Accepted refereed manuscript of: Börger T, Beaumont NJ, Pendleton L, Boyle KJ, Cooper P, Fletcher S, Haab T, Hanemann M, Hooper TL, Hussain SS, Portela R, Stithou M, Stockill J, Taylor T & Austen MC (2014) Incorporating ecosystem services in marine planning: The role of valuation. *Marine Policy*, 46, pp. 161-170. https://doi.org/10.1016/j.marpol.2014.01.019

1. Introduction

The need to understand the benefits of marine ecosystems in economic terms has never been more pressing. Marine ecosystems provide benefits to people through the provision of seafood and other resources worth trillions of dollars annually as well as regulation of the earth's climate and the modulation of global biogeochemical cycles [1], maintenance of water quality [2] and support of cultural and aesthetic uses [3]. Such marine ecosystem services are subject to degradation from anthropogenic sources including ocean acidification, climate change, deoxygenation, pollution, over-fishing and habitat degradation [4-6]. These global pressures are coupled with the ever increasing and broadening human uses of the marine environment such as through shipping, renewable energy generation, fisheries, recreation, aquaculture, oil, gas and aggregate extraction. Indeed, the Committee on International Capacity-Building for the Protection and Sustainable Use of Oceans and Coasts states that "it is vital to build capacity – the people, the institutions, and technology and tools – needed to manage ocean resources" [7].

To balance the competing demands on marine ecosystems and limit or reserve degradation, a variety of policies are being employed globally, including:

- UK Marine and Coastal Access Act 2009 (MCAA),
- EU Marine Strategy Framework Directive 2008 (MSFD),
- US National Ocean Policy 2013,
- EU Integrated Maritime Policy 2012,
- IMO Convention on Ballast Water Management 2004, and
- UN Convention on Biodiversity 1992.

Marine planning[1] has emerged in the US and UK as a pro-active approach for the sustainable management of the marine area. In the UK, the Marine Management Organisation (MMO) aims to prepare a first suite of marine plans for 11 marine areas in

[1] Originally referred to as marine spatial planning, this concept has of late increasingly been called marine planning (see, for example, [8]). We treat the terms as synonymous and use marine planning except where the literature specifically refers to marine spatial planning.

England [9]. In the US, the federal government has proposed as many as seven voluntary, regional planning bodies to bring marine planning into federal waters (i.e. seas beyond three miles from shore [10]).

An "ecosystem approach", which takes environmental, social and economic factors into consideration, is integral to marine planning in the US and UK. This approach requires direct consideration of ecosystem services, which have been defined as "the benefits that humans obtain from ecosystems" [11]. Ecosystem service valuation (ESV) is the process of assessing the values of these benefits and many publications and initiatives have created typologies and quantified the value of marine ecosystem services [3, 12, 13]. However, the implementation of these valuations in a marine policy context has been variable and often limited [14].

Applications of ESV to marine ecosystems arise from decades of research and development of valuation methods for market and non-market goods. Significant efforts have been made to estimate the values of coastal and marine ecosystem services (e.g. [3, 12, 15-21]).[2] Furthermore, a variety of technical tools and models are available to predict the way these integrated marine ecosystem service values may change due to policy intervention (e.g. Marine InVEST, MIMES, ARIES).

Ecosystem service valuation (ESV) in marine planning has potential to highlight hidden ecosystem benefits and costs that might be overlooked if only commercial revenues and costs were considered. It can also improve understanding of the economic trade-offs from different marine plans or scenarios, including trade-offs between different kinds of ecosystem services as well as between those services and commercial economic activities that do not depend on the condition of marine ecosystems, but may affect them. To date, however, the use of ESV in marine planning is still nascent. The time is right to think carefully about how and when ESV could be best used to inform marine planning.

[2] There are further initiatives like the Nature Capital Committee in the UK and the UN System of Environmental Economic Accounting (SEEA) [22], which will not be considered in this paper because they do not value marginal changes in ecosystem service provision.

This paper draws on lessons learned in the application of nonmarket environmental valuation for policy-making in the US and UK with the goal of providing guidance for the application of ESV for marine planning in these countries and elsewhere. While acknowledging that ESV clearly makes use of market and nonmarket approaches to valuation, we focus primarily on the nonmarket area given the methodological challenges and ensuing level of controversy that still accompanies the application of relevant approaches [23, 24]. In both countries, the basic methods used for valuation have developed in unison and the theoretical and methodological foundations of valuation are the same. The US and UK are considered to be at the vanguard of research regarding the application ESV in the marine environment [17]. However, there are clear differences in the geography, politics and demographics of ESV applications in the two countries. Therefore, there is significant benefit in comparing the policy drivers and applications of valuation to policy, which are historically different in each country. In addition both the US and UK are currently developing marine planning approaches, and would therefore benefit from this comparison of approaches to enable more effective and efficient marine planning.

