An interdisciplinary approach to marine management: Bridging the divide between natural and social sciences research

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PREFACE

Background of the Author

Having graduated with an Honours Degree in Marine Biology from the University of Stirling, I completed a multidisciplinary Taught MSc in Estuarine and Coastal Science and Management at the University of Hull in 2002. Since then I have been employed as a full-time researcher at the Institute of Estuarine and Coastal Studies (IECS), University of Hull. Having broadened my ecological expertise into the fields of ecosystem services, marine policy, marine management and economic valuation of natural resources, I now consider myself to be a truly interdisciplinary researcher and have used my expertise to publish numerous scientific papers (21), book chapters (4) and research reports (70+). The wide range of my research outputs, and the diverse authorship associated with these, reflect the interdisciplinary nature of my research. The current work constitutes the submission of my research portfolio to be examined for a PhD by published work.

Purpose and Structure of the Thesis

This thesis provides the evidence required for examination for a PhD by published work at the University of Hull, in accordance with the University Programme Regulations Chapter XXIII (v1 02, November 2014). Following University guidelines, this thesis is structured as follows: Abstract; Table of Contents; List of Figures; List of Tables; Chapter 1: Introduction to published work; Chapter 2: Final discussion, conclusions and personal reflection; References; Annex 1: List of published work; Annex 2: Testimonials for co-authored published work; Annex 3: Published papers; Annex 4: Book chapters; and Annex 5: Published papers (not included in this thesis).

Acknowledgements

I wish to express my sincere thanks to Professor Mike Elliott (Director of IECS) for providing sound advice and guidance throughout my career so far and for providing the encouragement and financial support which has enabled me to complete and submit this thesis. I also wish to thank Professor Jonathan Atkins (Hull University Business School) for introducing me to the world of environmental economics and for his subsequent support, enthusiasm and significant inputs to our collaborative research. In addition, I wish to thank all of the other researchers and academics whom I have had the pleasure to work with over the last 14 years, many are listed as co-authors within this thesis, but all have made valuable contributions to my interdisciplinary research. Finally, I wish to thank the various funding bodies who have supported my interdisciplinary research; they are individually acknowledged within each published work.

ABSTRACT

This thesis and the accompanying papers demonstrates the development of a number of bridging tools which have been successfully applied to the marine environment. Specifically, how a problem structuring framework and ecosystem service approaches have been developed for specific application in the marine environment and how a suite of ecosystem service indicators and economic valuation methods have been applied to identify, assess and value changes in marine ecosystem service provision. Integration of these approaches is discussed within the context of holistic marine management. An original conceptual framework is presented which allows for the integration of these tools, enabling researchers and managers to bridge the divide between natural and social science research and thus contribute towards more sustainable management of the marine environment in the future. This thesis concludes with a critique of these major research themes, including suggestions for further scientific study and further use of the information generated in marine management.

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CHAPTER 1: INTRODUCTION TO PUBLISHED WORK

This chapter provides the background and context of the published work presented in this thesis. References to the author's published work are highlighted in bold throughout.

1.1 The marine ecosystem

An ecosystem can be defined as '*a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit*' (CBD, 2000). Ecosystems form as the net result of structural elements or components and a series of key rate processes which constitute ecosystem functioning (**Elliott et al., 2006a**). In the context of the marine environment, these key processes relate to inter-relationships between the physico-chemical (abiotic) and biological (biotic) attributes (Table 1). The sum total of these interlinked processes therefore creates the observed marine ecosystem. Both anthropogenic activities and natural change can then be superimposed on this set of fundamental relationships which may in turn impact upon the structure and functioning of the ecosystem. These interlinked processes are shown as a conceptual model in Figure 1.

Table 1: Marine processes and inter-relationships (**Atkins et al., 2014**).

Processes	Meaning	Examples
'Environment–biology'	The physico-chemical system (e.g. salinity, temperature, sediment, geology, hydrography, etc.) creates the fundamental niches for colonisation by organisms.	Reduced water currents will allow the development of muddy substrata which will be colonised by deposit-feeding organisms; biogeographic regimes and physico-chemical oceanographic processes and gradients will thus create the conditions likely to be colonised by organisms.
'Biology–biology'	The resultant community is modified by biological processes and interactions such as predator–prey relationships, competition, and recruitment processes such as propagule supply and settlement.	The mud-dwelling invertebrates then compete with each other for space but also provide food for wading birds and fish.
'Biology–environment'	The biology may influence the physico-chemical system and the import and export of materials into and out of the system.	Benthic invertebrates bioturbate and alter the sedimentary regime, leading to chemical changes; oxygen demand is created by a large number of organisms occurring together.
'Environment–environment'	One or more elements of the physico-chemical system impact upon other elements of the physico-chemical system.	Changes in the hydrographic regime (e.g. currents, tides, etc.) result in changes to the sediment structure on the seabed.

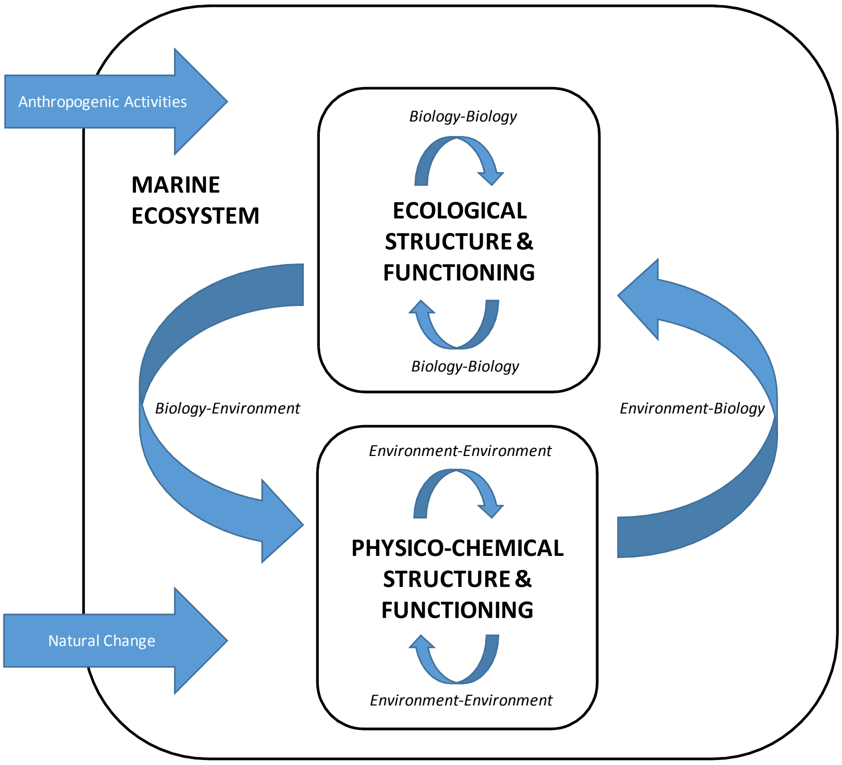


Figure 1: A conceptual model indicating the linking and feedback between abiotic and biotic attributes of the marine ecosystem (after **Elliott et al., 2006a**).

Within the marine environment, increasing and diverse use of the system is leading to human-induced changes to marine life, habitats and landscapes (**Atkins et al., 2011a**; **Cooper et al., 2013**). For example, a recent UK study identified 14 key marine sectors which include: aquaculture; carbon capture and storage; commercial fishing; commercial shipping; defence; marine aggregates; marine protected areas; nuclear energy; offshore renewables; oil and gas; ports, dredging and disposal; recreation; surface water and waste water management; and tourism (MMO, 2014a). In addition, with recent technological developments and an expanding global economy, there is now increasing pressure from human activities which are developing in the offshore marine environment (Stojanovic & Farmer, 2013). A number of these activities have historically been undertaken in the marine environment however the list also reflects a number of the recently expanding blue economy sectors which offer '*smart, sustainable and inclusive economic and employment growth from oceans, seas and coasts*' and includes marine energy extraction; aquaculture; maritime, coastal and cruise tourism; marine mineral resources; and blue biotechnology (DG MARE, 2012; EC, 2012). With the resulting pressures from these activities on offshore sites, the challenges for the management of remote parts of the marine environment become far greater (**Börger et al., 2014**). A range of case studies are presented within this thesis, which address potential management options for marine activities, including commercial fishing, marine aggregates extraction, marine protected areas and offshore renewable developments.

It has been suggested by Gibbs and Cole (2008) that the marine environment could be considered to be a Complex Adaptive System which is formed through the interconnection between natural systems (such as terrestrial, freshwater, estuarine, coastal and oceanic), designed systems (such as extractive industries, tourism, transportation and power generation) and social systems (such as environmental activist groups, fishing communities etc.) (**Atkins et al., 2011a**). As such holistic marine management practices are required which consider the environmental, economic and social impacts of all human activities. Such an approach would be consistent with an ecosystem approach.

Ecologists have long discussed an ecosystem approach as a concept in the study and understanding of ecosystems and thus a fundamental part of ecology (e.g. Likens, 1992). More recently, the ecosystem approach has been defined as '*a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way*' (COP 7 Decision VII/11, Annex 1). The ecosystem approach can therefore be regarded as a management philosophy for summarising the means by which the natural structure and functioning of an ecosystem can be protected and maintained while still allowing and delivering sustainable use and development by societal actors (**Elliott et al., 2006a**). In order to achieve sustainable management, the Convention for Biological Diversity (CBD) indicates that the implementation of the ecosystem approach should be based upon 12 guiding principles commonly referred to as 'The Malawi Principles' (Box 1 in **Atkins et al., 2011a**, Annex 3). It is notable that in the order proposed by the CBD, ecology is first mentioned in Principle 5, hence the central feature of the approach is the linking of natural aspects with the consideration and management of human activities.

The term 'the ecosystem approach' now appears in many EC Directives, OSPAR and nature conservation reports (Pope & Symes, 2000; Laffoley et al., 2004; ICES, 2005; Österblom et al., 2010; **Atkins et al., 2013**). For example, in the European context Article 1(3) of the 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*' (EC, 2008).

It has been observed that marine policy within Europe has been developed in a piecemeal fashion over many years as environmental threats and challenges have changed and developed (**Elliott et al., 2006b**) and has resulted in a plethora of marine legislation. For example, the marine environment within the UK is regulated by a raft of international, European and national legislation as illustrated by the ultimate 'horrendogram' in Boyes and Elliott (2014). Most recently, there has been a move from a sectoral approach, which focused on particular issues or sectors such as the EU Nitrates Directive (91/676/EEC), to a more holistic approach, as adopted by the MSFD for marine waters which is consistent with the ecosystem approach (**Elliott et al., 2006a**; Boyes & Elliott, 2014).

It is argued here that in order to fully achieve the ecosystem approach in marine management then an interdisciplinary approach is required which bridges the divide between natural and social sciences research. However it is recognised that for effective marine management, the complexity of the system and the links between the environment and society must first be understood by managers, policymakers and stakeholders (**Beaumont et al., 2007**).

1.2 Development and application of the DAPSI(W)R(M) framework

The DPSIR (*Drivers-Pressures-State changes-Impacts-Responses*) framework can be used as a problem structuring method (**Gregory et al., 2013**) which captures the key relationships between society and the environment (**Atkins et al., 2011a**). Developed from an OECD approach which aimed to link anthropogenic *Pressures* with *State changes* and *Impacts* (OECD, 1994), the DPSIR framework encompasses the *Drivers*, which are the key demands by society and creates *Pressures* (the causes of the problems), and recognises that *State changes* (the change in background environmental status) and *Impacts* (the changes in human welfare) then require management *Responses* from society (Figure 2).

The importance of feedback loops between the management *Responses* and the *Drivers* and *Pressures* is recognised, in addition to the effect of natural change on the system (Elliott, 2011). Applying the DPSIR framework to marine management is therefore consistent with the ecosystem approach (**Cooper et al., 2013**). In applying this approach, **Atkins et al. (2011a)** emphasise the importance of defining the boundary of the system being modelled as this has implications for what is being included in the evaluation and what is not, for example the boundary could encompass a particular sector such as the marine aggregates industry or could cover a geographical location such as the management of a marine protected area.

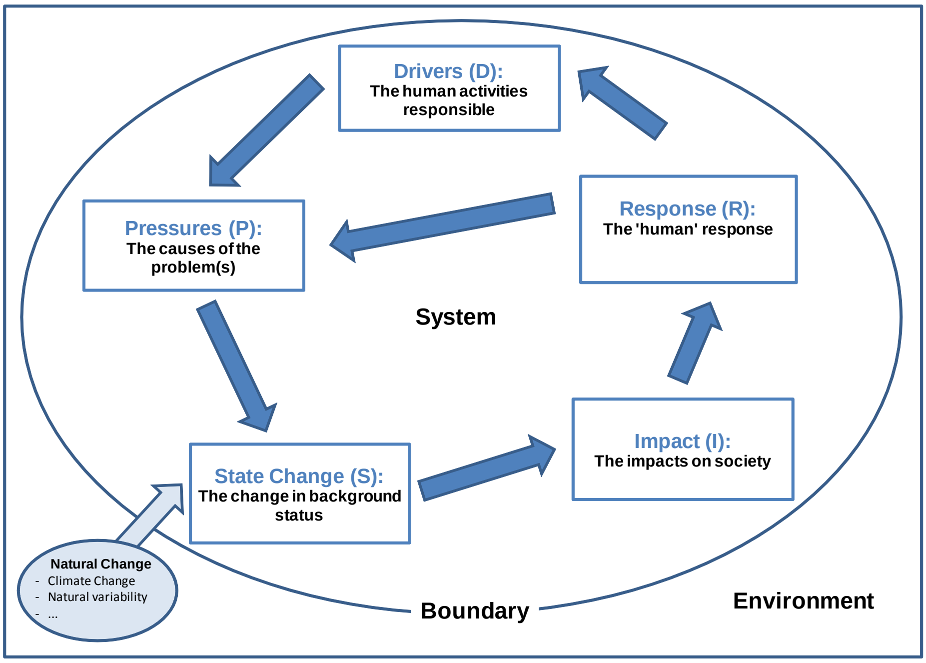


Figure 2: The DPSIR framework as a cycle and system in the environment (**Atkins et al., 2011a**).

The DPSIR framework has been adopted by the European Environment Agency and others over the last 17 years (e.g. EEA, 1999; Elliott, 2002; Borja et al., 2006; Maxim et al., 2009; Gray & Elliott, 2009) and more recently has been successfully applied by the author to a number of marine sectors. For example, the DPSIR framework has been applied to the management of the UK marine aggregates industry (Figure 3 below and further discussion in **Cooper et al., 2013**, Annex 3). The arrows (or arcs) illustrate linkages and the direction of effect between the various boxes (or nodes). A second sectoral example is presented and discussed in the context of coastal commercial fisheries (Fig. 2 in **Gregory et al., 2013**, Annex 3). Of note, the DPSIR cycle for coastal commercial fisheries has been taken a stage further by identifying root nodes (those which have many outgoing arcs and which consequently may be the source of multiple effects), central nodes (those which have many incoming and outgoing arcs and therefore may be the source of multiple effects) and end of chain nodes (those which have many incoming arcs and thus may be the point at which effects become visible). By further developing the DPSIR model in this way, pivot points can be highlighted which can be of value when trying to manage the marine environment.

In a further development, it was proposed by Cooper (2013) that DPSIR should be modified as DPSWR (*Drivers-Pressures-State changes-Welfare-Responses*), in order to avoid potential confusion between the impacts on the environment i.e. *State changes* within the basic form of DPSIR and the impacts on human *Welfare* i.e. *Impacts* in its basic form. Such a distinction was recently taken forward by the UK National Ecosystem Assessment Follow-On (UKNEAFO) project which refers to the application of a DPSWR model for the coastal and marine environment (**Turner et al., 2014; Turner et al., 2015**). In a further modification, following Elliott (2014), **Smyth et al. (2015)** propose that DPSWR should become DAPSI(W)R (*Drivers-Activities-Pressures-Impacts on Welfare-Responses*) thus recognising that it is *Activities* that cause *Pressures* not the *Drivers* themselves, and that *Impacts* are on *Welfare*. This modified DAPSI(W)R framework was applied in the context of the UK offshore wind energy development sector, with the focus on decommissioning as a management *Response* (Figure 4 below and text in **Smyth et al., 2015**, Annex 3).

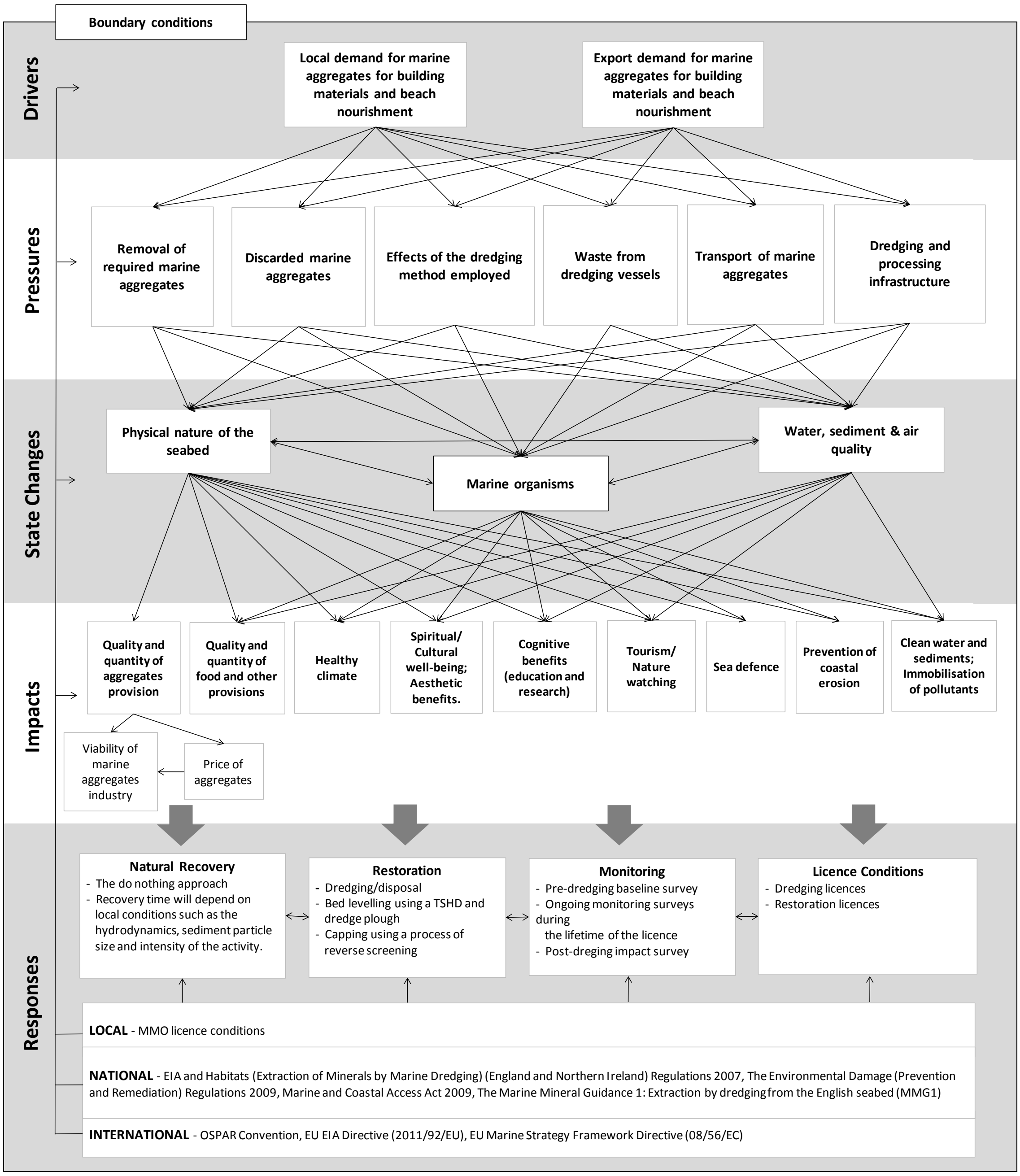


Figure 3: A DPSIR framework for the management of the UK marine aggregates extraction industry (**Cooper et al., 2013**).

