Marine Pollution Bulletin 62 (2011) 215–226

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Viewpoint

Management of the marine environment: Integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach

Jonathan P. Atkins [a,*], Daryl Burdon [b], Mike Elliott [b], Amanda J. Gregory [c]

[a] Centre for Economic Policy, The Business School, University of Hull, Hull HU6 7RX, UK
[b] Institute of Estuarine and Coastal Studies (IECS), University of Hull, Hull HU6 7RX, UK
[c] Centre for Systems Studies, The Business School, University of Hull, Hull HU6 7RX, UK

ARTICLE INFO

Keywords:
The Ecosystem Approach
DPSIR framework
Ecosystem services and societal benefits
Marine environment

ABSTRACT

Ever increasing and diverse use of the marine environment is leading to human-induced changes in marine life, habitats and landscapes, making necessary the development of marine policy that considers all members of the user community and addresses current, multiple, interacting uses. Taking a systems approach incorporating an understanding of *The Ecosystem Approach*, we integrate the *DPSIR framework* with *ecosystem services and societal benefits*, and the focus this gives allows us to create a specific framework for supporting decision making in the marine environment. Based on a linking of these three concepts, we present a set of basic postulates for the management of the marine environment and emphasise that these postulates should hold for marine management to be achieved. We illustrate these concepts using two case studies: the management of marine aggregates extraction in UK waters and the management of marine biodiversity at Flamborough Head, UK.

1. Introduction

Ever increasing and diverse use of the marine environment is leading to human-induced changes in marine life, habitats and landscapes, making necessary the development of marine policy that recognises and takes into consideration all members of the user community and addresses current, multiple, interacting uses. The marine environment can be perceived to be a system formed through the interconnection between natural systems on several scales (terrestrial, freshwater, estuarine, coastal and oceanic), designed systems (such as extractive industries, tourism, transportation, and power generation) and social systems (environmental activist groups, fishing communities, etc.). A holistic approach is therefore needed to gain an understanding of the connections that exist within and between these elements of the marine environment, and to support policy makers in their decision making. This is consistent with The Ecosystem Approach *sensu stricto* which aims to balance the needs of both the ecological and human aspects of the ecosystem (see below).

The DPSIR (*Drivers–Pressures–State Change–Impact–Response*) framework has developed as a systems-based approach which captures key relationships between society and the environment, and is regarded as a philosophy for structuring and communicating policy-relevant research about the environment. In essence, after being developed from an OECD approach which aimed to link pressures (created by human demands of the system) with the state changes and impacts, the systemic DPSIR framework encompasses *Drivers*, which are the key demands by society and creates *Pressures*, and recognises that *State Changes* and *Impacts* then require a *Response* by society. Fundamental to the DPSIR framework is the definition of the boundary of the system it describes, the demarcation of which depends on the particular issue of interest and its conceptualisation (Svarstad et al., 2008).

In this paper, we argue that the limits for marine management requires the coupling of the emerging concepts of DPSIR, The Ecosystem Approach and ecosystem services and the societal benefits emanating from those services. Integrating these concepts provides an opportunity to capture and evaluate, in a comprehensive way, the implications of *State Change* and *Impact* in the system. This requires the identification of the user community (be it local, regional or global) and, where possible, it also involves a scientific analytical and/or monetary evaluation of the ecosystem services and societal benefits. Thus, the scale of *State Change* and *Impact* as reflected in user communities and in their associated ecosystem services and societal benefits can be used to demarcate the boundary of the system depicted in the DPSIR framework. However, in presenting this, we note that the terminology involved in these concepts has evolved in recent years and hence we attempt to clarify it.

The integration of ecosystem services and societal benefits with the DPSIR framework in a way consistent with The Ecosystem Approach, and a consideration of the limitations of those concepts in marine management, enables us: (1) to contribute to our understanding of the three concepts, (2) to present basic postulates for

* Corresponding author. Tel.: +44 (0)1482 463054; fax: +44 (0)1482 463484.
E-mail address: J.P.Atkins@hull.ac.uk (J.P. Atkins).

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doi:10.1016/j.marpolbul.2010.12.012

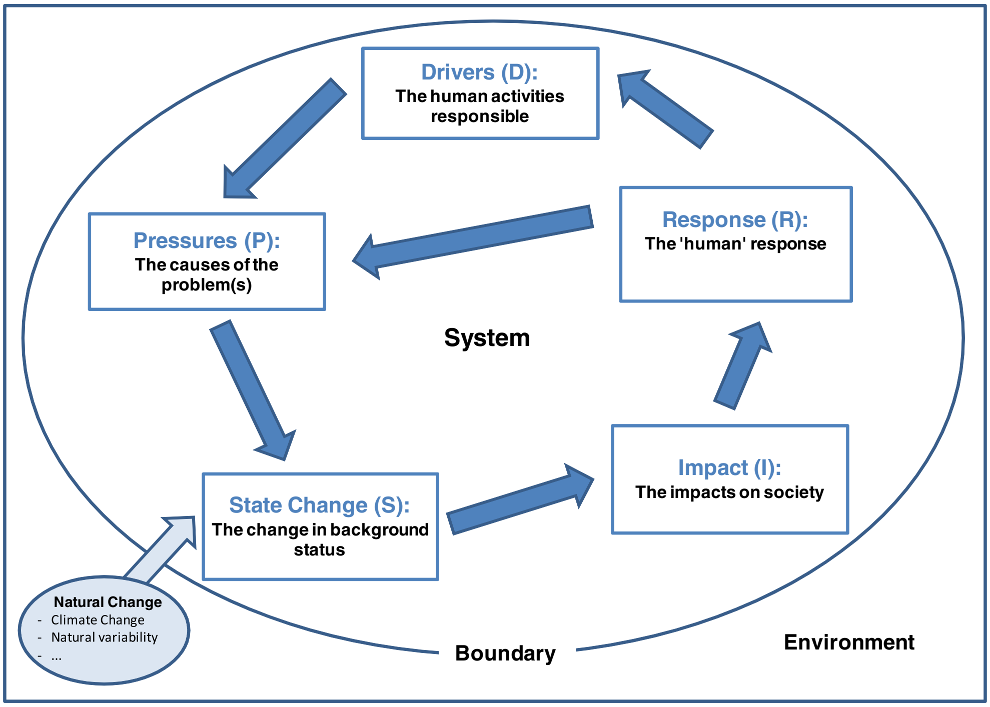

Fig. 1. The DPSIR framework as a cycle and system in the environment.

the management of the marine environment which integrate the concepts, and (3) to provide a specific framework for supporting decision making in the marine environment.