2. Valuation of nonmarket environmental goods for policy in the US and UK: 1960 to present

Understanding the use of nonmarket environmental valuation in policy could help to the future successful use of ESV in marine planning [25]. Influential policies have triggered the development and application of valuation methods in environmental cost-benefit analyses (CBA) in the US and UK. Much of the relevant literature reviewed here does not specifically relate to the valuation of marine resources, but the development and application of methods are applicable across ecological domains. Many of these methods have not been applied to ecosystem services directly but to a more loosely defined set of environmental goods since the development of most valuation approaches predate the mainstreaming of the ecosystem services concept, but these valuation approaches are directly applicable to ESV.

Starting in the 1960s, new legislation in the United States, such as the Clean Air Act 1963 (CAA), Clean Water Act 1972 (CWA), National Marine Sanctuaries Act 1972 as well as the establishment of the Environmental Protection Agency (EPA) ushered in a need for environmental valuation to assess the costs and benefits of new environmental policies and programmes (cf. Table 1). While valuation methods had been applied previously (e.g. contingent valuation [26], travel cost method [27, 28]), the CAA and CWA focused the need to refine methods for demonstrating the value of environmental improvements (and damages).

In the 1980s, two events led to rapid theoretical and practical development of nonmarket valuation methods in the US. Firstly, in 1981 Presidential Executive Order 12291 mandated the use of CBA for any federal project expending more than $100m, thus implicitly creating the need for empirical measures of values to support CBA of environmental change. The outcome of this need was the expansion of the theoretical underpinning necessary for policy applications of a subset of revealed-preference valuation methods known as travel cost models [29].

Secondly, the grounding of the Exxon Valdez tanker in 1989 led to a national valuation study [30, 31] that used contingent valuation to assess the passive use environmental values lost due to the accident for which the responsible party would be held financially liable. Partly due to the ensuing controversy, in 1992 the National Oceanic and Atmospheric Administration (NOAA) commissioned a panel of expert economists to assess the validity of using this valuation technique to measure passive use values [32]. In conditionally endorsing contingent valuation as a valid method, the NOAA Panel set the framework for stated-preference methods to be used to estimate values to support litigation and policy analyses in the US. Subsequent to the seminal work by Bockstael and McConnell [29] and the NOAA Blue Ribbon Panel Report, much of the academic literature has focused on methodological refinement and standardisation of practices for application of non-market valuation methods (e.g. [33, 34]).

The driving forces behind the relatively early incorporation of environmental valuation in CBA in the US have no contemporary parallels in the UK. Rather, the use of CBA and associated environmental valuation in UK public decision-making has developed in a more piecemeal fashion with a "chequered history" [35]. From experimental use in transport projects in the 1960s, developments in the use of CBA led to a recognition of its relevance to policy evaluation and as a means of incorporating environmental values into decision making, culminating in the (then) Department of the Environment's publication of Policy Appraisal and the Environment [36] (DoE 1991). Although Pearce [35] further cites an interdepartmental 'White Paper' [37] as signalling an acceptance of CBA in environmental policy the paper itself is not explicit on this count, referring to (amongst other things) the need for economic research on the costs and benefits of environmental protection measures. Perhaps more significant in this respect was a report commissioned by the Department of the Environment published as *Blueprint for a Green Economy* [38], which highlighted the potential roles of environmental valuation methods in decision-making and the use of such values in CBA.

As early as 1984 HM Treasury's 'Green Book' noted that non-market impacts may not be directly measured in money terms but might "sometimes still sensibly be given money values" ([38] p. 124). In its 2003 edition, the Green Book specifically referred to the need to capture "social and environmental costs and benefits for which there is no market price" ([39] p. 19) and included a separate annex dealing with non-market assessment, emphasising valuation. This annex has recently been supplemented with guidance on the valuation of environmental impacts using, for instance, contingent valuation and choice modelling [40, 41].

A mandate to consider environmental costs and benefits has also been included in UK legislation such as the Environment Act 1995 and the Climate Change Act 2008, in terms of the preparation of the government's first carbon budget. However, generally, the drive towards recognition of environmental values and CBA is more manifest in the recommendations of The Green Book than the requirements of primary legislation. Nevertheless, the integration of environmental values into government decision-making in the UK has been evident in several recent developments: The Department of Environment, Food and Rural Affairs (Defra) has promoted use of a standardised social cost of carbon [42] based on studies of the damage costs of climate change which was used in appraisal until being replaced by values based on market based values [43], the recent National Ecosystem Assessment supported by Defra [3] included monetary values for the environment where available, and in 2012 the government established a Natural Capital Committee to advise the Cabinet on the status of England's 'natural wealth'.

