Integrating natural and social sciences to sustainably manage vectors of change in the marine environment: Dogger Bank transnational case study.

Daryl Burdon[1*], Suzanne J. Boyes[1], Michael Elliott[1], Katie Smyth[1], Jonathan P. Atkins[2], Richard A. Barnes[3] & Rüdiger K. Wurzel[4]

[1] Institute of Estuarine & Coastal Studies, University of Hull, Hull, HU6 7RX, UK.
[2] Hull University Business School, University of Hull, Hull, HU6 7RX, UK.
[3] Law School, University of Hull, Hull, HU6 7RX, UK.
[4] School of Politics, Philosophy & International Studies, University of Hull, Hull, HU6 7RX, UK.
*Corresponding author: D.Burdon@hull.ac.uk; Telephone +44 (0) 1482 466786, Fax. +44 (0) 1482 466772

Abstract

The management of marine resources is a complex process driven by the dynamics of the natural system and the influence of stakeholders including policy-makers. An integration of natural and social sciences research is required by policy-makers to better understand, and manage sustainably, natural changes and anthropogenic activities within particular marine systems. Given the uncertain development of activities in the marine environment, future scenarios assessments can be used to investigate whether marine policy measures are robust and sustainable. This paper develops an interdisciplinary framework, which incorporates future scenarios assessments, and identifies four main types of evaluation needed to integrate natural and social sciences research to support the integrated management of the marine environment: environmental policy and governance assessments; ecosystem services, indicators and valuation; modelling tools for management evaluations, and risk assessment and risk management. The importance of stakeholder engagement within each evaluation method is highlighted. The paper focuses on the transnational spatial marine management of the Dogger Bank, in the central North Sea, a site which is very important ecologically, economically and politically. Current management practices are reviewed, and research tools to support future management decisions are applied and discussed in relation to two main vectors of change affecting the Dogger Bank, namely commercial fisheries and offshore wind farm developments, and in relation to the need for nature conservation. The input of local knowledge through stakeholder engagement is highlighted as a necessary requirement to produce site-specific policy recommendations for the future management of the Dogger Bank. We present wider policy recommendations to integrate natural and social sciences in a global marine context.

Keywords

Dogger Bank; Integrated Marine Management; Ecosystem Services; Modelling Tools; Future Scenarios; Risk Assessment.

Research Highlights

- Integrating natural and social sciences is essential for sustainable management
- A generic conceptual framework is proposed which identifies tools for integration
- Future scenarios assessments can be used to aid future management decisions
- Four types of integrating tools have been applied to the transnational Dogger Bank
- Stakeholder engagement is essential to produce site-specific policy recommendations

1. Introduction

The marine environment is a complex and dynamic ecosystem, formed by interactions between both biotic (biological) and abiotic (physico-chemical) processes which, if it has an appropriate structure and functioning, provides a range of ecosystem services which in turn lead to benefits for society (Elliott et al., 2006; Atkins et al., 2011; Börger et al., 2014; Hattam et al., 2015). Within European seas, anthropogenic activities and their resulting pressures are intense and increasing as new industries emerge and traditional ones relocate often further offshore (EEA, 2015). The mechanisms of change exerted by anthropogenic activities against a background of natural change, create pressures which may impact upon the structure and functioning of the ecosystem, thus affecting the delivery of ecosystem services and benefits for society (Atkins et al., 2011; Tett et al., 2013; Elliott, 2014). This requires holistic and integrated marine management in order to reduce, remove or mitigate against the impacts of all human activities on both the natural and social system.

The linking of science with policy is an important element of such integrated marine management. Traditionally this has been through the integration of natural and social sciences with the processes of decision-making and management, across the so-called science–policy interface (Bremer & Glavovic, 2013) or knowledge-practice interface (Puente-Rodriguez, 2015). Leith et al. (2014) argue that diagnosing fit-for purpose approaches to linking science and decision-making may be achievable by enabling the identification of appropriate processes, institutions, objects (e.g. tools, information products) and relationships that can facilitate outcomes. Nursey-Bray et al. (2014) further argue that in order to better understand how to build scientific research outputs into policy, decision-makers and researchers need to understand how knowledge works in practice and be able to incorporate both scientific and local knowledge into the decision-making process. To incorporate local knowledge into both integrated scientific research and policy, these studies all recognise the importance of including stakeholders both within marine research and marine management.

The ecosystem approach, first adopted as an underpinning concept of the Convention for Biological Diversity (CBD, 2000) and advocated by the European Marine Strategy Framework Directive (MSFD) (European Commission, 2008), provides the guiding principles for such integrated management (Elliott, 2014). 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'. The application of the Ecosystem Approach will help to reach a balance of the three objectives of the Convention: conservation, sustainable use and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources (COP 7 Decision VII/11, Annex 1). The EU's Blue Growth Strategy follows this approach by recognising that a balance must be achieved between promoting marine activities and achieving the objective of Good Environmental Status under the MSFD (2008/56/EC) by 2020 (EEA, 2015). Similarly, the EU Maritime Spatial Planning (MSP) Directive (2014/89/EU) (EC, 2014) focuses on economic development while fulfilling the MSFD.

Atkins et al. (2011) suggest that the marine environment can be perceived to be a system formed through the interconnection between natural systems (such as terrestrial, freshwater, estuarine, coastal and oceanic), designed systems (such as extractive industries, tourism, transport and power generation) and social systems (such as environmental Non-Governmental Organisations (ENGOs) and fishing communities). As such, holistic marine management practices should consider the environmental, economic and social impacts of all significant human activities (Elliott, 2014). The DAPSI(W)R(M) (*Drivers-Activities-Pressures-State changes-Impacts* (on human *Welfare*)-*Responses* (*as Measures*)) framework (Wolanski & Elliott, 2015, modified from *Drivers-Pressures-State change*s-*Impacts-Responses* in Atkins et al., 2011 and *Drivers-Activities-Pressures-State changes-Impacts* (on human *Welfare*)-*Responses* in Smyth et al., 2015), is a valuable problem-structuring method which is consistent with the Ecosystem Approach and can be readily applied to understand the complexity of the marine environment and the requirements for marine management (Gregory et al., 2013). This paper focuses on the current and future management measures (*Responses as Measures*) to marine vectors of change. In particular, such responses are required to address the hazards and risks posed by both natural and anthropogenic vectors of change in the marine environment (Elliott et al., 2014)

Given the uncertain development of activities in the marine environment and the associated ecosystem response, future scenarios assessments can be used to investigate whether current marine policy measures are robust and sustainable to aid future management decisions (Burdon et al., 2014; Groenveld et al., in press). Future scenarios assessments provide a valuable tool to enable new ways of thinking and to model changes in society, although for scenarios to be a useful tool, they must all be plausible and credible, thus requiring local knowledge gained through stakeholder engagement. As recognised by the UN Environment Programme (UNEP), scenarios do not have to be developed from first principles but can be adopted and adapted from the literature. Scenario testing has been used in many sectors of coastal management such as planning for storm surge flooding and loss of coastal wetlands (Nicholls, 2004; Conte & Lionello, 2013); provision of drinking water supplies (Marquès et al., 2013), and impacts of climate change (Philippart et al., 2011; Elliott et al., 2015). Following its earlier adoption by the Intergovernmental Panel on Climate Change (IPCC, 2000), the so-called four-quadrant approach has become commonplace (e.g. UKCIP, 2001; Hulme et al., 2002; Pinnegar et al., 2006; Langmead et al., 2007; Burdon et al., 2014; Tett & Mee, 2015). Table 1 provides a summary of the four contrasting future scenarios which are driven by local and global environmental policy and economic growth, with each being further described below (adapted from Pinnegar et al., 2006):

- Scenario A1 (World Markets) assumes that people aspire to personal independence, material wealth and greater mobility, to the detriment of wider societal and environmental goals;
- Scenario A2 (Protected Markets / National Enterprise) assumes that people aspire to personal independence and material wealth within a nationally-rooted cultural identity;
- Scenario B1 (Global Community) assumes that people aspire to high levels of welfare and a sound environment, and that these objectives are best achieved through cooperation at an international level; and
- Scenario B2 (Local Communities / Responsibilities) assumes that people aspire to sustainable levels of welfare in local communities, with ambitious public policy aiming to promote economic activities that are small-scale and regional in scope.

Table 1: General characteristics of future scenarios (adapted from IPCC, 2000).

	Autonomy		
Consumerism	**A2 Protected Markets / National Enterprise** (National / Consumerist) • Modest local environmental policy • Limited global environmental policy • Intermediate economic growth	**B2 Local Communities/Responsibilities** (National / Environmental) • Ambitious local environmental policy • Modest global environmental policy • Low economic growth	**Community**
	A1 World Markets (Global / Consumerist) • Modest local environmental policy • Modest global environmental policy • High economic growth	**B1 Global Community** (Global / Environmental) • Ambitious local environmental policy • Ambitious global environmental policy • Intermediate economic growth	
	Interdependence		

Linking future scenarios assessments, for which the main driving forces are environmental policy (both local and global) and economic growth, with possible future changes in marine *Activities*, their associated *Pressures*, and potential impacts on both the natural system (*State changes*) and society (*Impacts on Welfare*) requires a holistic approach, which integrates both natural and social sciences research. A conceptual framework (Figure 1) illustrates potential tools available (grey boxes) for linking natural science research (white boxes) and social science research (black boxes) for the purpose of integrated marine management. The future scenarios described above have been applied to the assessment of four integration tools for successful and sustainable management:

1) Environmental policy and governance assessments;
2) Ecosystem services, indicators and valuation;
3) Modelling tools for management evaluations, and
4) Risk assessment and risk management.