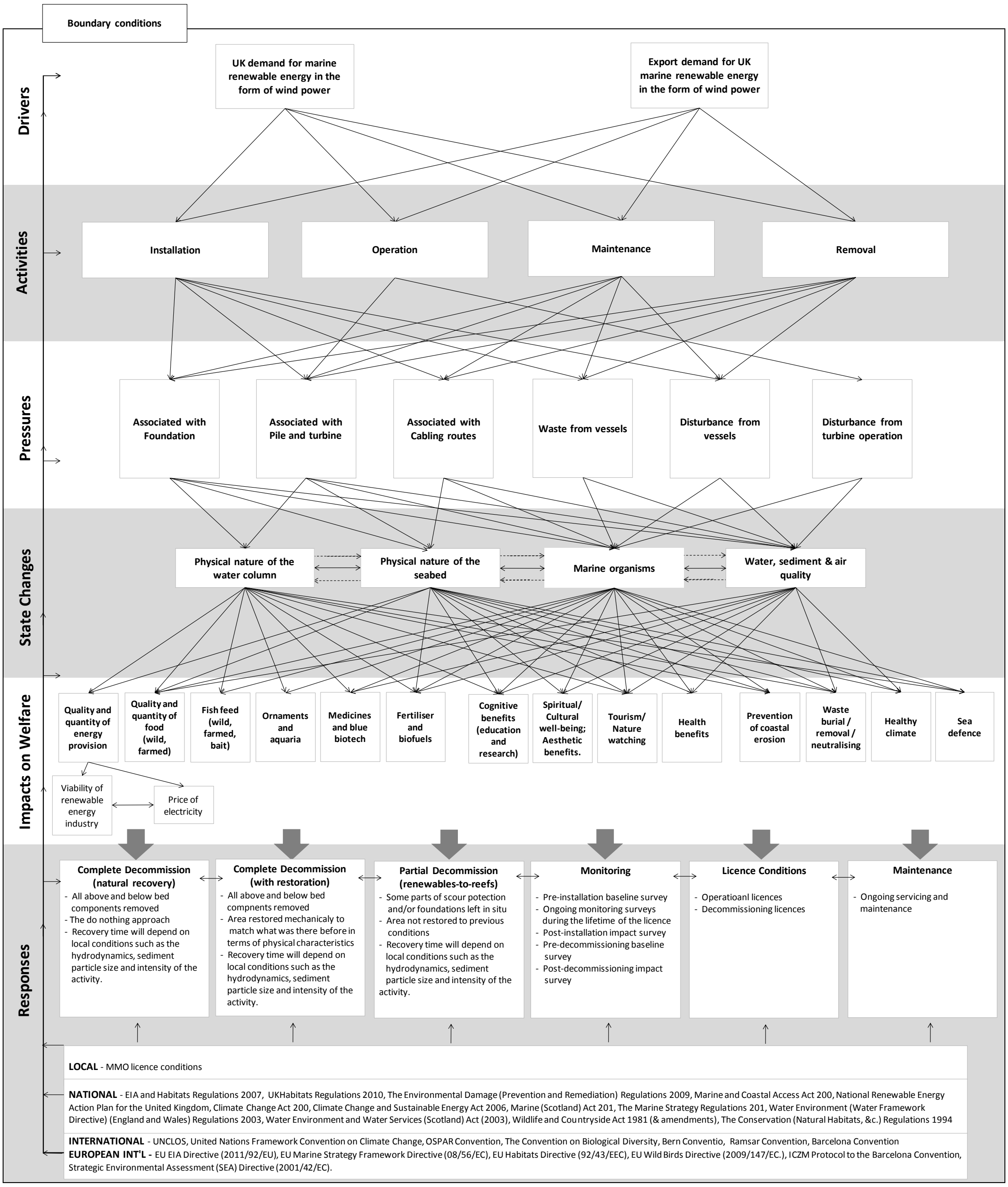


Figure 4: A DAPSI(W)R framework for the management of UK offshore wind energy development (**Smyth et al., 2015**).

Although initially developed on a sectoral basis, as demonstrated above, the requirement for a DPSIR model which represents multiple sectors would be required to truly embrace the ecosystem approach. The complexity of the marine environment can be illustrated by the multiple interactions which exist between various *Drivers*, *Pressures*, *State changes*, *Impacts* and *Responses* (Fig. 2 in **Atkins et al., 2011a**, Annex 3). This figure reflects the many competing uses of the marine environment and that each activity has the potential to effect other activities. For example, regulating fishing activity as a management *Response* to overfishing within a commercial fishing DPSIR model will influence the aquaculture DPSIR model.

This has been further illustrated in the case of the integrated management of the Flamborough Head European Marine Site (EMS). This coastal site has multi-user characteristics, with the site supporting a number of commercial sectors including fishing, tourism and recreation, waste disposal, and aggregate extraction, which all have to be managed within the regulations of the EMS designation (Stockdale, 2007). The integrated management of the site can be represented conceptually using what has been termed as a nested-DPSIR framework (Fig. 6 in **Atkins et al., 2011a**, Annex 3).

Building on the nested-DPSIR approach presented in **Atkins et al. (2011a)**, the recent DAPSI(W)R framework proposed by **Smyth et al. (2015)** and the DAPSI(W)R(M) framework given in Wolanski and Elliott (2015), which incorporates *Responses* (as *Measures*), a nested-DAPSI(W)R(M) framework could thus be developed for the integrated management of the marine environment (Figure 5 and Figure 6; **Elliott et al., in prep.**). This emphasises the importance of the relationships between competing uses of the marine environment, represented by the *Activities*, and their associated *Pressures* within each DAPSI(W)R(M) cycle. Following Elliott (2011), the nested-DAPSI(W)R(M) model presented here specifically recognises the impact of Exogenic Unmanaged Pressures (ExUP) and Endogenic Managed Pressures (EnMP) on the system. The former (ExUP) are those pressures considered outside the boundary of the model which cannot be managed, but for which we have to respond to the consequences of the pressure, such as climate change. The latter (EnMP) are those pressures which are within the boundary of the DAPSI(W)R(M) model and are considered to be manageable by society, for example management of the impacts of a particular sector such as commercial fisheries.

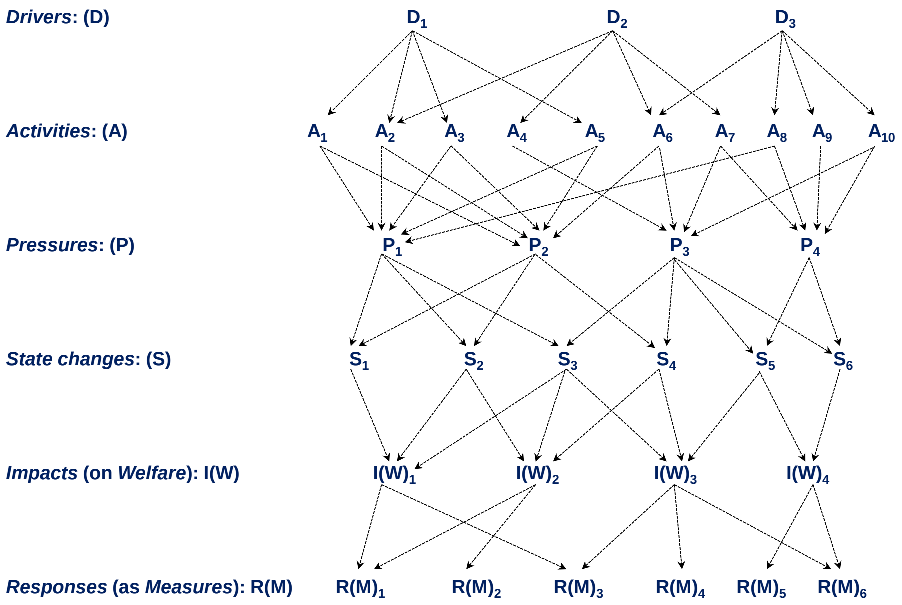
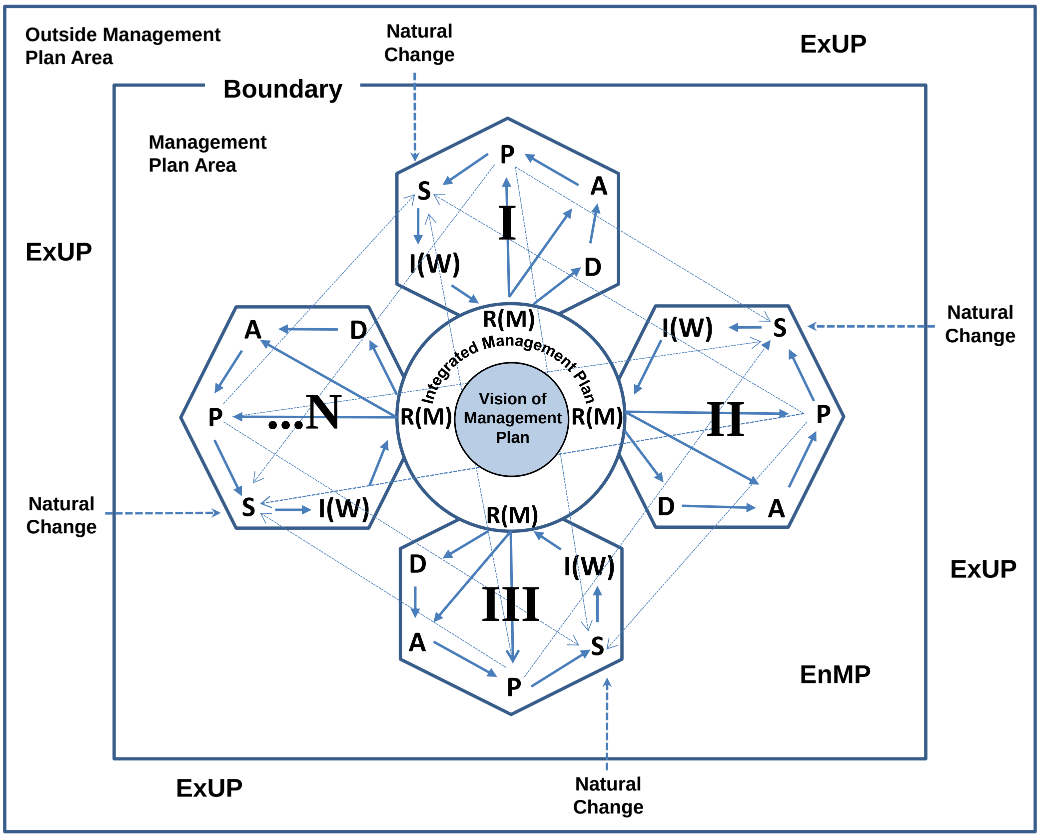


Figure 5: An illustration of the multiple interactions within the DAPSI(W)R(M) framework (**Elliott et al., in prep.**).



Key: D=*Drivers*; A=*Activities*; P=*Pressures;* S=*State changes;* I(W)=*Impacts* (on *Welfare*); R(M)=*Responses* (as *Measures*); ExUP=Exogenic Unmanaged Pressures; EnMP=Endogenic Managed Pressures; I, II, III,…N=Different marine sectors (e.g. commercial fisheries, aquaculture, recreation, industry, tourism, etc.).

Figure 6: A nested-DAPSI(W)R(M) framework for the integrated management of the marine environment (**Elliott et al., in prep.**).

1.3 Development of marine ecosystem service frameworks and indicators

There has been a growing interest in ecosystem services research since the work of Costanza et al. (1997) which attempted to value the world's ecosystem services and natural capital. One of the earliest definitions of ecosystem services was provided by Daily (1997) who defined ecosystem services as the '*conditions and processes through which natural ecosystems, and the species they include, sustain and fulfil human life*'. A number of definitions have since been proposed, for example:

- '*the outputs from ecosystems from which people and society derive benefits*' by the Millennium Ecosystem Assessment (MA, 2005);
- '*the direct and indirect benefits people obtain from ecosystems*' (**Beaumont et al., 2007**);
- '*the aspects of ecosystems utilised (actively or passively) to produce human well-being*' (Fisher et al., 2009);
- '*the link between ecosystems and things that humans benefit from, not the benefits themselves'* (Luisetti et al., 2011), and
- 'the benefits people obtain from ecosystems' by the UK National Ecosystem Assessment Follow-On project (UKNEAFO, 2014).

To date, there has been no agreed definition of ecosystem services, however following the work of Fisher et al. (2009) and Luisetti et al. (2011) ecosystem services are defined here as '*the link between ecosystems and the benefits that they provide for society*' recognising that ecosystem services are different to the benefits provided by the ecosystem which are valued by society.

It is suggested that once the ecological system (incorporating both the physico-chemical and biological aspects) is fully functioning then the system will provide a wide range of ecosystem services which in turn provide benefits for society (**Atkins et al., 2011a**). Ecosystem services are thus represented by the *State changes* to *Impacts* (*on Welfare*) link in the DAPSI(W)R(M) framework (Section 1.2 above). Therefore the application of an ecosystem services framework forms a key element of applying the ecosystem approach to marine management (**Atkins et al., 2011a**).

Taking the Millennium Ecosystem Assessment (MEA) as a starting point (MA, 2005), the development and application of a number of ecosystem service frameworks in the marine environment are discussed. A comparison of the ecosystem service frameworks are presented in Table 2. The frameworks developed within the featured papers and book chapters of this thesis are highlighted in bold.

The MEA identifies four categories of ecosystem services (MA, 2005):

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

As an indication of the evolution of the terms **Beaumont et al. (2007)**, informed by de Groot et al. (2002) and others, 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. (2007)** introduce a further category, ‘Option use values’, to those of the MEA (Table 2). Thus, their assessment framework comprises:

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

Fisher et al. (2009) 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 evaluation (**Atkins et al., 2011a**); the issue of double counting is further discussed in Section 1.4 below.

Table 2: Ecosystem service frameworks (table created for this thesis).

Paper	MA (2005) Millennium Ecosystem Assessment	**Beaumont et al. (2007) Marine biodiversity across Europe**	de Groot et al. (2010) The Economics of Ecosystems and Biodiversity (TEEB)	**Atkins et al. (2011a) Management of the marine environment**	Mace et al. (2011) UK NEA - generic framework (Final Ecosystem Services)	**Potts et al. (2014) VNN - marine framework (Goods/Benefits)**	**Turner et al. (2015) UK NEAFO - marine framework (Goods/Benefits)**	**Hattam et al. (2015a) VECTORS - marine framework**
Production Services	Food provision	Food provision	Food	Food provision	Crops, livestock, fish	Food	Food (wild, farmed)	Food provision (wild capture sea food)
								Food provision (farmed sea food)
	Fibre	Raw materials	Raw materials	Raw materials	Trees, standing vegetation, peat	Fish feed	Fish feed (wild, farmed, bait)	Other biotic raw materials
	Biochemicals / medicines		Medicinal resources		Wild species diversity (bioprospecting, medicinal plants)	Medicine and blue biotechnology	Medicines and blue biotechnology	Medicinal resources
	Genetic resources		Genetic resources					Genetic resources
	Ornamental resources		Ornamental resources			Ornaments (incl. aquaria)	Ornaments and aquaria	Ornamental resources
	Fuel					Fertiliser	Fertiliser and biofuels	
				Energy (wave & tidal)				
			Water (e.g. for drinking, irrigation, cooling)	Residential and industrial water supply	Water supply			
				Transport and navigation				
Regulating Services	Air quality and climate regulation	Gas and climate regulation	Climate regulation	Gas and climate regulation	Climate regulation	Healthy climate	Healthy Climate	Climate regulation
			Air quality regulation					Air purification
	Erosion control	Disturbance prevention	Erosion prevention	Disturbance prevention	Hazard regulation	Prevention of coastal erosion	Prevention of coastal erosion	Disturbance prevention or moderation
			Moderation of extreme events (storm protection, flood prevention)			Sea defence	Sea defence	Coastal erosion prevention
	Bioremediation of Waste	Bioremediation of Waste	Waste treatment (esp. water purification)	Bioremediation of Waste	Detoxification and purififcation in soils, air and water	Clean water and sediments	Waste burial / removal / neutralisation	Waste treatment and assimilation
	Water purification / detoxification					Imobilisation of pollutants		
	Water regulation and natural hazard protection		Regulation of water flows					Regulation of water flows
			Maintenance of soil fertility					
			Pollination		Pollination			
			Biological control		Disease and pest regulation			Biological control
Cultural Services	Spiritual and religious values	Cultural heritage and identity	Spiritual experience	Cultural heritage and identity	Environmental settings (spiritual/religious)	Spiritual / cultural well-being	Spiritual and cultural well-being	Spiritual experience
	Cultural heritage							Cultural heritage
								Cultural diversity
		Cognitive benefits	Information for cognitive development	Cognitive benefits		Education	Education, research	Information for cognitive development
	Recreation / tourism	Leisure and recreation	Opportunities for recreation & tourism	Leisure and recreation	Wild species diversity (recreation)	Tourism/nature watching	Tourism and nature watching	Leisure, recreation and tourism
					Environmental settings (recreation/tourism)			
		Feel good or warm glow		Feel good or warm glow				
	Inspiration		Inspiration for culture, art and design					Inspiration for culture art and design
	Aesthetic value		Aesthetic information			Aesthetic benefits	Aesthetic benefits	Aesthetic experience
	Social relations							
							Health benefits	
Option-use		Future unknown & speculative benefits		Future unknown & speculative benefits				
Habitat / Supporting Services		Resilience and resistance		Resilience and resistance				
		Biologically mediated habitat		Biologically mediated habitat				
	Biogeochemical cycling (nutrients, oxygen, water)	Nutrient cycling		Nutrient cycling	Nutrient cycling			
					Water cycling			
	Habitat			Physical habitat	Soil formation			
	Primary production				Primary production			
			Maintenance of life cycles of migratory species					Migratory and nursery habitat
			Maintenance of genetic diversity					Gene pool protection

In the UK, this distinction has been taken forward by the UK National Ecosystem Assessment (UKNEA) which focused on the processes that link human society and well-being to the natural environment (UKNEA, 2011). This national level assessment applied a generic ecosystem services framework to a wide range of terrestrial (mountains, moorlands & heaths, semi-natural grasslands, enclosed farmland, woodlands, and urban) and aquatic habitats (freshwaters, coastal margins, and marine) (UKNEA, 2011). Although this generic ecosystem services framework was applied to both coastal margins and marine ecosystems (UKNEA, 2011), it was specifically modified for the marine environment under the NERC-funded Valuing Nature Network coastal management project (**Potts et al., 2014**) and workshops within the UKNEAFO project, (**Turner et al., 2014**) (Table 2). The final UKNEAFO framework is presented in Figure 7, with a set of guiding notes and definitions provided in **Turner et al. (2015)** (Annex 4).