Momentum towards using environmental values in the UK may further be reinforced by EU policy. The use of environmental values in CBA in Europe has historically lagged that in the US [44, 45]. In 1981, US Presidential Executive Order 12291 required Regulatory Impact Analyses for major rules that included documentation of costs and the quantification of benefits to the extent feasible. About a decade later, Article 130r of the 1992 Treaty on European Union requires the integration of environmental considerations in the Commission's policies. In its Fifth Environment Action Programme [46] the Commission interpreted this requirement through a commitment to "analysis of the potential costs and benefits […] in developing specific formal proposals" (p97). More recent evidence suggests that the notion of the use of environmental values in CBA has become more firmly embedded in the Commission's thinking, as manifested in the requirements of the Water Framework Directive [47] and Marine Strategy Framework Directive [48, 49].

Table 1

During the past 50 years, in both the US and the UK, it has been progressively accepted that environmental factors should be incorporated into decision-making, even when no market prices are available. This acceptance of environmental values in CBA and policy-making has led to the acknowledgement of the capability of revealed- and stated-preference valuation approaches to inform such analyses, and an increasing support for such approaches. While the development of polices to motivate environmental valuation evolved early in the US, the acceptance of environmental valuation in decision-making has caught up in the UK. However, the application of environmental values in the UK has historically lagged that in the US and remains peripheral. Thus, insights from both nations are important in developing the foundations of environmental valuation to support marine planning but, despite their similarities in many ways, they can be distinguished by their use of environmental values in public decisions.

3. Ecosystem service valuation (ESV) in marine planning

While the precise implementation of marine (spatial) planning varies, it has been defined as a "public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives" ([50] p. 18). Critical to any marine planning process is recognition of the valuable benefits available to society derived from the effective governance of marine ecosystems. Marine planning is emerging as an important tool for governments to address the increasing human impacts on the marine environment in a strategic and integrated manner. At present, approximately 10% of global Exclusive Economic Zones are included within an approved marine spatial plan and when other plans underway are completed, this is expected to increase to 33% [51]. Here we sketch the development of marine planning in the US and the UK and then highlight the opportunities and challenges for the possible inclusion of marine ESV in that process.

In 2010 Executive Order 13547 “Stewardship of the Ocean, Our Coasts, and the Great Lakes” established the US National Ocean Council. The Council released the National Ocean Policy in 2013, which is laid out in the National Ocean Policy Implementation Plan [10], forming the administrative basis for marine planning. Prior to these events, marine planning in the US evolved organically, largely at the state level. Driven by emerging marine technologies and expanding uses of ocean resources, many of which could conflict with sustainable management of the marine area, states in the Northeast and West Coast of the US undertook marine planning processes. These efforts include Oregon’s Territorial Sea Plan[3], the California Marine Life Protection Act Initiative[4], the Massachusetts Ocean Partnership[5], and the Rhode Island Special Area Management Plan.[6]

Between 2009 and 2013, the UK government introduced a number of measures to deliver its vision of "clean, healthy, safe, productive and biologically diverse oceans and seas" [52] through the Marine and Coastal Access Act (MCAA) 2009, Marine [Scotland] Act 2010 and Marine Act (Northern Ireland) 2013. These measures included providing for the introduction of a marine planning system. The policy direction for the preparation and delivery of marine plans is provided by the UK Marine Policy Statement [8], which was adopted by all UK administrations and was built upon the UK-wide High Level Marine Objectives [53]. The marine planning framework contributes to meeting the UK’s European marine policy commitments [54, 55] and to the sustainable development of an ecosystem-based approach to the management of the UK’s marine and coastal areas.

Marine planning in the UK is progressing on a number of fronts. In 2012, the Northern Ireland Department of Environment notified relevant authorities of its intention to commence work on the Northern Ireland Marine Plan. In 2013 the Welsh Government followed suit, with the announcement to have a National Marine Plan for Wales in place by 2015. Having commenced marine planning earlier, in 2013 the Scottish Government undertook the formal

[3] http://www.oregon.gov/LCD/OCMP/Pages/Ocean_TSP.aspx
[4] http://www.dfg.ca.gov/mlpa
[5] http://www.massoceanpartnership.org
[6] http://seagrant.gso.uri.edu/oceansamp/index.html

consultation on the Scottish draft National Marine Plan, and the Marine Management Organisation (MMO), as the delegated marine planning authority for England, consulted on the draft East Inshore and East Offshore Marine Plans. In contrast to the Devolved Administrations, marine planning in England is being undertaken on a regional plan basis, and the remainder of this paper will focus on the comparison between the US and English planning approach.