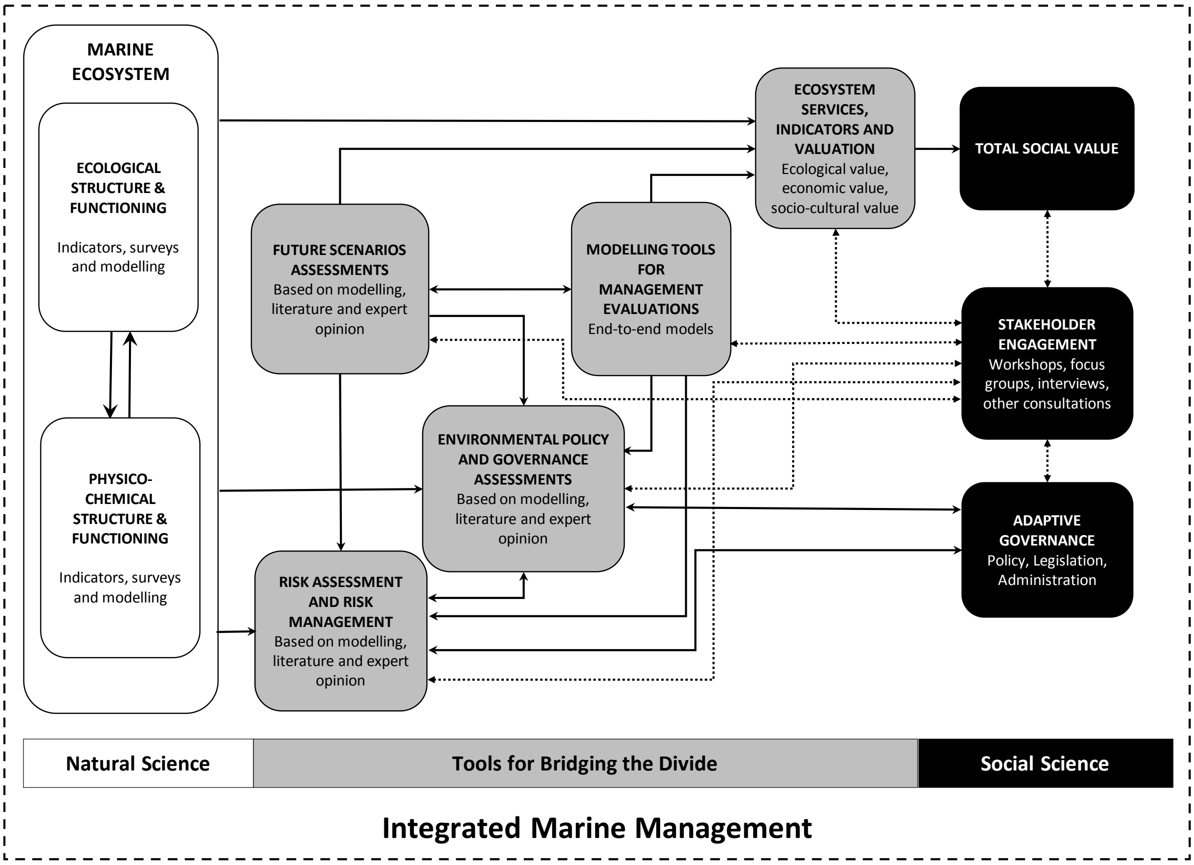

Figure 1: A framework for linking natural and social sciences for integrated marine management. (Solid lines reflect linkages between components; dashed lines reflect two-way aspects of stakeholder engagement).

This paper uses the Dogger Bank in the North Sea (Figure 2) as a case study to investigate the ecological, economic and social interests, costs and trade-offs of integrated transnational marine management. The area is of international ecological importance (with three international nature conservation designations), economically of great value (long-standing fishing grounds and the location of the largest proposed UK offshore wind farm) and is politically challenging for marine management as it is shared between four EU Member States (Denmark, Germany, the Netherlands and UK). Lessons learned from this case study are therefore important for other marine sites.

2. Dogger Bank Transnational Case Study

The Dogger Bank is the largest shallow sub-tidal bank in the North Sea, covering approx. 17,600 km^2 (Diesing et al., 2009) and within the Exclusive Economic Zones (EEZs) of the above mentioned four Member States (Figure 2). It was formed through glacial processes and submergence through sea-level rise (Stride, 1959; Veenstra, 1965). It is a transition zone between the distinct ecosystems in the northern and the southern North Sea, and is thus relatively well studied (Ducrotoy & Elliott, 2008). Its waters remain permanently mixed, with primary production occurring throughout the year, resulting in the highest production values in the southern North Sea during the winter months (Kröncke, 2011). It has typical boreal benthic communities which support a diverse demersal fish assemblage, including dab, plaice, sandeel, haddock, grey gurnard and lesser weever (Wieking & Kröncke, 2003; Kröncke, 2011; Sell & Kröncke, 2013). In particular the sandeel populations provide significant prey for commercial fish species (e.g. whiting, plaice, mackerel and cod), seabirds (such as fulmar and kittiwake) and cetaceans, especially the harbour porpoise (Diesing et al., 2009) for which the German Environment Ministry and ENGOs have demanded stringent protection measures. These links in abundance indicate the importance of maintaining a healthy sandeel stock for the wider Dogger Bank fish community (Cefas, 2007).

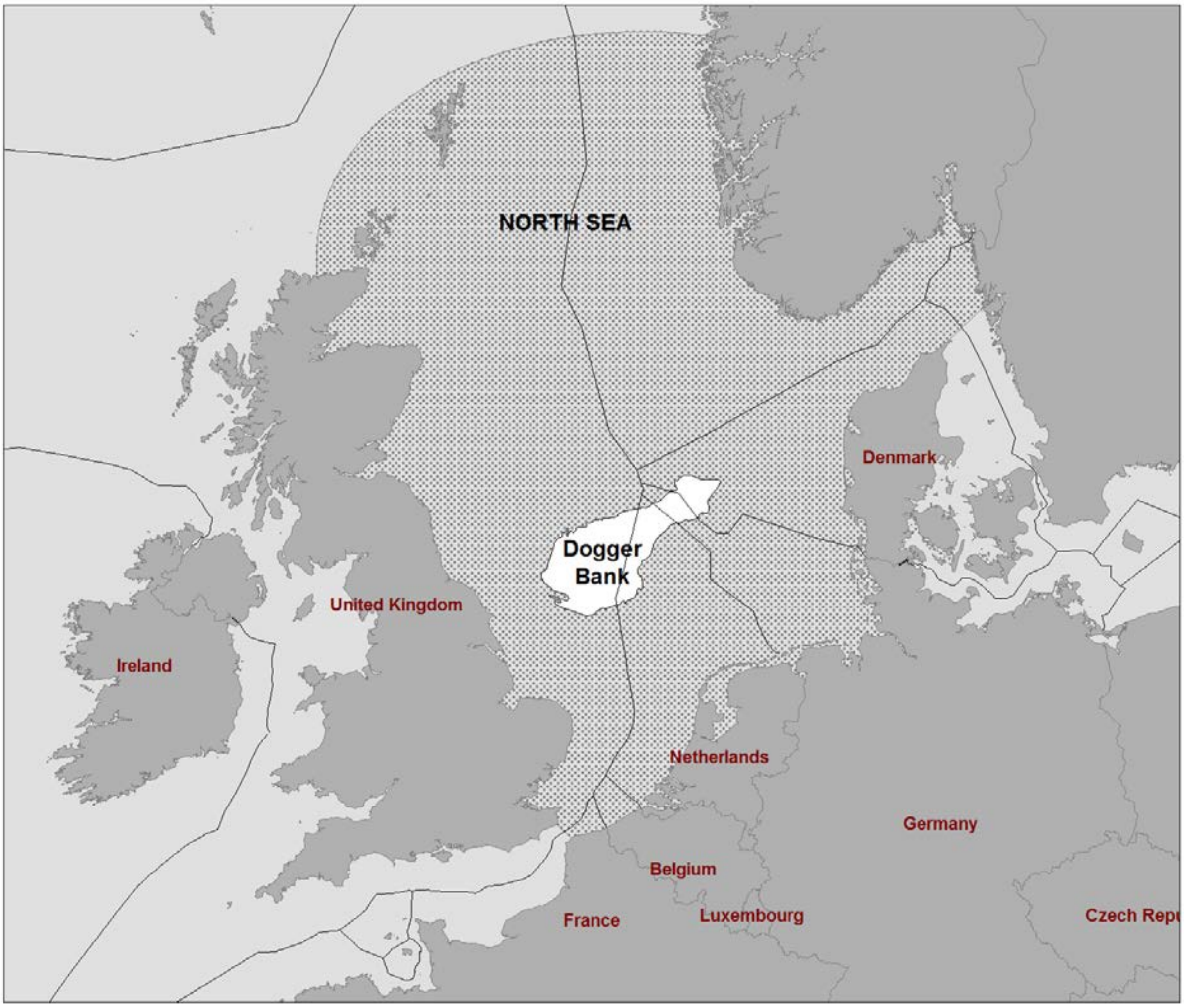

Figure 2: Location of the Dogger Bank (Hattam et al., 2015).

The Dogger Bank is historically of great economic importance as a rich fishing ground primarily for Dutch, German, Danish and UK fleets, where large-scale industrial trawlers target demersal species such as plaice, megrim and turbot, as well as sandeels (Hattam et al., 2015). It supports natural gas exploration and production, with five platforms still present on the bank, and aggregate extraction in two small licenced areas (JNCC, 2011). There are plans for the development of the largest wind farm in Europe on the UK sector of the Dogger Bank, covering 8,660 km^2 (Forewind, 2010). Its shallow depth precludes commercial shipping lanes situated near the Dogger Bank (JNCC, 2011) which together with many wrecks provide some recreational angling and diving (Forewind, 2013). It is therefore vulnerable to several pressures associated with economic activities, especially commercial fishing and the energy sector.

2.1 Current Governance and Stakeholder Engagement

Marine governance can be regarded as the policies, politics, administration and legislation required to inform and manage the marine environment and its many activities and pressures, each of which may create a vector of change; these should be managed or at least accommodated in order to achieve objectives set by society (Elliott, 2014). The many and varied stakeholders contribute to the problems and solutions including controls and management for both present and future problems (Elliott, 2014; Boyes & Elliott, 2015). The importance of a continuous multi-way dialogue between researchers and stakeholders (Elliott, 2014) is emphasised in Figure 1 by the double-headed dashed lines which represents a novel conceptual model, for successful and sustainable integrated marine management.

The complexity of the marine environment, with its many activities and features requires a complex European marine governance system which has created over 200 directives, regulations or other types of EU legislation that directly affect marine environmental management and are linked to the international and national level (Beunen et al., 2009; Boyes & Elliott, 2014; 2015). However, national, EU and international marine environmental legislation has historically developed piecemeal, producing a complex patchwork of policies for specific sectors or marine areas. Despite this, more recent legislation such as the MSFD has moved away from this compartmentalised and sectoral approach to become more holistic (Boyes & Elliott, 2014) thus aiming to protect and enhance the natural structure, processes and functioning while at the same time delivering the ecosystem services from which society can benefit (Elliott, 2011, 2013; Boyes & Elliott, 2015).

The Dogger Bank provides a complex governance case as international, EU and national laws and policies need to be harmonised or at least co-ordinated (Boyes et al., 2012; Elliott, 2014; Boyes & Elliott, 2014). With four countries claiming governance rights for their EEZs for conservation, fisheries and renewables exploitation, there is a complex and delicate balance to strike for a marine governance system of the Dogger Bank. To address the competition for maritime space and provide greater coherence to planning in the marine environment (Douvere, 2008; EC, 2013), the EU has adopted the MSP Directive (2014/89/EU) (EC, 2014). This Directive is focused on economic development and aims for the efficient and smooth application of MSP in cross-border marine areas such as the Dogger Bank. Although it is only now being implemented, the MSP Directive should increase coordination between the Member States, and afford greater marine protection based on a common framework and transposed into national legislation by 2016 with national maritime spatial plans developed by 2021 (EC, 2011).

Nature conservation on the Dogger Bank is protected by several international and EU legal instruments including the UN Convention on the Law of the Sea (UNCLOS) and the Convention on Biological Diversity (CBD). A network of Marine Protected Areas (MPAs) is promoted by both regional obligations (e.g. the OSPAR Convention for the Protection of the Marine Environment of the North-

East Atlantic and the Bern Convention on the Conservation of European Wildlife and Natural Habitats) and the implementation of EU Directives (e.g. Good Environmental Status under the MSFD and favourable conservation status for habitats and species under the Habitats Directive (92/43/EEC) and Birds Directive (2009/147/EC)) (Boyes & Elliott, 2014; Potts et al., 2014). The Dogger Bank provides a test case for how EU (and national) nature conservation legislation is implemented in an offshore marine area, with the UK, Germany and the Netherlands all designating within their respective jurisdictions Special Areas of Conservation (SAC), a form of MPA, under the EU Habitats Directive. Denmark has decided not to designate its area of the Bank as an SAC as it considers the Danish parts too deep to qualify as 'sandbanks which are slightly covered by water all of the time' (i.e. the category of Annex I Habitat H1110). No guidance is provided within the Habitats Directive for transboundary cooperation for areas like the Dogger Bank except that Article 18 states that 'transboundary cooperative research between Member States shall be encouraged'. Fock (2011) considers that based on very different national objectives, a diverse set of national management plans are likely to be developed for the Dogger Bank.