By way of application, two contrasting case studies are discussed. The first study relates to the management of marine aggregates extraction in UK waters and, therefore, centres on a particular sector. The second study is non-sectoral in its focus on marine biodiversity and the maintenance of the integrity of the marine environment at Flamborough Head, UK with particular reference to its nature conservation designations. Both case studies raise issues relating to the boundary of the system described by the DPSIR framework, and provide the opportunity to explore key elements of the perspectives of the user community, and of sustainable management in these specific contexts.

2. The Ecosystem Approach, the DPSIR framework and ecosystem services and societal benefits

2.1. The Ecosystem Approach

While 'an ecosystem approach' was initially an ecological term which referred to natural ecosystem functioning (Likens, 1992), since the early 1990s this has been adopted as 'The Ecosystem Approach' which aims to place human society as a central part in the ecosystem.

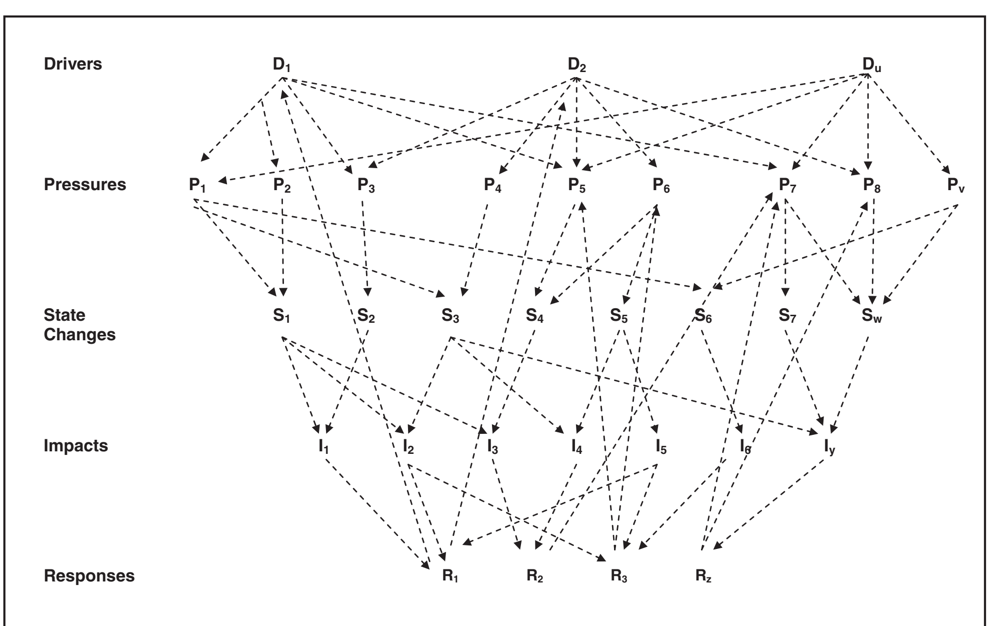

Fig. 2. An illustration of the multiple interactions within the DPSIR framework.

At its most comprehensive, the concept of The Ecosystem Approach was 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 Ecosystem Approach should be based on 12 guiding principles for the achievement of sustainable management (Box 1). It is notable that in the order proposed by the CBD, ecology is first mentioned at number 5. Hence the central 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 the ecological system functions while at the same time understanding the way society manages the exploitation of ecosystems and the potentially adverse and/or advantageous effects of its activities, including mitigation and/or compensation.

Box 1. The 12 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.

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 and Symes, 2000; Laffoley et al., 2004; ICES, 2005; Österblom et al., 2010).

2.2. The DPSIR framework

The DPSIR framework, adopted by the European Environment Agency and others (EEA, 1999; Elliott, 2002; Rogers and Greenaway, 2005; Borja et al., 2006; Maxim et al., 2009; Gray and 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 and 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, extraction of the seabed, demands for the conservation of coastal amenity and marine biodiversity, and the discharge of contaminated waters. As a result, a *State Change* of the system (e.g. the benthos or the water column) occurs and produces *Impacts* on society (e.g. degraded habitats, removal of species, loss of biodiversity, etc.), which through its links with human welfare can have positive and/or negative implications (the actual implications is, in part, dependent on whether we are viewing this from the perspective of society as a whole or from that of specific stakeholders). Where threshold levels are relevant, the *Impact* of *State Change* may follow accumulative effects of *State Changes* over a period of time. Finally, there is need to identify the societal *Response* to these changes in the marine system.

The human *Responses* include a set of tools at society's disposal for managing systems and so may be regarded as having 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 (Mee et al., 2008; Gray and Elliott, 2009; Elliott, 2010). Hence these aspects include governance (law, administration and politics), socio-economic demands, and the ability to change and manage the system through mitigation and compensation technologies (McLusky and Elliott, 2004; Mee et al., 2008; Gray and Elliott, 2009). Fig. 1 illustrates the accepted DPSIR framework, including feedback loops between *Responses* and *Drivers* and *Pressures*, and recognition that there are natural pressures (based on ecology, climate, geomorphology, and other dynamic conditions) on the ecosystem which can lead to *State Change*.

We further emphasise that the *Pressures* on the system can be separated into *endogenic managed pressures* where the causes of potential adverse effects (e.g. power generation, fisheries, land claim) come from within a system and require local, regional, and/or international management and *exogenic unmanaged* *pressures* (Elliott, 2010). The latter are those pressures such as climate change, geomorphic isostatic activity and movement of alien species, for which our local management cannot address the causes of change but only address the consequences. Furthermore, the complexity of *exogenic unmanaged pressures* is such that we do not yet have sufficient knowledge of how and why change occurs in such systems, or simply can do nothing (as with isostatic readjustment associated with the last Ice Age), and so our *Response* is not management of the *Pressure* but of the consequences of that *Pressure*. In the case of *endogenic managed pressures* we can manage both the causes and consequences of change, for example pipeline discharges can be controlled by licensing and the resulting polluted areas can be remediated.