3.1. Current calls for ecosystem service valuation in marine planning legislation

In the US, the National Ocean Policy Implementation Plan recognises explicitly the link between healthy marine ecosystems and economic value, stating that "the declining health of ocean, coastal, and Great Lakes ecosystems threatens their availability to provide the products and services on which our economy depends" ([10] p. 5). Although the Implementation Plan includes specific guidelines for the development of databases that include social science information needed to advance decision-making[7] and improve data accessibility, it does not explicitly call for ecosystem services valuation data. However, the Implementation Plan does call for the utilisation of "public input [...] and scientific information to help identify and communicate the **economic value** [emphasis added] of ecosystem services, such as healthy and productive wetlands that support spawning, breeding, and feeding of commercially and recreationally important fish species" ([10] p. 7). According to the US Marine Planning Handbook "marine plans incorporate ecosystem-based management, an approach that considers the dynamic and interconnected relationship between the ocean environment and human activity, to help make decisions that can better sustain the many benefits the ocean provides" ([56] p. 12). Thus, the intent of this planning effort goes beyond ecosystem services that support commercial and recreational activities to

[7] http://www.ocean.data.gov provides an overview of available data.

the broad spectrum of ecosystem services that affect human welfare. While marine planning in the US need not be accompanied by new rules or ocean zoning, the economic condition of ocean and coastal resources should be assessed, forecasted and analysed, and should include measures of service uses and the economic valuation of these uses along with the non-use benefits of ocean and coastal areas.

Once planning activities begin, economic valuation estimates can be used to guide scenario plans and provide decision-support data to help stakeholders weigh the economic trade-offs of proposed plans. For example, Raheem et al. [57] document likely ecosystem services in California and report values for these services that currently exist in the literature and a number of tools has been proposed to incorporate such ESV data in US-based marine planning [58]. Moreover, by being explicit in what valuation data are available and those which are not, planning efforts can set priorities for data collection efforts that will enhance the refinement of plans and the decision making that ensues from the plans.

When marine planning began in the England, the absence of robust primary evidence on the value of ecosystem services (and the use of simplifying assumptions in value estimation that do not hold true in reality) made it impossible to incorporate environmental costs and benefits into marine planning [59]. Furthermore, in certain parts of the UK the aligned process of establishing a network of marine conservation zones (MCZ) requires research to identify marine ecosystem services provided by the protected sites and how these services might change under a range of management scenarios [55, 61, 60]. Some practical examples both of primary valuation studies [62] and benefit transfers [63] in the context of the creation of MCZs do exist. However, Socio-economics has been identified as a priority research area by the MMO, with the “social benefit of coastal and marine activities and features, including public values and social asset valuation” highlighted as a key theme ([64] p. 9) and Ecosystem Services as a priority area of research of the MMO’s Strategic Evidence Plan [65]. Under this plan the MMO is currently undertaking research to develop a practical framework for improving the integration of an ecosystem approach into marine planning, including ESV. While it is clear that elements of this framework are already considered in the planning process, the research will make further recommendations with regards to both evidence and process.

3.2. The potential for ecosystem service valuation to support marine planning

The previous section demonstrated that the benefits of including ESV in marine planning are recognised and aspired to, but when and where ESV should be used in marine planning is not yet clear. This section investigates the needs of marine planning and the potential for ESV to address these needs.

Marine planning is a public process exemplified by Ehler and Douvere's [50] ten-step approach (Table 2) with ESV potentially implemented at different stages. At Step 2 even preliminary and limited ESV data can help define the potential scope of benefits that could come from better planning and thus motivate financial support for planning efforts. The relevance of ESV continues in Step 4, organising stakeholder participation, where it can provide structure to involve different stakeholder groups and identify preferences and opinions in a structured manner through survey-based and deliberative stated-preference approaches, such as contingent valuation, choice modelling, citizens' juries or multi-criteria analysis.

Step 5 requires the assessment of current conditions to highlight incompatible uses of marine resources that could produce negative environmental effects. In this type of assessment ESV can provide information on the relative importance of existing uses as reflected in their social and economic values.