International commitments, such as the ratification of the Kyoto Protocol and guidelines set within the EU Renewable Directive (2009/28/EC) have led to the setting of ambitious renewable energy targets around Europe. To ensure 20% of all EU energy is generated from renewables by 2020, Member States have set National Action Plan targets in support of the EU goals; Denmark and Germany have targets of 20% and 35% respectively (Christie et al., 2014; EC, 2015), with the UK Government aiming to generate 15% and The Netherlands 14% by 2020 (EC, 2015). Dogger Bank is the largest of the UK Round 3 zones identified for potential offshore renewable energy, but with water depths ranging from 18 to 63m, it is also one of the shallowest. It has the potential for approximately 4GW development capacity in less than 30m water depths (Forewind, 2015).

The management of fisheries in European marine waters is under the exclusive competence of the EU through the reformed (1 January 2014) Common Fisheries Policy (CFP) with measures coordinated at the EU-level. This provides a framework for managing European fishing fleets and fishing grounds and for conserving fish stocks and is designed to manage a common resource fairly between European fishing fleets to ensure that fish stocks are sustainably managed. Management of fishing methods is required to ensure the protection against the damaging effects of mobile demersal fishing activities. Fisheries management cooperation on the Dogger Bank therefore significantly differs, and should be distinguished from, cooperation on other management aspects of MPAs (Jansen et al., in press).

Both Germany and the Netherlands initiated national projects to explore fisheries management options in relation to MPAs. Germany, conducted the Environmentally Sound Fisheries Management in Marine Protected Areas (EMPAS) project (2006-2008) whilst the Netherlands carried out the Fisheries Measures in Protected Areas (FIMPAS) project (2009-2011) (Fock, 2011). These two projects concluded that the international nature of the Dogger Bank required a transnational management response. This was further supported by the EU-funded MASPNOSE project (2010-2012), which explored ecosystem-based MSP in the North Sea, with one of its two case studies focussing on the Dogger Bank (Pastoors et al., 2012).

Initially, the Dutch were the main driving force behind the transnational cooperation for either a single Dogger Bank-wide fisheries management plan or well-coordinated national fisheries management plans. Therefore, on their initiative, German, Dutch and UK officials formed a transnational Dogger Bank Steering Group (DBSG) with the European Commission and Denmark holding observer status. The DBSG invited the North Sea Advisory Council (NSAC, formerly the North Sea Regional Advisory Council), which consists mainly of representatives from the fisheries industry NGOs, to propose a fisheries management plan using a unique bottom-up approach. This novel approach reflected the need for a better understanding of the requirements of Dogger Bank stakeholders and conflict resolution attempts in this offshore marine area where economic activities are increasing.

The VECTORS project (www.marine-vectors.eu) conducted 22 interviews with stakeholders and policy-makers in Denmark, Germany, the Netherlands and the UK, and EU officials and NGO representatives in Brussels, which showed important differences in views and conflicting interests (Atkins et al., 2012). The main conflicts were between the users (e.g. fishermen), who wish to continue a high level of exploitation of natural resources (e.g. fish) and those stakeholders (e.g. ENGOs) who seek the highest possible level of environmental protection. In the case of fishing, there was disagreement amongst different types of stakeholders but sometimes also within the same type of stakeholder about the type of fishing gear which should be allowed and the size of the area which ought to be protected from any fishing. There are also important differences amongst national policy-makers. Although most interviewees agreed on the importance of harmonised standards in each of the three national parts of the Dogger Bank SAC, the Netherlands, Germany and UK have adopted somewhat different national environmental protection goals and policies. For example, although the protection of harbour porpoises is not part of the current international negotiations of fishery management plans or a common fisheries management plan (NSRAC, 2012), Germany deems it necessary to adopt specific protection measures for harbour porpoises in the Dogger Bank; this is not the case for the Netherlands which instead intends to promote North Sea wide protection measures for the species.

The NSAC constituted a unique negotiating forum because it encouraged a transnational bottom-up process which was dominated by stakeholders rather than governmental and/or EU institutional actors (e.g. the European Commission). Its decision-making process was novel in two respects. First, by encouraging a wide range of stakeholders to produce a bottom-up compromise proposal for transnationally-coordinated fisheries management plans, it diverged from the traditional EU decision-making methods (which is often referred to as Community method) and traditional international environmental diplomacy, which usually consists of Member States negotiating with each other rather than societal actors being directly involved. Second, it brought together stakeholders who, due to their conflicting interests, often find it difficult to work together (e.g. representatives from the fishing industry and ENGOs). Although this novel bottom-up decision-making process was welcomed by most stakeholders and policy-makers, it did not produce an integrated fisheries management plan as the conflicting stakeholders were unable to compromise although they came quite close to doing so. (BirdLife Europe announced on 17 April 2015 that following months of political wrangling, the Dutch Government has rejected the Dutch fishing industry's plans to protect less of the Dutch Natura 2000 Dogger Bank site from bottom trawl fisheries and has subsequently given its full approval for a joint Member States proposal for a Dogger Bank fisheries management plan (http://www.birdlife.org/sites/default/files/attachments/17042015PR_DoggerBank_0.pdf). The empirical research presented here was completed before these decisions took place).

Many barriers to the successful management of the Dogger Bank were identified by the stakeholders: (1) differing policy objectives between Natura 2000 legislation and the CFP; (2) conflicting interests and goals exist between different types of stakeholders (e.g. fishermen and ENGOs) and between different Member States (Germany, the Netherlands, UK and Denmark); (3) deep-seated national regulatory traditions and wider policy styles (including action guiding principles such as the precautionary principle which is most widely accepted in Germany) strongly influence national approaches to marine governance; (4) unrealistic or conflicting deadlines for certain marine management measures; (5) vague terms of reference for the NSAC allowed stakeholders to put forward widely differing proposals (ranging from 25-55% of closures of the Dogger Bank to fishing; (6) a lack of sufficient resources (including staff and funds) made it very difficult, if not impossible, to meet tight deadlines set by the NSAC; (7) considerable uncertainties in scientific evidence but also with regard to legal and political processes increased conflict between different types of stakeholders; (8) complexity of the multi-level governance decision-making process constituted a significant challenge for reaching a consensus amongst stakeholders with different goals and interests, and (9) incidents of 'venue shopping' took place when some stakeholders lobbied simultaneously or at sequentially different decision-making levels (including the local, regional, national, EU and international levels) in the hope that this will allow them to achieve more easily their objectives within a complex multi-level marine governance system.

3. Future Management of the Dogger Bank: Integrating Natural and Social Sciences Research

In order to provide additional scientific information, to inform the future management of the Dogger Bank, a number of evaluation tools were applied to bridge the natural and social sciences (Figure 1).

3.1 Environmental Policy and Governance Assessment

Given the uncertain development of marine activities, and the resulting state change of the ecosystem, the four contrasting future scenarios (see Table 1 and associated text) have been used to test whether current marine policy measures are robust and sustainable in relation to the Dogger Bank. The scenarios focus on the likely policy implications for three key drivers of change (nature conservation, fisheries and offshore renewable energy) with policy implications to 2050 (Figure 3). These results, which were discussed with stakeholders at a marine stakeholder workshop, show how the governance of these sectors would change based on the four future scenarios (Burdon et al. 2014).

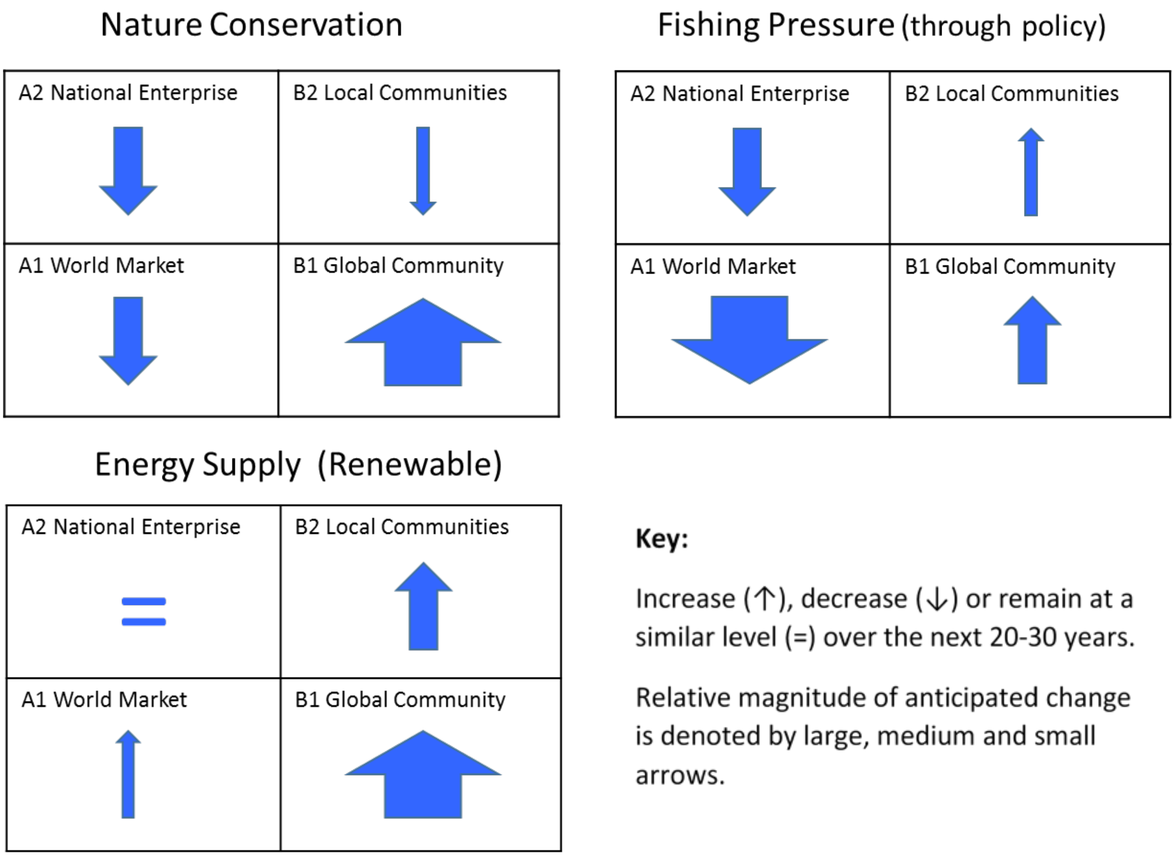

Figure 3: Drivers of change and policy implications of the four future scenarios for the Dogger Bank.