The focus of the DPSIR framework is a system.[1] As indicated above, the system is formed through the interconnection between natural systems, designed systems and social systems. The application of the DPSIR framework must note the essential features of the system it describes as well as its complexity and variety. This 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 the evaluation and what is not. We can imagine a DPSIR 'cycle' (as shown in Fig. 1) as being required for a particular marine sector; for example, wild fisheries, with its methods, impacts, consequences and responses is a single DPSIR cycle. However, we acknowledge that (a) one activity will impact on others, for example a reduction in wild fisheries could have a knock-on effect to aquaculture, and (b) the marine environment is composed of many sectors each interacting and demanding a share of the available resources. As a consequence of this, while one might attempt to model, for example, management of a fishery using a single DPSIR cycle which is narrowly or discretely bounded for that particular sector, to be consistent with The Ecosystem Approach, such a 'marine fishery's DPSIR cycle' is nested within a set of DPSIR cycles that encompasses many sectors (e.g. marine aggregates, energy generation, and aquaculture), with complex and non-linear linkages and feedback loops between parts of the whole (Fig. 2). Most notably, the *Responses* to one set of *Drivers* and *Pressures* can affect others. For example, *Responses* to over-fishing, by curtailing fisheries, will influence the aquaculture DPSIR cycle.

In essence, individual elements of the DPSIR approach must be considered to have multiple interactions. Fig. 2 illustrates a set of interactions where forward linkages are featured most prominently but it is emphasised that there are feedback loops between the elements. If this framework were to form the structure of a quantitative model then, in its most general form, each element of the DPSIR for the whole ecosystem might be as associated with 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 system, it should be transformed by an order-five tensor $D_{d,p,s,i,r}$ 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 'external natural change' and exogenic unmanaged pressures as identified above.

[1] It might be argued that the focus is a complex adaptive system, as defined for example by Buckley (1967) and Holland (1992), following Gibbs and Cole (2008) which examines whether the properties of a complex adaptive system are reflected in the marine environment.

2.3. Ecosystem services and societal benefits

Ecosystem services have been previously defined as the conditions and processes through which natural ecosystems, and the species they include, sustain and fulfil human life (Daily, 1997). As is evident from the EU's MSFD quotation 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 for Environment, Food and Rural Affairs (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*' 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*'. We argue that this creates two problems – firstly by suggesting services and benefits are synonymous and secondly by focussing on privileging human interests above others, for example the ecological, which is against a more holistic perspective.

There is no single agreed way of describing ecosystem services. Fisher et al. (2009) argue that the classification system should be linked to policy and management and therefore different interpretations may be needed depending on the context – different classifications can then be seen to be complimentary rather than competitive. 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). As these ecosystem services in turn provide a range of benefits that lead to a healthy and prosperous society then we emphasise here that the term 'services' should only be used as the means of providing endpoints and that the endpoints of interest are 'benefits' to society (see below).

As an indication of the evolution of the terms Beaumont et al. (2007), informed by De Groot et al. (2002) and others, refer to ecosystem goods and services as '*the direct and indirect benefits people obtain from ecosystems*'. They view ecosystem goods as 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. (*op. cit*) introduce a further category to those of the Millennium Ecosystem Assessment. Thus, their 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.
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, we can place 17 different types of ecosystem services (or goods and services) derived from the marine environment into the five broad groups (Table 1).

In a further extension to the Millennium Ecosystem Assessment (MEA, 2005), drawing on Boyd and Banzhaf (2007) and others, Fisher et al. (2009) modifies these concepts and proposes that ecosystem services '*are the aspects of ecosystems utilised* (*actively or passively*) *to produce human well-being*', hence consistent with the anthropocentric emphases. It is argued that, typically, the benefits that are secured from an ecosystem for human well-being require

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

Category	Ecosystem services
Production services	*Food provision* – extraction of 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 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 marine environment itself *Cognitive values* – education and research resulting from the marine environment *Leisure and recreation* – refreshment and stimulation of the human body and mind through the perusal and study of, and engagement with, the marine environment *Feel good or warm glow* – value derived from the marine environment without using it
Option use values	*Future unknown or speculative benefits* – currently unknown future uses of the marine environment
Over-arching support services	*Resilience and resistance* – life support by the marine environment and its response to pressures *Biologically mediated habitat* – habitat provided by living marine organisms *Physical habitat* – habitat provided by the physical (non-living) environment *Nutrient cycling* – the storage, cycling and maintenance of nutrients by marine environment

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. We share the view that ecosystem services are '*the link between ecosystems and things that humans benefit from, not the benefits themselves*' (Luisetti et al., 2010) and are ecological phenomena encompassing both ecosystem organisation or structure, which are the classes of the ecosystem (such as terrestrial, freshwater, estuaries, coastal areas and the open sea), and ecosystem processes and functions, which are the time-dependent ways in which the ecosystem operates. However, we emphasise that ecosystem services are the processes and functioning resulting from ecosystem structure, for example the physical and chemical processes which create the fundamental niches occupied and exploited by organisms, which then produce benefits exploited by society. By way of an illustration, the hydrodynamic regime creates suitable substrata, which is then occupied by sediment-dwelling organisms which in turn support commercially fished species (Gray and Elliott, 2009).

Fisher et al. (*op. cit*) make a further distinction by suggesting that ecosystem processes (a service that comes from other factors than the ecosystem itself) and ecosystem functions (the result of ecosystem process) lead 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 (scientific analytical, monetary or other) evaluation.

Here, we suggest the need to further refine this understanding of intermediate and final ecosystem services and benefits. We contend that the intermediate ecosystem services are defined as the bottom-up physico-chemical processes and regimes which set up the fundamental ecological niches which are then colonised by organisms (i.e. the *environment–biology* relationships, in Gray and Elliott, 2009); hence we suggest the intermediate services are better termed 'fundamental services'. In contrast, the final ecosystem services are defined here as the biotic processes whereby the communities set up under the fundamental niches then interact and modify the biota (what may be termed *biology–biology relationships* such as predator–prey and competition) and that these may then also modify the environment through, for example, bioturbation, chemical changes and organic removal (the *biology–environment* relationships, in Gray and Elliott, 2009). In summary, therefore, the ecosystem services can be referred to as the sum total of all ecosystem natural processes.