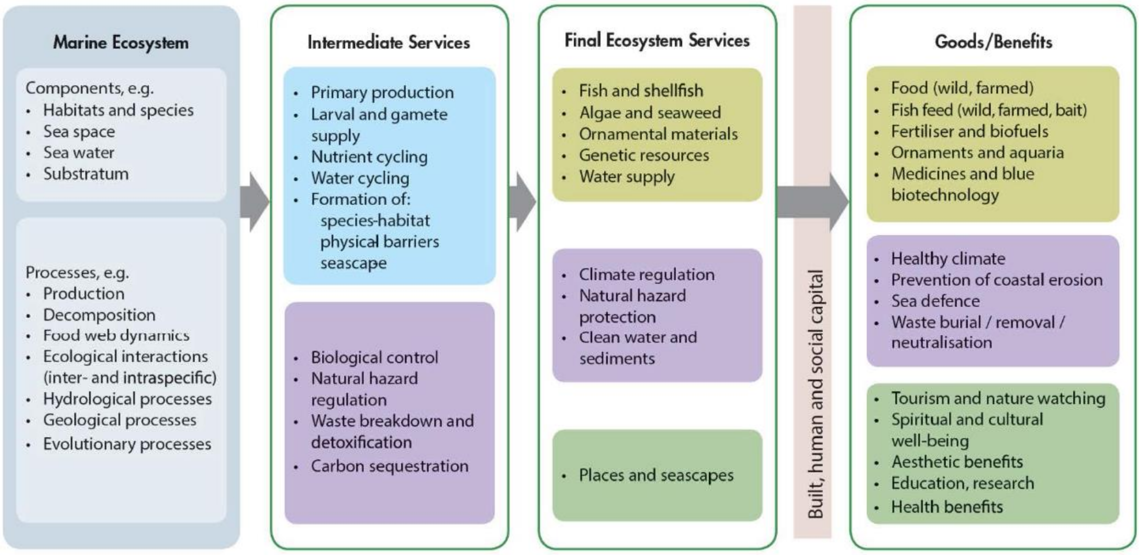


Figure 7: Ecosystem service classification (**Turner et al., 2015**).

Within Europe, The Economics of Ecosystems and Biodiversity (TEEB) project proposed an alternative ecosystem services framework (de Groot et al., 2010). This generic framework was based upon a conceptual model adapted from Haines-Young and Potschin (2010) and Maltby (2009) and, similarly to the MEA and UKNEA frameworks, was applied to a range of ecosystems (including marine/open ocean, coastal systems, wetlands, rivers/lakes, forest, deserts and urban areas). The pathway from ecosystem structure and processes to human well-being is illustrated in Figure 8 with a full list of the 22 main ecosystem service types provided in Table 2 above. It is of note that the TEEB framework does not include supporting services, however introduces a further category, 'habitat services', which comprises the maintenance of migratory species life cycles and genetic diversity (de Groot et al., 2010).

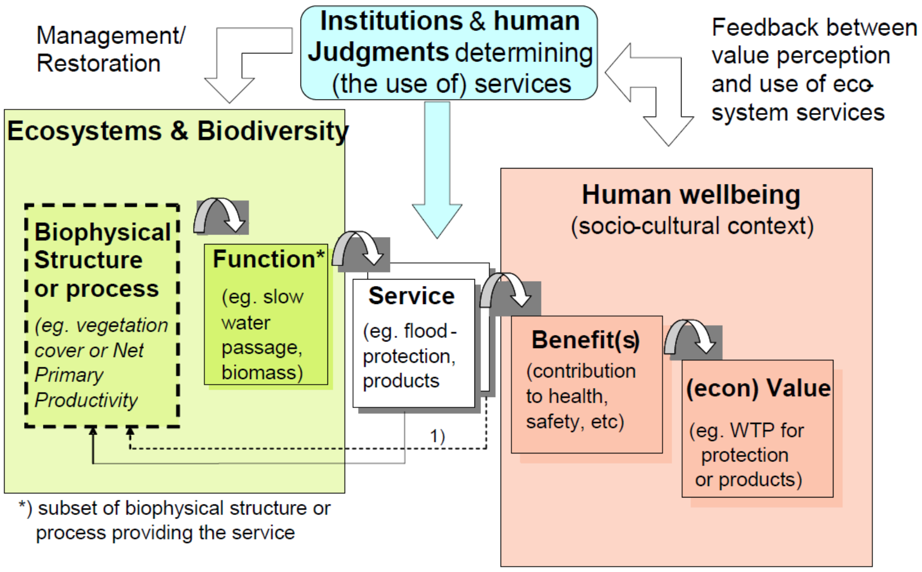


Figure 8: The TEEB pathway from ecosystem structure and process to human well-being (de Groot et al., 2010).

The TEEB approach was further modified for use in the EU FP7-funded VECTORS project (http://www.marine-vectors.eu/) for its specific application in the marine environment (**Hattam et al., 2015a**). The full list of marine ecosystem services is provided in Table 2, and was applied to a number of studies in relation to the Dogger Bank (**Hattam et al., 2014, 2015 a, b**; **Börger et al., 2014**; **Burdon et al., in press**).

Given the complexity of the marine environment (Gibbs & Cole, 2008) and the need for integrated management, indicators are required to provide insight into the behaviour and state of coastal and marine ecosystems, together with an indication of the trajectory of change due to natural and human events (Elliott, 2011; **Atkins et al., 2015**). It has been suggested that indicators have three basic functions: to simplify, to quantify and to communicate (Aubry & Elliott, 2006). Indicators can therefore be used to reflect the state of the science of an area (**Atkins et al., 2015**) and provide a useful tool for supporting management decisions (**Hattam et al., 2015a**).

A practicable set of ecosystem service indicators was proposed by **Atkins et al. (2015)** that meet operational requirements and are grounded within the UKNEAFO marine ecosystem services framework (Figure 7). The full list of indicators, including examples of national-level data sources available to support indicator use are presented in Annex 4 (Table 5.1 in **Atkins et al., 2015**). A generic application of these indicators is provided for fisheries and aquaculture, and carbon sequestration and storage. In addition, case studies are presented in relation to marine protected areas and managed realignment sites which demonstrate the importance of site-specific data sources.

Using a similar approach, **Hattam et al. (2015a)** identify a comparative suite of ecosystem service indicators. This study also highlights the need to identify indicators of ecosystem processes, ecosystem services, and ecosystem benefits (Tables 2-4 in **Hattam et al., 2015a**, Annex 3). Each indicator was assessed for its relevance and applicability to the environmental management of the Dogger Bank (North Sea) using an agreed set of criteria, including measurability, sensitivity, specificity, scalability and transferability. A number of challenges faced when selecting meaningful indicators are discussed, including problems associated with specificity, spatial disconnect and the considerable uncertainty about marine species, and the processes, functions and services they contribute to. A wider discussion and critique of the UKNEAFO (**Turner et al., 2015**) and VECTORS (**Hattam et al., 2015a**) ecosystem service frameworks and their associated ecosystem service indicators is provided in Chapter 2.

1.4 Applications of marine ecosystem service approaches and valuation

Since marine ecosystem services have the potential to lead to benefits for society it is appropriate to consider and determine their value (**Atkins et al., 2011a**; **Cooper et al., 2013**). In this context, value can be defined in terms of ecological value (the health of the system measured using ecological indicators), economic value (including both use and non-use values identified using market or non-market techniques) and/or socio-cultural value (for example relating to cultural identity and the degree to which that is related to ecosystem services) (MA, 2003). The concept of 'total social value' can be used to incorporate the views of society and their values associated with ecosystem service provision into the decision making process in order to determine policy options and management measures and comprises these three domains (Figure 9). Although ecological valuation does not feed directly into total social value, it does provide the basis for both assessments of economic value and socio-cultural value.

There has been an increasing attention given to ecosystem service valuation in science and this has recently been followed by an uptake and use by stakeholders. At the EU-level, an assessment of the value of ecosystem services is called for under the EU 2020 Biodiversity Strategy which emphasises the need '*to value ecosystem services and to integrate these values into accounting systems as a basis for more sustainable policies*'. The EU's Water Framework Directive (WFD) and MSFD also both explicitly call for the integration of valuation into environmental management processes. In the UK, valuation studies of ecosystem services have been commissioned by Defra (Beaumont et al., 2006), the Crown Estate (Saunders et al., 2010), the Wildlife Trusts (Fletcher et al., 2012a) and the Northern Ireland Marine Task Force (**Barnard et al., 2014**).

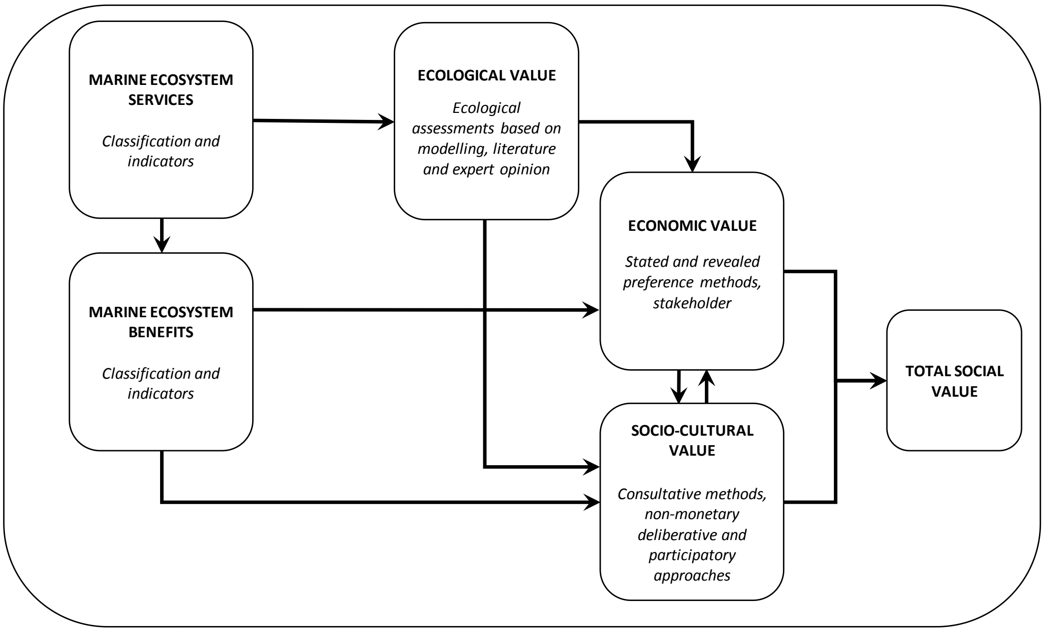


Figure 9: Valuation of marine ecosystem services (**Burdon et al., in press**).

The framework presented above (Figure 9) was developed and applied to a number of valuation studies assessing the current value of ecosystem services provision on the transnational Dogger Bank in the North Sea and how this might change in the future. These studies identified ecosystem service indicators (**Hattam et al., 2015a**), quantified changes in ecosystem service provision (**Hattam et al., 2014**), undertook an economic valuation using an online discrete choice experiment (**Börger et al., 2014**) and implemented a deliberative valuation workshop which focussed on socio-cultural value of the Dogger Bank based on the citizen jury method (**Hattam et al., 2014**). An assessment of the complementarities of these three approaches for valuing ecosystem services provided by the Dogger Bank has recently been undertaken (**Hattam et al., 2015b**) and is further discussed in Chapter 2.

The UK Government Department for Environment, Food and Rural Affairs propose a five-stage process for valuing ecosystem services under different policy options (Defra, 2007). These stages are outlined below, including a summary of the data requirements (Figure 10). Where primary data on marine ecosystem services cannot be obtained, a qualitative assessment for each ecosystem service might be undertaken based on evidence drawn from the literature and databases, and on expert judgement, including that elicited through focus groups and at stakeholder meetings (**Atkins et al., 2013**). This approach has been applied to assess policy options associated with seabed restoration and management responses for decommissioning offshore wind farms (Table 5 in **Cooper et al., 2013**, Annex 3 and Table 2 in **Smyth et al., 2015**, Annex 3).

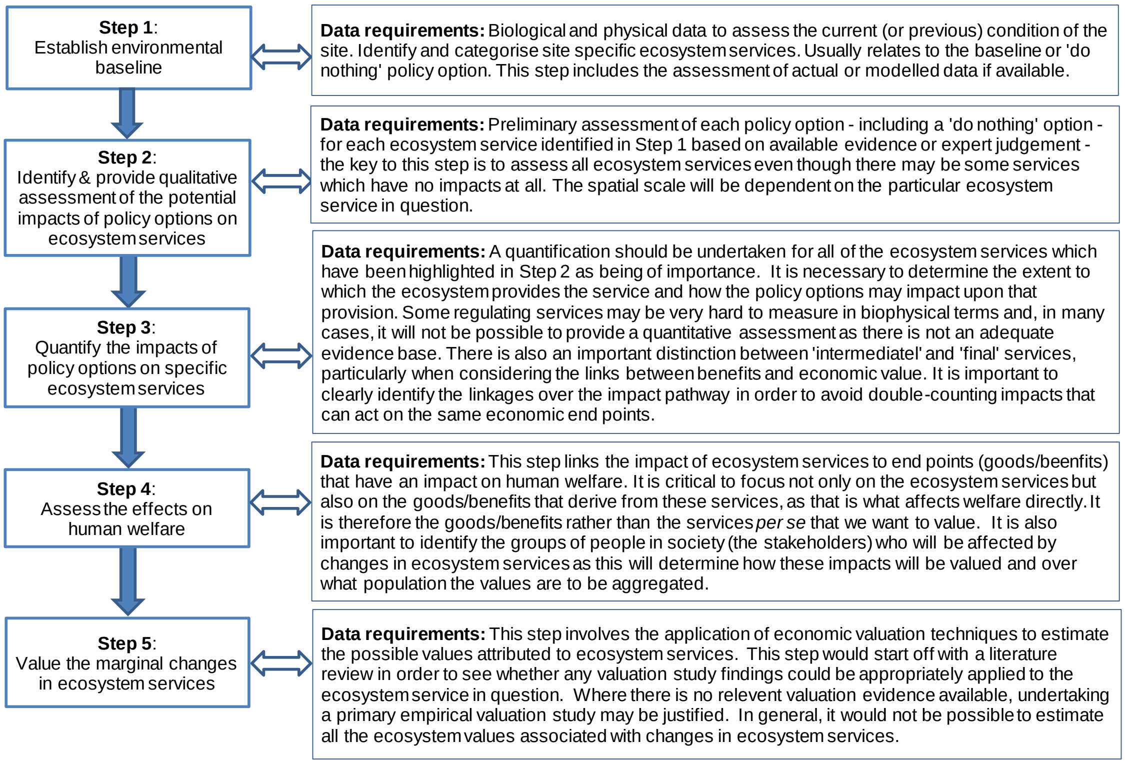


Figure 10: Evaluation of policy options using an ecosystem services approach (adapted from Defra, 2007 by **Atkins et al., 2011b**).

As part of the NERC-funded Valuing Nature Network programme, a desk-based study was undertaken to examine the potential relationships between the provision of coastal ecosystem services and the designation of marine protected areas (**Potts et al., 2014**). This study, building on the earlier work of Fletcher et al. (2012b), identified the relative importance of a range of UK protected habitats and species in ecosystem service provision. This structured assessment, based on evidence from the literature and expert opinion, enabled assessments to be undertaken on the potential additional goods/benefits provided by a range of existing UK marine protected areas (**Potts et al., 2014**, Annex 3). As a result of developments in the ecosystem service framework the matrices were further developed to include both physical and psychological health benefits, and designated features in Northern Irish waters (**Saunders et al., 2015**, Annex 4). The revised matrices are presented below for habitats (Figure 11) and species (Figure 12). Such an assessment provides a useful qualitative tool to assess wider benefits provided by existing and future MPAs. The potential for future development of this approach is discussed in Chapter 2.