3.1.1 Nature Conservation

Under the National Enterprise scenario (A2), nature conservation is not a priority and therefore the designation of the Dogger Bank as an MPA by all concerned countries may not be pursued. Marine ecosystems will be under greater pressures than at present with nature conservation policy being inadequate to restrict development pressures. Under the Local Communities scenario (B2), nature conservation would be more dominant with local efforts to preserve wildlife and sensitive habitats. However this may not extend to habitats outside Member State territorial waters and may therefore not afford any protection to the Dogger Bank. Under the World Market scenario (A1), there is a decline in most marine habitats due to climate change and decreased regulation of pollution controls. Within the B1 (Global Community) scenario, although there is an increased importance of co-location of marine activities, this is against a background of strong nature conservation legislation at all levels. More MPAs and closed areas may be established at the international level to protect biodiversity within the regional seas.

3.1.2 Fishing Pressure

In the National Enterprise scenario (A2), governments would assume greater responsibility and control over their territorial waters, with the CFP focusing mainly on resolving conflicts over straddling stocks. This would lead to a collapse of key fish stocks with increasing conflicts between different marine users. In contrast, the Local Communities scenario (B2) indicates that Member States would adopt a system of local governance and withdraw from the CFP, with fisheries management transferring to regional committees. In the A1 (World Market) scenario, the CFP plays only a minor role and becomes much less interventionist with fishing pressure continuing to be managed at a European scale although with greater emphasis on market forces, and fewer legal and technical restrictions. This will eventually lead to a collapse of stocks. In the Global Community scenario (B1) fisheries policy is enacted to balance high yields with low environmental impacts. The CFP is tightened up i.e. no discards would be allowed and other EU legislation is adhered to e.g. MSFD. This scenario would give the greatest protection to the Dogger Bank and indeed could be argued as occurring with recent governance developments.

3.1.3 Energy Supply (Renewable)

In the A2 (National Enterprise) scenario, the governmental main objective through its energy policy would be to ensure a supply of cheap and secure energy. Natural resources would still be exploited offshore but offshore wind would only be promoted if considered in the national interest. International targets may be breached e.g. Kyoto Protocol, in favour of national interests. In contrast, legislation under the Local Communities B2 scenario would promote the exploitation of a wide range of small-scale renewable energy technologies, particularly wind, however this may not extend offshore to the Dogger Bank. The main driver for renewables would be energy security. In the A1 (World Market) scenario, the market continues to be dominated by fossil fuels with natural gas exported from outside Europe. Renewable electricity generation is viable, but not widely adopted with the United Nations Framework – Convention on Climate Change (UNFCCC) and EU Renewable Energy Directive targets given low priority and seen as secondary to economic growth. Policy will only promote offshore wind power if it becomes commercially viable and there is a decline in fossil fuels, not because of any concern for the environment. In contrast the governance in the B1 (Global Community) scenario promotes major international action to reduce greenhouse gas emissions, and hence large-scale expansion of the offshore renewables industry beyond that currently proposed. Building offshore wind farms on the Dogger Bank would also afford potential marine conservation and biodiversity benefits such as artificial reefs and 'no-take' zones.

3.1.4 Summary

Although the four scenarios can be regarded as extremes, they all contain recognisable events with respect to the Dogger Bank, for example society is globalising but at the same time becoming more aware of environmental issues. It is presumed unlikely that any of the four scenarios will evolve in an unconstrained way for the Dogger Bank since future pathways are dependent upon existing legislation, obligations and conventions. Irrespective of that future trajectory, the continuing move from sectoral legislation and management to a more holistic approach is likely. It is likely that a future situation will contain elements of each of the scenarios rather than being solely any single scenario.

3.2 Ecosystem Services, Indicators and Valuation

The evaluation of ecosystem services integrates the natural and social sciences and is consistent with the Ecosystem Approach (Figure 1) (Beaumont et al., 2007; Atkins et al., 2011; Atkins et al., 2014). The importance of incorporating ecosystem services, and especially valuation, into marine planning has recently been recognised by Börger et al. (2014b). Ecosystem services are regarded here as the direct and indirect contributions that ecosystems make to creating societal benefits which then extend human well-being (modified from de Groot et al., 2010; Atkins et al, 2011). Ecosystem service indicators, when linked to future scenarios assessments, can reflect how service provision may change over time (Hattam et al., 2015). Since marine ecosystem services may lead to societal benefits it is appropriate to consider their value which may accrue to specific stakeholder groups (Atkins et al., 2011; Cooper et al., 2013). Attempts to secure the societal benefits associated with marine ecosystem services can lead to stakeholder tensions and/or conflict, for example, between those who seek to exploit marine resources and those who seek environmental protection. There has been increasing attention to ecosystem service valuation which has been used by stakeholders seeking to influence both the direction and the detail of marine policy as well as decision-making more generally. For example, of relevance to UK waters there has been the marine-based Valuing Nature Network (Potts et al., 2014), the National Ecosystem Assessment (Austen et al., 2011) and the National Ecosystem Assessment Follow-on Project (Turner et al., 2014; Atkins et al., 2014), in addition to projects for the Department of Environment, Food and Rural Affairs (Defra) (Beaumont et al., 2006), the Crown Estate (Saunders et al., 2010), the Wildlife Trusts (Rees et al., 2014) and the Northern Ireland Marine Task Force (Barnard et al., 2014). Applying an ecosystem services approach to the Dogger Bank enables the demands of society (e.g. the need for food and renewable energy), the economy (e.g. commercial activities such as fishing and wind farm developments) and the environment (e.g. nature conservation) to be integrated into its management, as required by the Ecosystem Approach.

A major challenge to the evaluation of ecosystem services is to establish Total Social Value (Figure 4). This comprises three main value domains (MA, 2003): ecological value which is the health state of an ecosystem measured in natural science terms using ecological indicators such as diversity and integrity (e.g. Tett et al., 2013); economic value where total economic value comprises both use and non-use values and can be valued using stated and revealed preference methods to give estimates of monetary values where market values do not exist, and socio-cultural value which includes the importance people give to, for example, the cultural identity and the degree to which that is related to ecosystem services (de Groot et al., 2002). Ecological valuation does not feed directly into the Total Social Value but is important for providing the basis for both the assessments of economic value and socio-cultural value (Hattam et al., under review). This step incorporates both scientific knowledge (through ecological assessments) and local knowledge (through stakeholder engagement) which can feed into the decision-making process. Estimates of Total Social Value can be incorporated into the marine management process (Figure 1).

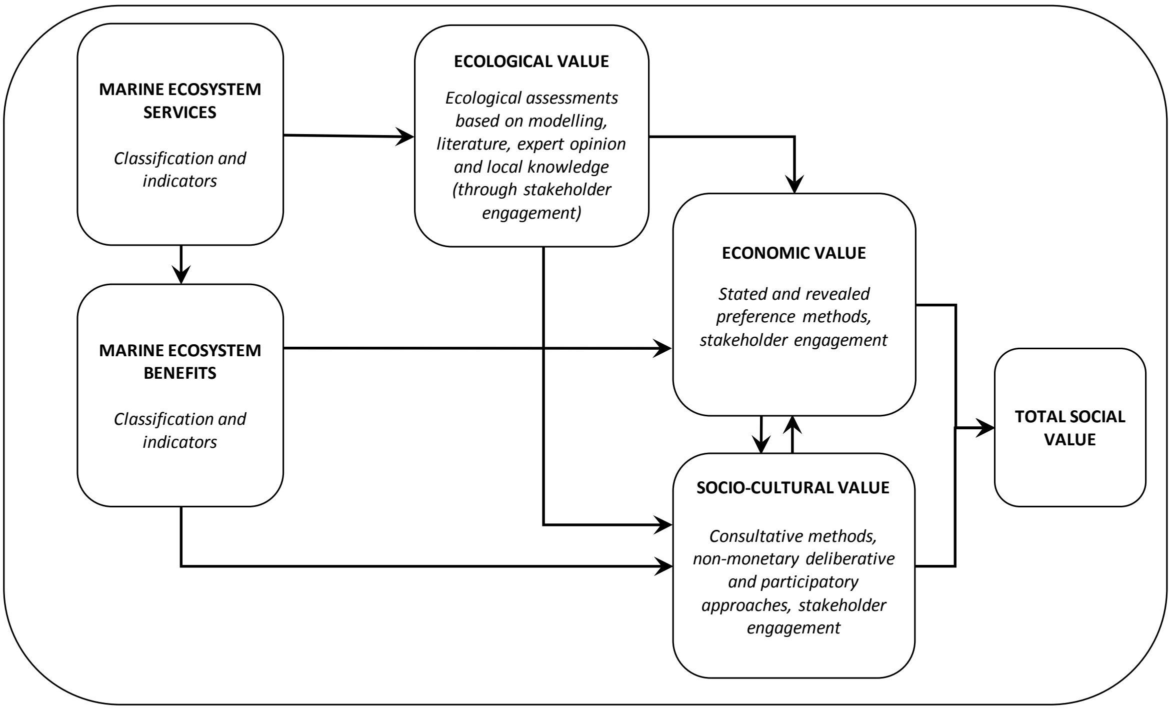

Figure 4: Total social value comprising ecological value, economic value and socio-cultural value.

Several studies have assessed the current value of the ecosystem services provision on the Dogger Bank and how this might change in the future. These studies identified ecosystem service indicators and quantified change in their provision under future scenarios (Hattam et al., 2014, 2015), evaluated the economic benefits of conservation of the Dogger Bank offshore MPA based on an online discrete choice experiment (Börger et al., 2014) and used a deliberative valuation workshop to focus on the socio-cultural value of the Dogger Bank based on a citizen's jury methodology (Hattam et al., 2014).

Given the complexity of the marine ecosystem and the need for integrated management, indicators quantify the behaviour and state of coastal and marine ecosystems and give the trajectories of change due to natural and human-induced events (Gibbs & Cole, 2008; Atkins et al., 2015). Hattam et al. (2015) identify generic indicators of ecosystem processes, ecosystem services and benefits, and subsequently assess each indicator for their relevance and applicability to the environmental management of the Dogger Bank using an agreed set of criteria. The criteria included their measurability, sensitivity, specificity, scalability and transferability. The indicators were then applied to assess both the recent past (2000-2009) and in future projections for the medium term (2040-2049) ecosystem service provision using two future scenarios (A2 National Enterprise and B1 Global Community – see Table 1 and associated text). This analysis used evidence from the literature and expert opinion, and modelled results for changes in climate and nutrients (see Kay & Butenschön, in press). This study finds that the primary driver of change in ecosystem service provision between the two scenarios would be changes to national and international policy, emphasising the importance of cooperative international policies in maintaining/increasing ecosystem service provision of offshore zones in the future. In the case of the Dogger Bank, insufficient data limited the measurability of many indicators, with only six out of these 15 ecosystem service indicators being measureable for present day (food provision, biotic raw materials (non-food), climate regulation, gene pool protection, migratory and nursery habitat, and leisure, recreation and tourism) and only one out of these 15 indicators, climate regulation, projected into the future using a modelling approach. In addition, indicator specificity was highlighted as being challenging as many of the indicators respond to multiple *Activities* and *Pressures*. However, while the indicators can show the extent of change in ecosystem services further analysis is required to establish the causes and to prescribe any management *Responses*. In this context, the complexity of the marine environment calls for a suite of indicators.