Once the ecological system (incorporating both the physico-chemical and biological aspects) is fully functioning then we take the view that it will produce benefits required by society – thus, the marine environment provides ecosystem services and societal benefits (ES&SB) (Fig. 3). We then advocate that the concept of ES&SB has a fundamental link to the DPSIR framework in that whereas ES&SB are associated with the production and delivery of the benefits for society, the DPSIR approach shows how the process of delivering those benefits can create, for example, adverse *State Changes* and *Impacts* which require a *Response*. To illustrate, the marine environment will deliver fish as food but if its extraction causes problems for the natural system then ultimately benefits will not be delivered unless we bring in a *Response* such as fishing quota restrictions. As such any adverse effects of human-derived pressures on the fundamental and final services represent the *Pressures* to *State Change* link in the DPSIR framework and any adverse consequences of *State Change* on societal benefits can reflect the *State Change* to *Impact* links in the DPSIR framework. Hence the cycle is then completed by having societal *Responses* (e.g. legally enforceable fishing quotas) to ensure that the benefits will be delivered sustainably. We emphasise therefore that protecting the naturally functioning system (services) both for its own sake and in order to deliver societal benefits is The Ecosystem Approach *sensu stricto* (Fig. 3).

The above concepts therefore link various approaches, such as that advocated by Luisetti et al. (2010), together with the ecosystem services (including societal benefits) defined in Table 1. Fig. 4, adapted here from Luisetti et al. (2010), identifies the constituent elements of the fundamental and final services and societal benefits for the marine environment. Of course, for completeness we should also add the adjoining ecosystem classes (terrestrial, freshwater, estuarine, and coastal) given their roles in the creation of a fully functioning marine system; as such each would imply a mutually non-exclusive set of fundamental and final services and societal benefits. The figure implies a sequence from the fundamental services through the final services to the societal benefits and of course this is the case in the fishing example used above. Nevertheless, it is possible to get societal benefits directly from the fundamental services, for example if the appropriate hydro-physical regime creates areas with sands and gravel then the societal benefit of aggregates for building can be achieved

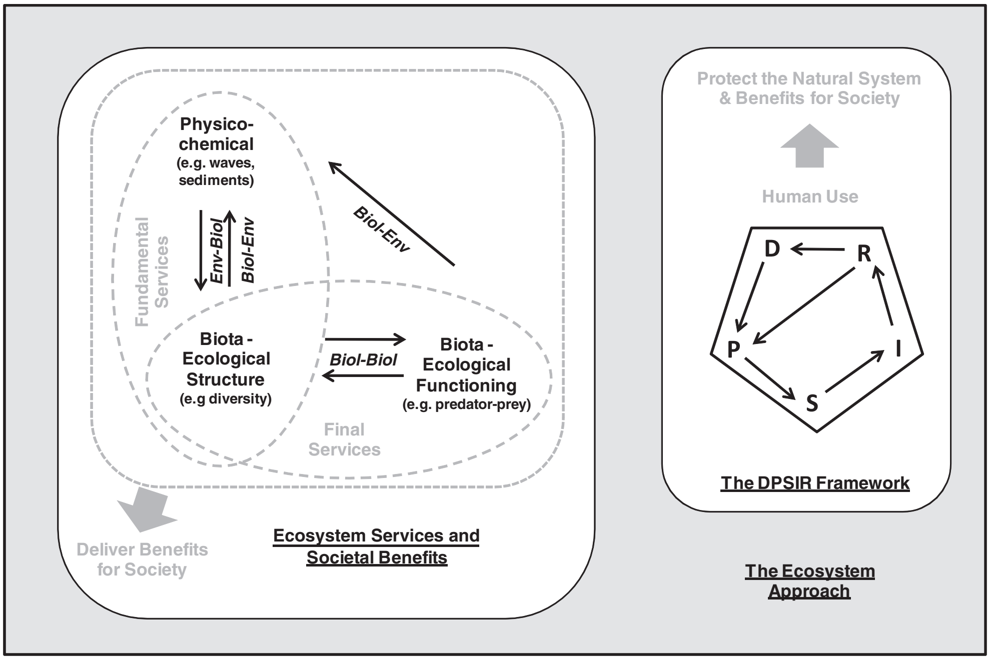

Fig. 3. The DPSIR framework and the ecosystem services and societal benefits set within an overall framework of The Ecosystem Approach.

irrespective of whether there are final (biological) services; however, this would not be The Ecosystem Approach *sensu stricto as* only one benefit would be produced with the potential for loss of other benefits.

The ES&SB evaluation therefore has fundamental links to the DPSIR framework, as discussed above, by providing a comprehensive basis for identifying and assessing the fundamental and final services and societal benefits provided by the ecosystem and the consequences of endogenic and exogenic pressures on the system. Evaluation implies the need to identify those of the user community affected by the system or changes in the system; it aspires to complete coverage, a clear knowledge of the specific interests of user community affected, provides a basis for exploring the legitimacy of these relationships and, in conjunction with scientific analytical enumeration and monetary valuation, offers the opportunity for their quantification. In seeking to capture all of the user community and evaluating, in a comprehensive way, the implications of *State Change* and *Impact* in the system in this way, we