Table 2

Step 6 in the marine planning process requires the analysis of alternative management strategies to determine the future impacts of each plan. Estimates of the value of baseline ecosystem conditions can support comparisons of benefits and costs resulting from alternative management plans. This type of trade-off analysis would not be possible without monetary value estimates to describe the economic trade-offs of alternative uses of marine resources. Steps 5 and 6 mirror the building blocks of a standard ESV study, which is typically an assessment of the change in social value following a change in the provision of ecosystem services. Such a change can be defined between the status quo and some future state or a comparison of different potential future states. Engaging stakeholders into this process at this stage is important to help them understand the consequences of actions where feed-back loops may not be obvious [66]. ESV and trade-off analyses are particularly beneficial in marine planning for developing alternative scenarios and to highlight consequences of these for stakeholders.

In Step 7 ESV estimates and analysis provide important data to be considered in the choice and approval of planning proposals. The use of these values could be in CBA, multi-criteria analysis, or any number of other decision support tools. In addition ESV can provide objective and transparent data and a framework to help decision makers track how management alternatives can affect marine ecosystems and ultimately people. Equally important, engaging stakeholders in the application of an ESV approach throughout the planning process potentially offer the opportunity to take ownership in the process and outcomes. This, in turn should enable Step 8, the successful implementation of the measures.

Finally, ESV should be considered in the monitoring of the success of a marine plan, required in Step 9 to assess and compare the expected and realised changes to the values under the implementation of the plan. Such transparent values are likely to prove useful when undertaking an objective assessment of the success of a plan. The ESV analyses conducted in Steps 5 and 6 also can identify which ecosystem services are most important to monitor from a social perspective.

Thus, there is a clear role for ESV at many stages of the marine planning process, and successful implementation requires their integration throughout the process. However, for this integration to occur it is critical that all parties have confidence in the ESVs used in plan development and implementation. The following section discusses some of the key challenges related to applying ESV to marine planning, with an aim of recommending future research directions to operationalize the application of ESV in marine planning.

3.3. Methodological challenges of applying ESV to marine planning

There is a wide range of challenges to applying ESV in a policy context. Laurans et al. [25] propose six key generic challenges: inaccuracies associated with valuation data; inadequate valuation data available; cost of valuation studies; training of policy makers to apply ESV; regulatory frameworks not conducive to ESV; the potential of ESV to hamper political strategies. These challenges apply to most environmental applications and are not unique to marine resources. A challenge that is more particularly clear in marine applications is the lack of adequate valuation data.

Here we focus on the methodological challenges, rather than the broader policy and politically orientated issues as it is considered that these wider issues cannot be addressed satisfactorily through academic development, while addressing methodological challenges lies within this sphere. The range of economic valuation methods applicable to support marine planning is broad and whilst there is a variety of potential conceptual and methodological challenges to each, the focus here is on challenges specifically relevant to the application of ESV in marine planning. Recommendations to overcome some of those challenges are outlined in section 4.

Experience with marine ESV is extremely unevenly distributed across types of marine habitats, ecosystem services and geographic locations [17, 57] with traditionally more studies assessing values of near-coast provisioning, regulating and cultural (especially recreational) services, such as beaches, fisheries and coastal properties [67-73], and minimal studies investigating the open ocean and deep sea or the less well recognised cultural services such as spiritual well-being and heritage [74, 75]. This uneven distribution in ESV arises from challenges in the practical application of existing values and valuation methods in marine planning. Although theoretically highly compatible with the ecosystem service approach, environmental valuation approaches have only recently been applied to ecosystem services [76]. Practitioners have traditionally linked value estimates to readily available environmental change information and have only recently begun to work closely with ecologists to develop values that link to clearly defined ecosystem services [77]. For example, survey-based valuation techniques should communicate complex ecosystem information to achieve “ecological content validity” [78]. This alone is difficult and is exacerbated by the remoteness and complexity of many marine ecosystem services, e.g. those associated with deep water coral habitats affected by an oil spill [79].

This lack of fundamental natural science knowledge regarding changes in marine ecosystem services is a major challenge to their valuation. Indeed, even selecting the baseline against which values are determined can be very difficult [80]. Recent efforts examine a variety of means of establishing and communicating to the public what previous baselines may have been which could be used to value aspirational baselines of marine ecosystem services [81, 82]. However, in many marine cases the issue of defining and communicating baselines remains a source of considerable uncertainty when undertaking ESV. The issue of environmental uncertainty is further complicated by environmental global changes, such as climate change and ocean acidification, in reality any given scenario will be influenced by such global changes but to a highly uncertain extent. Including and communicating such uncertainty in any valuation will be a significant challenge.