Feature Type†	EUNIS code Note: Eunis codes were identified using the JNCC EUNIS translation matrix. Some habitats do not have a direct relationship to the EUNIS code and this column should only be used as a guide.	Feature (Bold type represents Broadscale habitats, normal type represents habitat FOCI)	Primary production	Larval and gamete supply	Nutrient cycling	Water cycling	Formation of species habitat	Formation of physical barriers	Formation of seascape	Biological control	Natural hazard regulation	Waste breakdown and detoxification	Carbon sequestration	Food (wild, farmed)	Fish feed (wild, farmed, bait)	Fertiliser and biofuels	Ornaments and aquaria	Medicines and blue biotechnology	Healthy climate	Prevention of coastal erosion	Sea defence	Waste burial / removal / neutralisation	Tourism and nature watching	Spiritual and cultural well-being	Aesthetic benefits	Education and Research	Physical health benefits	Psychological health benefits
			Intermediate services											Goods/Benefits														
			Supporting services							Regulating services				from Provisioning services					from Regulating services				from Cultural services					
Existing Habitats protected under EU legislation																												
E,EU,W	A1.1	**High energy intertidal rock**	3	2	3	1	2	4	1		1	1	2	3	1	1			2	1	1	1	1	1	1	1	2	1
E,EU,W	A1.2	**Moderate energy intertidal rock**	3	2	3	1	2	4			1	1	2	3	1	1			2	1	1	1	1	1	1	1	2	1
E,EU,W	A1.3	**Low energy intertidal rock**	3	2	3	1	2	4			1	1	2	3	1	1			2	1	1	1	1	1	1	1	1	1
E,W	A2.2	**Intertidal sand and muddy sand**	3	3	3	1	3	1	3		3	1	2	1	2	1			2	3	3	1	1	1	3	1	3	3
E,W	A2.3	**Intertidal mud**	3	3	3	1	1	1	1		3	3	3	3	3	1			3	3	3	3	1	1	1	1	1	1
E,EU	A2.4	**Intertidal mixed sediments**	3	3	3	1	3	1	1		3	1	2	1	2	1			2	3	3	1	1	1	1	1		
E	A2.5	**Coastal saltmarshes and saline reedbeds**	2	3	3	1	3	3	3		3	3	3	3	1	3			3	3	3	3	3	1	3	1	1	1
EU,E,W	A2.6	**Intertidal sediments dominated by aquatic angiosperms**	2		3	1	2	1	1		1	3	1	3	1	3			1	1	1	1	1	1		1		
EU,E,W	A2.7	**Intertidal biogenic reefs**	1	1	2	1	3	1	1		2	1	1	2	2	2			1	2	2	2	1	1		1		
EU,E,W	A3.1	**High energy infralittoral rock**	2	2		1	2	4			1	1		3	1	1				1	1	1	1	1		1	1	
EU,E,W	A3.2	**Moderate energy infralittoral rock**	2	2		1	2	4			1	1		3	1	1				1	1	1	1	1		1	1	
EU,E,W	A3.3	**Low energy infralittoral rock**	2	2		1	2	4			1	1			1	1				1	1	1	1	1		1	1	
EU,E,W	A4.1	**High energy circalittoral rock**	2	2		1	2	1			1	1		1	1	1				1	1	1	1	1		1	1	
EU,E,W	A4.2	**Moderate energy circalittoral rock**	2	2		1	2	1			1	1		1	1	1				1	1	1	1	1		1	1	
EU,E,W	A4.3	**Low energy circalittoral rock**	2	2		1	2	1			1	1		1	1	1				1	1	1	1	1		1	1	
S	A5.1, A5.2	**Offshore subtidal sands and gravels**	1	1	1	1	1	1		1	1	1	1	1	3	1	1	1	1	1	1	1	1	1		1		
E,W	A5.2	**Subtidal sand**	3	3	3	1	3	1			3	1		2	3	1				3	3	1		1		1		
EU,E,W	A5.4	**Subtidal mixed sediments**	3	3	3	1	3	1			3	3		2	3	1				3	3	3		1		1		
EU,E,W	A5.5	**Subtidal macrophyte-dominated sediment**	3	2	2	1	2	1			1	2	2	3	1	3			2	1	1	2	1	1		1		
EU,E,W	A5.6	**Subtidal biogenic reefs**	1	2	3	1	2	1			3	3	1	3	1	2	1		1	2	2	1	1	1		1		
EU	X02	**Saline lagoons**		3	3	1	3		1					1	1	1							1	1		1	1	
EU, E, NI	A1.32	Estuarine rocky habitats	1	1		1	2	1	1		1	1		1	1					1	1	1	1	1	1	1	1	
EU	A1.44	Submerged or partially submerged sea caves				1	1	1	1		1	1	1		1	1			1	1	1	1	1	1		1		
E,W, NI	A4.12	Fragile sponge&anthozoan communities on subtidal rocky habitats		1		1	3	1		1	1	1		3	1	1				1	1	1	3	1		1	1	
W	A4.131, A4.2122	Subtidal rock with Ross 'coral' *Pentapora foliacea*		1		1	2	1		1		1		1	1	1						1	3	1		1	1	
E	A4.22	Ross worm *Sabellaria spinulosa* reefs		1	1	1	3	1		1	1	1	1	1	1				1	1	1	1	1	1		1		
All	A5.51	Maerl beds	3	1	1	1	3	1	1	1				3	1	1	1						1	1	1	1		1
S	A5.5112	Maerl or coarse shell gravel with burrowing sea cucumbers	3	1	1	1	3	1	1	1				3	1	1	1						1	1		1		
All	A5.53, A5.545, A2.61	Seagrass beds	2	1	2	1	3	1	1	2	1	2	2	3	1	2	2	1	2	2	2	2	2	1	2	1		
EU	A5.71	Submarine structures made by leaking gases			1	1	3	1			1	1	1	1	1	1		1	1	1	1	1		1		1		
New habitats proposed under new MPA legislation																												
E,W	A2.1	**Intertidal coarse sediment**	1	3	1	1	3	1	1		3	1		1	2	1	1			3	3	1	1	1	1	1	1	
E,W	A5.1	**Subtidal coarse sediment**	3	3	3	1	3	1			3	1		2	3	1				3	3	1		1		1		
E,W	A5.3	**Subtidal mud**	3	3	3	1	3	1			3	3		2	3	1				3	3	3		1		1		
W	A5.4, A5.3	**Subtidal mixed muddy sediments**	3	3	3	1	3	1			3	3		2	3	1				3	3	3		1		1		
S	A7.4, A7.7	**Salinity fronts**	1	1	1	1	1	1		1	1	2	1	1	1	1	1	1	1	1	1	2	1	1		1		
S	Various	**Low or variable salinity habitats**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	2	
E,W	A1.2142, A3.2112	Intertidal under boulder communities	1	1		1	2	1			1	1		2	1	1				1	1	1	1	1	1	1		
E	A1.127, A1.223, A4.231	Peat and clay exposures		1		1	2	1							1								1	1		1		
S	A1.325	Sea loch egg wrack beds	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1		
E	A1.441, B3.114, B3.115	Littoral chalk communities	1	1		1	3	1				1			1	1						1	1	1		1		
E,S,W, NI	A2.2, A2.7, A5.6	Blue Mussel beds	1	1	1	1	1	1	1	1	1	3	1	2	1	2	1	1	1	1	1	1	1	1		1		
NI	A2.23 or A5.2	Stable sands with associated fauna	1	1	1	1	2	2	2		3	1	1	1	2	1			1	1	1	1	1	1	1	1	1	
E,W	A2.71	Honeycomb worm *Sabellaria alveolata* reef		1	1	1	3	1		1	2	1	1	1	2				1	1	1	1	1	1		1		
S	A3.126, A3.213	Tide-swept algal communities (Laminaria hyperborea, Halidrys siliquosa)	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		
S	A3.126, A3.213, A1.15	Tide-swept algal communities	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		
S	A4.133, A4.211	Northern sea fan and sponge communities				1	1	1	1		1	1			1	1				1	1	1			1		1	
E	A4.23	Subtidal chalk		1		1	2	1				1			1	1						1	1	1	1	1		
E	A5.12, A5.13	Subtidal sands and gravels	1	1	1	1	2	1				1		2	3	1						1	1	1		1		
S	A5.133	Shallow tide-swept coarse sands with burrowing bivalves (Morella sp.)			1	1	1	1				1		1	1	1						1		1		1		
E,S, NI	A5.361	Sea-pen and burrowing megafauna communities	1	1	2	1	3	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1		
S	A5.371	Inshore deep mud with burrowing heart urchins	3	3	3	1	3	1			3	1		2	1	1				3	3	3		1		1		
W, NI	A6.5	Mud habitats in deep water	3	3	3	1	3	1			3	1		2	3	1				3	3	3		1		1		
E,W	A5.43, A2.41, A2.42	Sheltered muddy gravels		1	1	1	2	1				1	1	2	1	1			1			1	1	1		1		
E,S	A5.434	Flame/ File shell beds	1	1	3	1	3	1	1	1	3	1	1	3	1	1			1	1	1	1	1	1	1	1		
E,S,W, NI	A5.435	Native Oyster *Ostrea edulis* beds		1	1	1	1	1	1	1	1	1	1	3	1	1			1	1	1	1	1	1	1	1		
S	A5.52	Kelp and seaweed communities on sublittoral sediment	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
E,S,W, NI	A5.62	Horse mussel (Modiolus modiolus) beds	1	1	1	1	3	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1		
E, NI	A5.63	Cold-water coral reefs		1	1	1	2	3					1	1	1	1			1				1	1	2	1		
E,S	A6.61	Coral Gardens	1	1	1	1	3	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1	1	1		
S	A6.75	Carbonate mound communities	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1		
E,W	Various	Tide-swept channels		1		1	1	1			1				1	1				1	1		1	1		1		
W	Various	Sediment habitats with long lived bivalves			2	1	1	1		1		1		1	1	1						1	1	1		1		
E	N/A	Areas of high planktonic primary productivity	3	1	3	1	1	1		1	1		2	2	3	1			2	1	1	1	1	1		1		

Scale of ecosystem service supplied relative to other features

- # Significant contribution
- # Moderate contribution
- # Low contribution
- # No or negligible ESP
- Not assessed

Confidence in evidence

- 4 Obvious non-linkages
- 3 UK-related, peer-reviewed literature
- 2 Grey or overseas literature
- 1 Expert opinion or Obvious
- Not assessed

Feature type†

- S Scottish MPA search feature
- E English MCZ feature
- W Welsh HP MCZ feature
- NI Northern Ireland MCZ feature
- EU EU Habitats Directive Annex 1 feature or sub-feature

Figure 11: Relative importance of designated habitats in providing intermediate ecosystem services and goods/benefits (**Saunders et al., 2015**).

Feature Type †	Species Names	Scientific Name	Intermediate Services: Supporting services							Intermediate Services: Regulating services				Goods/Benefits: from Provisioning services					Goods/Benefits: from Regulating				Goods/Benefits: from Cultural services					
			Primary production	Larval and gamete supply	Nutrient cycling	Water cycling	Formation of species habitat	Formation of physical barriers	Formation of seascape	Biological control	Natural hazard regulation	Waste breakdown and detoxification	Carbon sequestration	Food (wild, farmed)	Fish feed (wild, farmed, bait)	Fertiliser and biofuels	Ornaments and aquaria	Medicines and blue biotechnology	Healthy climate	Prevention of coastal erosion	Sea defence	Waste burial / removal / neutralisation	Tourism and nature watching	Spiritual and cultural well-being	Aesthetic benefits	Education	Physical health benefits	Psychological health benefits
Existing species protected under EU legislation																												
EU	Allis shad	*Alosa alosa*	1	3	3	1		1			1	1	1	1	1	1			1	1	1	1	1			1	1	1
EU	Twaite shad	*Alosa fallax*	1	3	3	1		1			1	1	1	1	1	1			1	1	1	1	1			1	1	1
EU	Atlantic salmon	*Salmo salar*	1	3	3	1		1			1	1	1	3	1	1			1	1	1	1	3	1	2	1	1	1
EU	Sea lamprey	*Petromyzon marinus*	1	3		1		1	1	2	1	1	1	2	1	1			1	1	1	1	1			1	1	1
EU	River lamprey	*Lampetra fluviatilis*	1	3		1		1		2	1	1	1	2	1	1			1	1	1	1	1			1	1	1
EU	Grey seal	*Halichoerus grypus*	1			1	1	1	1		1	1	1	1	1	1	1		1	1	1	1	3		2	3	1	1
EU	Common seal	*Phoca vitulina*	1			1	1	1	1		1	1	1	1	1	1	1		1	1	1	1	3		2	3	1	3
EU, S	Bottlenose dolphin	*Tursiops truncatu*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	3	1	1	1
EU, S, NI	Harbour porpoise	*Phocoena phocoena*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	3	1	1	1
EU	Otter	*Lutra lutra*	1			1		1	1			1	1	1	1	1			1		1	1	3	3	1	3	1	1
New species proposed for protection under new MPAs - highly mobile																												
E	Smelt	*Osmerus eperlanus*	1	3		1		1			1	1	1	3		1	3		1	1	1	1	3	1		1	1	1
E	European eel	*Anguilla anguilla*	1	3	1	1		1			1	1	1	3		1	3		1	1	1	1	1	1	1	1	1	1
S	Blue ling	*Molva dypterygia*	1	1	1	1	1	1			1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1
S	Orange roughy	*Hoplostethus atlanticus*	1			1	1	1			1	1	1	2		1	1		1	1	1	1	1	1		1	1	1
S	Sandeels		1			1					1	1	1	1	3	1			1	1	1	1	1	1	1	1	1	1
NI	Sole	*Solea solea*	1	3		1		1			1	1	1	3		1			1	1	1	1	1	1			1	1
NI	Plaice	*Pleuronectes platessa*	1	3		1		1			1	1	1	3		1			1	1	1	1	1	1			1	1
E	Undulate ray	*Raja undulata*	1			1		1			1	1	1	1		1			1	1	1	1				1	1	1
NI	Spotted ray	*Raja montagui*	1	3		1		1			1	1	1	2		1			1	1	1	1	1	1			1	1
NI	Thornback ray	*Raja clavata*	1	3		1		1			1	1	1	2		1			1	1	1	1	1	1			1	1
NI	Cuckoo ray	*Leucoraja naevus*	1	3		1		1			1	1	1	2		1			1	1	1	1	1	1			1	1
S, NI	Common skate	*Dipturus batis*	1	1	1	1	1	1	1		1	1	1	3		1			1	1	1	1	1	1	1	1	1	1
S	Basking shark	*Cetorhinus maximus*	1	1	1	1	1	1	1		1	1	1	1		1	1	1	1	1	1	1	1	1	2	1	1	1
S	Minke whale	*Balaenoptera acutorostrata*	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	2	1	1	1	1	1
S	Risso's dolphin	*Grampus griseus*	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1
S	White-beaked dolphin	*Lagenorhynchus albirostris*	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1
New species proposed for protection under new MPAs - Low or limited mobility species																												
E, W	Peacock's tail	*Padina pavonica*	2		1	1	2	1			1			1		1		1		1	1					1	1	1
E, W	Burgundy maerl paint	*Cruoria cruoriaeformis*	1	1	1	1	1	1		1	1			1		1	1			1	1		1	1		1	1	1
E, W	Grateloup's little-lobed weed	*Grateloupia montagnei*	1	1	1	1	1	1		1	1			1		1	1			1	1		1	1		1	1	1
E, W	Coral maerl	*Lithothamnion corallioides*	3	1	1	1	3	1	1					3		1	1							1		1	1	1
E, W	Common maerl	*Phymatolithon calcareum*	3	1	1	1	3	1	1					3		1	1							1		1	1	1
W	Bearded red seaweed	*Anotrichium barbatum*	1			1		1			1			1		1				1	1			1		1	1	1
NI	A brown alga	*Ascophyllum nodosum ecad mackayii*	3		1		2	1			1					1				1	1						1	1
NI	A red alga	*Atractophora hypnoides*	3		1		2	1			1					1				1	1						1	1
E	Tentacled lagoon-worm	*Alkmaria romijni*	1			1		1			1		1	1		1			1	1	1			1		1	1	1
E	Lagoon sandworm	*Armandia cirrhosa*	1			1		1			1		1	1		1			1	1	1			1		1	1	1
E	Giant goby	*Gobius cobitis*	1			1		1			1		1	2		1			1	1	1		1			1	1	1
E	Couch's goby	*Gobius couchi*	1			1		1			1		1	3		1			1	1	1		1			1	1	1
E	Long snouted seahorse	*Hippocampus guttulatus*	1	3		1		1	1		1		1	2		1	1	1	1	1	1		1	3		3	1	3
E	Short snouted seahorse	*Hippocampus hippocampus*	1	3		1		1	1		1		1	2		1	1	1	1	1	1		1	3		3	1	3
E	Trembling sea mat	*Victorella pavida*	1			1		1			1			1		1				1	1			1		1	1	1
NI	Ross coral / Potato crisp bryozoan	*Pentapora foliacea*	1			1	2	1	2		1					1				1	1		1				1	1
NI	Football sea squirt	*Diazona violacea*	1			1	2	1	2		1		1			1			1	1	1		1				1	1
S, W	Burrowing sea anemone aggregations	*Arachnanthus sarsi*	1		1	1	1	1			1		1	1		1			1	1	1		1	1		1	1	1
E	Sea-fan anemone	*Amphianthus dohrnii*	1			1	1	1	1		1		1	1		1			1	1	1			1		1	1	1
E,W	Pink sea-fan	*Eunicella verrucosa*	1			1	1	1	1		1		1	1		1			1	1	1		1	1		3	1	1
E,W	Kaleidoscope jellyfish	*Haliclystus auricula*	1			1		1			1		1	1		1			1	1	1					1	1	1
E	Sunset cup coral	*Leptopsammia pruvoti*	1			1	2	1	1		1			1		1				1	1		3			1	1	1
E,W	Stalked jellyfish	*Lucernariopsis campanulata*	1			1		1			1			1		1				1	1					1	1	1
E	St. John's jellyfish	*Lucernariopsis cruxmelitensis*	1			1		1			1			1		1				1	1					1	1	1
E	Starlet sea anemone	*Nematostella vectensis*	1			1		1			1			1		1				1	1					2	1	1
E	Lagoon sand shrimp	*Gammarus insensibilis*	1			1		1			1		1	1		1			1	1	1					1	1	1
E	Gooseneck barnacle	*Pollicipes pollicipes*	1			1	3	1	1		1		1	3		1			1	1	1		1			1	1	1
E, S	Spiny lobster	*Palinurus elephas*	1	1	1	1	1	1	1		1	1	1	3		1	1	1	1	1	1	1	1	1	1	1	1	1
E, S, W, NI	Ocean quahog	*Arctica islandica*	1			1		1	1		1			3		1				1	1		1	1		1	1	1
E, S, W	Fan mussel	*Atrina pectinata*	1		1	1	1	1	1		1	1		1		1	1			1	1	1	1	1		1	1	1
E, W	Native oyster	*Ostrea edulis*	1		1	1	1	1	1	1	1	1	1	3		1			1	1	1	1	1	1		1	1	1
W	Smooth venus clam	*Callista chione*	1			1		1			1			1		1		2		1	1			1		2	1	1
S	Heart cockle aggregations	*Glossus humanus*	1			1		1			1			1		1				1	1		1	1		1	1	1
NI	Queen scallop	*Aequipecten opercularis*	1		1	1		1			1			3		1				1	1						1	1
NI	Brackish cockle	*Cerastoderma glaucum*	1		1	1		1			1			3		1				1	1						1	1
E	Defolin's lagoon snail	*Caecum armoricum*	1			1		1			1		1	1		1			1	1	1			1		1	1	1
E	Sea snail	*Paludinella littorina*	1			1		1			1		1	1		1			1	1	1					1	1	1
E	Lagoon sea slug	*Tenellia adspersa*	1			1		1	1		1		1	1		1			1	1	1					1	1	1
S	Northern feather star aggregations on mixed substrata	*Leptometra celtica*	1			1		1	1		1			1		1				1	1		1	1		1	1	1
NI	Cushion star	*Porania pulvillus*	1			1		1			1		1			1			1	1	1						1	1
NI	Drummond's sea cucumber	*Thyonidium drummondi*	1			1		1			1		1			1			1	1	1						1	1

Scale of ecosystem service supplied reative to other features

- # (black) Significant contribution
- # (dark grey) Moderate contribution
- # (light grey) Low contribution
- # (white) No or negligible ESP
- (empty) Not assessed

Confidence in evidence

- 3 UK-related, peer-reviewed iterature
- 2 Grey or overseas literature
- 1 Expert opinion or Obvious
- (empty) Not assessed

Feature type †

- S Scottish MPA search feature
- E English MCZ feature
- W Welsh HP MCZ feature
- NI Northern Ireland MCZ feature
- EU EU Habitats Directive Annex 1 feature or sub-feature

Figure 12: Relative importance of designated species in providing intermediate ecosystem services and goods/benefits (**Saunders et al., 2015**).

1.4.1 ECONOMIC VALUATION

With regard to economic valuation, for some marine ecosystem services market prices may reflect their value (e.g. fish landed for human consumption), but for others a market price either does not exist or is inadequate (e.g. spiritual and cultural well-being). As discussed above, it is not appropriate to value basic marine processes and intermediate services without identifying explicitly the associated final ecosystem services and goods/benefits which have human welfare implications (**Turner et al., 2015**). A suite of economic valuation methods, including market and non-market approaches, are available which can be applied to value changes in the provision of ecosystem services. A brief description of these techniques and examples of their relevance to valuing marine ecosystem services is presented in **Cooper et al. (2013)** (Table 1, in Annex 3). Many of the techniques are categorised as non-market valuation approaches as they do not rely on market prices; such methods are gaining wider acceptance and are advocated by the UK Government for policy evaluations (HM Treasury, 2011).