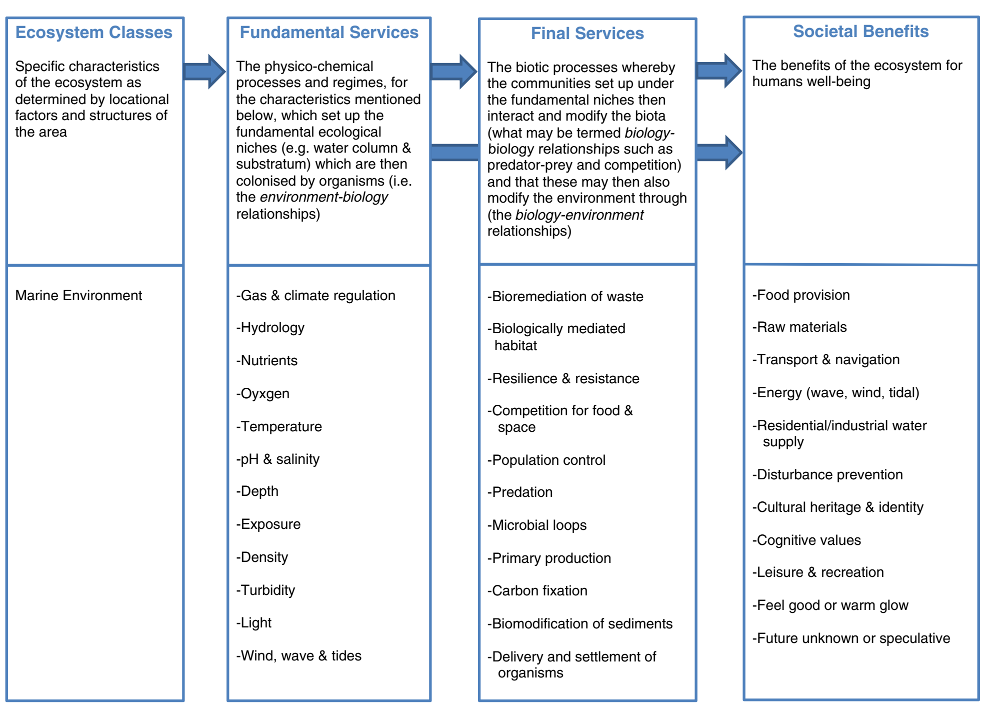

Fig. 4. The separation of marine ecosystem processes and functions into fundamental and final services and societal benefits (modified and greatly expanded from Luisetti et al., 2010).

can use the concept of ES&SB to demarcate the boundary of the system depicted in the DPSIR framework. By user community we refer to broadly defined stakeholders – individuals, households, business organisations, government and government agencies, and/or other societal/civil groups and communities. These may be local, regional, or global depending on the specific characteristics of the ecosystem services and societal benefits 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. At the same time, that same use may have implications for the user community 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 global level, depending on the particular site characteristics.

Also with regard to evaluation, the approach calls for a scientific analytical and/or monetary enumeration of the ecosystem fundamental and final services and societal benefits. We generally take the view that the ecosystem fundamental and final services are more appropriately measured using scientific techniques. For example nutrient cycling and carbon sequestration can be measured by sedimentary and chemical techniques whereas the structure and functioning of the biota can be measured by diversity indices, ecological energetics, population dynamics, etc. However, this is not to rule out the possibility of monetary evaluation of services such as carbon sequestration where widely accepted valuation procedures exist (Defra, 2007a).

With regard to the societal benefits, where these are marketable, their market price may reflect their social worth and can be adopted for valuation purposes. However, for many societal benefits it is evident that either market prices do not reflect society's true valuations, or markets do not actually exist and the benefits are provided at a price of zero which, again, is not a reflection of their true social worth – for example, unregulated recreational angling may represent a case in point. 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 for example Turner et al., 2001, 2010; Birol et al., 2006; Beaumont et al., 2008). It should be noted that these techniques are not all consistent with each other. In general terms, those techniques seeking to value 'benefits' through 'willingness to pay' or 'willingness to be compensated' approaches (e.g. contingent valuation method) are a 'better' guide to the underlying economic value than those based on costs. However, it is often the case that methods like 'replacement costs' are the only available option with data and therefore are under some circumstances an adequate proxy.

In capturing the implications of all *State Changes* and *Impacts of* a system in the way described above, a strong realist view on knowledge is being taken. The role of the expert and analyst is emphasised, while more critical discursive interpretations, for example, are not revealed (Svarstad et al., 2008).

2.4. Linking ecosystem services and societal benefits to the DPSIR framework

The DPSIR framework reflects a system dominated by human activities and, traditionally, in its application purports to show the way in which perceived adverse changes occur, their cause and consequences and the methods of responding to them. We can expect that in order to provide the fundamental and final services within an ecosystem that lead to societal benefits, we need a fully functioning ecosystem which is protected from adverse anthropogenic impacts. For example, if the physico-chemical processes are as expected under specific physiographic areas then they will lead to niche creation; organisms will then occupy those niches and once the organisms interact then this leads to ecological functioning (Gray and Elliott, 2009). In turn, for example, low energy marine systems with weak currents and moderate tides will lead to muddy areas which are then colonised by mud-tolerant organisms, and the fine sediments will recycle nutrients and may sequester carbon as well as pollutants. Hence the area supports ecosystem services which in turn produce societal benefits (the mud organisms produce food for fishes which are then harvested). Given all of this, it becomes axiomatic that if adverse *State Changes* and human *Impacts* occur then the system is in danger of not delivering ecosystem services and societal benefits unless we create suitable *Responses* to control the adverse effects of the *Drivers* and *Pressures*. Despite this, however, it is conceivable that we can initiate *Responses* in order to enhance societal benefits, for example recreating wetland habitats (see Elliott et al., 2007) will act as a technological response to the exogenic unmanaged pressure of sea-level rise caused by global climate changes and isostatic readjustment by providing economic benefits (prevention of excessive spending on dyke raising) and public safety (preventing flooding) but also it creates habitats and carbon sequestration areas, a so-called 'win–win–win' situation.

3. Case studies

Although examples have been included throughout the previous description of concepts, two case studies provide further insight.

3.1. Case study 1: the management of marine aggregates extraction in UK waters

The first case study demonstrates the application of the DPSIR framework and the importance of identifying ecosystem services in the management of the marine aggregates (sands and gravels) extraction industry in the UK. The marine system therefore provides a fundamental service (aggregates of the right type and location which can be exploited) which leads to benefits for the industry and thus society. The marine aggregates extraction industry may be regarded as one of many sectors in the marine environment and the multi-user needs and uses of marine ecosystem services provides the context for the application of the DPSIR framework, as outlined above, which can be used to highlight the system components relevant to the aggregates extraction activity and an assessment of management options. As dredging companies may operate close to other activities, such as commercial shipping and leisure sailing, port operations, fishing, and offshore energy, and may preclude future developments such as the laying of seabed pipelines, this can result in the potential for spatial conflict between activities (BMAPA, 2010). These competing activities all imply the potential for specifying alternative DPSIR cycles and the need to be critical in defining what is included within the system and the focus of evaluation, and what is assigned to the environment beyond the system's boundary. For this generic case study, a full assessment of the ecosystem services (fundamental and final) and societal benefits is outside this paper, as these would be specific to any given marine extraction site. This case study therefore focuses on the activity at a generic level, with the presented framework being applicable to any specific case study site.