Other valuation methods, such as travel cost or hedonic methods, are limited to marine ecosystem services that people are aware of and that affect choices in related markets, such as recreation trips and property purchases. These revealed-preference methods are not applicable to many marine ecosystem services, such as those provided by the deep sea, due to a lack of any direct effect on market activities and values. Thus, survey-based stated-preference methods, such as contingent valuation or choice experiments, which require careful descriptions of ecosystem services in the survey designs, are still required for most marine ESV applications. The demand for values of certain ecosystem services has led to an increasing use of these methods with marked variability in the quality of questionnaire design in some cases [57]. A way to overcome those problems lies in the combination of qualitative and quantitative approaches [83].

As many marine ecosystems are remote, the assessment of non-use values[8] is particularly relevant for marine planning. People who do not actively engage with many marine ecosystem services may hold significant (non-use) values for these resources. Non-use values, motivated by bequest to future generations or pure existence of resources, are held independent of any current or future use [84]. Appropriate valuation methods are contingent valuation and choice experiments. Previous research on non-use values for marine ecosystem services has mostly focused on charismatic species such as marine mammals and turtles [85- 90], or prominent ecosystems such as corals [75, 91, 92].

Another major challenge is that marine ecosystem services are not all location-specific. While corals and shipwrecks for instance are clearly spatially anchored, many marine resources such as fish and mammal species, as well as the ecosystem components such as plankton that support them, can be highly mobile crossing national jurisdictions and locations in different regions in different seasons or at different times in their life cycles. This complicates value estimation. The spatial scale at which valuation takes place is crucial in this respect, especially regarding non-use values which do not necessarily decrease with

[8] These are also referred to as existence or passive-use values.

distance to the ecosystem [93]. Thus, some marine ecosystem services are not restricted to individual countries, and people in one country can hold values for such services in other countries, which is an important consideration/complication for country-specific marine planning. Rather than spatial distance, cultural or cognitive distance might affect people's non-use and use values [94]. This cognitive distance adds to the methodological challenge of conveying details about an environment with which most respondents to valuation surveys are unfamiliar and which is perceived as relatively unimportant [95].

Original valuation studies in support of marine planning may be difficult due to time or cost constraints. In such instances benefit transfers can be used where existing value estimates are transferred to a new planning application [96]. Here, again, there are challenges [83, 97]. Firstly, the scarcity and inadequacy of primary valuation data continues as a problem [71]; before benefit transfers can be effectively operationalized steps are needed to create comprehensive and quality assured marine ESV databases (e.g. [98]) to facilitate benefit transfer. Double-counting has been mentioned as a potential threat to the accuracy of aggregating environmental values [83], yet progress in developing ecosystem service classifications has helped to curb this problem. Beyond data scarcity the potential lack of similarity of marine sites is an important consideration in the validity of transfer [99]. An example is transferring values of beach attributes from the US to the UK: sociocultural factors, uses of beaches and climatic factors may all influence the values placed on beaches [97, 100].

The decadal time frame of marine plans is challenging for original valuation studies and benefit transfers. Stated-preference value estimates can be relatively stable over shorter periods of time [101] but it may be difficult for people to respond to stated-preference questions for resource changes projected 15 to 20 years into the future. Benefit transfer over long periods of time is challenging because preferences change over time and past values may not always reflect future preferences. When impacts of plans with differing time frames are to be assessed, accurate discounting is indispensable to make values comparable [66].

Even where commercial economic values are more accessible than those for ecosystem services, their use in cost-benefit analysis to support marine planning has been limited. For example, in England, the potential of this technique to inform planning decisions involving conflicts between alternative uses of marine space, such as between offshore renewable energy installations and shipping, has been recognised [102]. However, the evidence base for England's first marine plan areas [103] and the resulting draft plans [104] do not rely on economic analysis. This may suggest more general issues in its application or acceptability, the MMO ([103] p. 205) notes that the assessment of multiple activities is "very much a work in progress".

From the natural science perspective the relationship between ecosystem services and underlying marine ecosystem processes and biodiversity is still not well established and largely theoretical. There is little directly relevant evidence or data to validate current theory and models. Thus the reliance of ecosystem service provision on biodiversity and ecosystem processes is also poorly understood. This limits the use of ESV in policy which needs to govern not only which ecosystem services to improve or maintain, which is informed by valuation, but also how this can be achieved, which is informed by natural science evidence and understanding. Ongoing development in modelling approaches will partially overcome these problems, particularly for projecting future change, and these are introduced in Box 1.

These challenges imply that caution must be used when applying existing ecosystem service values to marine planning and there is a need for a systematic research effort to fill gaps in key ESV methods and values that are needed to support marine planning.