A key purpose in distinguishing ecosystem processes and intermediate services from final ecosystem services is to avoid double counting in the valuation of ecosystem services (Fisher & Turner, 2008). For example, consider an assessment of the ecosystem services and goods/benefits associated with nursery habitat ('formation of species habitat' intermediate supporting service) and food provision (good/benefit). If the value of nursery grounds for commercially valuable marine species is measured in terms of the value of the landed catch and, separately, the value of the stock of specific species (a final provisioning service) is also valued by the landed catch then the value of species harvested are being double counted in any overall assessment of ecosystem services. Turner and Schaafsma (2015) recognise that to be of most use for policy, ecosystem services must be assessed within their appropriate spatial and policy context ('spatial explicitness') and economic valuation should provide 'marginal change' estimates of value (avoiding 'double-counting') that can feed into decisions at the appropriate scale, and which recognise possible 'non-linearities' and are well within the bounds of safe minimum standards ('threshold effects').

With respect to the UK marine environment, the scarcity of primary data valuation studies was highlighted by **Atkins et al. (2013)** who report that between 1995 and 2013 there were only 22 studies within the peer-reviewed literature which collected primary economic valuation evidence. Their review also highlighted that there is currently incomplete coverage of the range of marine ecosystem services, with the majority of studies focussing on provisioning services associated with fisheries, regulating services associated with a healthy climate, natural hazard reduction and improvements in water quality, and cultural services associated with recreation and tourism. Other ecosystem services, for example those associated with many cultural services, still cannot be valued in monetary terms.

Given the current paucity of economic valuation data, there is a growing requirement for undertaking primary economic valuation studies to fill the gaps with respect to ecosystem service valuation. A number of economic valuation surveys in the estuarine, coastal and marine environment have been published in the featured research papers with respect to improvements in estuarine water quality (**Atkins & Burdon, 2006**; **Atkins et al., 2007**), the conservation of marine biodiversity (**Ressurreição et al., 2012**), and the conservation of offshore MPAs (**Börger et al., 2014**). The details of each study are summarised below (Table 3), with further details on the methods and results provided in the relevant papers in Annex 3. The role of primary valuation studies within marine management is further discussed in Chapter 2.

Primary data collection can be costly with respect to time and resources, therefore management decisions may need to be based upon other methods, such as value (or benefit) transfer. This approach uses primary valuation research results from one area (the study site) to make secondary predictions about values at a different area (the policy site) (**Atkins et al., 2013**). Within the UK, Defra published its official guidance on value transfer which recognises it is a quicker and lower cost approach to generating economic valuation evidence when compared to commissioning a site-specific primary valuation study (eftec, 2010). This makes value transfer a practical tool for policy analysis given the time and resources constraints decision-makers regularly face. A number of limitations were also highlighted in the guidance, relating to the potential scarcity of suitable studies, the introduction of transfer errors, and the requirement for expert judgement to select and adjust the values from the literature.

The transference of values tends to be between sites which are similar in both environmental and social structure (**Atkins et al., 2013**). For example, the study undertaken by **Luisetti et al. (2014)** and further developed by **Luisetti et al. (2015)**, investigated the suitability of value transfer valuations for a number of ecosystem services provided by managed realignment sites in the Blackwater and Humber Estuaries, using the ecosystem service framework developed by **Potts et al. (2014)**. These studies focussed on the change in provision, valued in biophysical and welfare terms, of a healthy climate, food and nature recreation (see **Luisetti et al., 2014** in Annex 3 and **Luisetti et al., 2015** in Annex 4 for results and further discussion).

Table 3: Summary of published primary valuation surveys in which the author took part (table created for this thesis).

Citation	**Atkins & Burdon (2006); Atkins et al. (2007)**	**Ressurreição et al. (2012)**	**Börger et al. (2014)**
Journal	*Marine Pollution Bulletin*	*Biological Conservation*	*Ecological Economics*
Study Location(s)	Randers Fjord, Denmark	Azores Islands, Portugal Gulf of Gdansk, Poland Isles of Scilly, UK	The Dogger Bank, North Sea
Survey mode	Postal	Face-to-face	Online
Date of pilot survey	September 2003	Spring 2007	Summer 2013
Number of responses	13 (out of 66)	129 (Total): 64 (Azores); 30 (Gdansk); 35 (Scilly)	29 semi-structured face-to-face interviews; 19 face-to-face ('think aloud') interviews; 60 online responses
Date of main survey	October to December 2003	Summer 2007	December 2013
Number of responses	226 (out of 1,510)	1,502 (Total): 507 (Azores); 512 (Gdansk); 483 (Scilly)	1,022 (Total)
Survey population	General public of Århus County	Residents and visitors at each site	UK general public
Focus of study	Water quality improvements as a result of reduced eutrophication	Marine species conservation	Impacts of fisheries and wind farm development on marine life
Ecosystem service / benefit assessed	Water quality linked to recreational activities	10% or 25% reduction in total number of species per taxa (as a proxy for marine biodiversity)	Diversity of species Protection of porpoises, seals and seabirds Invasive species
Valuation methodology	Contingent Valuation	Contingent Valuation	Discrete Choice Experiment
Currency	Collected in Danish Krone (DKK) reported in Euros (€)	Collected in Euros (Azores), Zloty (Gdansk) and UK Pounds (Scilly) reported in US Dollars	Collected and reported in UK pounds (£)
Payment vehicle	Increase in monthly taxes over a 10-yr period	One-off payment into a conservation trust fund	Increase in annual household tax over a 5-yr period
Elicitation format	Open-ended	Payment cards	Choice cards
Statistical techniques applied	Descriptive statistics Box plots Decision Tree Analysis	Descriptive statistics Independent samples t-tests Regression modelling	Descriptive statistics Conditional logit Mixed logit

1.5 Integrating approaches for marine management

Since the 1990s, there has been a shift in marine management thinking from a sectoral (single activity) approach towards a more holistic (ecosystem) approach which recognises the interactions between anthropogenic activities and nature (**Elliott et al., 2006a**). The ecosystem approach embraces the importance of integrated management of natural resources and necessitates a deeper understanding of the linkages and dynamic relationships between ecological, social and economic systems (Borja et al., 2010; **Atkins et al., 2011a**). The importance of integrating approaches for marine management has been highlighted throughout the featured published work. For example:

- **Elliott et al. (2006b)** recognise the need for integrated marine management to enact the ecosystem approach in the UK;
- **Beaumont et al. (2007)** suggest that application of an ecosystem services approach has the capacity to play a fundamental role in the ecosystem approach, by enabling the pressures and demands on society, the economy and the environment to be integrated into environmental management;
- **Atkins et al. (2011a)** advocate that integrating the DPSIR framework with ecosystem services and societal benefits allows us to create a specific framework for supporting decision-making in the marine environment;
- **Ressurreição et al. (2012)** recognise that bridging the divide between marine science and management provides valuable information for policy-makers and marine managers, and as such effective policies for management must not only be scientifically valid and economically feasible but also culturally adaptable;
- **Cooper et al. (2013)** acknowledge the importance of applying an integrated approach to marine management within the context of seabed restoration. Their study, undertaken by a multidisciplinary group of marine ecologists, policy experts and environmental economists, applies the DPSIR framework as a problem structuring method and integrates both natural and social sciences within an assessment of potential costs and wider ecosystem benefits of physical seabed restoration;
- **Luisetti et al. (2014)** recognise the requirement for an integrated approach with respect to coastal and marine decision-making and highlight the need for the integration of knowledge about the value of ecosystem services from diverse disciplines from natural sciences (e.g. biogeochemistry, ecology, marine biology)

to social sciences and environmental economics for improved decision-making when applying value transfer methodologies;

- **Atkins et al. (2014)** attempt to further integrate some of these concepts (Figure 13; the underlying assumptions of this conceptual model are provided in Annex 3). Their approach recognises the important linkages between the biotic and abiotic components of the natural marine environment and the pathways from the natural functioning of the system, through ecosystem service provision and the resulting benefits which are of value to society. This integrated approach also recognises the importance of inputting built, human and social capital for the realisation of goods and benefits for society;
- **Smyth et al. (2015)** advocate the use of an integrated marine management framework for assessing decommissioning options for the offshore wind power industry, which should include an application of the DAPSI(W)R and 10-tenets frameworks (after Barnard & Elliott, 2015), a SWOT analysis and an assessment of changes in ecosystem services provision;
- **Turner et al. (2015)** advocate an interdisciplinary approach and developed an adaptive management strategy for the UK coastal and marine environment based on pluralism, pragmatism and precautionary principle. They provide a practical framework for implementation of the ecosystem approach and ecosystem services concepts. A practical decision support system is proposed which encompasses interdisciplinary scoping, ecosystem services indicators, future scenarios assessments, tools (including models) to enable a scientific, economic and social appraisal, and monitoring, review and guidance, and
- Finally, **Burdon et al. (in press)** recognise that an integration of natural and social sciences research is required by marine policy-makers to better understand, and manage sustainably, natural changes and anthropogenic activities. This paper developed and applied an original conceptual framework to the integrated management of the Dogger Bank in the North Sea (Figure 14). This conceptual framework identifies the key links between natural and social sciences and highlights the importance of integrating governance and stakeholder engagement throughout the research and the management process. This framework is further discussed in Chapter 2.

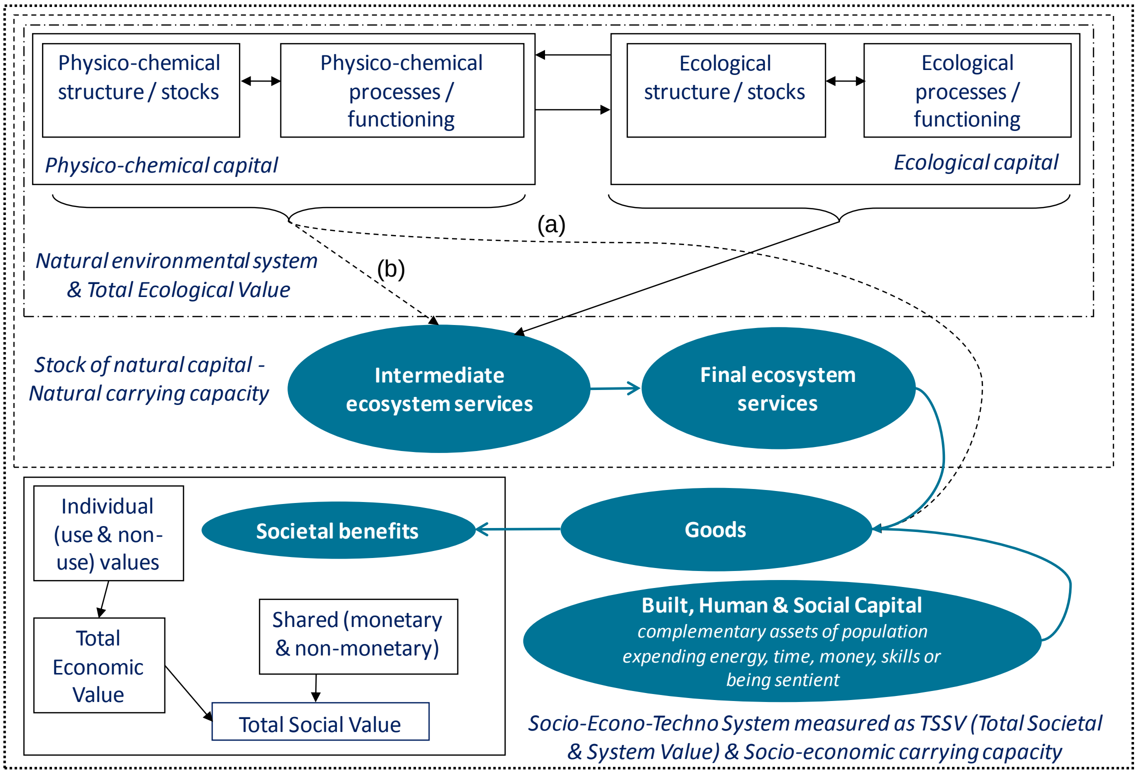
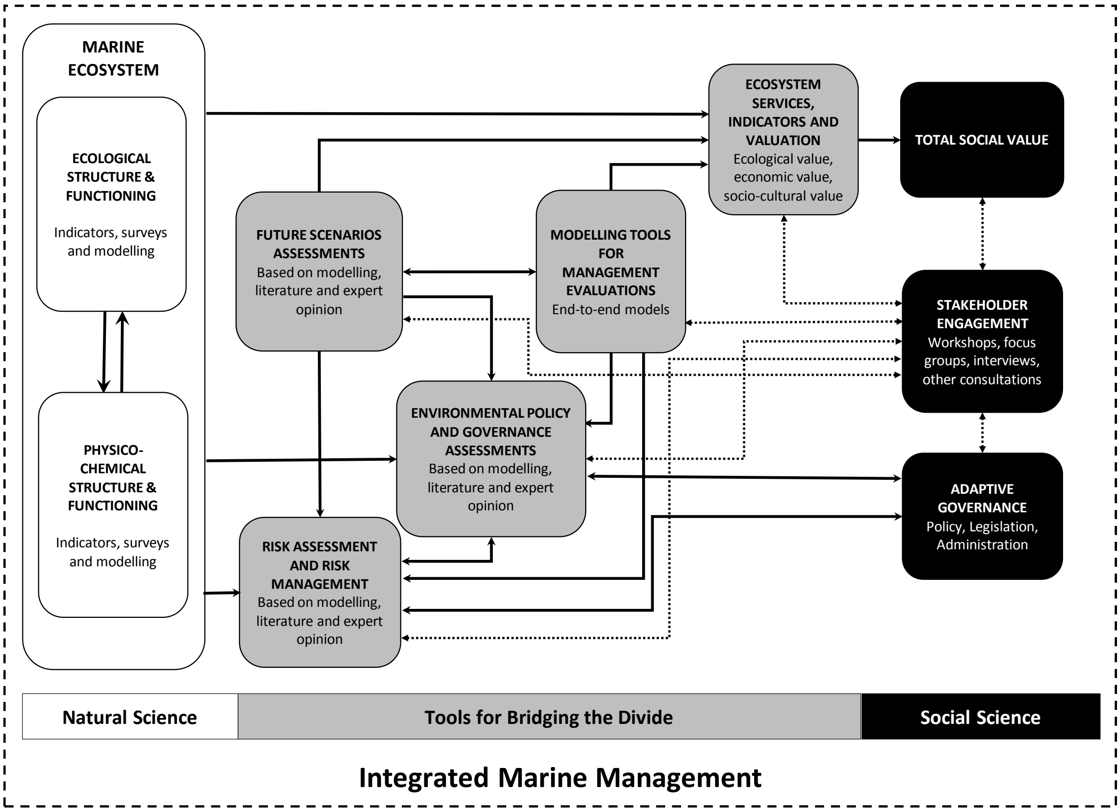


Figure 13: Natural and social sciences: Integrating concepts (**Atkins et al., 2014**).



Note: Solid lines reflect linkages between components; dashed lines reflect two-way aspects of stakeholder engagement.

Figure 14: A framework for linking natural and social sciences for integrated marine management (**Burdon et al., in press**).

CHAPTER 2: FINAL DISCUSSION, CONCLUSIONS AND PERSONAL REFLECTION

This chapter will address three key questions: (1) What is the background, context and contribution to scholarship of the research presented? (2) What are the strengths and weaknesses of the research? (3) What are the next steps for the research? Conclusions and a personal reflection are provided at the end.

2.1 Background, context and contribution to scholarship

The marine environment is a complex system formed by interactions between both ecological structure and functioning and physico-chemical processes (Section 1.1). Within this dynamic ecosystem anthropogenic activities are intense and increasing and pressures from these activities impact upon both the natural environment and society. Management of the marine environment therefore requires a holistic approach that recognises the complexity of the system and accommodates the diverse range of uses and users. As such, there is a need for integrated marine management which considers the environmental, economic and societal impacts of all activities. The ecosystem approach provides the guiding principles for such integrated management.

Section 1.2 showed that DPSIR is a useful problem structuring framework which can be used to assess the causes, consequences and responses to change in a holistic way. DPSIR models can be applied to any system and the boundary of the system is dependent on the issue of interest and its conceptualisation. The DPSIR framework should be modified to DAPSI(W)R(M) to avoid confusion between *Activities* and *Pressures*, and *State changes* and *Impacts* (on *Welfare*). Nested-DAPSI(W)R(M) frameworks are advocated to reflect the true complexity of the marine system.

Increasingly ecosystem service approaches are being incorporated into marine policy and management to recognise the impact of environmental change on human welfare (Section 1.3). The classification system used to define ecosystem services should be linked to policy and management and therefore different interpretations may be needed depending on the context. In this way different classifications can be seen to be complimentary rather than competitive. A suite of indicators can be applied to quantify changes in marine ecosystem service provision, with the final selection of the most practicable ecosystem service indicator(s) being dependent on the context and operational needs.

Section 1.4 showed that since ecosystem services have the potential to lead to benefits for human well-being it is appropriate to consider their value. Total social value incorporates the three domains of valuation: ecological value, economic value and socio-cultural value. A range of methods is available to assess the values that are placed on ecosystem goods/benefits, with the use of non-market techniques gaining wider acceptance. There is a scarcity of primary valuation studies in the marine environment, with published studies generally focusing on a limited number of goods/benefits. Value transfer is an alternative approach to generating economic valuation evidence, however careful consideration in the use and application of value transfer both in biophysical estimates and welfare value estimates, is required to supply reliable information for policy and decision-making.

Section 1.5 showed that there has been a shift in marine management thinking from a sectoral approach toward a more holistic ecosystem approach. Adoption of the ecosystem approach requires the integration of environmental, economic and social factors, thus requiring an integrated understanding of both natural and social science disciplines. Initial attempts have been made to integrate natural and social sciences research, for example within the context of the DAPSI(W)R(M) framework and ecosystem service approaches, however, the need for further integration of approaches was recognised. A generic framework for bridging the divide between natural and social sciences research for integrated marine management has been developed and was successfully applied to the transnational Dogger Bank in the North Sea.

Based on the background and context provided above, a summary of my key contributions of the featured published work to scholarship are summarised in Table 4.

Table 4: Summary of my key contributions to scholarship (table created for this thesis).