Following Fig. 5, *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).

There is a growing literature assessing the *State Changes* associated with marine aggregate extraction and including, for example, the benthos (Boyd et al., 2003, 2005; Cooper et al., 2008; Ware et al., 2009), fish populations (Stelzenmüller et al., 2010) and habitats (Erftemeijer and Robin 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.) and thus have the ability to impact upon the benefits which society obtains from the marine environment. As discussed above, the ES&SB methodology can be applied to put into context the *State Changes* resulting from the *Pressures*.

There is very little literature evaluating ecosystem services with respect to the marine aggregate industry, and this is at the site-specific level. Austen et al. (2009) focuses on aggregate extraction sites located within the Eastern English Channel Marine Natural Area (ECMNA), UK. Their study identifies and quantifies the impacts of the marine aggregate extraction industry on some ecosystem services and notes systemic issues. The area is identified as a principle source of aggregate supply in the UK, with landings of 6.7 million tonnes (29% of the UK marine 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. (2009) note that crab breeding areas in these sands and gravels raises issues for the management of the marine aggregates sector. The ECMNA also provides fundamental and final ecosystem services which deliver other societal benefits including leisure and recreation such as sea angling and seaside day trips (£1096 million), food provision including both fish and shellfish landings (£10.5 million), and gases and climate regulation (£1.4 million–£6.6 million).

The societal *Responses* then include governance issues. The UK seabed is owned by The Crown Estate which has responsibility for managing aggregate 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; Cooper et al., 2010). Individual licences also require an indication of the social need and economic costs and benefits of marine aggregate use as well as consideration of rehabilitation post-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 (e.g. see Cooper et al., 2010). For each of these restoration options it is important to identify and quantify the ecosystem services provided by the marine environment before the dredging took place, to understand how the dredging activities have affected these and to assess the potential for restoration options to restore the services back to their original state. This issue is currently being addressed by a project funded through the Marine Aggregate Levy Sustainability Fund (contract no. MEPF 09/P115) which is due to report in 2011.

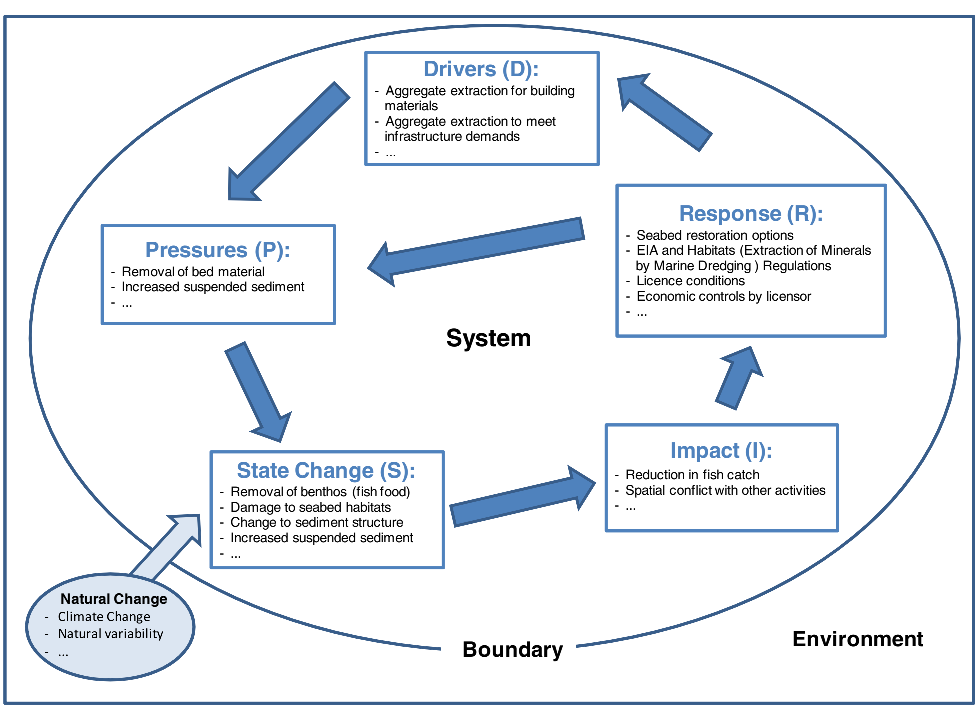

Fig. 5. The DPSIR framework for the management of marine aggregates extraction in the UK.

3.2. Case study 2: the management of marine biodiversity at Flamborough Head, UK

The second case study applies the methodology to the management of biodiversity at Flamborough Head, UK. This coastal site has multi-user characteristics and is especially distinctive for being designated as a European Marine Site (EMS) for its diverse habitats (designated as a Special Area for Conservation (SAC) under the EU Habitats Directive 92/43/EEC) and abundant seabird colonies (designated a Special Protection Area (SPA) under the EU Wild Birds Directive 79/409/EEC) (for further details see Burdon and Atkins, 2007). At the same time, it has many of the uses and users of other marine areas, such as fishing, recreation, waste disposal, aggregate and oil and gas resources. As with the previous case study, defining system boundaries is central to the application of the DPSIR framework, although in contrast to the aggregate case study, its EU designations restrict activities and influence other management interventions. An assessment of the ecosystem (fundamental and final) services and societal benefits provided by the Flamborough Head marine environment highlights potential conflicts between the user community's activities and the integrity of the site.

As an EMS, 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. This led to the Flamborough Head Maritime Forum being established to provide user community involvement in the management of the EMS. The Management Scheme was reviewed in 2007 to give 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.

