).

Another activity addressed in the Management Plan is water quality. With respect to bathing water quality around Flamborough Head, Yorkshire Water Plc has recently made large scale improvements to sewage treatment works along the Yorkshire coast which exceed the requirements of the EU Bathing Waters Directive 76/160/EEC. Both secondary treatment and UV disinfection facilities have been installed together with the construction of long sea outfalls in an attempt to comply with both the mandatory or Imperative standards and the Guideline standards (Mazik & Elliott, 2003).

The procedures necessary to establish the current site designations have already required the quantification of some elements of the ecosystem services provided. A summary of the ecosystem services identified at Flamborough Head are presented in Table 5.

Table 5: A summary of the ecosystem services provided by the marine environment at Flamborough Head.

Category	Ecosystem services	Description
Intermediate services	Gas and climate regulation	Kelp forests, present between Bempton cliffs and Cattlemere, act as a source and/or sink for $CO2$.
	Physical habitat	The extensive chalk sea cliffs of Flamborough and Bempton provide habitat for many nationally and internationally important breeding populations of seabirds, whilst the waters surrounding the headland contain other important features including littoral and sublittoral reefs, submerged/slightly submerged sea caves, rocky shores, kelp forests and subtidal faunal turf communities.
	Nutrient cycling	The communities found at the north and south cliff, differ noticeably due to the Flamborough Front, which is the boundary of the change in water characteristics between the northern and southern North Sea during the summer. Additional mixing of water masses during this time creates a very productive, nutrient-rich environment.
Final services	Bioremediation of waste	There has been a history of anthropogenic activity in the area e.g. distilling, brewing and food malt production take place at Flamborough Maltings (Muntons plc.) and sewage treatment works discharge from Flamborough, North Landing, Bempton and Bridlington.
	Biologically mediated habitat	Significant kelp forests (Laminaria hyperborea) and forests of Laminaria saccharina with red algal undergrowth in nearshore. Physical habitats include chalk reefs, sea caves and maritime cliff vegetation.

Category	Ecosystem services	Description
	Resilience and resistance	There has been a history of anthropogenic activity in the area. Current site designations would suggest that the area is characterised by a relatively high level of resilience and resistance. This, however, is not understood at present.
Benefits	Food provision	The site supports a high level of commercial and recreational fisheries including trawling, netting, potting and lines in order to exploit the mixed fishery. There is also a developing sea bass fishery in the area using pair trawling techniques.
	Raw materials	Intertidal areas around the headland have historically been subject to the collection of bait and fossils. Bait digging occurs from Sewerby to Flamborough Head, whilst fossil collection takes place at Sewerby and the South Cliffs.
	Transport and navigation	Due to the presence of chalk reefs, obscured outcrops and strong tidal currents Flamborough Head has always been a dangerous place for shipping. In 1806, Trinity House decided to build a lighthouse at Flamborough in order prevent the increasing numbers of wrecks off the coast; this lighthouse is still present at the site today.
	Energy	There is no evidence of energy generation within the marine waters surrounding Flamborough Head however proposed offshore wind farm sites and gas storage facilities are located to the south of the EMS.
	Residential and industrial water supply	Although there is no evidence of water being abstracted for residential and industrial uses, the water within the EMS do receive industrial discharges from Muntons plc and various sewage treatment works.
	Disturbance prevention	Not understood at present.

Category	Ecosystem services	Description
	Cultural heritage and identity	The Heritage Coast covers 19km between Reighton and Sewerby, and covers 3,265ha. Features include Danes Dyke, Flamborough's two lighthouses, the Battle of Flamborough (1779), outstanding natural features and traditional fishing techniques etc.
	Cognitive values	Flamborough Head is an educational resource and is regularly used by schools and universities for education and research, in addition to statutory monitoring which is undertaken by relevant authorities.
	Leisure and recreation	Flamborough is a popular tourist destination, with over 56,000 visitors per year. Recreational activities include angling, bathing, canoeing, walking, bird watching (from both land and sea), rock-pooling, boating and diving.
	Feel good or warm glow	Existence values are considered likely to be positive because of the sites outstanding natural features.
	Future unknown or speculative benefits	Widespread current user values suggest that option use values will be positive.

Valuation of some of these ecosystem services have been undertaken. Burdon and Atkins (2007) have examined public perceptions of and elicited willingness-to-pay valuations for the protection of marine biodiversity through a contingent valuation survey. A sample survey of 222 visitors to the site (there are 56,000 annual visitors) produced a mean willingness-to-pay to conserve marine biodiversity at Flamborough Head, through a one off payment, of £71.91 (std. dev. = £123.41), whilst the median value was £40.00.

ACKNOWLEDGEMENTS

The authors acknowledge the support of the European Commission (Contract Number GOCE-CT-2003-505446) and members of the Marine Biodiversity and Ecosystem Functioning EU Network of Excellence (MarBEF), and the support of the Marine Environment Protection Aggregate Levy Support Fund (Ref: MEPF 09/P115).

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