Box 1

4. Conclusions and recommendations

This paper explores the potential application of ecosystem service valuation to marine planning. While environmental valuation in the US and UK has evolved very differently, the techniques and applications have converged, and environmental CBA has become established in legislative and administrative practice in these countries over the last five decades. In both countries, although more so in the US, valuation has become an important part of the routine analysis of environmental policies and damages to environmental resources [40, 41, 44, 119]. This development has also fostered the increasing acceptability of environmental valuation as reflected by the increasing calls for such valuation in marine planning legislation laid out in section 3.1. In the US, UK and elsewhere, ESV is recognised as a potentially important tool in the marine planning process, but the application of valuation estimates for marine ecosystem services is still rare in that process.

Marine planning is an ideal area to test the capacity of ESV to feed into the policy context. This is in part due it's relatively recent origins, but also due to its place-based nature and tendency to follow the principles of adaptive management. This means that we can begin to develop a baseline of ecological and economic valuation data in a place-based setting. Further, we can initiate research to better understand the ecological processes that link planning options with the ecological outcomes that matter most to people. The adaptive management component of marine planning provides both the opportunity to include new valuation findings in planning and also will require such data as marine plans are consistently reviewed in the future.

As outlined in this paper there are numerous, but surmountable challenges that inhibit the use of ecosystem services values in marine planning. These include a lack of valuation data for many marine services and physical areas; methodological challenges when using stated and revealed preference approaches in the marine context; an inability to link planning scenarios to ecological outcomes and values; the high mobility of certain marine resources; problems around the assessment of non-use values; and short time frames that often accompany marine planning processes. As a result, our ability to use valuation to incorporate ecosystem service values in marine planning remains limited. A longer term approach to building a base of planning-relevant understanding for marine ecosystem services would benefit from a number of concrete and staged efforts. Recommendations include the need for:

- Improved understanding of the ecological underpinnings of ecosystem service provision, including the identification and communication of realistic baselines, and especially to detect and highlight potentially irreversible changes and thresholds in the production of ecosystem services [83]. As some ecological uncertainty will always remain methods to handle and communicate this uncertainty are also required.
- Targeted work sessions of economists, ecologists and marine managers to undertake a gap analysis of ESV data and barriers to use and application of ESV data in the context of marine planning. From this analysis a detailed research agenda should be developed to address the challenges to implementing ESV in marine planning. A planning-relevant science agenda would help marine managers weigh proposed and anticipated planning scenarios.
- Long-term funding to sustain collection of baseline and time series of ecological and economic data to support research and marine planning alike, particularly in marine plan areas.
- Continued development of integrated valuation databases such as the MSEP and NOEP. Including quality assurance of data therein for use in marine planning. These databases should be developed on international scale to enable maximum utility of the data.
- Further standardisation and development of valuation approaches in an ESV context. To this end methodological development of stated preference approaches is necessary to apply those methods to marine ecosystem services and to improve ecological content validity. Stated preference valuation must make use of innovative

tools to convey complex ecological information in the interview setting to broaden the set of marine ecosystem services that these approaches can be applied to. It should be noted that this also includes the exploration of clearer boundaries of the applicability of this methodology in the marine context.

- Targeted development of integrated modelling approaches that will support marine planning. These should be designed specifically to link planning to ecological processes, to changes in ecological outcomes and to economic valuations of these outcomes with checks built into these efforts to address modelling limitations (Box 1).

Marine planners, managers and decision makers need to be engaged in all of the above activities so that their concerns will be heard and they will have interest in, and confidence in using economic information that is provided to support their marine planning efforts. If ESV is going to be used more extensively for marine planning, the values calculated through ESV methods must be credible and focused on the key elements of marine policy choices and planning decisions. It is important therefore that when considering future methods of and approaches to ESV for marine planning, that they are tailored to the policy context and to what is considered acceptable evidence by policy-makers, decision-makers, and those affected by the policy and planning choices, including stakeholders and the public.

A review of the use of environmental valuation in the US and UK has shown a history of ad hoc valuation studies. If we follow the same course with marine ecosystem service valuations, it is likely that even after a decade of marine planning, we will still be unable to address the basic challenges required to incorporate marine ecosystem service values in planning. Fortunately, marine planning is ideally suited to overcoming these challenges, and it is anticipated the discussions and recommendations provided here will enable this process.

Acknowledgements

The authors acknowledge the UK's Science and Innovation Network (SIN https://www.gov.uk/government/world/organisations/uk-science-and-innovation-network), which is jointly funded by the Department for Business, Innovation and Skills and the Foreign & Commonwealth Office, for their assistance in convening an international workshop to bring together US and UK experts to inform the production of this paper. The research leading to these results was also partially funded from the European Community's Seventh Framework Programme (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).

This work was supported by the European Commission's Seventh Framework project 'Options for Delivering Ecosystem-Based Marine Management' (ODEMM, Theme ENV.2009.2.2.1.1).