Section	Research Theme	Identified gap in understanding	My key contributions to scholarship	Featured Published work
1.2	DPSIR Framework	Limited applications of DPSIR to marine sectors.	Development of marine sector specific models.	Cooper et al., 2013; Gregory et al., 2013; Smyth et al., 2015.
1.2	DPSIR Framework	Confusion over terminology.	DPSWR framework development. DAPSI(W)R framework development. DAPSI(W)R(M) framework development.	Turner et al., 2015. Smyth et al., 2015. [Elliott et al., in prep.]
1.2	DPSIR Framework	Oversimplification of reality.	Nested-DPSIR framework. Nested-DAPSI(W)R(M) framework.	Atkins et al., 2011a. [Elliott et al., in prep.]
1.3	Ecosystem service frameworks	Ecosystem service frameworks are generic in nature.	Development of marine specific ecosystem service frameworks.	Beaumont et al., 2007; Atkins et al., 2011a; Potts et al., 2014; Hattam et al., 2015a; Turner et al., 2015.
1.3	Ecosystem service indicators	Limited ecosystem service indicators have been identified for the marine environment.	Developed a practicable set of marine ecosystem service indicators which are embedded within operational frameworks.	Atkins et al., 2015; Hattam et al., 2015a.
1.3	Ecosystem service indicators	Limited applications of ecosystem services in the marine environment.	Application of ecosystem service indicators to the Dogger Bank, North Sea.	Hattam et al., 2015a.
1.4	Ecosystem service approaches	Limited understanding of the wider ecosystem services and benefits provided by marine protected areas.	Development and application of ecosystem service matrices for UK protected habitats and species.	Potts et al., 2014; Saunders et al., 2015.
1.4	Valuation	Lack of primary valuation data in the marine environment.	Development and implementation of primary data collection using contingent valuation and choice experiment methods.	Atkins & Burdon, 2006; Atkins et al., 2007; Ressurreição et al., 2012; Börger et al., 2014.
1.4	Valuation	Limited marine studies on mixed methods approaches to valuation.	Integration of methods for ecosystem service assessment and valuation.	Hattam et al., 2015b.
1.4	Valuation	Limited studies undertaking value transfer in the marine environment.	Implementation of value transfer methodologies in relation to managed realignment sites.	Luisetti et al., 2014; Luisetti et al., 2015.
1.5	Integration of approaches	Limited studies have attempted to integrate tools for marine management purposes.	Development of original integrated frameworks for marine management.	Atkins et al., 2014; Turner et al., 2015; Burdon et al., in press.

2.2 Critique of the published work presented in Chapter 1

THE DEVELOPMENT OF THE DPSIR / DAPSI(W)R(M) FRAMEWORK

One of the key strengths of the DPSIR framework is that it captures in a simple manner the key relationships between factors in society and the environment (Svarstad et al., 2008). The linking of natural and social systems is an essential component of this thesis and therefore the use of DPSIR as a problem structuring framework in the marine environment is advocated. Despite its strengths, the DPSIR framework has been subject to much criticism within the literature and as such has evolved in response. For example, criticisms include (after Berger & Hodge, 1998; Rapport et al., 1998; Rekolainen et al., 2003), DPSIR:

- cannot take into account the dynamics of the system it models;
- cannot handle cause-consequence relationships;
- suggests linear unidirectional causal chains; and
- ignores key non-human drivers of environmental change.

Historically, there has been much confusion over the terminology used in the DPSIR framework, in particular between how *Drivers* and *Pressures* are defined and also the distinction between *State changes* and *Impacts*. A review undertaken by Smith et al. (2014) identified 20 different modified 'DPSIR' frameworks which have been used in a range of EU-funded marine and coastal research projects and highlights the importance of defining the components of the system. To be useful for management purposes, it was recognised that this confusion needed to be addressed. The evolution of the DPSIR model (**Atkins et al., 2011a**) into DPSWR (**Turner et al., 2015**), DAPSI(W)R (**Smyth et al., 2015**) and finally into DAPSI(W)R(M) (Wolanski & Elliott, 2015; **Elliott et al., in prep.**) has attempted to address this criticism.

A further criticism of DPSIR, is that it oversimplifies the complexity of the environment. For example, Maxim et al. (2009) argue that DPSIR downplays uncertainty and complexity regarding environmental and socio-economic systems. However, Smith et al. (2014) suggest that whilst a single DPSIR model or cycle represents a vast over-simplification of the 'real-world', it can nevertheless be used to help build a conceptual understanding of the relationships between environmental change, anthropogenic pressures and management options. From its conception, DPSIR was perceived to be a series of linear, one-directional cause-effect chains. However, **Atkins et al. (2011b)** suggest that by relaxing these linear chains it recognises some of the complexity of the marine environment. **Atkins et al. (2011b)** also recognise DPSIR has evolved by moving from a model that captures reality to a heuristic device that facilitates stakeholder engagement and evaluation of policy options. This demonstrates a shift in making the process less expert driven and more participatory, thus being more holistic and, consequently, determining more sustainable marine policy.

Presenting DPSIR models as cycles, rather than a linear form, highlights the importance of feedback loops between the *Responses* and the *Drivers*, *Pressures* and *State changes* for management purposes and for understanding some of the complexity of the environment. In addition, with the introduction of nested-DPSIR models (**Atkins et al., 2011a**) and the further development of nested-DAPSI(W)R(M) models (**Elliott et al., in prep.**) this allows linkages between sectors to be illustrated and therefore begins to re-introduce complexity back into the model. It has also been recognised in the literature that DPSIR models ignore key non-human drivers of environmental change (**Atkins et al., 2011b**). Building on the work of Elliott (2011) the DAPSI(W)R(M) models presented in Section 1.2 recognise the importance of non-human drivers in the form of 'natural change' and 'exogenic' and 'endogenic' pressures on the system (Figure 6). In so doing, this illustrates that there are both internal and external factors which must be addressed whilst managing the system defined within the boundary of any given DAPSI(W)R(M) model.

Ecosystem Service Frameworks and Indicators

The comparison of ecosystem service frameworks presented in Table 2 (Section 1.3) illustrates similarities and differences between the frameworks presented. It is apparent that the classification proposed by the MEA, runs throughout all of the ecosystem service frameworks presented (MA, 2005). Subsequently, a number of generic (de Groot et al., 2010; Mace et al., 2011) and marine specific (**Beaumont et al., 2007**; **Atkins et al., 2011a**; **Potts et al., 2014**; **Turner et al., 2015**; **Hattam et al., 2015a**) frameworks have been developed. It is of note that **Beaumont et al. (2007)** introduced the additional category of 'option use value' i.e. values associated with safeguarding the option to use an ecosystem in an uncertain future. This category, however, was not included in subsequent frameworks. It is considered that all ecosystem services will likely contribute to option use value and therefore may lead to double-counting if valuation is required. In addition, further classification systems have been cited within the literature, for example the Common International Classification of Ecosystem Services (CICES) formed part of the analytical framework for ecosystem service assessments under Action 5 of the EU Biodiversity Strategy (Maes et al., 2014) and was also adapted for application at a local level within Belgium (Turkelboom et al., 2013). However, as yet there is no agreement within the scientific community of the best classification system to use, and it has been argued by Fisher et al. (2009) that the classification system used to define ecosystem services should be linked to policy and management and therefore different interpretations may be needed depending on the context. de Groot et al. (2010) suggest that '*perhaps we should accept that no final classification can capture the myriad of ways in which ecosystems support human life and contribute to human wellbeing*' and '*that no fundamental categories or completely unambiguous definitions exist for such complex systems'*. In this way different classifications can be seen to be complimentary rather than competitive (**Atkins et al., 2011a**).

One of the most controversial issues with respect to ecosystem service frameworks is whether they should be solely focussed on biotic (living) factors which are delivered from nature, or whether they should also take into account abiotic (physico-chemical) factors. **Atkins et al. (2014)** illustrate this contentious topic (Figure 13). Based on the definition of an ecosystem cited in Section 1.1, **Atkins et al. (2011a)** argue for the inclusion of 'the non-living environment' elements such as energy, water supply and abiotic provisioning services (e.g. aggregates) in their marine ecosystem service framework. **Cooper et al. (2013)** also argue for the inclusion of abiotic factors within their marine ecosystem service framework, given their focus on aggregate extraction. In contrast, **Turner et al. (2015)** focuses on ecosystem services originating solely from coastal and marine biota, and thus excludes goods and services derived from the abiotic (physico-chemical) environment such as the provision of oil and marine aggregates. It is however recognised that the use of categories may be adapted to different policy contexts when there is a pre-defined policy objective that society has agreed to (**Turner et al., 2015**).

MARINE ECOSYSTEM SERVICE APPROACHES AND VALUATION

Despite the increase in ecosystem services research over the last two decades, the use of valuation evidence within policy and decision-making is still currently lacking. As a recent UK example, the Marine Conservation Zone (MCZ) project undertook Economic Impact Assessment to investigate both the costs and benefits of establishing new MCZs. A critical review undertaken on behalf of the Wildlife Trusts (**Atkins & Burdon, 2013**) concluded that whilst the Economic Impact Assessments provided a range of costs associated with the designation of MCZs, there appeared to be no attempt to value the benefits of the MCZs and thus there is currently insufficient evidence to complete the Impact Assessment. This suggestion was supported by Fletcher et al. (2012a) who demonstrated that further benefit assessments could have been undertaken to support the policy decisions based on existing data and using the approved methodologies.

When it comes to economic valuation, it has been recognised by the UK's Natural Capital Committee (2013) that without an economic price, the natural environment has often been assumed to be of zero value, and thus has not been managed appropriately. A suite of economic valuation methods, including market and non-market approaches, are available which can be applied to value changes in the provision of ecosystem services (**Cooper et al., 2013**). A useful summary of the merits of the various valuation techniques used to value biodiversity can be found within the literature (for example Christie et al., 2006; Christie et al., 2012). Such methods are gaining wider acceptance, however despite support, for example from the UK Government, there is still ongoing debate within the scientific community about the use of such valuation methods and even whether we should put a value on nature in the first place.

The featured research presented in Section 1.4.1 has demonstrated the successful application of a number of these valuation techniques in the estuarine and marine environment, including market analysis (**Cooper et al., 2013**), contingent valuation (**Atkins & Burdon, 2006**; **Atkins et al., 2007**; **Ressurreição et al., 2012**), choice experiments (**Börger et al., 2014**), the citizen jury method (**Hattam et al., 2014**; **Hattam et al., 2015b**) and value transfer (**Luisetti et al., 2014**; **Luisetti et al., 2015**). Full details of each of these valuations is presented in the respective papers (Annex 3) and book chapters (Annex 4).

The choice of valuation method to employ, relates to the particular ecosystem service(s) that is of interest, and the size and distribution of the required survey population. For example, the study by **Atkins and Burdon (2006)** focussed on valuing changes in coastal water quality (a non-market good) and therefore a stated preference contingent valuation survey was chosen. Resources and the language barrier restricted a face-to-face survey and therefore a postal survey was the chosen method, with the questionnaire being translated into Danish. The questionnaire contained very few open-ended questions given the cost associated with translating the responses. It was recognised that postal questionnaires would likely achieve a lower return rate (15%, n=226), than for example face-to-face or online studies, but given the limited resources that were available for the study then that was the preferred option.

A second contingent valuation survey was undertaken by **Ressurreição et al. (2012)**, to investigate the public's willingness-to-pay to conserve marine biodiversity (a non-market good) at a number of coastal sites across Europe. This study required responses from both locals and visitors and therefore a face-to-face questionnaire was designed, recognising that it had to be translated for use at multiple coastal sites across Europe. A large sample was generated (n=1,502) from this survey method, however this could only be achieved by the large investment of staff/student resources to undertake the questionnaire surveys with the public.

The final example, relates to a discrete choice experiment survey that was used to gain insight into the management of an offshore sandbank in the North Sea (**Börger et al., 2014**). In order to gain a UK-wide response, an online approach was selected, which proved a successful method and very quickly generated a large sample of respondents (n=1,022). This approach relied upon a market research company who administered the online survey, and ensured that the sample provided a good coverage of the UK population, however this required a significant resource. It is also recognised that there will inevitably be sample bias given that the sample was randomly selected from a market research database, which included people who had already registered interest in participating in such studies and who have access to the internet.

These three valuation studies have therefore demonstrated the pros and cons of a number of valuation techniques, and have illustrated that the methodology employed needs to take into account the ecosystem service(s) of interest, the sample population and the resources available. In addition, the study by **Hattam et al. (2015b)** concluded that integrating the findings of mixed-method approaches is advantageous to environmental managers beyond studies applying single methods in isolation. In the case of the Dogger Bank, the integration of valuation findings can highlight complexities and contentious issues, for example in relation to fishing and fisheries management, which would not become apparent using a single method approach. This emphasises the importance of the selection of valuation method to employ and also supports the call for integrated valuation assessments when the outputs are to be included within any management and decision-making process.

As stated by **Atkins et al. (2011b)** the collection of primary economic evidence can be costly in terms of both time and resources; hence values obtained in other studies may be used. Value transfer is a valuable alternative (**Luisetti et al., 2014, 2015**) as it offers the opportunity for time and resource savings associated with the use of existing primary data, and it supports a wider scale perspective of values (**Atkins et al., 2013**). However a few notes of caution must be highlighted. While the method is relatively simple, care must be taken when transferring values between sites as there is significant potential for error in the transference of values, particularly between different environmental settings. Therefore, a good understanding of both the primary dataset, including the assumptions and conditions under which it was derived and the case study sites are essential (**Atkins**

et al., 2013). It is anticipated that as the body of primary valuation evidence grows the capacity for, and quality of, value transfer will improve.

INTEGRATING APPROACH FOR MARINE MANAGEMENT

It is argued here that applying an integrated interdisciplinary approach to marine management provides a number of strengths which cannot be achieved by the application of tools in isolation. Interdisciplinary research, as presented throughout this thesis, enables shared learning between disciplines and thus strengthens the research outputs for use in the real-world. Linking the inputs and outputs from research tools allows for a greater understanding of system complexity and therefore provides a greater evidence base from which to manage change within the marine system.

A key component of the integrated framework (Figure 14) is the requirement for stakeholder engagement, and especially multi-directional stakeholder engagement to ensure that local knowledge is fed into both the research and management process. One particular challenge with stakeholder engagement is ensuring that sufficient resources are available, however undertaking integrated research initiatives to achieve integrated marine management should be a more cost-effective approach. Stakeholder engagement activities can then be scheduled for the most appropriate time within the process, and the particular types of activities undertaken can be jointly tailored to meet the needs of stakeholders and researchers. Co-ordinating stakeholder engagement between disciplines will also reduce stakeholder fatigue and will be a more efficient use of project and stakeholder resources. It is argued here that for the ecosystem approach to be achieved within marine management, communication is required at a number of different levels:

- **Between researchers** from a range of different natural and social science disciplines. The complexity of the marine environment requires a truly interdisciplinary approach to ensure that there is shared learning and that the research outputs are integrated for end-users. The provision of an integrated evidence base is essential to provide advice to marine managers and policy-makers which is understandable and from which they can base management decisions. Such interdisciplinary research can present a challenge when it comes to communication between different disciplines. This needs to be addressed at the outset of the process to ensure that a common terminology is agreed. The use of the DAPSI(W)R(M) framework and ecosystem service approaches to structure integrated research projects attempts, in part, to address some of these issues.

- **Between researchers and stakeholders** - stakeholder engagement is an essential component of such an integrated approach. Engaging stakeholders early in the process, allows them to input throughout the research programme rather than just disseminating the findings to them at the end. It also allows for the real-world testing of the research outputs, the results of which can be fed back into the final research deliverables. A major challenge associated with stakeholder engagement is to gain trust between researchers and stakeholders and this can only be achieved over time; the participation of researchers in local marine stakeholder networks is seen as a useful approach.
- **Between different groups of stakeholders** - given the increasing pressure on the marine environment from a wide range of uses and users, integrated management requires stakeholders to communicate between themselves. This is often an overlooked component of stakeholder engagement, but facilitation both within stakeholder groups and between stakeholder groups is an element which needs to be further developed.

Scenarios analysis is advocated for use within all of the tools identified in the framework (Figure 14), and by taking an interdisciplinary approach, this would ensure that the scenarios used within each tool are compatible. It is recognised that scenarios can be used to ‘test’ which policy actions are robust and sustainable and provide a valuable tool for conceptually modelling future societal changes. However it is noteworthy that scenarios must not be too conservative, the extremes need to be considered in order to think the unthinkable. One of the big challenges associated with using scenarios analysis is communicating the findings of the scenarios research effectively to stakeholders and policy-makers given that there may be some politically difficult elements of the scenarios which will need sensitive handling. An understanding of the governance structures and administrations is also an essential component within any integrated framework.

Incorporation of ecosystem service concepts, indicators and valuations into marine policy and planning will improve understanding of the value of marine environments and allow for better communication of their importance to society. By defining indicators to quantify changes in ecosystem service provision, and valuation methods to evaluate the change in benefits for society allows for a greater understanding of the wider benefits provided by the marine environment, which can then be incorporated into management decisions. In particular, the application of economic valuation methods allows for the ecosystem changes to be monetised, a language which is more readily understood by politicians and decision-makers.

The management of natural resources against a background of human uses and users is a complex process which requires robust approaches with clear management objectives (**Burdon et al., 2014**). In order to achieve such management objectives, Member States need to develop appropriate modelling tools. Modelling initiatives are required at different stages throughout the integrated management framework (Figure 14), with a multi-way dialogue between modellers, researchers and stakeholders recognised as an important step in the process.

Finally, a number of administrative challenges need to be overcome to be able to implement such an interdisciplinary approach. Despite the growing support of interdisciplinary research, there are often administrative boundaries both within and between research institutions. In addition, research funding within the UK often does not lend itself to interdisciplinary research, with funding bodies often not willing to support interdisciplinary research. A recent Green Paper recommended that an overarching body (proposed to be known as Research UK) is established in the UK with clear accountabilities and responsibilities, which is able to support the whole system of research funding (Nurse, 2015). This may overcome some of the administrative problems highlighted above.

2.3 Recommendations for future research and use of information in management

A number of areas for future work and integration of research outputs into the management process have been identified:

There is a need to link the DAPSI(W)R(M) framework with other bridging tools, such as ecosystem service indicators and valuation. The application of ecosystem service indicators will allow *State changes* to *Impacts* (on *Welfare*) to be quantified, and where data allows to be valued, and therefore this evidence can be used in the policy and decision-making process.

There is scope to further develop the integration of the DAPSI(W)R(M) framework with for example the Bow-tie approach for risk assessment and risk management (Figure 5 in **Burdon et al., in press**, Annex 3). By building on the work of Cormier et al. (2013) and Smyth and Elliott (2014), and linking this method to the DAPSI(W)R(M) framework, it enables scoping, identification and analysis of: the *Drivers* leading to the main events (through *Activities* and *Pressures*); anticipatory prevention measures (as management *Response Measures*), including those limiting the severity of the main event; the consequences of the events (*State changes* and *Impacts* on *Welfare*); and mitigation and compensation measures (as management *Response Measures*) aimed at minimising those consequences.

There is a need to further develop the idea of linking nested-DAPSI(W)R(M) models between ecosystems. This not only recognises the complexity of relationships between adjacent ecosystems, but recognises the potential effect of anthropogenic *Activities* on the natural and human system throughout the catchment. This is demonstrated for aquatic systems in Figure 15, but this could also be further expanded to consider the interrelationships between aquatic systems and their adjacent terrestrial systems.