Given the lack of site-specific ecosystem service data for the Dogger Bank, an economic valuation survey was undertaken which assessed a series of management options to regulate fisheries and future wind farm construction on the Dogger Bank (Börger et al., 2014). An online survey of UK households employed a discrete choice experiment methodology (Hanley et al., 1998) to quantify certain ecosystem benefits for which market data were absent. Respondents supported an increase in species diversity and the protection of charismatic species such as porpoises, seals and seabirds on the Dogger Bank as a result of fisheries restrictions as well as a reduction in the spread of invasive species associated with offshore wind farms. Willingness-to-pay (WTP) estimates for these attributes indicate the mean expected change in well-being of respondents resulting from the management measures suggested, thus being used to inform future management decisions for the site.

In order to explore in more depth the public perceptions and priorities for the Dogger Bank, the third study reports on a citizen's jury workshop (Spash, 2007) involving 20 members of the UK general public (Hattam et al., 2014). Participants were provided with information from expert witnesses (one representative from both fishing and wind farm user groups, an ENGO and a marine ecologist) about the uses of the Dogger Bank and their impacts on its environment. Two main themes emerged from subsequent facilitated discussions: that fishing should be prioritised over wind farm development given the historical legacy of fishing, and that conservation should be a priority, recognising the intrinsic value of the Dogger Bank, and that conservation should not exclude the use of the Dogger Bank for economic purposes. Many participants agreed that multiple activities should be allowed on the Dogger Bank and that a system of zoning of activity may be an appropriate management option for the site. These findings are consistent with those of the MASPNOSE project in relation to the Dogger Bank (Pastoors et al., 2012).

The complementarities of these three approaches for valuing ecosystem services provided by the Dogger Bank have been assessed (see Hattam et al., under review) and concludes that integrating the findings of mixed-method approaches is advantageous to environmental managers beyond studies applying single methods. In the case of the Dogger Bank, the integration of valuation findings can highlight complexities including stakeholder tensions and/or conflicts, for example in relation to fishing and fisheries management, which would not become apparent using a single method approach. However, this may require careful consideration if societal demands are to be balanced with conservation needs.

3.3 Modelling Tools for Management Evaluations

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 through the integrated management framework (Figure 1), with a two-way dialogue between modellers and stakeholders recognised as an important step in the process. In general, there are four types of spatially explicit model: 1) bio-climate envelope and other statistical species distribution models, 2) physiology-based, biophysical models of single life stages or the whole life cycle of species, 3) food web models, and 4) end-to-end models (Peck et al., in press and references therein). End-to-end models (e.g., physics to fish to human sectors) of various complexity most likely assess how multiple pressures may interact to cause changes in living marine resources as well as the costs and trade-offs of different spatial management strategies.

Greater insight can be gained from assessing model structural uncertainty through biological ensemble modelling (see Peck et al., in press).

With respect to the Dogger Bank, several modelling approaches have been applied which may be of value for management. Several integrated models are particularly relevant to assess the impact of different management options for commercial fishing, offshore wind farm development and area closures associated with nature conservation designations. For example, there is growing interest in bio-economic models as tools for understanding pathways of fishery behaviour to assess the impact of policy options on natural resources. One such model, FishRent, is a bio-economic optimisation and simulation model which has been successfully applied to the North Sea saithe (*Pollachius virens*) fishing fleet (see for example Simons et al., 2014, 2015). The original model was extended to strengthen the ecological components in order to fully integrate the catch age composition, the growth of individuals and the estimation of recruitment with the dynamics of multiple fleet segments. In order to demonstrate the suitability of this model for management evaluations for the Dogger Bank, it was run by Simons (2014) under two contrasting scenarios (A2 National Enterprise and B1 Global Community – see Table 1 and associated text). Under Scenario B1, 63% of the Dogger Bank would be closed for nature conservation areas and 30% for offshore wind farms; given that some areas would be reserved for both wind farms and nature conservation the total closure to fisheries would be around 67%; under Scenario A2, 62% of the area would be closed to fishing (Peck et al., 2014). The use of the advanced FishRent model, and validation of outputs through consultation with stakeholders, can therefore be of value when designing a management plan as it can be applied to different fleets to indicate how fishermen might respond to management measures within the plan and also to ecological or economic changes that can occur simultaneously.

A second modelling approach, using 'Ecopath with Ecosim' (EwE) (see Christensen & Pauly 1992) provides a multispecies modelling framework which has been used extensively to investigate the impacts of multiple pressures on complex marine food-webs including all components of the ecosystem from detritus and bacteria up to large predatory fish and marine mammals. The 'Ecospace' model, developed by Walters et al. (1999) as a way to replicate Ecosim dynamics over a spatial grid, has been used to determine the direct and indirect consequences of introducing MPAs on marine ecosystems and on commercial fisheries. It was parameterised for the North Sea, at the resolution of ICES rectangles, to investigate the consequences of introducing large scale MPAs and other spatial closures (Pinnegar et al., 2014). Two alternate management scenarios were tested specifically on the Dogger Bank: (1) designation of 21,403 km^2 (based on the closure of 6 ICES rectangles) as 'Special Areas of Conservation' covering Annex 1 habitats of the EU Habitats Directive, and (2) permitting of 'Round 3' wind farms proposed for the UK sector of the Dogger Bank. In Scenario 1, total North Sea catch (of all fish) increased by 3.2% when fisheries were excluded from the MPA, but total catch of sandeels remained virtually unchanged (+0.4%) largely because fishing effort was displaced from the Dogger Bank towards the Firth of Forth (Eastern Scotland). The biomass of sandeels within the Dogger Bank SAC increased by 6.2% and many predators also increased in abundance within the SAC (e.g. adult whiting by 15.8%, spurdog by 23%). Overall catches of plaice and dab increased by 5% and 18% respectively. Profits in the demersal trawl fleet were projected to increase by 27% overall, despite the fishery being excluded from some of their most important fishing grounds. The second scenario (Round 3 wind farm) showed similar results for the SAC scenario with cod, haddock, spurdog, monkfish, sandeels and plaice all significantly increasing their biomass, whereas seabirds and discards declined in the wind farm area.

The final modelling example is ATLANTIS, a state-of-the art ecosystem modelling tool which includes all components of the maritime system (biophysical, economic and social) and is therefore complex with high data requirements (Pinnegar et al., in press). The ATLANTIS model was developed in Australia (see Fulton et al., 2004a-c) but has since been applied to multiple marine systems worldwide from single bays to millions of square kilometres of open ocean (Fulton et al., 2011). An ATLANTIS model was developed for the North Sea, which includes full characterisation of species abundances, hydrodynamic fluxes and human activities on the Dogger Bank, one of the 25 spatial polygons included in the model (Hufnagl et al., in press). A fully parameterised model (Hufnagl et al., in press) has the potential for investigating ecological, economic and social impacts of changes in fishing practices, climate change, and spatial management in the region, including the introduction of MPAs and the construction of wind farms, which are particularly relevant in the case of the Dogger Bank.

3.4 Risk Assessment and Risk Management

Risk assessment is a well-established industrial concept implicitly or explicitly embedded within any impact assessment such as Environmental Impact Assessment (EIA), Appropriate Assessment, Strategic Environmental Assessment, etc. (Elliott, 2014; Smyth & Elliott, 2014). It has long been used by industries where there is potential for serious consequences of malfunction or accident (for example, nuclear, aviation, space exploration, oil, rail and military) as a means of reducing and mitigating risks. Risk assessment is increasingly incorporated into marine management (e.g. Cormier et al., 2013) for example, the amended EIA Directive (2014/52/EU) now requires consideration of climate change and biodiversity, and so will be increasingly dependent on reliable modelling and risk assessment approaches. As potential consequences (the risk) of a cause (the hazard) can occur for different types of asset, methods for assessment of risk may differ between industries and whether the risk assessment refers to financial decisions, environmental concerns, human health concerns, or damage to a physical structure. Different scenarios will have different end-points which may be health related (e.g. mortality), ecology/environmental related (e.g. a permanent habitat change), financial related (e.g. revenue loss) or physical in nature (e.g. properly loss/damage) (Elliott et al., 2014). There are many methods of performing a risk assessment which depend on which risks, assets and endpoints are of concern, with each risk assessment being unique (Smyth & Elliott, 2014). In essence, a risk will have a set of causes, which management has to address to prevent the risk, and a set of consequences, each of which needs mitigation or even compensating.

As a site proposed for a major wind farm development, the Dogger Bank has the potential to not only deliver societal benefits but also has the potential for adverse environmental change. Hence, Risk Assessment and Risk Management, as a tool to investigate how wind farms can affect the surrounding environment and vice versa, has been applied to the Dogger Bank. All anthropogenic marine installations require thorough EIAs and health and safety based Risk Assessments including the types of hazard and risk (Elliott et al., 2014). The risk assessment undertaken aims to perform analyses for events such as climate change, political change and cumulative effects of several wind farms operating in the same basin. The Bow-tie method was used for the Dogger Bank and offshore wind farm, as it is a highly graphical approach that can be clearly understood by personnel of all levels of an organisation and encompassing detailed information and quantitative aspects (Cormier et al., 2013).

The EU MSFD regards changes to populations, habitats and species as negative if they cause a deviation from Good Environmental Status, however the foundations and scour protection of wind farms develop a new habitat, albeit often one different to what was there before (Langhammer & Wilhelmsson, 2009; Wilson & Elliott, 2009). Furthermore, in terms of marine spatial planning and management, co-locating other marine activities in and around wind farms can ease demands on limited space (Christie et al., 2014) and even after decommissioning it has been suggested that a renewables-to reefs programme could allow protecting valuable habitats created in areas developed for wind energy (Smyth et al., 2015). As with any Risk Assessment and Risk Management approach, the Bow-tie analysis method is a qualitative model for displaying links between causes, hazards and consequences (see Figure 5), but can be further developed with quantitative modelling. By linking this method to the DAPSI(W)R(M) framework, it enables scoping, identification and analysis of: i) the drivers leading to the main events; ii) anticipatory prevention measures, including those limiting the severity of the main event; iii) the consequences of the events; and iv) mitigation and compensation measures aimed at minimising those consequences. In the case of Dogger Bank, the major wind farm will experience hazards over its lifespan. For instance, climate modelling indicates a certain mean global temperature rise over the next 100 years, the central hazard, which would lead to a certain set of potential consequences each with probabilities for those set of conditions (e.g. Elliott et al., 2015). The modelling predicts how incorporating prevention and mitigation measures would reduce these probabilities, which can then be mapped onto the Bow-tie diagram to give a 'before' and 'after' picture of how management measures can reduce negative consequences or even prevent the central hazard.