Given the many uses and users of this and most other marine sites then we can envisaged the areas as requiring multiple DPSIR cycles. Hence, the complexity of the management of this protected site is demonstrated conceptually in Fig. 6. It recognises the multiple activities undertaken at Flamborough Head through the DPSIR framework of multiple users within the boundary of this system. Importantly, *Responses* in the DPSIR framework are guided by the Management Plan, hence its place at the centre of the figure. The several sectoral activities are depicted in Fig. 6 by DPSIR 'cycles' (I, II, III, IV…N). The boundary of the system is placed so that all of these activities are placed within the system. It is also recognised that the system will be subject to exogenic unmanaged pressures and natural change. The complexity of this system is reflected by the linkages and feedback loops drawn between the DPSIR cycles.

In the case of Flamborough Head the activities include for example, fishing, industrial development and recreational amenity. The coastal waters support a high level of commercial and recreational fishing activity exploiting a mixed fishery through potting, trawling, netting and lines. The municipal sewage treatment works discharge treated wastes as does an industry – distilling, brewing and food malts for domestic and export markets. All of these activities are managed within the framework of the integrated Flamborough Head Management Plan.

Several *Pressures*, resulting from these activities, are placed upon the system, including the exploitation of fisheries and industrial discharges have to coexist with the demand for conservation of biodiversity. For example, there are currently nine inshore vessels (<10 m) registered at Flamborough, all with shellfish licences, which exploit populations of European lobster, edible crab, velvet crab and whelks. Sewage treatment works discharge into the area,

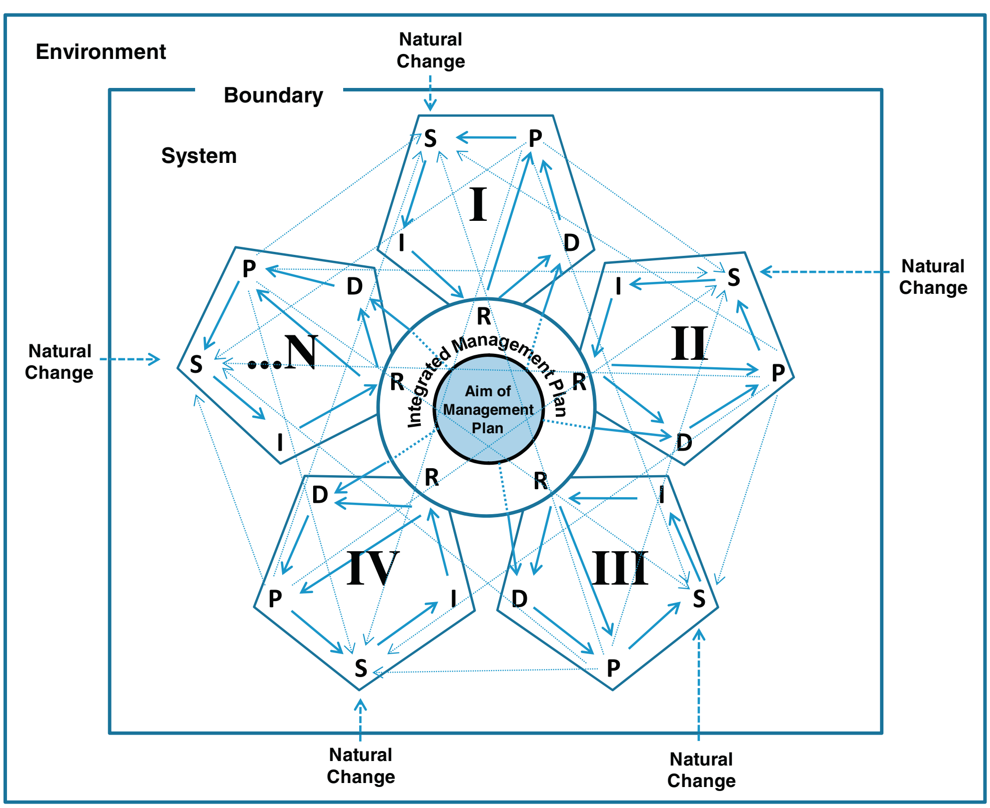

Fig. 6. A nested-DPSIR framework for the management of the marine environment at Flamborough Head, UK.

north and south of the headland and industry discharges a maximum of 2500 m^3/day consented for 100 mg/l of suspended solids, 300 mg/l of BOD and 10 mg/l of ammonia (Cefas discharge consent database, 2000). The outstanding natural features associated with Flamborough Head, in addition to its proximity to tourist resorts, attracts over 56,000 visitors per year (East Riding News, September 2006).

The *Pressures*, in turn, can lead to *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.

It is of note that although *State Changes* can be monitored (for example by monitoring shellfish stocks and water quality), it is more difficult to provide direct evidence of cause and effect relationships given the complexity of competing uses in the marine environment and natural change in the system. *State Changes* in the environment are of importance if they 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 fundamental and final services for food and shelter; a loss in fish populations (especially sand eels) may also reduce both bird numbers at the local seabird reserve and wildlife watchers visiting the site; and a reduction in bathing water quality, as an effect of industrial discharges, may result in fewer tourists visiting the beaches.

The aim of the Flamborough Head Management Plan and its legal status provide an integrative basis for managing *Pressures* and determining *Responses* associated with the various activities. For example, commercial fisheries 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*'. Projects within the NESFC district which represent human *Responses* to *Pressures* on the system include:

- The establishment of three Prohibited Trawl Zones (PTZ) (see Allen, 2008) to protect static gear fisheries and to prevent conflict between mobile and static gear interests and potentially have wider benefits for marine diversity by contributing to resource management, conservation and habitat enhancement (Thomson et al., 2010).
- An agreement in April 2008 to designate an experimental No Take Zone (NTZ) (Thomson et al., 2010). The designation is consistent with 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 protect the interest features and ensure that the NESFC is meeting its statutory duties.

Water quality is also addressed in the Management Plan. For bathing water quality there have been large scale improvements to sewage treatment works which now 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 and Elliott, 2003).

A summary of the ecosystem services (fundamental and final) and societal benefits identified for Flamborough Head are presented in Table 2. The governance procedures followed to establish the current site designations have already required quantifying some elements of these ecosystem services, and some valuation has also been attempted. For example, Burdon and Atkins (2007) examine public perceptions of and elicited willingness-to-pay valuations for the protection of marine biodiversity at Flamborough

Table 2
Examples of the ecosystem services and societal benefits provided by the marine environment at Flamborough Head.