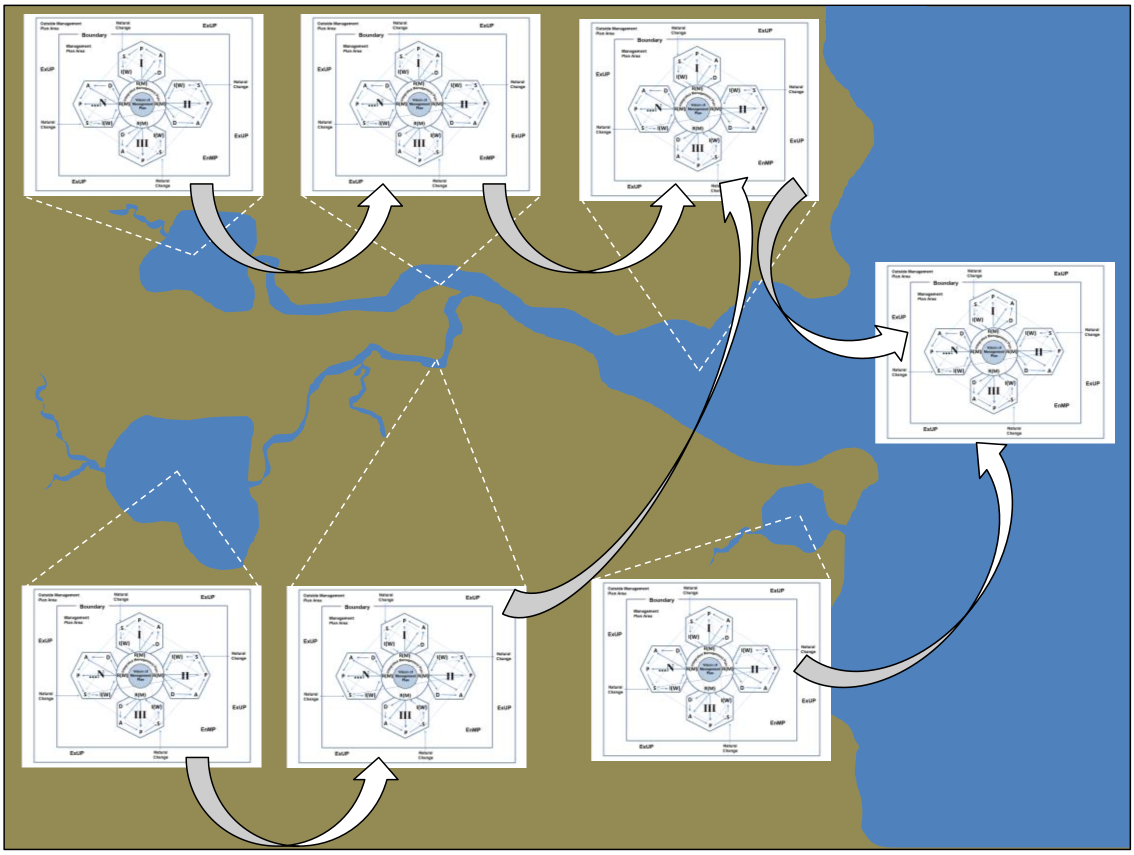


Figure 15: Catchment linked-DAPSI(W)R(M) models (**Elliott et al., in prep.**).

There is a requirement to test the practicable ecosystem service indicators developed by **Atkins et al. (2015)** in order to further refine the list of indicators for the UK coastal environment. Although potential UK data sources were identified, no real-world application of the indicators was undertaken. Once the indicators have been applied at different spatial and temporal scales, gaps in data availability can be identified which would then lead to the identification of additional areas for future research.

There is a need to promote the collection of time series data for marine ecosystem service indicators. Without this primary time series data, changes in ecosystem service provision will have to rely on expert opinion to qualitatively or at best semi-quantitatively identify changes in ecosystem service provision. This will then have a knock-on effect on the valuation of such changes.

Every effort should be made to quantify the benefits provided by the marine environment (even if only partially) when valuation evidence is called for to support decision-making and policy design. At present there are a number of studies which have only taken qualitative assessments of changes in ecosystem service provision, which are largely based on literature and expert opinion (e.g. **Cooper et al., 2013**; **Smyth et al., 2015**).

The growing importance of economic valuation in the design and implementation of national and international marine policy calls for a greater primary evidence base, increasing the number of valuation studies and their coverage of the range of marine ecosystem services (especially of regulating and cultural services). At present, the majority of studies focus on a small range of provisioning services (e.g. fisheries), regulating services (e.g. carbon sequestration, flood defence) and cultural services (e.g. recreation, tourism).

Given the expansion of a number of marine sectors further offshore as a result of the blue growth agenda, this emphasises the importance of refining valuation methods for application away from the coast to ensure that valuation evidence is available for use in marine management decisions (such as **Börger et al., 2014**).

There is considerable scope to further develop the MPA matrices (Figure 11 and Figure 12). The matrices should be expanded to include sea birds, which are currently not taken into account within the assessment, and are the focus of a number of MPA designations within the UK. It would also be valuable to make the matrices more interactive for use by marine managers, for example evidence behind each cell could be made available to the user, thus strengthening the transparency of information when it comes to decision-making. It would also be valuable to link these ecosystem service matrices with existing UK habitat sensitivity matrices to aid the management of marine protected areas. The matrices were developed for the UK marine environment, and were applied by the Scottish Government within their MPA process. However it would be good to test the approach in other geographical areas across Europe and further afield, for example the ecosystem service matrices are currently being adapted for application to marine protected areas in China[1].

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[1] This study is part of a joint research collaboration between the University of Aberdeen (funded by the Royal Society of Edinburgh) and the University of Xiamen (funded by the National Natural Science Foundation of China). The author was named as an external collaborator given his expertise in ecosystem service provision associated with Marine Protected Areas in the UK.

Although not addressed within this thesis, a recently developing field of research relates to the use of Payments for Ecosystem Services (PES) in the coastal and marine environment. The term PES is used to describe schemes in which the beneficiaries, or users, of ecosystem services provide payment to the stewards, or providers, of ecosystem services (Smith et al., 2013). PES schemes have been applied globally over the last 10-15 years and have focussed mainly on the terrestrial and freshwater environments, for example in relation to forestry practices, agricultural land-use and catchment water quality. However there may be scope to further investigate the potential use of PES in estuaries (e.g. using constructed wetlands for dealing with wastewater discharges, or in relation to natural flood defence schemes) and coastal environments (e.g. in relation to commercial fisheries, management of MPAs, or nature-related tourism).

A clear set of priorities needs to be identified regarding future marine hazards and risks which would allow the regulatory framework to be structured to meet these needs. The hazards and risks need to be addressed in combination with appropriate mitigation and/or compensation measures implemented. The Bow-tie approach is a valuable methodology to assess risks in the marine environment but it requires further development to account for such combined pressures and cumulative impact assessments.

In order to fully integrate modelling into an integrated marine management framework, there is a need for the increased availability of highly spatially and temporally resolved information on human activities in the marine environment as this forms an important part of supporting decision-making in marine spatial planning. There is also the need for integrated, ecosystem-level analysis of spatially and temporally resolved data, which is sufficiently user-friendly to be understood by managers and policy-makers.

Finally, a number of administrative challenges need to be addressed to ensure that interdisciplinary research is something that researchers want to aspire towards in the future.

2.4 Conclusions

In conclusion, this thesis has:

- Demonstrated how the DAPSI(W)R(M) framework and ecosystem service approaches have been developed for application in the marine environment and how a suite of ecosystem service indicators and economic valuation methods have been applied to identify, assess and value changes in marine ecosystem service provision;
- Identified a suite of interdisciplinary tools which will aid future marine management decisions, recognising that the list of tools selected is not exhaustive, allowing for additional tools to be selected according to the specific issue being addressed, and
- Advocated that applying an integrated framework, which bridges the divide between natural and social science research, enables the complexity of the marine environment to be better understood, and assessed in response to both natural and anthropogenic change.

2.5 Personal reflection

Completing a PhD by published work has been a challenging yet enjoyable experience. Given that a decade has passed between the publication of my first peer-reviewed paper, and the submission of my PhD by published work, this provides an opportunity to reflect on the significant changes which I have observed within my own research as well as research undertaken by others within the marine environment. In this final section I reflect on what I have learned during this process but also on how the direction of my research has changed in response to broader changes within the field.

During my undergraduate studies in marine biology and my postgraduate studies in estuarine and coastal science and management, I developed a broad knowledge base which I have been able to draw upon during my research career to date. Since publishing my first peer-reviewed paper in 2006, the majority of my research has developed around the concept of ecosystem services as a way of linking the natural environment and society. This thread of research has required me to build on my experience in the natural sciences, but has encouraged me to take a more holistic approach to my research, taking research techniques and ideas from environmental economics, systems science, and other social science disciplines and apply them in an integrated way within the marine environment.

The final structure of the supporting document for my PhD has evolved over time, and has benefitted from valuable feedback received from presenting my work at conferences, scientific meetings, and undergraduate and postgraduate lectures. For example, the linking of my research outputs was strengthened during the preparation and presentation of lecturers at undergraduate and postgraduate level, in which I gave the students a flavour of my research by presenting them with real-world case studies where interdisciplinary approaches have been developed and applied.

In general, my research contributions have focussed on conceptual modelling of both the management of the marine system (e.g. using the DAPSI(W)R(M) framework) and the underlying ecological interactions (e.g. using 'horrendograms'), and linking the functioning of the natural environment with the provision of ecosystem services. I took a leading role in the development of an ecosystem service framework specific for the UK marine environment and have applied this framework within a number of management contexts. Where possible I have tried to quantify the impacts of management measures on ecosystem service provision using appropriate indicators. However my research has often been limited by data availability and/or scientific knowledge about relationships between ecosystem functioning and service provision and therefore my research has often relied on qualitative analyses of policy impacts. I have always advocated the need for valuation of the natural environment, so that the value of the natural system is not under-estimated or ignored within policy and management decisions, and therefore where possible I have contributed primary data to this growing field of research using a number of market and non-market techniques.

In part, the development of my research path has reflected wider changes within the field. For example, the last decade has seen an increase in the number and types of users in the marine environment, with new sectors developing (e.g. carbon capture and storage), and historic activities moving further offshore (e.g. aquaculture) as part of the recently developing Blue Growth Agenda. Within marine policy, there has been a shift from a sectoral approach focussing on managing activities in isolation (e.g. diffuse pollution from agriculture under the EU Nitrates Directive) to holistic management of the system (e.g. under the EU WFD and particularly the EU MSFD). The need to adopt an ecosystem approach to marine management has required the development of ecosystem service approaches to operationalise this within management. There has been an increasing emphasis placed on valuing nature, for example within the UK by the Valuing Nature Network (**Turner et al., 2013**) and the National Ecosystem Assessment (UKNEA, 2011) and its follow-on project (UKNEAFO, 2014). The use of non-monetary techniques to value nature is now supported by the UK Government (HM Treasury, 2011) and as such the value of the natural environment is now being included within marine management decisions (e.g. MMO, 2014b). The involvement of stakeholders throughout research programmes has also gained wider acceptance, with stakeholders now often involved as early as the proposal writing stage, which enables them to provide a real-world steer to the direction of the research, thus ensuring that the outputs and outcomes of the research are fit-for-purpose and can be actively used within marine management.

The research contained within my PhD by published work, has thus reflected some of these changes in the wider field, and it is hoped that my research outputs will contribute to more sustainable marine management in the future. It is my career aspiration to further develop the integration of natural and social sciences and continue to advocate the inclusion of valuation evidence in marine management decisions. It is hoped that further opportunities will arise to develop my undergraduate and postgraduate lecturing experience whilst further developing and publishing my interests in developing an integrated approach to link natural and social sciences for marine management.

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ANNEX 1: LIST OF PUBLISHED WORK

The following published papers and book chapters, listed in reverse chronological order, are submitted as evidence for the author to be examined for award of a PhD by published work at the University of Hull. Supplementary published works (Section A1.3) are provided as additional evidence but are considered to be outside the scope of the thesis and as such are not intended to be examined directly. Testimonials for the specific contributions of the author to each published work are provided in Annex 2.

A1.1 Published papers

1. **Burdon, D.**, Boyes, S.J., Elliott, M., Smyth, K., Atkins, J.P., Barnes, R.A. & Wurzel, R.K., in press. Integrating natural and social marine science to manage sustainably vectors of change: Dogger Bank transnational case study. *Estuarine, Coastal and Shelf Science* (2015), http://dx.doi.org/10.1016/j.ecss.2015.09.012.

2. Hattam, C., Böhnke-Henrichs, A., Börger, T., **Burdon, D.**, Hajimicheale, M. Delaney, A., Atkins, J.P., Garrard, S. & Austen, M.C., 2015b. Integrating methods for ecosystem service assessment and valuation: mixed methods or mixed messages? *Ecological Economics*, 120, pp. 126–138.

3. Smyth, K., Christie, N., **Burdon, D.**, Atkins, J.P., Barnes, R.A. & Elliott, M., 2015. Renewables-to-Reefs? - Decommissioning options for the offshore wind power industry. *Marine Pollution Bulletin*, 90, pp. 247-258.

4. Hattam, C., Atkins, J.P., Beaumont, N., Börger, T., Böhnke-Henrichs, A., **Burdon, D.**, de Groot, R.S., Hoefnagel, E., Nunes, P., Piwowarczyk, J., Sergio, S. & Austen, M.C., 2015a. Marine ecosystem services: linking indicators to their classification. *Ecological Indicators*, 49, pp. 61-75.

5. Atkins, J.P., **Burdon, D.**, Elliott, M., Schaafsma, M. & Turner, R.K., 2014. Coastal and marine ecosystem services. *Environmental Scientist,* 23(4), pp. 26-30.

6. Börger, T., Hattam, C., **Burdon, D.**, Atkins, J.P. & Austen, M., 2014. Valuing conservation benefits of an offshore marine protected area. *Ecological Economics*, 108, pp. 229-241.

7. Luisetti, T., Turner, R.K., Jickells, T., Andrews, J., Elliott, M., Schaafsma, M., Beaumont, N., Malcolm, S., **Burdon, D.**, Adams, C. & Watts, W., 2014. Coastal zone ecosystem services: from science to values and decision making: a case study. *Science of the Total Environment*, 493, pp. 682-693.

8. Potts, T., **Burdon, D.**, Jackson, E., Atkins, J.P., Saunders, J., Hastings, E. & Langmead, O., 2014. Do marine protected areas deliver flows of ecosystem services to support human welfare? *Marine Policy*, 44, pp. 139–148.

9. Cooper, K., **Burdon, D.**, Atkins, J.P., Weiss, L., Somerfield, P., Elliott, M., Turner, R.K., Ware, S. & Vivian, C., 2013. Can the benefits of physical seabed restoration justify the costs? An assessment of a disused aggregate extraction site off the Thames Estuary, UK. *Marine Pollution Bulletin*, 75, pp. 33-45.

10. Gregory, A.J., Atkins, J.P., **Burdon, D.** & Elliott, M., 2013. A problem structuring method for ecosystem based management: the DPSIR framework. *European Journal of Operational Research,* 227, pp. 558–569.

11. Ressurreição, A., Gibbons, J., Bentley, C., **Burdon, D.**, Atkins, J.P., Kaiser, M., Austen, M.C., Santos, R., Dentinho, T.P., Zarzycki, T. & Edwards-Jones, G., 2012. Different cultures, different values: the role of cultural variation in public's willingness to pay for marine species conservation. *Biological Conservation*, 145, pp. 148-159.

12. Atkins, J.P., **Burdon, D.**, Elliott, M. & Gregory, A.J., 2011a. Management of the marine environment: integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. *Marine Pollution Bulletin*, 62, pp. 215-226.

13. Atkins, J.P., Gregory, A.J., **Burdon, D.** & Elliott, M., 2011b. Managing the marine environment: is the DPSIR framework holistic enough? *Systems Research and Behavioural Science*, 28, pp. 497–508.

14. Atkins, J.P., **Burdon, D.** & Allen, J.H., 2007. An application of contingent valuation and decision tree analysis to water quality improvements. *Marine Pollution Bulletin*, 55, pp. 591-602.

15. Beaumont, N.J., Austen, M.C., Atkins, J.P., **Burdon, D.**, Degraer, S., Dentinho, T.P., Derous, S., Holm, P., Horton, T., Van Ierland, E., Marboe, A.H., Starkey, D.J., Townsend, M. & Zarzycki, T., 2007. Identification, definition and quantification of goods and services provided by marine biodiversity: Implications for the ecosystem approach. *Marine Pollution Bulletin*, 54, pp. 253-265.

16. Atkins, J.P. & **Burdon, D.**, 2006. An initial economic evaluation of water quality improvements in the Randers Fjord, Denmark. *Marine Pollution Bulletin*, 53(1-4), pp. 195-204.

A1.2 Book chapters

1. Turner, R.K., Mee, L., Elliott, M., Schaafsma, M., **Burdon, D.**, Atkins, J.P., Saunders, J., Potts, T., Jickells, T., Beaumont, N. & Bee, E., 2015. Chapter 2: Conceptual framework. In: Turner, R.K. & Schaafsma, M. (Eds.) *Coastal zones ecosystem services: from science to values and decision making*. Studies in Ecological Economics, Volume 9, Springer, Switzerland.

2. Atkins, J.P., **Burdon, D.** & Elliott, M., 2015. Chapter 5: Identification of a practicable set of indicators for coastal and marine ecosystem services. In: Turner, R.K. & Schaafsma, M. (Eds.) *Coastal zones ecosystem services: from science to values and decision making*. Studies in Ecological Economics, Volume 9, Springer, Switzerland.

3. Saunders, J., Potts, T., Jackson, E., **Burdon, D.**, Atkins, J.P., Hastings, E., Langmead, O. & Fletcher, S., 2015. Chapter 9. Linking ecosystem services of marine protected areas to benefits in human wellbeing? In: Turner, R.K. & Schaafsma, M. (Eds.) *Coastal zones ecosystem services: from science to values and decision making*. Studies in Ecological Economics, Volume 9, Springer, Switzerland.

4. Luisetti, T., Turner, R.K., Jickells, T., Andrews, J., Elliott, M., Schaafsma, M., Beaumont, N., Malcolm, S., **Burdon, D**., Adams, C. & Watts, W., 2015. Chapter 11. What future for the English coastline? A case study exploring managed realignment benefits. In: Turner, R.K. & Schaafsma, M. (Eds.) *Coastal zones ecosystem services: from science to values and decision making*. Studies in Ecological Economics, Volume 9, Springer, Switzerland.

A1.3 Published papers (not included in this thesis)

1. **Burdon, D.**, Callaway, R., Elliott, M., Smith, T. & Wither, A., 2014. Mass mortalities of bivalve populations: a review of the edible cockle *Cerastoderma edule* (L.). *Estuarine, Coastal and Shelf Science*, 150, pp. 271-280.

2. Callaway, R., **Burdon, D.**, Deasey, A., Mazik, K. & Elliott, M., 2013. The riddle of the sands: population dynamics provides clues to causes of high cockle mortality. *Journal of Applied Ecology*, 50(4), pp. 1050–1059.

3. Pascual, M., Borja, A., Franco, J., **Burdon, D.**, Atkins, J.P. & Elliott, M., 2012. What are the costs and benefits of biodiversity recovery in a highly polluted estuary? *Water Research*, 46, pp. 205-217.

4. Elliott, M., **Burdon, D.**, Hemingway, K.L. & Apitz, S., 2007. Estuarine, coastal and marine habitat and ecosystem restoration: confusing management and science. *Estuarine, Coastal and Shelf Science*, 74, pp. 349-366.

5. Elliott, M., Boyes, S.J. & **Burdon, D.**, 2006. Integrated marine management and administration for an island state - the case for a new Marine Agency for the UK. *Marine Pollution Bulletin*, 52(5), pp. 469-474.

ANNEX 2: TESTIMONIALS FOR CO-AUTHORED PUBLISHED WORK

The following testimonials confirm the specific contribution of the author to each published work as listed in Annex 1.