For the Dogger Bank, Figure 5 shows three examples of the many pressures (*causes*) on the system as a result of climate change that could lead to a loss of or decrease in the production of wind energy (see Smyth & Elliott, 2014 for the full analysis). For example, climate change could *cause* shipping lanes to change, increasing risks of accidents resulting in a loss of wind energy production. Possible *consequences* from these could be damage to the physical system of the wind farm, damage to infrastructure relating to the wind farm, or new ecosystem impacts. There are several possible *prevention measures* to reduce the likelihood of this, these are to use improved navigational technology, to separate activities either spatially or temporally (or both), and to make use of existing marine spatial planning tools. Should such measures fail, some of the consequences will occur. At this point there are only the options to *mitigate* – i.e. to reduce the severity of the effects, or to *compensate* affected parties. For example, ways of *mitigating* infrastructure damage are mainly through multiple energy routes such as the planned North Sea Supergrid, taking advantage of alternative or backup routes to get the energy to shore and increasing servicing and maintenance of existing structures to reduce the likelihood of shipping accidents causing permanent damage. Some *prevention* and *mitigation* measures are limited by *escalation factors* which can affect the efficacy of the measure. For example, to be effective the Supergrid requires EU cooperation as well as for the technology to be available (which it is not at the time of writing).

Each risk, due to climate change, to the maintenance of energy generation at the Dogger Bank requires its own assessment and thus a Bow-tie diagram. Hence several Bow-ties could be linked to form one overall model of the system and incorporate the DAPSI(W)R(M) principles to enable users to see how one *Pressure* from an *Activity* may lead to many *State changes* (on the natural system), and that each individual *State change* could lead to a range of potential *Impacts* (on human *Welfare*), across different environmental scales. The management *Responses* (as *Measures*) are then incorporated into the model as the various prevention and mitigation measures. The role of future scenarios assessments is complimentary to modelling as a way of informing Bow-tie development, enabling the incorporation of the magnitude of the changes and the system ability to respond to the changes and recover from the changes, dependent on certain scenarios. Such expandability suggests that, with development, Bow-tie analysis and complementary future scenarios assessments and modelling could be a key tool in the management of the Dogger Bank and other such wind energy locations.

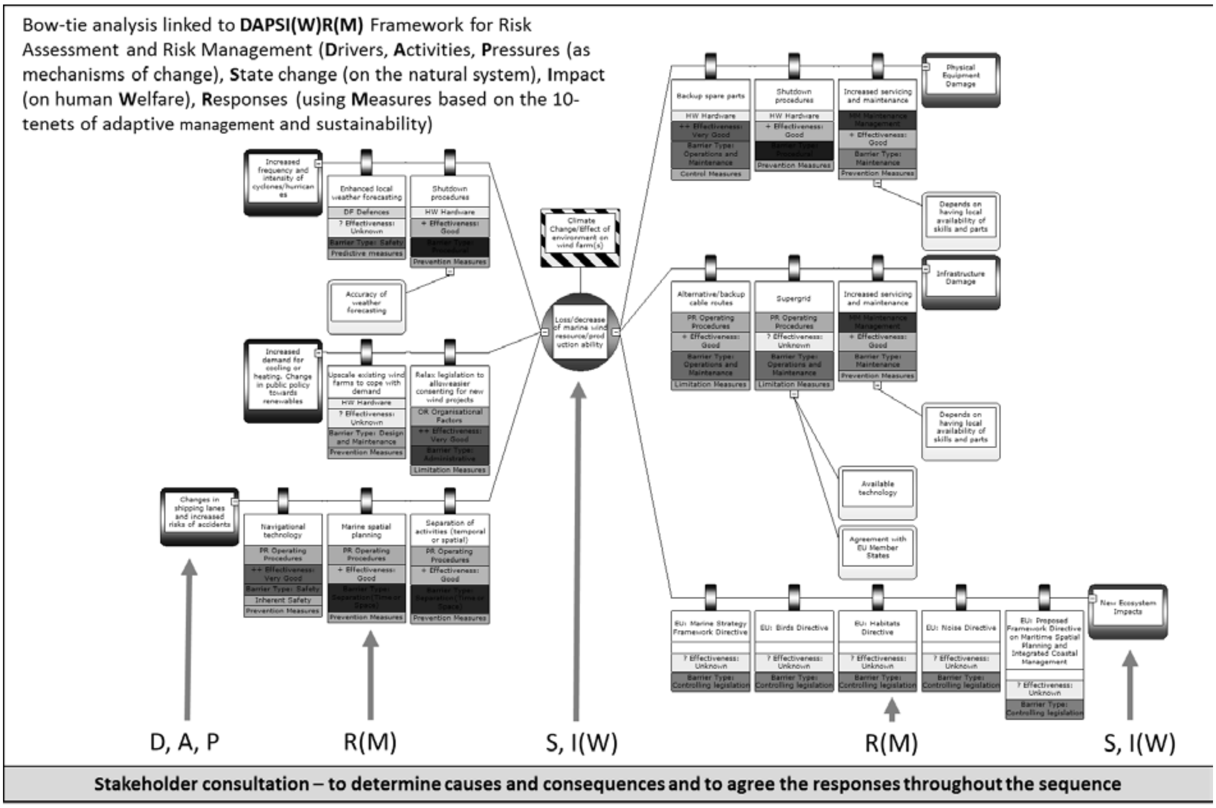

Figure 5: Examples of causes (left) of the hazard (centre), preventative measures (left of centre), mitigation measures (right of centre), consequences (right), and escalation factors (hanging boxes). Hazard in this example = climate change resulting in a loss or reduction in the wind power resource.

4. Lessons Learned and Policy Recommendations

As argued above, marine spatial planning initiatives for fisheries, conservation and offshore wind within the Dogger Bank pose additional transnational management issues. Each of the four Member States has rights within their EEZs (and over their continental shelves) but the European Commission, ICES and OSPAR all have a management or at least an advisory role. With three out of the four Member States proposing (at different times) a SAC within their respective Dogger Bank EEZs, joint management initiatives have been established and measures proposed to protect the transnational SAC from detrimental fishing activities. To avoid a disjointed management approach, it is essential that all four Member States cooperate in an integrated and coherent manner to ensure the overall protection of such a unique marine area. The multidisciplinary scientific research presented above can be used to provide solutions and tools for relevant stakeholders and policy-makers for the future management of the Dogger Bank.

The conceptual framework presented in this paper (Figure 1), was successfully applied to the transnational case study of the Dogger Bank, in order to illustrate the importance of linking natural and social sciences research in order to aid sustainable and integrated marine management. The interdisciplinary studies have provided greater insight into the challenges associated with, and of value to, the integrated management of the Dogger Bank. The particular focus of the Dogger Bank studies has been on investigating the potential impacts and associated management options to address two key marine vectors of change, namely commercial fisheries and offshore wind farm developments, and nature conservation as a primary driver of management. The Dogger Bank is a complex environment to manage, given its multiple uses and users and transnational location, however continued stakeholder engagement throughout the studies has provided valuable insight into what aspects of management have been successful and what policy recommendations can be made to improve future management of this important transnational offshore site. Elements of good practice have been highlighted within this paper, for example models of cooperation and collaboration at the national and transnational level both between Member States and stakeholders, which can be transposed to other areas. There were also a number of perceived barriers to the successful management of the Dogger Bank raised by stakeholders, such as conflicting interests and goals both between Member States and different types of stakeholders.

The interdisciplinary scientific research and stakeholder engagement within the context of a co-ordinated fisheries management plan specifically for the Dogger Bank have led to several policy recommendations being proposed:

- Successful stakeholder involvement in bottom-up decision-making processes between stakeholders with differing goals requires not only sufficient time but also additional staff or financial resources.
- As unrealistically tight deadlines make it difficult to achieve consensus on management plans, better consideration is required for timescales.
- Expectations need to be managed by stakeholders, managers and policy-makers. Stakeholders need to be aware of the limits of their likely influence on the final outcome of the decision-making process as they will otherwise become frustrated and possibly abstain from future cooperation.
- For stakeholder negotiation processes it is important to clarify how tasks and responsibilities are distributed. Terms of reference (e.g. for the NSAC) should be as clear as possible to avoid conflicting interpretations.
- There should be closer and better cooperation between the Dogger Bank Steering Group, NSAC, ICES and the European Commission as well as between Member States.
- There is a need for better scientific data which can be generated through research projects such as VECTORS (http://www.marine-vectors.eu/) and coordinated monitoring across Member States. However, policy-makers should make sure that claims of a lack of scientific proof cannot be used as a tactic to delay or even avoid the adoption of urgently needed environmental protection measures.
- Policy-makers need to balance the interests of different stakeholders while avoiding both excessive protection and serious environmental damage.
- Conflict resolution strategies need to take into account the different interests of the main stakeholders. However, they also ought to be sensitive to cultural differences and differences in national marine management traditions and wider environmental policy styles which show a preference for certain action guiding principles (e.g. the precautionary principle instead of the scientific certainty principle).

With respect to the importance of stakeholder engagement for the Dogger Bank, Pastoors et al. (2012) also recognised the need to distinguish between 'front-stage transparency' (involving the general public in the objective setting, identification of stakeholders and when they should be engaged in the process) and 'back-stage transparency' (which engages with those stakeholders who are directly involved in the process such as fishermen, wind farm developers, ENGOs, etc.). Their study also identified the importance of geo-spatial interdisciplinary research for the Dogger Bank, for example the requirement to analyse present conditions, future scenarios and potential effects of measures (including cumulative effects); some of these issues have also been addressed within this paper.

Based on wider marine stakeholder engagement throughout the VECTORS project, a number of general policy recommendations can be made to ensure the successful application of such an interdisciplinary approach to integrated marine management (Table 2). These policy recommendations have been broken down under the key components of the framework (Figure 1).

Table 2: General policy recommendations for integrated marine management.

Topic	Policy Recommendation
Future scenarios assessments	Scenarios can be used to 'test' which policy actions are robust and sustainable and provide a valuable tool for conceptually modelling future societal changes. Scenarios must not be too conservative, the extremes need to be considered in order to think the unthinkable. Given future uncertainties, all four scenarios should be applied. However a concerted effort should be made to address the likely combined scenarios. The big challenge for 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.
Marine governance	Linking Maritime Spatial Planning, Integrated Coastal Zone Management and Strategic Environmental Assessments is essential to integrate governance across sectors. Future marine governance should focus on particular activities, for example sectors of the Blue Growth agenda (e.g. large scale offshore aquaculture, seabed mining, blue biotechnology) for which limited regulation is in place and little is known about the ecosystems in which the activities take place. Harmonising definitions of status assessments between the different Directives is required (e.g. MSFD, WFD, and the Habitats Directive) in relation to activities, pressures and impacts and their management.
Stakeholder engagement	Sufficient resources should be allocated to fully integrate stakeholders in both the research and the management process, and that stakeholder input is managed more efficiently to avoid stakeholder fatigue. A 'one-stop-shop' be established within each Member State from which all marine data can be accessed and which acts as a focal point for decision-making (e.g. the MMO model presented by Boyes & Elliott, 2015).
Ecosystem services, indicators and valuation	Incorporation of ecosystem service concepts, indicators and valuations into marine policy and planning will improve understanding of the value of marine environments to society and allow a better communication of this importance to society. As such, 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. 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).
Modelling tools for management evaluations	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 the need for integrated, ecosystem-level analysis of spatially and temporally resolved data, in a transparent manner that is sufficiently user-friendly to be understood by managers and policy-makers.

Topic	Policy Recommendation
Risk assessment and risk management	The breadth of present and future risks which may significantly affect human societies, e.g. shipping, marine litter, invasive species, ocean acidification, climate change, oil and gas developments, noise and the blue growth sector, needs the causes of change to be addressed in combination and mitigation and/or compensation measures to be implemented. 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 Bow-tie methodology is an appropriate methodology to assess risks in the marine environment but it requires further development to account for combined pressures and cumulative impact assessments.