One author acknowledges funding from the European Centre for Environment and Human Health (part of the University of Exeter Medical School) which is part financed by the European Regional Development Fund Programme 2007 to 2013 and European Social Fund Convergence Programme for Cornwall and the Isles of Scilly.

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Table 1: Significant Environmental and Marine Policy Regulations and Events Affecting Environmental Valuation Development and Use in the United States and United Kingdom (1960 to present)

	Environmental Valuation Policy Drivers	
Year	**United States**	**United Kingdom**
1960 - 1969	• Clean Air Act (1963) • National Environmental Policy Act (1969)	
1970 - 1979	• Clean Air Act Amendments, , Environmental Protection Agency, National Oceanic and Atmospheric Administration (1970) • Clean Water Act, Marine Protection, Research and Sanctuaries Act (1972) • Endangered Species Act (1973) • Principles and Standards for Water and Related Land Resource Planning (US Water Resource Council 1979)	
1980 - 1989	• Comprehensive Environmental Response, Compensation and Liability Act (CERCLA aka Superfund), Act to Prevent Pollution from Ships (MARPOL) (1980) • Executive Order 12291 (Reagan) (1981) • Exxon Valdez Oil Spill (1989)	• The Green Book (1984) • “Blueprint for a Green Economy” [38][a]
1990 - 1999	• Oil Pollution Act (1990) • NOAA Blue Ribbon Panel on Contingent Valuation (1992)	• “Policy Appraisal and the Environment” [36] • Environment Act (1995)
2000 - 2009		• EU Water Framework Directive (2000) • The Green Book (2003) • Climate Change Act (2008)
2010 - 2013		• National Ecosystem Assessment (2011) • EU Marine Strategy Framework Directive (2012)

[a] Based on a report to the Department of the Environment

Table 2: Ten-step approach to marine (spatial) planning [50]

1. **Identifying need and establishing authority**
2. **Obtaining financial support**
3. **Organising the process through pre-planning**
4. **Organising stakeholder participation**
5. **Defining and analysing existing conditions**
6. **Defining and analysing future conditions**
7. **Preparing and approving the spatial management plan**
8. **Implementing and enforcing spatial management plan measures**
9. **Monitoring and evaluating performance**
10. **Adapting the spatial management process**

Box 1: Coupled ecosystem and human behavioural modelling

Dynamic coupled and spatially resolved marine ecosystem and human behavioural models are being developed and applied for fisheries management in relation to food production goals. Examples include:

- coupling of the spatially resolved ecosystem model ERSEM with models of fish production and fisheries associated livelihoods [105-109].
- development of spatially resolved modular models such as ISIS-fish and more recently ATLANTIS that link hydrography, ecosystems, maritime resource use and economic models [110-117].

Such models are being developed more broadly in the marine environment in EU and nationally funded projects so that although the literature is in its infancy we expect rapid improvements in joint modelling exercises.

In these modelling approaches policy interventions of marine planning represent spatially explicit exogenous shocks to the dynamic system. Policies in one sense may serve to push the system from an undesirable state to a desirable state, or may serve as insurance barriers to prevent a system from slipping into undesirable or reversible states in the face of other exogenous shocks, such as climate change that might be induced by terrestrial human activities. In either case, policy intervention in a dynamic coupled system creates dynamic changes in the set of ecosystem services provided. For example in modelling the effects of policies concerning coastal beach renourishment in North Carolina, Gopalakrishnan et al. [118] combine geomorphologic models of coastal erosion with hedonic coastal property valuations to demonstrate the impact of including dynamic ecological effects in traditional valuation models. They find that the magnitude of the effect of beach width on coastal property values is nearly five times that estimated from a model that fails to account for dynamic ecological feedbacks.

Empirical estimates of ESV are necessary to parameterise these dynamic programming models. Even with the limitations of these models, they can be used to help stakeholders understand important feedback loops that may not be immediately obvious without such modelling. Or in the absence of empirical estimates of ESV, dynamic models can be used to simulate policies to investigate the implied values, shadow prices, of policies to implement marine planning activities to understand the potential economic consequences of trade-offs.

Fundamental economic and ecological research is required to enable development of existing and new modelling approaches. For example, traditional measures of value for environmental changes rely heavily on partial equilibrium static analysis. Left unanswered are uneasy questions such as where do the ecological and economic thresholds for irreversible effects occur? How to measure value in a dynamic non-steady state system with potential threshold effects? How to value resilience versus changes in steady states? Does traditional welfare theory carry over to the coupled-dynamic setting? If not, what do traditional measures of value mean in the new modelling setting?