A2.1 Published papers

Burdon, D., Boyes, S.J., Elliott, M., Smyth, K., Atkins, J.P., Barnes, R.A. & Wurzel, R.K., in press. Integrating natural and social marine science to manage sustainably vectors of change: Dogger Bank transnational case study. *Estuarine, Coastal and Shelf Science* (2015), http://dx.doi.org/10.1016/j.ecss.2015.09.012.

This paper is an original research article accepted for publication in a Special Issue of ECSS on VECTORS of Change. Daryl was the lead author of this paper and as such conceived the idea behind the paper, was responsible for developing the structure of the paper, co-ordinating the contributions of the other co-authors, developing the integrated framework for marine management, undertaking the final editing and submission of the manuscript, and addressing the reviewers comments.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Sue Boyes, University of Hull, 8 March 2016

Hattam, C., Böhnke-Henrichs, A., Börger, T., **Burdon, D.**, Hajimicheale, M. Delaney, A., Atkins, J.P., Garrard, S. & Austen, M.C., 2015b. Integrating methods for ecosystem service assessment and valuation: mixed methods or mixed messages? *Ecological Economics*, 120, pp. 126–138.

This paper was an output from the EU-funded VECTORS project and built on two previously published papers which Daryl co-authored (Hattam et al., 2015a and Börger et al., 2014). Daryl made significant contributions to the writing and editing of this comparative methods paper, focussing on the ecological assessments and DCE and the production of Figure 2.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Caroline Hattam, Plymouth Marine Laboratory, 24 February 2016

Smyth, K., Christie, N., **Burdon, D.**, Atkins, J.P., Barnes, R.A. & Elliott, M., 2015. Renewables to Reefs? – Decommissioning options for the offshore wind industry. *Marine Pollution Bulletin*, 90, pp. 247-258.

This paper was an output from the EU-funded VECTORS project and was led by Dr Katie Smyth (UHULL). Daryl was responsible for the analysis and reporting of the qualitative ecosystem service provision assessment and the development of an amended DPSIR framework for the offshore wind farm sector – this was a further development of the DPSIR framework presented in **Cooper et al., 2013**. As one of the leading authors, Daryl made significant contributions to the structuring, drafting and editing of this research paper.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Katie Smyth, University of Hull, 3 November 2014

Hattam, C., Atkins, J.P., Beaumont, N., Börger, T., Böhnke-Henrichs, A., **Burdon, D.**, de Groot, R.S., Hoefnagel, E., Nunes, P., Piwowarczyk, J., Sergio, S. & Austen, M.C., 2015. Marine ecosystem services: linking indicators to their classification. *Ecological Indicators*, 49, pp. 61–75.

This paper is an output from the EU-funded VECTORS project which was co-ordinated by Plymouth Marine Laboratory. Daryl made significant contributions to the drafting and editing of the paper and provided specific case study expertise in relation to the ecology and management of the Dogger Bank in the North Sea. Daryl took a leading role in the development of the ecosystem services framework and the identification of ecosystem service indicators, particularly those associated with provisioning ecosystem services.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Caroline Hattam, Plymouth Marine Laboratory, 15 October 2014

Atkins, J.P., **Burdon, D.**, Elliott, M., Schaafsma, M. & Turner, R.K., 2014. Coastal and marine ecosystem services. *Environmental Scientist*, 23(4), pp. 26-30.

This paper is an output from the UK National Ecosystem Assessment Follow-On Project which was co-ordinated by Prof Kerry Turner at the University of East Anglia. Daryl took a leading role in the production of this paper, including the drafting of the text and associated figure and tables. Daryl also took responsibility for the submission of the paper including correspondence with the journal's editorial team during the production process.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Professor Kerry Turner, University of East Anglia, 24 February 2015

Börger, T., Hattam, C., **Burdon, D.**, Atkins, J.P. & Austen, M.C., 2014. Valuing conservation benefits of an offshore marine protected area. *Ecological Economics,* 108, pp. 229-241.

This paper is an output from the EU-funded VECTORS project which was co-ordinated by Plymouth Marine Laboratory. Daryl made significant contributions to the development and implementation of a discrete choice experiment, providing ecological and marine management expertise for the development of choice attributes for the Dogger Bank, and undertaking a series of scoping interviews during the development of the online survey. Daryl took a leading role in the structuring, drafting and editing of the paper and contributed to the interpretation of the analysis of the survey data, which was undertaken by Dr Tobias Börger.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Tobias Börger, Plymouth Marine Laboratory, 3 November 2014

Luisetti, T., Turner, R.K., Jickells, T., Andrews, J., Elliott, M., Schaafsma, M., Beaumont, N., Malcolm, S., **Burdon, D.**, Adams, C. & Watts, W., 2014. Coastal zone ecosystem services: from science to values and decision making: a case study. *Science of the Total Environment*, 493, pp. 682-693.

This paper is an output from the NERC-funded Valuing Nature Network (Coastal Management) and was co-ordinated by Dr Tiziana Luisetti. Daryl provided local knowledge of the Humber Estuary to this paper and contributed to the drafting and editing of the wider paper. This paper built on some of Daryl's earlier research which developed an ecosystem service framework for the marine environment which was published in **Potts et al. (2014)** and which identified ecosystem services provided by saltmarsh habitat in the Humber Estuary (**Burdon et al., 2011**).

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Tiziana Luisetti, Cefas, 20 October 2014

Potts, T., **Burdon, D.**, Jackson, E., Atkins, J.P., Saunders, J., Hastings, E. & Langmead, O., 2014. Do marine protected areas deliver flows of ecosystem services to support human welfare? *Marine Policy*, 44, pp. 139–148.

This paper is a research output from the NERC-funded Valuing Nature Network (WP3b Coastal Ecosystem Services) which was co-ordinated by Dr Tavis Potts. Daryl took a leading role in the development of both an ecosystem services framework for the marine environment and the development of the habitats and species matrices and the drafting and editing of the manuscript. Daryl was responsible for the presentation of both the ecosystem service framework and the habitats and species matrices in the manuscript. Daryl was the lead author for the Lundy case study and was responsible for revising the manuscript in response to a number of the reviewer's comments.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Tavis Potts, University of Aberdeen, 15 October 2014

Cooper, K., **Burdon, D.**, Atkins, J.P., Weiss, L., Somerfield, P., Elliott, M., Turner, R.K., Ware, S. & Vivian, C., 2013. Can the benefits of physical seabed restoration justify the costs? An assessment of a disused aggregate extraction site off the Thames Estuary, UK. *Marine Pollution Bulletin*, 75, pp. 33-45.

Daryl was the Principle Investigator for the socio-economic components of this research project, which was funded by the Marine Aggregate Levy Support Fund, and was led by Dr Keith Cooper. Daryl was responsible for establishing and undertaking an assessment of potential changes in ecosystem service provision as a result of seabed restoration, and for constructing a DPSIR model for the marine aggregates sector which was used as a framework to structure the paper. Daryl took a leading role in the drafting and editing of the manuscript, including responding to reviewers comments.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Keith Cooper, Cefas, 22 October 2014

Gregory, A.J., Atkins, J.P., **Burdon, D.** & Elliott, M., 2013. A problem structuring method for ecosystem based management: the DPSIR framework. *European Journal of Operational Research,* 227, pp. 558–569.

This paper was led by Dr Amanda Gregory. Daryl made a number of significant contributions to this paper, including constructing the initial DPSIR model for management of Flamborough Head commercial fishing sector and providing expert local knowledge about the coastal ecology and management of the Flamborough Head EMS which was used as the basis for developing the case study text. Daryl also contributed to the wider drafting and editing of the paper.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Amanda Gregory, University of Hull, 21 October 2014

Ressurreição, A., Gibbons, J., Bentley, C., **Burdon, D.**, Atkins, J.P., Kaiser, M., Austen, M.C., Santos, R., Dentinho, T.P., Zarzycki, T. & Edwards-Jones, G., 2012. Different cultures, different values: the role of cultural variation in public's willingness to pay for marine species conservation. *Biological Conservation*, 145, pp. 148-159.

This paper was an output from the EU-funded MarBEF project (Theme 3 Socio-economics) and was led by Dr Adriana Ressurreição (an FCT funded PhD student). Daryl provided comments on both the pilot and final survey questionnaire design and contributed to the interpretation of the data analysis and editing of the manuscript.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Adriana Ressurreição, Centre of IMAR, University of the Azores, 4 November 2014

Atkins, J.P., **Burdon, D.**, Elliott, M. & Gregory, A.J., 2011a. Management of the marine environment: integrating ecosystem services and societal benefits with the DPSIR framework in a systems approach. *Marine Pollution Bulletin*, 62, pp. 215-226.

This paper was led by Professor Jonathan Atkins. As co-author, Daryl made significant contributions to the drafting and editing of this paper, and took a leading role in the development of the two cases studies: management of marine aggregates extraction in UK waters and the management of marine biodiversity at Flamborough Head, UK (the latter which built on **Beaumont et al., 2007**). Daryl was also responsible for the development and production of the figures.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Professor Jonathan Atkins, University of Hull, 4 November 2014

Atkins, J.P., Gregory, A.J., **Burdon, D.** & Elliott, M., 2011b. Managing the marine environment: is the DPSIR framework holistic enough? *Systems Research and Behavioural Science*, 28, pp. 497–508.

This research paper was led by Professor Jonathan Atkins. As co-author, Daryl made significant contributions to the drafting and editing of this paper, in particular to the sections on the DPSIR Framework, Ecosystem Services, and Evaluation of Ecosystem Services. This contribution builds on that made by Daryl to both **Beaumont et al. (2007)** and **Atkins et al. (2011a)**.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Professor Jonathan Atkins, University of Hull, 4 November 2014

Atkins, J.P., **Burdon, D.** & Allen, J.H., 2007. An application of contingent valuation and decision tree analysis to water quality improvements. *Marine Pollution Bulletin*, 55, pp. 591-602.

This paper was a second output from the EU-funded EUROTROPH project and built on the work previously presented in **Atkins & Burdon (2006)**. Daryl was the joint co-author of this paper and as such was responsible for drafting and editing of this paper and responding to reviewers comments. Daryl was responsible for the descriptive analysis of the CVM survey data and the interpretation of the decision tree analysis outputs, which was undertaken by Dr James Allen.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Professor Jonathan Atkins, University of Hull, 4 November 2014

Beaumont, N.J., Austen, M.C., Atkins, J.P., **Burdon, D.**, Degraer, S., Dentinho, T.P., Derous, S., Holm, P., Horton, T., Van Ierland, E., Marboe, A.H., Starkey, D.J., Townsend, M. & Zarzycki, T., 2007. Identification, definition and quantification of goods and services provided by marine biodiversity: Implications for the ecosystem approach. *Marine Pollution Bulletin*, 54, pp. 253-265.

This paper was an output from the EU-funded MarBEF project (Theme 3 Socio-Economics), and was led by Dr Nicola Beaumont. Daryl was specifically responsible for undertaking an initial assessment of the goods and services provided by the Flamborough Head European Marine Site and providing the evidence and associated case study text required for the paper. Daryl made a significant contribution to the identification and definition of ecosystem services in the marine environment and to the drafting and editing of this paper.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Nicola Beaumont, Plymouth Marine Laboratory, 15 October 2014

Atkins, J.P. & **Burdon, D.**, 2006. An initial economic evaluation of water quality improvements in the Randers Fjord, Denmark. *Marine Pollution Bulletin*, 53(1-4), pp. 195-204.

This paper was one of the outputs from the EU-funded EUROTROPH project. As joint lead-author, Daryl made a significant contribution to the drafting and editing of the paper, and presented the findings at an international scientific conference. Daryl took a leading role in the development of the postal contingent valuation survey, and was responsible for the administration of both the pilot and final surveys, and the subsequent data input, some analysis and reporting.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Professor Jonathan Atkins, University of Hull, 4 November 2014

A2.2 Book chapters

Turner, R.K., Mee, L., Elliott, M., Schaafsma, M., **Burdon, D.**, Atkins, J.P., Saunders, J., Potts, T., Jickells, T, Beaumont, N. & Bee, E., 2015. Chapter 2: Conceptual framework. In: Turner, R.K. & Schaafsma, M. (Eds.) *Coastal zones ecosystem services: from science to values and decision making*.

This edited book is a joint output from the NERC-funded Valuing Nature Network (Coastal Ecosystem Services) and the Defra-Funded UK National Ecosystem Assessment Follow-On Project (WP3b Marine Economics). Daryl made a significant contribution to this book chapter, specifically in the development of an ecosystem services framework for the coastal and marine environment and its associated definitions. Daryl also contributed text on the application of the DPSIR framework to the marine environment, and provided more general written contributions and comments to the chapter.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this book chapter.

Professor Kerry Turner, University of East Anglia, 16 October 2014

Atkins, J.P., **Burdon, D.** & Elliott, M., 2015. Chapter 5: Identification of a practicable set of indicators for coastal and marine ecosystem services. In: Turner, R.K. & Schaafsma, M. (Eds.) *Coastal zones ecosystem services: from science to values and decision making*.

This edited book is a joint output from the NERC-funded Valuing Nature Network (Coastal Ecosystem Services) and the Defra-Funded UK National Ecosystem Assessment Follow-On Project (WP3b Marine Economics). As joint author, Daryl took a leading role in identifying a practicable set of indicators for each coastal / marine component and process, intermediate service, final service and good/benefit (following the framework established in **Turner et al., 2015**) and also developed and produced the figures for the chapter. Daryl was the lead author of both the Lundy case study and the managed realignment case study, and made a significant contribution to the structuring, drafting and editing of the chapter.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this book chapter.

Professor Jonathan Atkins, University of Hull, 4 November 2014

Saunders, J., Potts, T., Jackson, E., **Burdon, D.**, Atkins, J.P., Hastings, E., Langmead, O. & Fletcher, S., 2015. Chapter 9. Linking ecosystem services of marine protected areas to benefits in human wellbeing? In: Turner, R.K. & Schaafsma, M. (Eds.) *Coastal zones ecosystem services: from science to values and decision making*.

This edited book is a joint output from the NERC-funded Valuing Nature Network (Coastal Ecosystem Services) and the Defra-Funded UK National Ecosystem Assessment Follow-On Project (WP3b Marine Economics). This chapter further develops the work undertaken by **Potts et al. (2014)** and Daryl made a number of significant contributions. Daryl took the lead on updating the matrices to include habitats and species designated in Northern Irish waters (which were previously not covered by **Potts et al., 2014**), and adapting the matrices to reflect the changes in the marine ecosystem services framework (after **Turner et al., 2015**). Daryl was responsible for writing a section on the incorporation of ecosystem services in the policy and management of Northern Ireland marine waters and took a leading role in the drafting and editing of the overall chapter.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this book chapter.

Dr Tavis Potts, University of Aberdeen, 15 October 2014

Luisetti, T., Turner, R.K., Jickells, T., Andrews, J., Elliott, M., Schaafsma, M., Beaumont, N., Malcolm, S., **Burdon, D.**, Adams, C. & Watts, W., 2015. Chapter 11. What future for the English coastline? A case study exploring managed realignment benefits. In: Turner, R.K. & Schaafsma, M. (Eds.) *Coastal zones ecosystem services: from science to values and decision making*.

This edited book is a joint output from the NERC-funded Valuing Nature Network (Coastal Management) and the Defra-Funded UKNEAFO (WP3b Marine Economics). Daryl contributed to this chapter in relation to ecosystem services provided by saltmarsh in the Humber Estuary, with a particular focus on their potential links to commercial fisheries (following work presented in **Burdon et al., 2011**). Daryl also provided general comments and text during the drafting and editing of this chapter.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this book chapter.

Dr Tiziana Luisetti, Cefas, 20 October 2014

A2.3 Published papers (not included in this thesis)

Burdon, D., Callaway, R., Elliott, M., Smith, T. & Wither, A., 2014. Mass mortalities of bivalve populations: a review of the edible cockle *Cerastoderma edule* (L.). *Estuarine, Coastal and Shelf Science*, 150, pp. 271-280.

This paper forms a research output from an interdisciplinary project, funded by the Welsh Government, which investigated cockle mortalities in the Burry Inlet, South Wales. Daryl was responsible for the development of a conceptual model, based upon an earlier model produced by Professor Mike Elliott, which was used to structure the paper. As lead author, Daryl was responsible for reviewing the literature, co-ordinating the contributions from the co-authors, editing and submitting the final manuscript and revising the manuscript in response to the reviewers comments.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Ruth Callaway, University of Swansea, 3 November 2014

Callaway, R., **Burdon, D.**, Deasey, A., Mazik, K. & Elliott, M., 2013. The riddle of the sands: population dynamics provides clues to causes of high cockle mortality. *Journal of Applied Ecology*, 50(4), pp. 1050–1059.

This paper forms a research output from an interdisciplinary project, commissioned by the Welsh Government, which investigated cockle mortalities in the Burry Inlet, South Wales. This paper was led by Dr Ruth Callaway. Daryl made significant contributions to the drafting and editing of the paper and was responsible for providing the benthic data which he had previously analysed as part of the wider project.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Ruth Callaway, University of Swansea, 3 November 2014

Pascual, M., Borja, A., Franco, J., **Burdon, D.**, Atkins, J.P. & Elliott, M., 2012. What are the costs and benefits of biodiversity recovery in a highly polluted estuary? *Water Research*, 46, pp. 205-217.

This paper was an output from Dr Marta Pascual's internship at IECS, and built on some of Daryl's previous published works (including **Elliott et al., 2007**; **Beaumont et al., 2007**; **Atkins et al., 2011a**). Daryl provided advice and guidance on both biological and economic valuation techniques, provided relevant references and supporting evidence, and subsequently contributed to the drafting and final editing of the manuscript.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Dr Marta Pascual, University of Queensland, 15 October 2014

Elliott, M., **Burdon, D.**, Hemingway, K.L. & Apitz, S., 2007. Estuarine, coastal and marine habitat and ecosystem restoration: confusing management and science. *Estuarine, Coastal and Shelf Science*, 74, pp. 349-366.

This review paper is an output from a research contract awarded by the CCW (Prof Mike Elliott was the Principle Investigator). Daryl took a leading role in producing this manuscript, having undertaken the reviews of terminologies and concepts and written a number of the case studies presented. Daryl was responsible for developing and producing the conceptual models, and responding to a number of the reviewer's comments on the manuscript.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Professor Mike Elliott, University of Hull, 1 November 2014

Elliott, M., Boyes, S.J. & **Burdon, D.**, 2006. Integrated marine management and administration for an island state - the case for a new Marine Agency for the UK. *Marine Pollution Bulletin*, 52(5), pp. 469-474.

Professor Mike Elliott was the lead author of this MPB Editorial. Daryl made significant contributions to the writing and editing of this paper and updated the administration figures included in the paper in collaboration with Sue Boyes.

I confirm that the above statement is a true reflection of the contribution made by Daryl Burdon to this paper.

Professor Mike Elliott, University of Hull, 1 November 2014

ANNEX 3: PUBLISHED PAPERS

ANNEX 4: BOOK CHAPTERS

ANNEX 5: PUBLISHED PAPERS (NOT INCLUDED IN THIS THESIS)