5. Concluding Remarks

Elliott (2014) proposed a general model of marine management which incorporates the main features and considerations – the need to understand the source of internal and external pressures, risk assessment and risk management for those pressures, the stakeholder typology which requires horizontal integration and the governance hierarchy which requires vertical integration, the underlying desire to ensure the system provides ecosystem services which deliver societal benefits, and lastly the means to achieve the Ecosystem Approach. As emphasised for the Dogger Bank, successful and sustainable marine management requires this complexity to be understood by managers, policy-makers and stakeholders and for natural and social science to deliver the appropriate concepts, data and information. This requires integrating natural and social science research in order to fulfil marine management obligations. The conceptual framework presented here (Figure 1) 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. The importance of stakeholder engagement was also recognised in a number of other national and EU-level studies, for example VECTORS (Burdon et al., 2014), EMPAS and FIMPASS (Fock, 2011) and MASPNOSE (Pastoors et al., 2012). Following the successful application of the conceptual framework to the Dogger Bank, such an approach is advocated here for future interdisciplinary marine studies which aim to feed into an integrated marine management process. The suite of interdisciplinary tools identified by the conceptual framework, to bridge the gap between natural and social science disciplines, is recommended for application elsewhere, however it is recognised that the choice of approach needs to be tailored according to the specific issue being addressed. This list of tools is not exhaustive, with the flexibility of the framework allowing for additional tools to be included to aid future marine management decisions.

Acknowledgements

This study was funded by the EU 7th Framework Programme for research, technological development and demonstration (FP7/2007-2013) within the Ocean of Tomorrow call under Grant Agreement No.266445 for the project Vectors of Change in Oceans and Seas Marine Life, Impact on Economic Sectors (VECTORS). The authors wish to thank the two anonymous reviewers for their valuable comments which have greatly strengthened this paper.

References

Atkins, J.P., Berner, L., Delaney, A., Frangoudes, K., Krueger, I., Magni, P., Piñol, L., Piwowarczyk, J., Rodriguez, L. & Wurzel, R., 2012. *Understanding stakeholder and policy maker needs*. Deliverable 6.1 (Part B) of the EU FP7 VECTORS Project (Grant Agreement: 266445).

Atkins, J.P., Burdon, D. & Elliott, M., 2015. Chapter 5: Identification of a practicable set of ecosystem 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.

Atkins, J.P., Burdon, D., Elliott, M., Schaafsma, M. & Turner, R.K., 2014. Coastal and marine ecosystem services. *Environmental Scientist*, 23, pp. 26-30. ISSN: 0966 8411.

Atkins, J.P., Burdon, D., Elliott, M. & Gregory, A.J., 2011. 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.

Austen, C.M., Malcolm, S.J., Frost, M., Hattam, C., Mangi, S., Stentiford, G., Benjamins, S., Burrows, M., Butenschön, M., Duck, C., Johns, D., Merino, G., Mieszkowska, N., Miles, A., Mitchell, I., Pimm, E. & Smyth, T., 2011. Marine. In: *The UK National Ecosystem Assessment Technical Report*. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge. 40pp.

Barnard, S., Burdon, D., Strong, J. & Atkins, J.P., 2014. *The ecological coherence and economic and social benefits of the Northern Ireland MPA network*. Report to the Northern Ireland Marine Task Force (YBB238-F-2014).

Beaumont, N., Townsend, M., Mangi, S. & Austen, M., 2006. Marine biodiversity: an economic valuation. Defra, London.

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.

Beunen, R., van der Knaap, W.G.M. & Biesbroek, G.R., 2009. Implementation and integration of EU environmental directives. Experiences from the Netherlands. *Environmental Policy and Governance*, 19, pp. 57–69.

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

Börger, T., Beaumont, N.J., Pendleton, L., Boyle, K.J., Cooper, P., Fletcher, S., Haab, T., Hanemann, M., Hooper, T.L., Hussain, S.S., Portela, R., Stithou, M., Stockill, J., Taylor, T. & Austen, M.C., 2014b. Incorporating ecosystem services in marine planning: The role of valuation. Marine Policy, 46:161-170.

Boyes, S., Barnes, R., Burdon, D., Barnard, S. & Elliott, M., 2012. *Understanding policy and legal frameworks at the international, European and national levels in relation to VECTORS thematic topics*. Deliverable 6.1 (Part A) of the EU FP7 VECTORS Project (Grant Agreement: 266445).

Boyes, S.J. & Elliott, M. 2015. The excessive complexity of national marine governance systems - has this decreased in England since the introduction of the Marine and Coastal Access Act 2009? *Marine Policy*, 51, pp. 57-65.

Boyes, S.J. & Elliott, M., 2014. Marine legislation – the ultimate ‘horrendogram’: International Law, European Directives & National Implementation. *Marine Pollution Bulletin*, 86, pp. 39-47.

Bremer, S. & Glavovic, B., 2013. Mobilizing knowledge for coastal governance: re-framing the science–policy interface for Integrated Coastal Management. *Coastal Management*, 41(1), pp. 39-56.

Burdon, D., Boyes, S.J., Elliott, M., et al., 2014. *Policy and governance synthesis as a tool for stakeholders*. FP7 – OCEAN- 2010. Project number 266445, VECTORS of Change in Oceans and Seas Marine Life, Impact on Economic Sectors. Deliverable D60.6. September 2014.

CBD, 2000. Convention on Biological Diversity. http://69.90.183.227/doc/legal/cbd-un-en.pdf.

Cefas, 2007. *Multispecies fisheries management: A comprehensive impact assessment of the sandeel fishery along the English east coast*. Cefas Contract Report MF0323/01.

Christensen V. & Pauly D., 1992. Ecopath II - a software for balancing steady-state ecosystem models and calculating network characteristics. *Ecological Modelling*, 61, pp. 169-185.

Christie, N., Smyth, K., Barnes, R. & Elliott, M., 2014. Co-location of activities and designations: A means of solving or creating problems in marine spatial planning? *Marine Policy*, 43, pp. 254-261.

Conte, D. & Lionello, P. 2013. Characteristics of large positive and negative surges in the Mediterranean Sea and their attenuation in future climate scenarios. *Global and Planetary Change*, 111, pp. 159-173

Cooper, K., Burdon, D., Atkins, J.P., Weiss, L., Somerfield, P., Elliott, M., Turner, 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.

Cormier, R., Kannen, A., Elliott, M., Hall, P. & Davies, I.M. (Eds). 2013. *Marine and Coastal Ecosystem-based Risk Management Handbook*. ICES Cooperative Research Report, No. 317, March 2013, International Council for the Exploration of the Sea, Copenhagen, 60pp, ISBN 978-87-7472-115-1.

de Groot, R.S., Alkemade, R., Braat, L., Hein, L. & Willemen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, 7, pp. 260–272

de Groot, R.S., Wilson, M.A. & Boumans, R.M.J., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, 41, pp. 393-408.

Diesing M., Ware S., Foster-Smith R., Stewart H., Long D., Vanstaen K., Forster R. and Morando A. 2009. *Understanding the marine environment – seabed habitat investigations of the Dogger Bank offshore draft SAC*. Joint Nature Conservation Committee, Peterborough. JNCC Report No. 429, 5 Appendices.

Douvere, F., 2008. MSP in ecosystem-based sea use management. *Marine Pollution Bulletin*, 32, pp. 762– 771.

Ducrotoy, J.-P. & Elliott, M., 2008. The science and management of the North Sea and the Baltic Sea: Natural history, present threats and future challenges. *Marine Pollution Bulletin*, 57, pp. 8–21.

EEA, 2015. *The European environment — state and outlook 2015: synthesis report*. European Environment Agency, Copenhagen.

Elliott, M., 2011. Marine science and management means tackling exogenic unmanaged pressures and endogenic managed pressures – a numbered guide. *Marine Pollution Bulletin*, 62, pp. 651-655.

Elliott, M., 2014. Integrated marine science and management: wading through the morass. *Marine Pollution Bulletin*, 86, pp. 1-4.

Elliott, M., Borja, Á., McQuatters-Gollop, A., Mazik, K., Birchenough, S., Andersen, J.H., Painting, S. & Peck, M., 2015. Force majeure: will climate change affect our ability to attain Good Environmental Status for marine biodiversity? *Marine Pollution Bulletin*, 95, pp. 7-27.

Elliott, M., Burdon, D. & Hemingway, K., 2006. *Marine ecosystem structure, functioning, health and management and potential approaches to marine ecosystem recovery: a synthesis of current understanding*. CCW Policy Research Report No. 06/5.

Elliott, M., Cutts, N.D. & Trono, A., 2014. A typology of marine and estuarine hazards and risks as vectors of change: A review for vulnerable coasts and their management. *Ocean & Coastal Management*, 93, pp. 88-99.

European Commission, 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). *Official Journal of the European Union*, L164, pp. 19–40.

European Commission, 2011. Maritime spatial planning in the EU - Achievements and future development (ECCOM(2010)771). EC, Brussels, http://ec.europa.eu/maritimeaffairs/documentation/publications/documents/com_2010_771_brochure_en.pdf (accessed March15).

European Commission, 2013. MEMO – Questions and Answers on proposed Directive on Maritime Spatial Planning and Integrated Coastal Management. Brussels, 13 March 2013.

European Commission, 2014. Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a Framework for Maritime Spatial Planning

European Commission, 2015. National Action Plans: accessed March 2015 http://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans

Fock, H.O., 2011. Natura 2000 and the European Common Fisheries Policy. *Marine Policy*, 35, pp. 181–188.

Forewind, 2010. *Dogger Bank Zonal Characterisation Report*. Version 4, October 2010.

Forewind, 2013. *Dogger Bank Environmental Statement – Chapter 23 Tourism and Recreation*. April 2013. Ref. F-ONC-CH-023 Issue 3.

Forewind, 2015. *Dogger Bank*. http://www.forewind.co.uk/dogger-bank/overview.html (accessed March 2015)

Fulton, E.A., Fuller, M., Smith, A.D.M. & Punt, A.E., 2004a. Ecological indicators of the ecosystem effects of fishing: final report. Australian Fisheries Management Authority Report R99/1546, pp. 116.

Fulton, E.A., Link, J.S., Kaplan, I.C., et al., 2011. Lessons in modelling and management of marine ecosystems: the Atlantis experience. *Fish & Fisheries*, 12, pp. 171–188.

Fulton, E.A., Parslow, J.S., Smith, A.D.M. & Johnson, C.R., 2004b. Biogeochemical marine ecosystem models II: the effect of physiological detail on model performance. *Ecological Modelling*, 173, pp. 371–406.

Fulton, E.A., Smith, A.D.M. & Johnson, C.R., 2004c. Effects of spatial resolution on the performance and interpretation of marine ecosystem models. *Ecological Modelling*, 176, pp. 27–42.

Gibbs, M. & Cole, A., 2008. Oceans and coasts as complex adaptive systems. In: *Ecological Economics of the Oceans and Coasts*. Edward Elgar Publishing, Cheltenham, UK.

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.