Category	Ecosystem services	Description
Fundamental services	Gas and climate regulation	Kelp forests act as a source and/or sink for CO_2
	Physical habitat	The extensive chalk sea cliffs provide habitat for many nationally and internationally important breeding populations of seabirds, whilst the waters 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, a summer oceanographic boundary between the northern and southern North Sea creating 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 and sewage treatment discharges
	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
	Resilience and resistance	Despite the anthropogenic activity in the area, current site designations suggest a relatively high level of resilience and resistance although further evidence is needed
Societal 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
	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
	Energy	There is no marine energy generation although offshore wind farm sites are proposed and gas storage facilities are located to the south of the EMS
	Residential and industrial water supply	There is no evidence of water being abstracted for residential and industrial uses
	Disturbance prevention	Not understood at present
	Cultural heritage and identity	The Heritage Coast covers 19 km and includes archaeological and historical features
	Cognitive values	Flamborough Head is an educational and research resource used by schools and universities as well as statutory monitoring 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 site's outstanding natural features
	Future unknown or speculative benefits	Widespread current user values suggest that option use values will be positive

Head through a contingent valuation survey undertaken in 2007. A sample survey of 222 visitors to the site produced a mean willingness-to-pay, associated with a one off payment, to conserve marine biodiversity of £71.91 (std. dev. = £123.41), with a median willingness-to-pay of £40.00.

4. Discussion

The management of the marine environment requires an approach that recognises the complexity of the system and accommodates the full user community and their current, multiple, interacting uses. This can be provided by an integrated methodology based on the DPSIR framework and ES&SB, thereby encompassing The Ecosystem Approach. It acknowledges the need to protect and maintain the ecosystem fundamental and final services as a means of delivering societal benefits which we argue are a means to capture and evaluate, in a comprehensive way, the implications of *State Changes* and *Impacts* of the marine system. By applying the methodology to a specific (sectoral) activity, in the case of marine aggregates extraction in the UK, and to a specific management aim, in the case of conservation of biodiversity and the integrity of a multiuser site at Flamborough Head, we have shown that there is a set of fundamental concepts and directions which link the three philosophies (The Ecosystem Approach, DPSIR and ES&SB approaches). For these concepts to be accepted and to be integrated, and acknowledging the complexity of the marine environment, we propose basic postulates for sustainable management of the marine environment, referred to here as the *DPSIR–ES&SB* postulates:

- That the fundamental and final services refer to the sum total of ecosystem natural processes.
- That the fundamental services are the physico-chemical processes and regimes which set up the fundamental ecological niches which are then colonised by organisms.
- That the final ecosystem services are the biotic processes whereby the biological communities occupying the fundamental niches then interact and are modified and that these may then also modify the environment through, e.g. bioturbation, chemical changes, organic removal.
- That the ecosystem services will lead to societal benefits and that a fully functioning ecosystem, as defined by the fundamental and final services, is needed in order to sustain benefits for society.
- That whereas economic techniques are favoured for evaluating the societal benefits, the fundamental and final ecosystem services are more often evaluated by scientific analytical (physical, chemical and biological) measurements.
- That *Drivers* and *Pressures* will lead to adverse *State Changes* unless the system can absorb the *Pressures* or there are thresholds which have not been exceeded (i.e. resistance to change).
- That the desirable state for the marine environment is to maintain and protect the natural ecological features while at the same time sustainably meeting societal needs.
- That systems which have an ability to withstand some stressors or change their state but then return to a pre-defined and desirable state once a stressor has been removed are deemed to be resilient (see also Elliott et al., 2007).
- That *State Changes* will lead to *Impacts* on the human system (i.e. societal impacts) unless the system can tolerate and absorb such changes without long-term adverse consequences, what has been called environmental homeostasis (see Elliott and Quintino, 2006).
- That *Drivers* and *Pressures* will lead to adverse *State Changes* unless society agrees to and adopts *Responses.*
- That some pressures may emanate from within the system and have their causes and consequences managed, i.e. endogenic managed pressures, but others are from external to the system whereby only their consequences can be managed, i.e. exogenic unmanaged pressures.
- That the adverse societal *Impacts* need to be countered by *Responses* (covering economic instruments, governance, technology, etc.) otherwise the societal benefits are sooner or later compromised.
- That the system can be managed through *Responses* to give better fundamental and final services (e.g. by habitat creation) and thus can produce additional societal benefits.
- That adverse *State Changes* will by definition hinder the processes required for a fully functioning ecosystem.
- That the scale of *State Change* and *Impact*, as reflected in the user community and on the ecosystem services and societal benefits, can be used to demarcate the boundary of the system.

Within these 15 postulates, we are assuming that the *State Changes* and the *Impacts* within the DPSIR framework are perceived to be adverse but one might perceive positive *State Changes* and *Impacts*. If they are positive then we can get more societal benefits, for example, if thermal effluent from a power plant increases the growth of a species in the receiving area then a greater harvest could result. However if the growth and dominance of that species was to the detriment of other species then this might be a net negative effect. Similarly, the postulates have attempted to encapsulate that the 'desirable state' is from both natural and human capital perspectives. While there exists a clear potential for privileging one perspective (e.g. economic or ecological) over another (e.g. ecological or economic) in the management of the marine environment, the systemic methodology proposed recognises the range of perspectives and identifies the consequences of privileging one group of the user community over another. It emphasises that giving privilege to one or other of its ecological or socio-economic origins over the other is neither fulfilling The Ecosystem Approach nor is a sustainable and socially desirable outcome. Thus, in developing and applying the *DPSIR–ES&SB* methodology this paper focuses on fundamental questions about the marine environment and its management, and identifies key issues for taking our understanding further.

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 Aggregate Levy Sustainability Fund (Ref: MEPF 09/P115) and discussions with members of the Seabed Restoration Project. This study forms part of the European projects WISER (Grant Agreement 226273, 7th Framework Programme) and TiDE (Interreg 4c). The authors also benefited from comments received from participants of the 54th Annual Meeting of the International Society for the Systems Sciences entitled 'Governance for a Resilient Planet', Waterloo, Canada, 18–23 July 2010.

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