Groenveld, R. et al., in press. Interdisciplinary scenarios for the marine environment. *Estuarine, Coastal and Shelf Science*, VECTORS Special Issue.

Hanley, N., Wright, R.E. & Vic, A., 1998. Using choice experiments to value the environment. *Environmental Resource Economics*, 11, pp. 413–428.

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

Hattam, C., Böhnke-Henrichs, A., Börger, T., Burdon, D., Hajimicheale, M. Delaney, A., Atkins, J.P., Garrard, S. & Austen, M., under review. Integrating methods for ecosystem service assessment and valuation: mixed methods or mixed messages? Resubmitted to *Ecological Economics* (06 August 2015).

Hattam, C., Börger, T., Garrard, S., Austen, M., Atkins, J.P., Burdon, D., Piwowarczyk, J., Kedra, M., Weslawski, J.M., Delaney, A., Hadjimichael, M., Sastre, S., Canepa, A., Maynou, F., Piñol, L., Nunes, P.A.L.D., Loureiro, M., Voltaire, L., Serra, C., Otrachshenko, V., Bosello, F., Böhnke-Henrichs, A. & de Groot, R. 2014. *Impacts of change on ecosystem services and their values*. FP7 – OCEAN- 2010. Project number 266445, VECTORS of Change in Oceans and Seas Marine Life, Impact on Economic Sectors. Deliverable D32.1. May 2014.

Hufnagl, M., et al. in press. Development of a North Sea Atlantis type model. *Estuarine, Coastal and Shelf Science*, VECTORS Special Issue.

Hulme, M., Jenkins, G.L., Lu, X., Turnpenny, J.R., Mitchell, T.D., Jones, R.G., Lowe, J., Murphy, J.M., Hassell, D., Boorman, P., McDonald, R. & Hill, S. 2002. *Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report*. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK. 120pp.

IPCC, 2000. Special Report on Emissions Scenarios (SRES). Nakicenovic, N. and Swart, R. (Eds.). International Panel on Climate Change, Cambridge University Press, Cambridge, UK 612pp.

Jansen et al., in press. Integration of fisheries in marine spatial planning: Quo vadis? *Estuarine, Coastal and Shelf Science*, VECTORS Special Issue.

JNCC 2011. *Dogger Bank SAC Final Impact Assessment*. 4 July 2011. Joint Nature Conservation Committee, Peterborough, UK.

Kay, S. & Butenschön, M., in press. Projections for change in environmental conditions in European Marine Protected Areas under two scenarios of climate change. *Estuarine, Coastal and Shelf Science*, VECTORS Special Issue.

Kröncke, I. 2011. Changes in Dogger Bank macrofauna communities in the 20th century caused by fishing and climate. *Estuarine Coastal and Shelf Science*, 94, pp. 234-245.

Langhammer, O. & Wilhelmsson, D., 2009. Colonisation of fish and crabs of wave energy foundations and the effects of manufactured holes – A field experiment. *Marine Environmental Research*, 68, pp. 151-157.

Langmead, O., McQuatters-Gollop, A. & Mee, L.D. (Eds.). 2007. *European Lifestyles and Marine Ecosystems: Exploring challenges for managing Europe's seas*. 43pp. University of Plymouth Marine Institute, Plymouth, UK.

Leith, P., O'Toole, K., Haward, M., Coffey, B., Rees, C. & Ogier, E., 2014. Analysis of operating environments: a diagnostic model for linking science, society and policy for sustainability. *Environmental Science & Policy*, 39, pp. 162–171.

MA, 2003. Ecosystems and human well-being: A framework for assessment. Island Press, Washington.

Marquès, M., Bangash, R.F., Kumar, V., Sharp, R. & Schuhmacher, M. 2013. The impact of climate change on water provision under a low flow regime: A case study of the ecosystems services in the Francoli river basin. *Journal of Hazardous Materials*, 263(1), pp. 224-232

Nicholls, R.J., 2004. Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios. *Global Environmental Change*, 14, pp. 69–86.

NSRAC, 2012. Position paper on fisheries management in relation to nature conservation, including a zoning proposal, for the combined area covered by the 3 national Natura 2000 sites (SACs) on the Dogger Bank. http://nsrac.org/wp-content/uploads/2012/07/NSRAC-1112-7-2012-04-09-Dogger-Bank-SACs-Position-Paper-FINAL.pdf

Nursey-Bray, M.J., Vince, J., Scott, M., Haward, M., O'Toole, K., Smith, T., Harvey, N. & Clarke, B., 2014. Science into policy? Discourse, coastal management and knowledge. *Environmental Science & Policy*, 38, pp. 107-119.

Pastoors, M., Hommes, S., Maes, F., Goldsborough, D., de Vos, B., Stuiver, M., Bolman, B., Sørensen, T.K. & Stelzenmüller, V., 2012. *MASPNOSE (Preparatory Action on Maritime Spatial Planning in the North Sea) Final Report*. Deliverable D1.3.3, March 2012.

Peck, M. et al., 2014. Synthesis report of the VECTORS findings that are relevant to the issues of the North Sea Regional Sea. FP7 – OCEAN- 2010. Project number 266445, VECTORS of Change in Oceans and Seas Marine Life, Impact on Economic Sectors. Deliverable D4.2.1, July 2014.

Peck, M. et al., in press. Understanding and projecting changes in the distribution and productivity of living marine resources: A critical review of modelling approaches. *Estuarine, Coastal and Shelf Science*, VECTORS Special Issue.

Philippart, C.J.M., Anadón, R., Danovaro, R., Dippner, J.W., Drinkwater, K.F., Hawkins, S.J., Oguz, T., O'Sullian, G. & Reid, P.C., 2011. Impacts of climate change on European marine ecosystems:

Observations, expectations and indicators. *Journal of Experimental Marine Biology and Ecology*, 400, pp. 52–69.

Pinnegar, J.K. et al., in press. Application of the holistic modelling framework ATLANTIS to European Shelf Seas: lessons learnt and continuing challenges. *Estuarine, Coastal and Shelf Science*, VECTORS Special Issue.

Pinnegar, J.K., Hufnagl, M., Sinerchia, M., Palacz, A.P., Giardin, R., Travers-Trolet, M., Fulton, E.A. & Gorton, R., 2014. *Holistic framework(s) for assessing multiple drivers*. FP7 – OCEAN- 2010. Project number 266445, VECTORS of Change in Oceans and Seas Marine Life, Impact on Economic Sectors. Deliverable D5.1.2, December 2014.

Pinnegar, J.K., Viner, D., Hadley, D., Dye, S., Harris. M., Berkout, F. & Simpson, M. 2006. *Alternative future scenarios for marine ecosystems*: technical report. Cefas Lowestoft, 109pp.

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.

Puente-Rodriguez, D., Giebels, D. & de Jonge, V.N., 2015. Strengthening coastal zone management in the Wadden Sea by applying ‘knowledge-practice interfaces’. *Ocean & Coastal Management*, 108, pp. 27-38.

Rees, S.E, Fletcher, S., Gall, S.C., Friedrich, L.A., Jackson, E.L. & Rodwell, L.D., 2014. Securing the benefits: Linking ecology with marine planning policy to examine the potential of a network of Marine Protected Areas to support human wellbeing. *Marine Policy*, 44, pp. 335-341.

Saunders, J., Tinch, R. & Hull, S. 2010. *Valuing the Marine Estate and UK Seas: An ecosystem services framework*. The Crown Estate, 54 pages, March 2010. ISBN: 978-1-906410-15-5.

Sell, A.F. & Kröncke, I., 2013. Correlations between benthic habitats and demersal fish assemblages - a case study on the Dogger Bank (North Sea). *Journal of Sea Research*, 80, pp. 12-24.

Simons, S.L., 2014. The suitability of FishRent as a tool for management evaluations. In: Burdon, D., Boyes, S.J., Elliott, M., et al., 2014. *Policy and governance synthesis as a tool for stakeholders*. FP7 – OCEAN- 2010. Project number 266445, VECTORS of Change in Oceans and Seas Marine Life, Impact on Economic Sectors. Deliverable D60.6. September 2014.

Simons, S.L., Bartelings, H., Hamon, K.G., Kempf, A.J., Döring, R. & Temming, A. 2014. Integrating stochastic age-structured population dynamics into complex fisheries economic models for management evaluations: the North Sea saithe fishery as a case study. *ICES Journal of Marine Science*, 71(7), pp. 1638–1652.

Simons, S.L., Döring, R. & Temming, A., 2015. Combining area closures with catch regulations in fisheries with spatio-temporal variation: Bio-economic implications for the North Sea saithe fishery. *Marine Policy*, 51, pp. 281-292.

Smyth, K. & Elliott, M., 2014. *Develop risk assessments leading to best practice: resource exploitation – renewable energy*. FP7 – OCEAN- 2010. Project number 266445, VECTORS of Change in Oceans and Seas Marine Life, Impact on Economic Sectors. Deliverable D60.5. March 2014.

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

Spash, C.L. 2007. Deliberative monetary valuation (DMV): Issues in combining economic and political processes to value environmental change. *Ecological Economics*, 63, pp. 690-699.

Stride, A., 1959. On the origin of the Dogger Bank, in the North Sea. *Geological Magazine*, 96, pp. 33-44.

Tett, P. & Mee, L., 2015. Chapter 7: Scenarios Explored with Delphi. 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.

Tett, P., Gowen, R., Painting, S., Elliott, M., Forster, R., Mills, D., Bresnan, E., Capuzzo, E., Fernandes, T., Foden, J., Geider, R., Gilpin, L., Huxham, M., McQuatters-Gollop, A., Malcolm, S., Saux-Picart, S., Platt, T., Racault, M.-F., Sathyendranath, S., Molen, Jvd, Wilkinson, M., 2013. Framework for understanding marine ecosystem health. *Marine Ecological Progress Series*, 494, pp. 1–27 (+ suppl. material).

Turner, K., Schaafsma, M., Elliott, M., Burdon, D., Atkins, J., Jickells, T., Tett, P., Mee, L., van Leeuwen, S., Barnard, S., Luisetti, T., Paltriguera, L., Palmieri, G., & Andrews, J., 2014. *UK National Ecosystem Assessment Follow-on. Work Package Report 4: Coastal and marine ecosystem services: principles and practice*. UNEP-WCMC, LWEC, UK.

UKCIP, 2001. *Socio-economic scenarios for climate change impact assessment: a guide to their use in the UK Climate Impacts Programme*. UKCIP, Oxford. 123pp.

Veenstra, H.J., 1965. Geology of the Dogger Bank area, North Sea. *Marine Geology*, 3, pp. 245-262.

Walters, C., Pauly, D. & Christensen, V. 1999. Ecospace: Prediction of mesoscale spatial patterns in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas. *Ecosystems*, 2, pp. 539–554.

Wieking, G. & Krönke, I. 2003. Macrofauna communities of the Dogger Bank (central North Sea) in the late 1990s: spatial distribution, species composition and trophic structure. *Helgoland Marine Research*, 57(1), pp. 34-46.

Wilson, J. & Elliott, M., 2009. The potential for habitat creation produced by offshore wind farms. *Wind Energy*, 12, pp. 203-212.

Wolanski, E. & Elliott, M., 2015. *Estuarine ecohydrology: An introduction*. Second Edition. Elsevier Science, Amsterdam, 322pp.